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Establishment of reference levels for regulatory control of workplaces where materials are processed which contain enhanced levels of naturally occurring radionuclides

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ESTABLISHMENT OF REFERENCE LEVELS FOR REGULATORY CONTROL OF WORKPLACES WHERE MINERALS ARE PROCESSED WHICH CONTAIN ENHANCED LEVELS OF NATURALLY OCCURRING RADIONUCLIDES

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ABSTRACT

The revised Basic Safety Standards specify the requirements for a regulatory control system for the protection of workers and the public from sources of ionising radiation. In the special case of occupational exposure of workers to natural radiation sources, competent national authorities may determine which work activities require controls. However there is a need for the harmonisation of approaches in the EU. This report describes a study performed by NRPB and CEPN for the European Commission to establish a classification system and reference levels for the regulatory control of workplaces involved in the processing of materials containing enhanced natural radionuclides.

The methodology for the assessment of workplace exposure to materials containing naturally occurring radionuclides is described in a separate paper. This methodology was used to derive reference levels for a number of materials in the non-nuclear industry. Four reference levels were derived for each material, corresponding to different dose criteria and hence different levels of regulatory control. It is the aim that these assist competent national authorities in identifying work areas that may pose a radiological hazard to workers in the non-nuclear industry who are exposed to materials containing enhanced levels of naturally occurring radionuclides.

INTRODUCTION

Certain minerals contain significant levels of naturally occurring of radionuclides in conjunction with elevated quantities of other elements for which they are extracted and processed. These materials, their by-products from processing and the end products may expose both workers and members of the public to ionising radiation.

The revised Basic Safety Standards [1] provide a regulatory control system for the protection of workers and the public from sources of ionising radiation; however they do not necessarily apply to the exposure of workers to natural radiation sources. In this case competent national authorities may determine which work activities require controls but there is a need to harmonise the approach in the European Union (EU). This paper describes a European Commission (EC) study set up to address the problem by establishing reference levels for the regulatory control of the workplaces involved [2]. In order to establish reference levels it was necessary to develop a methodology for the generic assessment of workplace exposure to materials containing elevated levels of naturally occurring radionuclides. This is described in another paper. To summarise, one scenario or exposure situation was developed per material. This approach avoids complications in relating radionuclide concentrations in by-products and finished products to those in feedstock. Two sets of parameter values were developed, one relating to "normal" and one to "unlikely" assumptions concerning the exposure of the worker (see reference [2]). These scenarios were used to derive the activity concentration in each material that relates to an individual dose criterion. These "derived levels" were then used to obtain screening and reference levels based on different levels of regulation.

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TERMINOLOGY

Modelling natural decay chains

The U-238, Th-232 and U-235 decay chains each contain a number of radionuclides. However, many of these radionuclides are very short lived, with half lives of less than one year, and these can be considered to be in secular equilibrium with their parent radionuclide. This means that the chains can be simplified into a smaller number of key radionuclides and chain segments, where chain segments are nuclides together with their short lived daughters assumed to be in secular equilibrium with them. Chain segments are denoted with the symbol "+" throughout this paper. For example, 1 Bq g^{-1} of U+238 is modelled as 1 Bq g^{-1} of each of U-238 and Th-234 together with 0.998 Bq g^{-1} of Pa-234m and 0.0033 Bq g^{-1} of Pa-234. Hence, chain segments are essentially treated as individual radionuclides with composite characteristics. The natural decay chains may be in secular equilibrium. Exceptions are modelled by varying the concentrations of the key nuclides or chain segments.

Derived levels

Before describing the derivation of reference and screening levels, it is necessary to introduce the concept of derived levels. A derived level for a particular material is the activity concentration of a radionuclide that gives rise to a certain dose, the dose criterion. The derived level always refers to the concentration of a single radionuclide (or head of a chain segment) but it needs to be made clear whether the actual value does or does not allow for the contributions from other radionuclides that are present in other chains or chain segments.

There are three different types of derived level that have been used in this study:

a) Derived nuclide level

This derived level takes into account only the contribution of a single nuclide or chain segment.

$$DL_N(n) \ (Bq\ g^{-1}) = \frac{\text{Dose criterion (Sv)}}{\text{Nuclide (segment) dose per unit activity (Sv per Bq g}^{-1})} = \frac{c}{D(n)}$$

It should be noted that the derived nuclide level for members of the segment is equal to the derived level for the parent nuclide of the segment, multiplied by the appropriate factor taking into account the state of equilibrium within the segment.

The derived nuclide levels are very useful when only a single radionuclide or chain segment is present in a material, but they do not take into account contributions from other radionuclides (segments) or other chains.

For natural radionuclides it is usual for the entire decay chain to be present. It is made up of several nuclides (segments) each having a particular activity and these need to be taken into account.

b) Derived chain level

This accounts for the contributions of other radionuclides in a decay chain by incorporating an appropriate state of equilibrium between the key nuclides (segments) of the chain. This state of equilibrium may vary from material to material. The state of equilibrium is expressed by the activity of a nuclide (segment) relative to the activity of the head of chain and given the name R_N. The relative contributions for all *m* radionuclides in a single decay chain are included by using the following method.

$$\text{Derived chain level for nuclide n: } DL_{CH}(n) = \frac{c}{\Sigma_m\{D(m) \times R_N(m)\}} \quad R_N(n)$$

The derived chain level for any other nuclide (segment) can be obtained by multiplying the relevant DL_{CH} by the activity of the nuclide (segment) relative to the activity of the head of chain, in the considered state of equilibrium. Now any radionuclide (segment) in a decay chain can be compared to its derived chain level and other radionuclides present in the decay chain are automatically taken into account. However the contributions from the two other natural decay chains will still need to be allowed for if they are present.

c) *Derived indicator levels*

This derived level takes into account the contributions from radionuclides in all natural decay chains, considering a particular state of equilibrium in each chain, and a particular ratio of activities between chains. This composition will vary from material to material. Each radionuclide (segment) is assumed to have a given activity (given the name R_C) relative to the head of the reference chain. Therefore for a total of **m** nuclides in all chains, the derived indicator levels for nuclide (segment) **n** is:

$$\text{Derived indicator level for nuclide n: } DL_I(n) = \frac{c}{\Sigma_m\{D(m) \times R_C(m)\}} R_C(n)$$

A derived indicator level for any nuclide segment *n* may be used as an indicator for <u>all</u> the radionuclides present. As only a single nuclide needs to be compared to its derived indicator level these values are the simplest to interpret for regulatory purposes.

Reference levels and screening levels

The reference levels and screening levels are derived levels based on particular combinations of dose criteria and assumptions. They are called reference levels when expressed in terms of nuclide levels and screening levels when expressed as indicator levels.

INDIVIDUAL DOSE CRITERIA FOR THE CLASSIFICATION SYSTEM

Philosophy of the classification system

The purpose of the classification system is to provide a clear link between an activity concentration of radionuclides in a material and the degree of regulation needed to provide adequate protection of workers from the radiological hazard. Levels of regulation are based on both the implied individual doses and the assumptions made in calculating it (is it a "normal" or an "unlikely" situation?). To assist in the development of a system, relevant existing approaches were reviewed.

ICRP recommendations

The ICRP recommendations, published in 1991 [3], provide a framework for the protection of workers and members of the public from ionising radiation. ICRP recommends effective dose limits (to reduce the risk of stochastic effects to tolerable levels): these are 1 mSv y^{-1} for members of the public and 100 mSv y^{-1} over a 5 year period for workers, with a limit of 50 mSv in any one year. ICRP also recommends skin equivalent dose limits (to prevent deterministic effects) of 50 mSv y^{-1} for members of the public and 500 mSv y^{-1} for workers. When discussing the classification of workplaces, ICRP recommends the designation of work areas into controlled areas and supervised areas. It recommends that the designation should be based on the expected level of individual annual dose and also that it should take into account likely variations and the potential for accidents. However, ICRP 60 [3] does not recommend a particular value of dose at which a controlled area should be defined.

The revised Basic Safety Standards

The revised BSS [1] adopt the dose limits recommended by ICRP. Again, they do not rigidly define controlled and supervised areas in terms of expected individual dose but in Title VI, Article 21 it defines two categories of workers: Category A who are liable to receive an effective individual dose greater than 6 mSv per year or an equivalent dose greater than 3/10 of the organ dose limits for workers, and Category B who are liable to receive lower doses.

The structure of similar workplace classifications in the nuclear industry
Four fundamental classes of workplace are considered in the nuclear industry, all defined by the dose that is received under normal conditions.

If the normal dose received is less than the public dose limit, radiological considerations give rise to no additional regulatory requirements placed on the workplace to govern the working practices in it. If the dose is normally between this and 3/10 of the worker limit then the area is designated a "supervised" area and there is some degree of regulation. More complex regulatory control comes into force if the dose, under normal conditions, is greater than 3/10 of the worker limit. Finally there is the worker dose limit. Work practices giving rise to doses above these levels are forbidden as they are deemed to give rise to an unacceptable level of risk.

It is interesting to note that in practice these dose criteria are commonly interpreted by operational health physicists as applying to unlikely rather than normal conditions.

DEFINITION OF THE CLASSIFICATION SYSTEM

Defining the reference points for the classification system
The proposed classification system for natural radionuclides in the non-nuclear industry contains five distinct regions defined by four reference points. Each region describes a level of protection consistent with the possible radiation hazards and each reference point is a combination of individual dose criteria relating to normal and unlikely assumptions. This study has considered four components for each reference point: the dose criterion for effective dose under normal conditions, the dose criterion for effective dose under unlikely conditions, the dose criterion for skin dose under normal conditions and the dose criterion for skin dose under unlikely conditions. The chosen scheme is presented graphically in Figure 1. The five distinct regions are described in turn.

a) *Doses below the first reference point, the conservative lower limit to regulation:*
Unlikely assumptions $D \leq 1\ mSv\ y^{-1}$, $H \leq 50\ mSv\ y^{-1}$

If the dose a worker is unlikely to ever exceed the dose limits for members of the public, there is clearly no need for regulating work activities.

b) *Doses below the second reference point, the lower limit to regulation based on normal assumptions:*
Normal assumptions $D \leq 1\ mSv\ y^{-1}$ *and* $H \leq 50\ mSv\ y^{-1}$ *and Unlikely assumptions* $D \leq 6\ mSv\ y^{-1}$, $H \leq 500\ mSv\ y^{-1}$

If the effective dose to a worker is normally below 1 mSv y^{-1}, but may be slightly higher in unlikely situations then there is probably no need for regulatory control. The dose is below the public dose limit in almost all situations, but could breach it in some cases. Similar arguments may be made in the case of the skin equivalent dose. Hence there is no need for regulation based on normal assumptions.

c) *Doses between the second and third reference points, the region of the lower level of regulation:*
Normal assumptions D between 1 and 6 $mSv\ y^{-1}$ *and Unlikely assumptions* $D < 20\ mSv\ y^{-1}$, $H < 500\ mSv\ y^{-1}$ *in all cases*

As stated above, if the effective dose to a worker in normal conditions is above 1 mSv y^{-1} or the skin dose is above 50 mSv y^{-1} , then some level of regulation of the workplace is necessary as the person is receiving more than the public dose limit. However, it can be argued that if effective doses do not exceed 6 mSv y^{-1} normally and do not exceed 20 mSv y^{-1} even in unlikely situations, then a lower level of regulation is acceptable as long as the skin equivalent dose is below 500 mSv y^{-1}. This corresponds to a "supervised area" in the nuclear industry scheme and Category B workers.

d) *Doses between the third and fourth reference points, the region of the higher level of regulation:*
Normal assumptions D between 6 and 20 mSv y^{-1} and Unlikely assumptions $D < 50$ mSv y^{-1}, $H < 500$ mSv y^{-1} in all cases

If the worker effective dose is more than 6 but less than 20 mSv y^{-1} (under normal conditions) and the skin dose is below 500 mSv y^{-1}, then a higher level of regulation is needed to more carefully ensure that radiation protection philosophy is being applied to the practice. This corresponds to the "controlled area" in the nuclear industry and Category A workers.

e) *Doses above the fourth reference point, the upper limit to classification:*
Normal assumptions $D > 20$ mSv y-1 and Unlikely assumptions $D > 50$ mSv y-1 , $H > 500$ mSv in both cases

If the effective doses are greater than 20 mSv y^{-1} in normal conditions or a maximum of 50 mSv y^{-1} in unlikely conditions, and the skin equivalent dose limit is exceeded, the practice is clearly unacceptable in its current form as it implies unacceptable risks. The practice would need to cease unless it was possible to derive factory specific reference levels or do detailed dose assessments that showed that the doses were indeed below the worker dose limits for that specific case. In other words the level would require a thorough review of working practices etc.

SCREENING LEVELS AND REFERENCE LEVELS

Results

Derived nuclide levels were calculated for each reference point by using the four dose criteria described above, the scenarios described in reference [2], and by selecting the minimum of the four concentrations. Two different sets of results are presented. The first set is called screening levels. These are derived indicator levels that correspond to the four reference points and hence they take into account the contributions from all the other nuclides present in the material. They are given in Table 1 for the most significant nuclide for each material. There is one column per reference point. The second set is called reference levels. These are derived nuclide levels that correspond to the four reference points and hence do not allow for contributions from other radionuclides present in the material. These are given in Table 2 for selected materials. The complete set of results is in reference [2]. It is envisaged that the screening levels are used to give a first estimate of the classification of a particular workplace by using the logic described in 4.1. This would then be followed by an analysis of the radionuclide composition of the material used in the workplace and a more precise classification of the workplace using the reference levels.

Discussion

It can be seen from Tables 1 and 2 that the screening or reference level for a particular nuclide varies considerably from material to material, even when considering the same reference point. This means that it would not be advisable to select a nuclide screening or reference level that would apply to all materials.

It was found that 16 out of the 42 materials considered in this study have maximum concentrations below the screening level for the third reference point, implying that the higher level of regulation may be necessary for the remaining 26 materials.

The screening levels incorporate both the relative activity of different natural radionuclide decay chains and their state of equilibrium. They may be recalculated for a mixture of radionuclides different from that which has been assumed, if a competent national authority feels that the activity concentrations used in this study do not adequately reflect the types of raw materials or by products that are found in their country.

The interaction of screening/reference levels with transport regulations requires addressing, as it would be advisable that any material regarded as unregulated during processing should not require regulation when transported: there are some cases where the transport exemption level is more restrictive than the lowest two screening levels. Similarly, it is worth noting that the BSS [1] exemption levels for natural radionuclides are of a similar order of magnitude to the reference levels. It is therefore very important that care is taken to distinguish between the two sets of levels.

SUMMARY

A classification system has been proposed for non-nuclear industries in which enhanced levels of naturally occurring radionuclides are encountered. The classification system has five regions defined by four reference points. Each reference point considers an effective dose criterion and a skin dose criterion for both normal and unlikely conditions. The five regions describe the levels of protection consistent with the possible radiation hazard and are as follows: no regulation necessary; no regulation based on normal assumptions; lower level of regulation; higher level of regulation; and forbidden.

A generic methodology was used to calculate doses from representative working conditions appropriate to a range of industries and materials. These were used to derive screening levels and reference levels that correspond to the four reference points in the classification system. Screening levels allow for the contributions of other nuclides present in the material; reference levels do not. It was found that these screening and reference levels had to be material specific as there was such a wide range of values. A preliminary review of the screening levels indicates that some degree of regulation may be required for many of the materials containing enhanced levels of natural radionuclides.

REFERENCES

[1] Council directive 96/29/Euratom of 13 May 1996 laying down the Basic Safety Standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation.

[2] EC. Establishment of reference levels for regulatory control of workplaces where minerals are processed which contain enhanced levels of natural radionuclides. Report by NRPB and CEPN under contract no 95-ET-009. *To be published*

[3] ICRP. 1990 recommendations of the International Commission on Radiation Protection. ICRP 60. *Ann ICRP,* **21** Nos 1-3 (1991)

Table 1: Screening levels in Bq g^{-1} for some selected materials

Material	Indicator nuclide or segment	Effective dose criteria of classification			
		$U \leq 1$ mSv y^{-1}	$U \leq 6$ mSv y^{-1} $N \leq 1$ mSv y^{-1}	$U \leq 20$ mSv y^{-1} $N \leq 6$ mSv y^{-1}	$U \leq 50$ mSv y^{-1} $N \leq 20$ mSv y^{-1}
Phosphogypsum	U+238	$5\ 10^{-2}$	0.1	0.7	2
Tin smelting Po precipitates	Po-210	70	400	$1\ 10^{3}$	$3\ 10^{3}$
Zircon sands	Th-232	$2\ 10^{-2}$	$5\ 10^{-2}$	0.3	1
Oil/gas radium scales	Ra+226	6	30	100	300
NPK fertiliser	K-40	3	8	50	100

NOTE

U Indicates the dose criteria was compared against the predicted doses from unlikely assumptions

N Indicates the dose criteria was compared against the predicted doses from normal assumptions

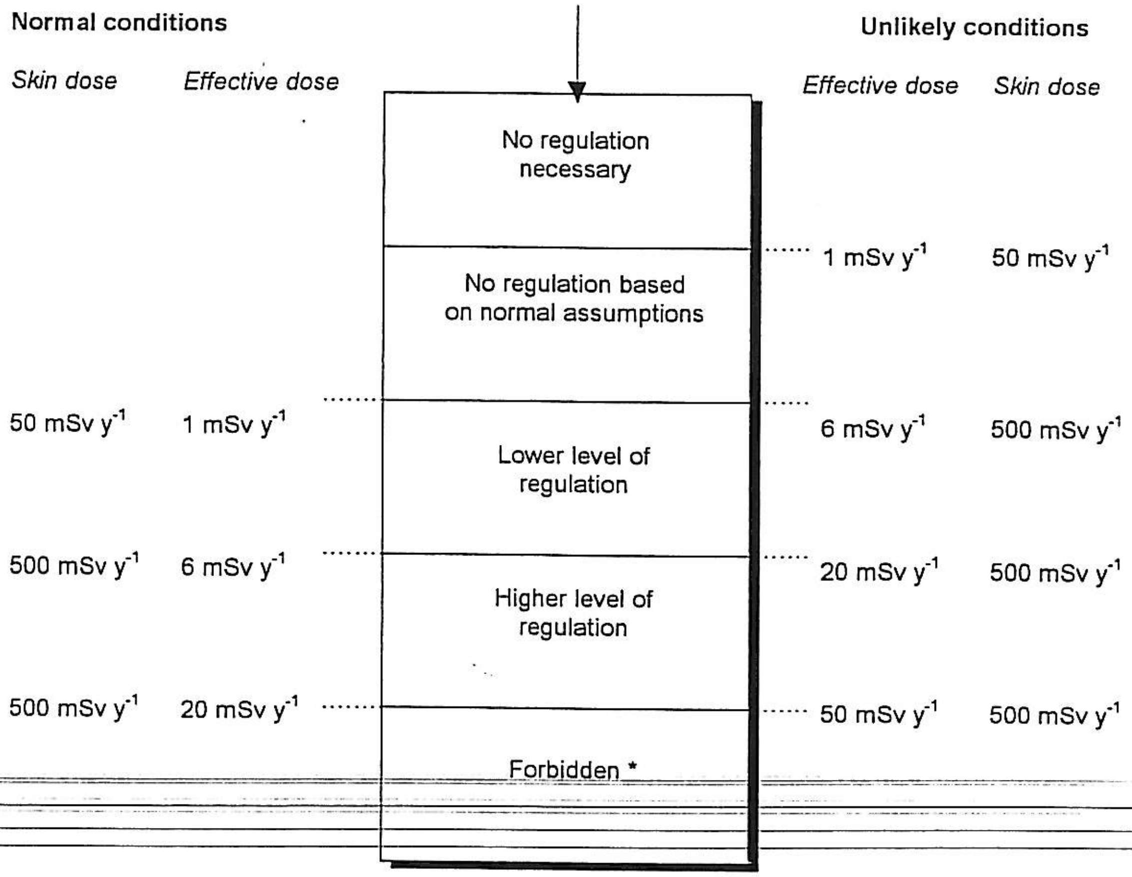
Table 2: Reference levels in Bq g^{-1} for some selected materials and several levels of regulation

Material	Th-232	Ra+228	Th+228	U+238	U-234	Th-230	Ra+226	Pb+210	Po-210	U+235	Pa-231	Ac+227	K-40
No regulation under normal assumptions (N ≤ 1 mSv y^{-1}, U ≤ 6 mSv y^{-1})													
Phosphogypsum	10	10	5	80	70	20	1	300	200	50	6	0.8	80
Tin smelting Po precipitates	-	-	-	-	-	-	-	-	400	-	-	-	-
Zircon sands	7	10	4	40	40	9	1	200	100	40	2	0.4	80
Oil/gas Ra residues	-	300	20	-	-	-	40	-	-	-	-	-	-
NPK fertiliser	10	10	5	80	70	20	1	300	200	40	6	0.8	80
Lower level of regulation (N ≤ 6 mSv y^{-1}, U ≤ 20 mSv y^{-1})													
Phosphogypsum	40	40	20	300	200	60	5	$1\ 10^3$	700	200	20	3	300
Tin smelting Po precipitates	-	-	-	-	-	-	-	-	$1\ 10^3$	-	-	-	-
Zircon sands	20	50	10	100	100	30	4	600	400	100	9	1	300
Oil/gas Ra residues	-	800	50	-	-	-	100	-	-	-	-	-	-
NPK fertiliser	40	40	20	300	200	60	5	$1\ 10^3$	700	100	20	3	300
Higher level of regulation (N ≤ 20 mSv y^{-1}, U ≤ 50 mSv y^{-1})													
Phosphogypsum	100	100	40	600	600	200	4	$3\ 10^3$	$2\ 10^3$	400	50	6	700
Tin smelting Po precipitates	-	-	-	-	-	-	-	-	$3\ 10^3$	-	-	-	-
Zircon sands	50	100	30	400	300	80	10	$2\ 10^3$	900	300	20	3	700
Oil/gas Ra residues	-	$2\ 10^3$	100	-	-	-	300	-	-	-	-	-	-
NPK fertiliser	200	200	60	$1\ 10^3$	$1\ 10^3$	300	10	$4\ 10^3$	$3\ 10^3$	700	90	10	$1\ 10^3$

NOTE: U - Indicates the dose criteria was compared against the predicted doses from unlikely assumptions

N - Indicates the dose criteria was compared against the predicted doses from normal assumptions

FIGURE 1: Graphical representation of the classification system



NOTE

* A thorough review of the working practices is necessary to obtain detailed dose assessments. If these doses are above the worker dose limits, the practice must cease.