Application of the International Safety Standards to Radon and NORM

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1. Abstract

In terms of its Statute, the IAEA, in consultation/collaboration with other bodies such as the ILO, establishes radiation protection standards and provides for their application. The *International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources* (the BSS) are supported by various Safety Guides and Safety Reports, several of which deal specifically with occupational exposure to natural sources of radiation. The standards provide the necessary framework and guidance for protection of workers against exposure to radon and NORM. IAEA Safety Reports describing good practices and giving practical examples and detailed methods that can be used to meet safety requirements in certain NORM industry sectors are starting to become available. In terms of the standards, occupational exposure to radon is subject to an action level for intervention through remedial action of 1000 Bq/m^3. Occupational exposure to NORM falls within the scope of the requirements for practices if the radionuclide activity concentration in the material exceeds 1 Bq/g for uranium and thorium series radionuclides (other than radon and its short-lived progeny) or 10 Bq/g for potassium-40. If the relevant activity concentration level for radon or NORM is exceeded, a 'graded approach' to regulation should be applied, in terms of which the stringency of regulation is commensurate with the characteristics of the operation and the exposures involved. At the lowest level of the graded approach, the regulatory body decides that the optimum regulatory option is not to apply regulatory requirements to a given type of operation or process. Control of occupational exposure to gamma radiation and dust is likely to be warranted only if the effective dose arising from such exposure exceeds 1–2 mSv in a year. The number of materials that may require initial regulatory consideration in terms of the standards is fairly limited and the types of operation likely to require regulation may be much fewer than suggested previously on the basis of dose modeling using generic exposure scenarios and assumptions — the level of radiological hazard in these types of operation varies over a wide range, underlining the importance of adopting a graded approach to regulation.

Marilee Williams, Editor
Proceedings of the 9th EAN ALARA Workshop
18-21 October 2005
Augsburg, Germany

2. International safety standards

Although several organizations are involved in the international harmonization of radiation protection and safety, the IAEA is specifically authorised under the terms of its Statute to establish, in consultation and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialised agencies concerned, standards of safety for the protection of health and the minimization of danger to life and property (including such standards for labour conditions). The standards are established on the basis of international consensus. The IAEA is also authorised to provide for the application of these standards to its own operations as well as to operations making use of IAEA assistance, and is actively engaged in promoting the application of the standards for the management and regulation of all activities involving nuclear and radioactive materials as part of a framework for co-operative efforts to build and strengthen an international safety and security regime.

The regulatory related publications by means of which the IAEA establishes safety standards are issued in the IAEA Safety Standards Series, comprising three categories: Safety Fundamentals, Safety Requirements and Safety Guides.[1] A key document in the Safety Requirements category is the *International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources* (IAEA 1996), commonly referred to simply as the Basic Safety Standards (the BSS).[2] The ILO, as one of the cosponsors of the BSS, uses this document as a basis for the implementation of the Radiation Protection Convention, C115 (ILO 1960). The BSS provide the basic requirements to be fulfilled in all activities involving radiation exposure, including exposure to radionuclides of natural origin. At the more detailed level, three Safety Guides are particularly relevant to occupational exposure to radon and NORM: *Occupational Radiation Protection* (IAEA 1999), *Occupational Radiation Protection in the Mining and Processing of Raw Materials* (IAEA 2004a) and *Application of the Concepts of Exclusion, Exemption and Clearance* (IAEA 2004b). The first two of these publications were sponsored jointly by the IAEA and the ILO.

In support of the standards, the IAEA issues reports on radiation protection and safety in other series, in particular the IAEA Safety Reports Series, as informational publications. Safety Reports may describe good practices and give practical examples and detailed methods that can be used to meet safety requirements. Safety Reports on *Radiation Protection against Radon in Workplaces other than Mines* (jointly sponsored by the IAEA and the ILO) (IAEA 2003a) and on *Radiation Protection and the Management of Radioactive Waste in the Oil and Gas Industry* (IAEA 2003b) are examples of reports dealing with exposure to natural sources. Further Safety Reports in this area are being developed, including reports on other industry sectors such as the phosphate industry, the zircon/zirconia industry, the titanium dioxide industry, and the industrial uses of thorium.

[1] Safety Guides recommend actions, conditions or procedures for meeting safety requirements.
[2] This publication is sponsored jointly by the Food and Agriculture Organization of the United Nations, the IAEA, the ILO, the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development, the Pan American Health Organization and the World Health Organization.

3. Application of the standards to occupational exposure to radon

In most situations, occupational exposure to radon is incidental to the work being carried out, and is therefore considered in the first instance as a chronic exposure situation that is subject to the requirements for intervention.[3] In terms of these requirements, an action level for intervention through remedial action has to be determined using an approach based on the optimisation of protection. The guideline value for the optimised action level is specified in the standards as a yearly average concentration of 1000 Bq of ^{222}Rn per cubic meter of air (IAEA 1996).

The standards recommend that the regulatory body identify or determine, by means of a survey or otherwise, those workplaces with radon concentrations above the action level. Consideration should then be given to whether such concentrations can reasonably be reduced below the action level. Where sufficient reduction in concentrations cannot reasonably be achieved, the requirements for practices (including the radiation protection requirements of justification, dose limitation and optimisation of protection) should be applied.[4] In such circumstances the numerical value of the action level takes on a conceptually different significance — instead of being used as the basis for a decision on intervention, it is used as the basis for a decision to consider the exposure to be arising from a practice (IAEA 1999).

4. Application of the standards to occupational exposure to NORM

Radionuclides of natural origin are ubiquitous in the environment at variable, but generally low, activity concentrations. The regulation of human activities involving material containing these radionuclides at activity concentrations that would invoke widespread regulatory consideration, in circumstances where it is unlikely to achieve any improvement in protection, would not be an optimum use of regulatory resources. Therefore, values of activity concentration in material — 1 Bq/g for uranium and thorium series radionuclides (other than radon and its short-lived progeny) and 10 Bq/g for potassium-40 — are specified in the standards as being values below which it is usually unnecessary to regulate, irrespective of the quantity of material or whether it is in its natural state or has been subject to some form of processing (IAEA 2004b).[5] These values were selected by considering the upper end of the world-wide distribution of activity concentrations in soil (UNSCEAR 2000). They are intended to apply to all types of material except drinking water and foodstuffs. The same activity concentration values can also be used as criteria for release of material from regulatory control.

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[3] Situations where occupational exposures to radon are not regarded as incidental to the work include the mining and processing of uranium ore and thorium ore — such exposures (other than those whose magnitude or likelihood are essentially unamenable to control) are automatically subject to the requirements for practices.

[4] Unless the exposure is excluded (unamenable to control) or the practice or source is exempted.

[5] It is noted in the standards that the use of some building materials with activity concentrations below these values may need some regulatory consideration. It is also noted that ground and building materials making up the workplace, and containing concentrations of radionuclides of natural origin that are sufficiently elevated to warrant attention being given to gamma radiation dose rates, could be treated using an approach similar to that for radon in workplaces, with a guideline action level for intervention through remedial action in this case being a gamma dose rate of 0.5 μSv/h or some multiple of it.

5. Graded approach to regulation

If the relevant activity concentration value for radon or NORM is exceeded, the regulatory body needs to ensure that the application of the BSS requirements for practices is commensurate with the characteristics of the operation and the material involved, and with the magnitude and likelihood of the exposures. This reflects the so-called 'graded approach' to regulation, consistent with the principle of optimisation of protection. For situations involving occupational exposure to NORM, it implies that the regulatory body needs to go beyond just looking at radionuclide activity concentrations in materials — it should consider particular types of operation, process and material in more detail, including some form of exposure assessment, in order to determine the optimum regulatory approach.

The graded approach applies to exposure to all sources of radiation subject to regulation, not just natural sources. However, it is particularly relevant to operations involving exposure to radon and/or NORM, because the exposures are generally (but not always) moderate, with essentially no likelihood of extreme radiological consequences from accidents, and because occupational health and safety (OHS) measures already in place to control other (non-radiological) hazards in the workplace may well provide some protection against radiological hazards as well. The main types of exposure arising from work with NORM are external exposure to gamma radiation and internal exposure to inhaled dust and radon. While specific radiological measures such as control of occupancy time or even shielding may sometimes be appropriate to minimise external exposure to NORM, exposure to dust and radon is often the area in greatest need of attention. In many countries, exposure to dust in workplaces is likely to be controlled already in terms of general OHS regulations, and control of the air quality for this purpose may also help to reduce radon concentrations. Therefore, it would be sensible for the regulatory body to first establish the extent to which existing OHS controls are effective against minimising workers' radiation exposure before deciding to impose additional controls for purely radiological reasons.

The first, most basic, level in the graded approach is where the regulatory body decides that the optimum regulatory option is not to apply regulatory requirements to the legal person responsible for a given type of operation or process. The mechanism for giving effect to such a decision could take the form of an exemption. Although the decision is in principle one based on optimisation, it is implicit in ICRP guidance (ICRP 1997), and in the standards (IAEA 1999), that management and control of exposure of workers to gamma radiation and dust is only likely to be warranted if the effective dose arising from such exposure is more than about 1–2 mSv in a year. In determining whether exemption is the optimum regulatory option on the basis of whether a particular level of effective dose is likely to be exceeded in a particular operation, the effect (and effectiveness) of existing OHS controls, for instance ventilation systems or personal protective equipment, should be taken into account, as mentioned previously.

Where the regulatory body decides that there is a need to apply regulatory requirements to a particular type of operation or process, the next level in the graded approach is the requirement for the legal person to formally submit a notification to the regulatory body. Notification alone could be sufficient where exposures are unlikely to exceed a small fraction of the relevant limits but where it is important for the regulatory body to be kept informed. Again, the existence of more general OHS measures would be an important factor in deciding whether notification alone was the optimum regulatory option.

Where the nature of the hazard is such that further obligations beyond notification need to be placed on the legal person, the standards require that such person apply to the regulatory body for an authorization. In terms of the graded approach to regulation, the authorization may take the form of either a registration or a license, the difference being essentially in the level of stringency of regulation. Registration, which typically places only limited obligations on the legal person, may provide a sufficient level of control in many operations involving significant, but nevertheless moderate, exposures to radon and/or NORM (e.g. a few millisieverts per year). In situations where optimised protection can only be achieved through the enforcement of specific exposure control measures, licensing may be the more appropriate form of authorization. Authorization in the form of licensing represents the highest level in the graded approach to regulation, and the need for licensing of operations giving rise to exposure to radon and/or NORM will probably be largely limited to operations involving significant quantities of material with very high radionuclide activity concentrations.

6. Possible future revisions of the BSS with regard to exposure to radon and NORM

The BSS are based primarily on the recommendations of the ICRP. At the time of the endorsement of the BSS a decade ago, the available quantitative recommendations of the ICRP for protection against exposure to natural sources were confined to radon. This is reflected in the statement in the BSS that “the General Obligations for practices concerning protection against natural sources will be that exposure to natural sources, which is normally a chronic exposure situation, should be subject to intervention and the requirements for practices should generally be limited to exposure to radon, the exposure to other natural sources being expected to be dealt with by exclusion or exemption of the source or otherwise at the discretion of the Regulatory Authority”. In the years that followed, more specific guidance was provided through the publication of the three IAEA Safety Guides mentioned previously, but there remain some inconsistencies and ambiguities.

The first steps are now being taken towards producing a new version of the BSS and, while no major changes with respect to exposure to natural sources are anticipated by experts involved so far with the review, this presents an opportunity to address any shortcomings in the current version. For instance, there would seem to be a need to clarify how the concept of exemption applies to practices and sources giving rise to occupational exposure to NORM. At present, the Safety Guide on *Occupational Radiation Protection* implies that such exposure should only become subject to the requirements for practices if the doses received by workers exceed 1−2 mSv in a year, and that this dose level could therefore effectively act as a means of defining when the practice or source giving rise to such exposures is exempted. However, the dose criterion for exemption specified in the BSS is a value of the order of 10 μSv in a year — a criterion that has practical significance only for radionuclides of artificial origin.

Another area that is being looked at is the applicability of the action level for radon. The standards state that occupational exposure to radon is subject to the requirements for practices if the exposure is “required by or directly related to” the work, irrespective of whether the exposure is higher or lower than the action level, and that this would apply, for instance, in mines intended to produce radioactive ores. Although this is generally interpreted as referring to work involving uranium and thorium ores, there is ambiguity in the wording, and the question could be asked: why should occupational exposure associated with uranium ore or thorium ore (the definition of which can depend on, among other things, market price) be treated any differently from occupational exposure associated with other types of NORM?

7. Implications for industrial processes involving occupational exposure to NORM

The activity concentration levels defined in the standards below which it would be usually unnecessary to regulate — 1 Bq/g for uranium and thorium series radionuclides (other than radon and its short-lived progeny) and 10 Bq/g for potassium-40 — provide a very practical and effective way of narrowing down the range of materials that might need regulatory consideration. Based on information provided by experts contributing to the ongoing development of various IAEA publications related to NORM, and on data gathered in other studies including studies sponsored by the European Commission (Penfold 1999, European Commission 2005), a preliminary list of such materials has been compiled and is shown in Table 1.[6]

While the list of materials in Table 1 is not necessarily exhaustive, it probably captures the vast majority of materials that need to be considered. Already, this makes the problem of deciding what to regulate considerably more manageable. However, such a decision cannot be made on activity concentrations alone. When considering the need for regulation of operations on the basis of occupational exposure, it is important to consider the effective dose likely to be received by workers, and in particular whether such dose is likely to exceed 1–2 mSv in a year.

This might introduce other types of operation into the picture, although experience strongly suggests that, for a given type of operation involving NORM, doses received by members of the public are likely to be only a small fraction of the doses received by workers. The wide range of worker doses indicated in Table 2 illustrates the importance of applying the graded approach to regulation.

[6] For some materials, reports of activity concentrations falling significantly outside the ranges given in Table 1 may be found in the literature, but these are not considered to be typical of material used in current industrial processes.

Table 1. NORM that should be considered for regulation on the basis of activity concentration.

Category of material	Material	Dominant radionuclide(s)	Typical activity concentration (Bq/g)
Raw materials	Monazite sand	^{232}Th+	40 to 600
	Metal ores, e.g. Nb/Ta, Cu, Au	^{238}U+, ^{232}Th+	Up to 10
	Zircon sand	^{238}U+	1 to 4
	Phosphate rock	^{238}U+	0.03 to 3.1
	Feedstocks, TiO_2 production	^{238}U, ^{226}Ra	0.001 to 1.9
	Bauxite	^{232}Th+	0.035 to 1.4
Bulk residues	Phosphogypsum, HCl process	^{226}Ra	2 to 10
	Red mud, alumina production	^{238}U, ^{232}Th	0.1 to 3
	Phosphogypsum, H_2SO_4 process	^{226}Ra	0.015 to 2.1
Slags	Niobium extraction	^{232}Th	20 to 120
	Tin smelting	^{232}Th	0.07 to 15
	Copper smelting	^{226}Ra	0.4 to 2.1
	Thermal phosphorus production	^{238}U	0.3 to 2
Scales, sludges, sediments	Scale, oil and gas production	^{226}Ra	0.1 to 15 000
	Scale, phosphoric acid production	^{226}Ra	0.003 to 4000
	Residue, rare earth extraction	^{228}Ra	23 to 3150
	Scale, TiO_2 pigment production	^{228}Ra, ^{226}Ra	<1 to 1600
	Scale, rare earth extraction	^{226}Ra, ^{228}Th	1000
	Sludge, oil and gas production	^{226}Ra	0.05 to 800
	$BaSO_4$ precipitate, niobium extraction	^{228}Ra	200
	Scales, coal mines with Ra-rich inflow water	^{226}Ra, ^{228}Ra	Up to 200
	Scale, iron smelting	^{210}Pb, ^{210}Po	Up to 200
	Scale, coal combustion	^{210}Pb	>100
	Sludge, iron smelting	^{210}Pb	12 to 100
	Residues, TiO_2 pigment production	^{232}Th, ^{228}Ra	<1 to 15
	Sludge, water treatment	^{226}Ra	0.1 to 14
Precipitator dust	Thermal phosphorus production	^{210}Pb	1000
	Fused zirconia production	^{210}Po	600
	Niobium extraction	^{210}Pb, ^{210}Po	100 to 500
	Metal smelting	^{210}Pb, ^{210}Po	Up to 200
Intermediate products	Thorium compounds	^{232}Th	Up to 2000
	Thorium concentrate	^{232}Th	Up to 800
	Pyrochlore concentrate, niobium extraction	^{232}Th	80
	Cerium concentrate, glass manufacture	^{232}Th	10
	Fused zirconia	^{238}U	2.1 to 3.9
Products	Gas mantles	^{232}Th	500 to 1000
	Thoriated glass	^{232}Th	200 to 1000
	Thorium-containing optical polishing powders	^{232}Th	150
	Thoriated welding electrodes	^{232}Th	30 to 150
	Thorium alloys	^{232}Th	46 to 70
	Zircon refractories	^{238}U	2.6
	Phosphate fertilisers	^{238}U	0.4 to 2.3
	Technical grade phosphoric acid	^{238}U	0.14 to 2
	Phosphogypsum plasterboard[a]	^{226}Ra	0.004 to 0.7

[a] Although this material has an activity concentration of less than 1 Bq/g, it is included because it is a building material.

Table 2. Types of operation involving NORM identified as requiring regulation on the basis of worker dose.

Type of operation	NORM involved			Worker dose (mSv/a)
	Description	Dominant radionuclide(s)	Activity concentration (Bq/g)	
Rare earth extraction from monazite	Monazite Thorium concentrate Scale Residue	^{232}Th ^{232}Th ^{228}Ra ^{228}Ra	40 to 600 Up to 800 1000 23 to 3150	Could approach or exceed dose limit
Production of thorium compounds	Thorium concentrate Thorium compounds	^{232}Th ^{232}Th	Up to 800 Up to 2000	Typically 6 to 15
Manufacture of Th-containing products	Thorium compounds Products	^{232}Th ^{232}Th	Up to 2000 Up to 1000	<1 to a significant fraction of dose limit
Processing of niobium/tantalum ore	Ore Pyrochlore concentrate $BaSO_4$ precipitate Slag Precipitator dust	^{238}U+, ^{232}Th+ ^{232}Th ^{228}Ra ^{232}Th ^{210}Pb, ^{210}Po	1 to 8 80 200 20 to 120 100 to 500	Could reach a significant fraction of dose limit
Some underground mines	Ore Scales from Ra-rich water	^{238}U+, ^{232}Th+ ^{226}Ra, ^{228}Ra	Up to 10 Up to 200	<1 to a significant fraction of dose limit[b]
Oil and gas production	Scales during removal from pipes/vessels	^{226}Ra	0.1 to 15 000	<1 to a significant fraction of dose limit
TiO_2 pigment production	Scales during removal from pipes/vessels	^{228}Ra, ^{226}Ra	<1 to 1600	<1 to 6
Thermal phosphorus production	Fume and precipitator dust	^{210}Pb	1000[c]	0.2 to 5
Fused zirconia production	Fume and precipitator dust	^{210}Pb, ^{210}Po	Up to 600[c]	0.25 to 3

- Dose mainly from radon progeny.
- These figures refer to the activity concentration of the precipitator dust.

Table 2 lists the types of operation involving NORM that have been identified, on the basis of worker doses, as needing to be subject to regulatory requirements - the worker doses listed are based to a large extent on information provided by experts and reflect, as far as possible, actual operating experience and measurements. Again, this list is not exhaustive, but probably captures most of the relevant types of operation. It shows that there are relatively few types of operation that are likely to need formal regulation.[7] Of course, public exposure will also have to be considered.

[7] Similar assessments have been made in the past, such as those made for NORM industries in European countries (Penfold 1999), but these were based on modelling using generic exposure scenarios and involving assumptions that often bore little or no resemblance to actual work situations. Such studies tended to predict much higher doses. More recent studies, based to a greater extent on facility-specific exposure scenarios, predicted worker doses more in line with those listed in Table 2 (European Commission 2005).

8. Conclusions

The international safety standards provide the necessary framework and guidance for protection of workers against exposure to radon and NORM, and no major changes are anticipated over the next few years. However, because the standards have evolved over the course of a decade, there are some inconsistencies and ambiguities that will most likely need to be addressed in the next version of the BSS. Supporting informational material for publication in the IAEA Safety Reports series, describing good practices and giving practical examples and detailed methods that can be used to implement the standards within specific industry sectors, is under development and starting to become available.

Two key issues in applying the standards to operations involving exposure to radon and NORM are the determination of what needs to be considered for regulation and the importance of making full use of the options available within the graded approach to regulation. The use of criteria expressed in terms of activity concentration enables the range of materials requiring regulatory consideration, and hence the types of operation involved, to be narrowed down to manageable proportions. The availability of reliable information on worker doses in specific types of operation is essential for determining the most appropriate regulatory option, including the option of not applying any regulatory requirements at all (exemption). Studies based heavily on modelling using generic exposure scenarios and assumptions have been shown to give unreliable predictions of worker doses, with a tendency for overestimation. Preliminary information based to a greater extent on measurements in real situations indicates that only relatively few types of operation may require regulatory control but that these differ widely in the level of radiological hazard involved, and thus in the level of stringency of control required.

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