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Radiological Protection Principles concerning the Natural Radioactivity of Building Materials

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Foreword

A working party of the Group of Experts established under the terms of Article 31 of the Euratom Treaty has examined the issue of regulatory control of building materials with regard to their content of naturally occurring radionuclides.

The working party developed guidance on the basis of a study providing information about natural radioactivity in building materials and relevant regulations in Member States[1]. This guidance was adopted by the Article 31 Group of Experts at its meeting on 7-8 June 1999 and is now published with a view to harmonisation of controls by Member States, in particular in order to allow movement of building products within the European Union.

This guidance will be a useful reference document for the European Commission when considering possible regulatory initiatives at Community level.

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[1] Contract No 96-ET-003, STUK (Finland), Enhanced Radioactivity of Building Materials, Radiation Protection 96, 1999

RADIOLOGICAL PROTECTION PRINCIPLES CONCERNING THE NATURAL RADIOACTIVITY OF BUILDING MATERIALS

CONTENT

1. INTRODUCTION

(1) The European Basic Safety Standards Directive[1] (BSS) sets down a framework for controlling exposures to natural radiation sources arising from work activities. Title VII of the directive applies to work activities within which the presence of natural radiation sources leads to a significant increase in the exposure of workers or of members of the public. The Member States shall identify work activities which may be of concern.

(2) The BSS directive does not apply to exposure to radon in dwelling or to the natural level of radiation, i.e. to aboveground exposure to radionuclides present in the undisturbed earth's crust. The term undisturbed earth's crust means the earth's crust where no quarrying, underground or open cast mining is carried out. Excavation or refill as part of construction work is not considered to disturb the earth's crust.

(3) The Commission Recommendation on Radon in Dwellings[2] introduces a design level for radon exposure in future constructions. The design level corresponds to an annual average radon gas concentration of 200 Bq m^{-3}. The design level is to be used to aid the relevant authorities in establishing regulations, standards or codes of construction practices for circumstances under which the design level might otherwise be exceeded.

(4) Amongst the activities identified in the BSS as potentially of concern are those "which lead to the production of residues … which contain naturally occurring radionuclides causing significant increase in the exposure of members of the public…". Such materials may include coal ash from power stations, by-product gypsum and certain slags which are produced in large volumes and which may potentially be used as building materials.

(5) The Construction Products Directive[3] lays down essential requirements for construction works. The construction works must be designed and built in such a way that the emission of dangerous radiation will not be a threat to the health of the occupant or neighbours. However, it is the Member States which are responsible for ensuring that works on their territory are designed and executed in a way that does not endanger the safety of persons. These national provisions influence the construction products and how they may be used in the works.

(6) In practice, different radiological considerations seem to apply to the use of natural materials and by-products as building materials. To some extent this distinction is appropriate, particularly where long established building practices are concerned. However, it would be incongruous if very different criteria were applied to decide on the acceptability of alternative materials containing similar levels of natural radionuclides and such differences are minimised in the control scheme proposed here.

(7) Some Member States have already established specific regulations on the radioactivity of building materials. While transposing the new BSS to national

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[1] Council Directive 96/29/EURATOM of 13 May 1996 laying down the basic safety standards of the health of workers and the general public against the danger arising from ionising radiation.

[2] Commission Recommendation of 21 February 1990 on the protection of the public against indoor exposure to radon.

[3] Council Directive of 21 December 1988 on the approximation of laws, regulations and administrative provisions of the Member States related to construction products.

legislation, also other Member States need to consider whether specific regulations should be established. It is desirable that controls should be sufficiently uniform to allow movement of building materials within the EU.

(8) The purpose of the following recommendations is to provide guidance for setting controls on the radioactivity of building materials. This guidance is not intended to be applied to existing buildings.

(9) In this document “building materials” means any material which is produced for incorporation in a permanent manner in buildings.

2. NATURAL RADIOACTIVITY OF BUILDING MATERIALS

(10) All building materials contain various amounts of natural radioactive nuclides. Materials derived from rock and soil contain mainly natural radionuclides of the uranium (^{238}U) and thorium (^{232}Th) series, and the radioactive isotope of potassium (^{40}K). In the uranium series, the decay chain segment starting from radium (^{226}Ra) is radiologically the most important and, therefore, reference is often made to radium instead of uranium. The world-wide average concentrations of radium, thorium and potassium in the earth's crust are about 40 Bq kg^{-1}, 40 Bq kg^{-1} and 400 Bq kg^{-1}, respectively. The results of a literature study (Ref. 1) on the radioactivity of building materials in the EU are summarised in Table 1.

(11) Radiation exposure due to building materials can be divided into external and internal exposure. The external exposure is caused by direct gamma radiation. Table 2 presents examples of the annual effective dose due to external exposure. The calculations have been carried out with a computer program published in reference (Ref. 2). For example, an inhabitant living in an apartment block made of concrete with average activity concentrations (40 Bq kg^{-1}, 30 Bq kg^{-1} and 400 Bq kg^{-1} for radium, thorium and potassium, respectively) receives an annual effective dose of about 0.25 mSv (excess to the dose received outdoors). Enhanced or elevated levels of natural radionuclides in building materials may cause doses in the order of several mSv a^{-1}.

(12) The internal exposure is caused by the inhalation of radon (^{222}Rn), thoron (^{220}Rn) and their short lived decay products. Radon is part of the radioactive decay series of uranium, which is present in building materials. Because radon is an inert gas, it can move rather freely through porous media such as building materials, although usually only a fraction of that produced in the material reaches the surface and enters the indoor air. The most important source of indoor radon is the underlying soil but in some cases and some Member States also the building materials may be an important source. In most cases the main part of indoor radon on the upper floors of a building originates from building materials. Typical excess indoor radon concentration due to building materials is about 10 –20 Bq m^{3}, but in some zones and in rare cases it may rise up to greater than 1000 Bq m^{-3}. Building materials are the most important source of indoor thoron. However, thoron concentrations are usually rather low. Indoor thoron can be an important source of exposure only under some rare conditions where the building materials contain high concentrations of thorium.

3. RADIATION PROTECTION PRINCIPLES

(13) The purpose of setting controls on the radioactivity of building materials is to limit the radiation exposure due to materials with enhanced or elevated levels of natural radionuclides. The doses to the members of the public should be kept as low as reasonably achievable. However, since small exposures from building materials are ubiquitous, controls should be based on exposure levels which are above typical levels of exposures and their normal variations.

(14) The concentrations of natural radionuclides in building materials vary significantly between and within the Member States. Investigations may need to be undertaken of the activities in various building materials where such information is not already available from earlier surveys.

(15) All building materials contain some natural radioactivity. Small, unavoidable exposures need to be exempted from all possible controls. A uniform exemption level within the European Union would allow free movement of most building materials within the EU.

(16) Restricting the use of certain building materials might have significant economical, environmental or social consequences locally and nationally. Such consequences, together with the national levels of radioactivity in building materials, should be assessed and considered when establishing binding regulations.

(17) The amount of radium in building materials should be restricted at least to a level where it is unlikely that it could be a major cause for exceeding the design level for indoor radon introduced in the Commission Recommendation (200 Bq m^{-3}).

(18) Exceptionally high individual doses should be restricted. Within the European Union, gamma doses due to building materials exceeding 1 mSv a^{-1} are very exceptional and can hardly be disregarded from the radiation protection point of view. When gamma doses are limited to levels below 1 mSv a^{-1}, the ^{226}Ra concentrations in the materials are limited, in practice, to levels which are unlikely to cause indoor radon concentrations exceeding the design level of the Commission Recommendation (200 Bq m^{-3}).

(19) Controls on the radioactivity of building materials can be based on the following radiological criteria and principles:

a) Dose criterion for controls

Controls should be based on a dose criterion which is established considering overall national circumstances. Within the European Union, doses exceeding 1 mSv a^{-1} should be taken into account from the radiation protection point of view. Higher doses should be accepted only in some very exceptional cases were materials are used locally (see Paragraph 30). Controls can be based on a lower dose criterion if it is judged that this is desirable and will not lead to impractical controls. It is therefore recommended that controls should be based on a dose in the range 0.3 – 1 mSv a^{-1}. This is the excess gamma dose to that received outdoors.

b) Exemption level

Building materials should be exempted from all restrictions concerning their radioactivity if the excess gamma radiation originating from them increases the annual effective dose of a member of the public by 0.3 mSv at the most. This is the excess gamma dose to that received outdoors.

(20) Separate limitations for radon or thoron exhaling from building materials should be considered where previous evaluations show that building materials may be a significant source of indoor radon or thoron and restrictions put on this source is found to be an efficient and a cost effective way to limit exposures to indoor radon or thoron.

(21) Investigation levels can be derived for practical monitoring purposes. Because more than one radionuclide contribute to the dose, it is practical to present investigation levels in the form of an activity concentration index. The activity concentration index should also take into account typical ways and amounts in which the material is used in a building. A methodology which can be used to derive such indexes is described in Annex I. The following activity concentration index (*I*) is derived for identifying whether a dose criterion is met:

$$I = \frac{C_{Ra}}{300\ Bq\ kg^{-1}} + \frac{C_{Th}}{200\ Bq\ kg^{-1}} + \frac{C_K}{3000\ Bq\ kg^{-1}}$$

where C_{Ra}, C_{Th}, C_K are the radium, thorium and potassium activity concentrations (Bq kg^{-1}) in the building material. The activity concentration index shall not exceed the following values depending on the dose criterion and the way and the amount the material is used in a building (these values are derived in Annex I):

Dose criterion	**0.3 mSv a^{-1}**	**1 mSv a^{-1}**
Materials used in bulk amounts, e.g. concrete	$I \leq 0.5$	$I \leq 1$
Superficial and other materials with restricted use: tiles, boards, etc.	$I \leq 2$	$I \leq 6$

(22) The activity concentration index should be used only as a screening tool for identifying materials which might be of concern. Any actual decision on restricting the use of a material should be based on a separate dose assessment. Such assessment should be based on scenarios where the material is used in a typical way for the type of material in question. Scenarios resulting in theoretical, most unlikely maximum doses, should be avoided.

4. APPLICATION

(23) The purpose of controls is to restrict the highest individual doses. Therefore, the dose criterion used for national controls should be chosen in a way that the majority of normal building materials on the market fulfil the requirements. Usually measurements

of activity concentrations are needed only in cases where there is a specific reason to suspect that the dose criterion for controls might be exceeded. The Member States should require, as a minimum, the measurement of types of materials which are generically suspect. Table 4 provides some indication where measurements might be needed.

(24) Appropriate dose assessments should be performed if it is discovered that the reference value of the activity concentration index (see Paragraph 21) is exceeded. Normally the producer or dealer would be responsible for ensuring and showing that a material put on the market fulfils the radiological requirements set by the Member State. However, other approaches might also be applied according to national circumstances and administrative practices, e.g. the builder or designer of the building could be the responsible party for ensuring that a new building complies with the radiological requirements set by a Member State.

(25) Materials should be exempted from all controls concerning their radioactivity if it is shown that the dose criterion for exemption is not exceeded. This can be done by comparing results of activity concentration measurements with the activity concentration index, or as appropriate, by means of a material-specific dose assessment. An exempted material should be allowed to enter the market (including import and export within the EU) and to be used for building purposes without any restrictions related to its radioactivity. In the case of export within the EU, it is understood that the value of the activity concentration index or a declaration of exemption should be included in the technical specifications of the material.

(26) Measurements of activity concentrations in building materials should be made with appropriate equipment which has undergone approved calibration and quality assurance programmes.

(27) Member States should ensure that advice and assistance is available to producers of, or dealers in, building materials, and as appropriate to the designers or builders, on methods of assessing doses to demonstrate compliance with the radiological requirements.

(28) When industrial by-products are incorporated in building materials and there is reason to suspect that these contain enhanced levels of natural radionuclides, the activity concentrations of these nuclides in the final product should be measured or assessed reliably from the activities of all component materials. Where necessary, also other nuclides than ^{226}Ra, ^{232}Th and ^{40}K shall be considered. The dose criterion should be applied to the final product.

(29) Industrial by-products are sometimes used in building materials. Such practices may avert the application of more stringent radiological criteria which have been established for the disposal of waste containing enhanced or elevated levels of natural radionuclides. In these circumstances, Member States should consider the introduction of separate controls on such by-products at the point of entry into the building material industry. The use of industrial by-products containing natural radionuclides in building materials which could result in activity concentration indices exceeding the values specified in these recommendations should be justified on a case by case basis by Member States. It is expected that such justification would include non-radiological criteria.

(30) Some traditionally used natural building materials contain natural radionuclides at levels such that the annual dose of 1 mSv might be exceeded. Some of such materials may have been used already for decades or centuries. In these cases, the detriments and costs of giving up the use of such materials should be analysed and should include financial and social costs.

References

1. Mustonen R., Pennanen M., Annanmäki M. and Oksanen E. Enhanced Radioactivity of Building Materials. Final report of the contract No 96-ET-003 for the European Commission. Radiation and Nuclear Safety Authority – STUK, Finland, 1997; Radiation Protection 96, Luxembourg, 1999.

2. Markkanen M. Radiation Dose Assessments for Materials with Elevated Natural Radioactivity. Report STUK-B-STO 32, Radiation and Nuclear Safety Authority – STUK, 1995.

Table 1. Typical and maximum activity concentrations in common building materials and industrial by-products used for building materials in the EU. Typical concentrations are population-weighted national means of different Member States. Maximum concentrations are maximum values reported in reference (Ref. 1). Higher values might have been reported elsewhere.

Material	**Typical activity concentration (Bq kg^{-1})**			**Maximum activity concentration (Bq kg^{-1})**		
Most common building materials (may include by-products)	^{226}Ra	^{232}Th	^{40}K	^{226}Ra	^{232}Th	^{40}K
Concrete	40	30	400	240	190	1600
Aerated and light-weight concrete	60	40	430	2600	190	1600
Clay (red) bricks	50	50	670	200	200	2000
Sand-lime bricks	10	10	330	25	30	700
Natural building stones	60	60	640	500	310	4000
Natural gypsum	10	10	80	70	100	200
Most common industrial by-products used in building materials						
By-product gypsum (Phosphogypsum)	390	20	60	1100	160	300
Blast furnace slag	270	70	240	2100	340	1000
Coal fly ash	180	100	650	1100	300	1500

Table 2. The annual external gamma dose caused by building materials in four different hypothesises of their activity concentrations . The dose is the excess to the average background originating from the earth's crust (50 nGy h^{-1}). The parameter values used for calculating the doses are given in Table 3.

	Activity concentrations, Bq kg^{-1}			
	Low activity material	**Average concrete**	**Upper level of normality**	**Enhanced concentrations**
^{226}Ra	10	40	100	200
^{232}Th	10	30	100	200
^{40}K	300	400	1000	1500
Structures in a building causing the irradiation:	**Annual excess dose**			
Floor, ceiling and walls (all structures)	less than dose from background	0.25 mSv	1.1 mSv	2.3 mSv
Floor and walls (e.g. wooden ceiling)	less than dose from background	0.10 mSv	0.74 mSv	1.6 mSv
Floor only (e.g. wooden house with concrete floor)	less than dose from background	less than dose from background	0.11 mSv	0.41 mSv

Table 3. Parameter values used in calculating the doses given in Table 2 and in deriving the activity index (Annex I). The specific dose rates are calculated with a computer program published in reference (Ref. 2).

Dimensions of the model room	4 m x 5 m x 2.8 m		
Thickness and density of the structures	20 cm, 2350 kg m^{-3} (concrete)		
Annual exposure time	7000 hours		
Dose conversion	0.7 Sv Gy^{-1}		
Background	50 nGy h^{-1}		
	Specific dose rate, nGy h^{-1} per Bq kg^{-1}		
Structures in a building causing the irradiation	^{226}Ra	^{232}Th	^{40}K
Floor, ceiling and walls (all structures)	0.92	1.1	0.080
Floor and walls (wooden ceiling)	0.67	0.78	0.057
Floor only (wooden house with concrete floor)	0.24	0.28	0.020
Superficial material: tile or stone on all walls (thickness 3 cm, density 2600 kg m^{-3})	0.12	0.14	0.0096

Table 4. General evaluation on the possibility of exceeding 0.3 mSv or 1 mSv because of the use of certain building materials. See Table 1 for typical activity concentrations.

Building material	**Exposure above 0.3 mSv / circumstances or explanation**	**Exposure above 1 mSv / circumstances or explanation**
Concrete	POSSIBLE/almost anywhere where bulk amounts are used	POSSIBLE/ if bulk amounts are used and the concrete contains large amounts of blast furnace slag, fly ash or natural sand or rock rich in natural radionclides
Aerated and light-weight concrete	POSSIBLE/if blast furnace slag, fly ash or natural materials rich in natural radionuclides is used.	NOT LIKELY/used only in walls
Clay bricks	POSSIBLE/if clay rich in natural radionuclides is used	NOT LIKELY/used only in walls
Sand-lime bricks	NOT LIKELY / low activity concentrations, limited use (only walls)	NOT LIKELY / low activity concentrations, used only in walls
Natural building stones	NOT LIKELY/ superficial or other minor use POSSIBLE/if used in bulk amounts	NOT LIKELY/superficial or other minor use POSSIBLE/if used in bulk amounts
Gypsum boards or blocks	NOT LIKELY/Natural gypsum POSSIBLE/ if radium rich by-product gypsum is used	NOT LIKELY/ superficial use or used only in walls

ANNEX I: DERIVATION OF ACTIVITY CONCENTRATION INDICES FOR BUILDING MATERIALS

The following activity index is derived to indicate whether the annual dose due to the excess external gamma radiation in a building may exceed 1 mSv. The activity index is calculated in the following way (see Table 3 for the parameter values):

The factor for radium:

Dose criterion 1 mSv a^{-1} = 10^{-3} Sv·a^{-1} = $(0.92 \mathrm{x} C_{Ra}-50) \cdot 10^{-9}$ Gy h^{-1} x 0.7 Sv Gy^{-1} x 7 000 h·a^{-1}

=> C_{Ra} = 276 Bq kg^{-1}

The factor for thorium:

Dose criterion 1 mSv a^{-1} = 10^{-3} Sv·a^{-1} = $(1.1 \mathrm{x} C_{Th}-50) \cdot 10^{-9}$ Gy h^{-1} x 0.7 Sv Gy^{-1} x 7 000 h·a^{-1}

=> C_{Th} = 231 Bq kg^{-1}

The factor for potassium:

Dose criterion 1 mSv a^{-1} = 10^{-3} Sv·a^{-1} = $(0.080 \mathrm{x} C_{K}-50) \cdot 10^{-9}$ Gy h^{-1} x 0.7 Sv Gy^{-1} x 7 000 h·a^{-1}

=> C_K = 3176 Bq kg^{-1}

In the final activity concentration index, the values computed above are rounded to the nearest full 100 Bq kg^{-1} (radium and thorium) or 1000 Bq kg^{-1} (potassium):

$$I = \frac{C_{Ra}}{300\ Bq\ kg^{-1}} + \frac{C_{Th}}{200\ Bq\ kg^{-1}} + \frac{C_K}{3000\ Bq\ kg^{-1}} \leq 1$$

where C_{Ra}, C_{Th}, C_K are the radium, thorium and potassium activity concentrations in Bq kg^{-1}.

The corresponding factors for a dose criterion of 0.3 mSv a^{-1} are 121 Bq kg^{-1}, 101 Bq kg^{-1} and 1390 Bq kg^{-1} for radium, thorium and potassium, respectively. The same activity concentration index can be used if its limit value is set at 0.5 instead of 1.

A background dose rate of 50 nGy h^{-1} corresponding to an average value outdoors in Europe has been used in deriving the activity concentration index. An other approach would be to use the average gamma dose rate indoors (about 70 nGy h^{-1}) as the background. This approach would not change significantly the factors of the activity concentration index.

The following activity indexes are derived to indicate whether the annual dose due to the excess external gamma radiation caused by superficial material may exceed 0.3 mSv. The activity index is calculated in the following way (see Table 3 for the parameter values):

The factor for radium:

Dose criterion 0.3 mSv a^{-1} = $0.3 \cdot 10^{-3}$ Sv a^{-1} = $0.12 x C_{Ra} \cdot 10^{-9}$ Gy h^{-1} x 0.7 Sv Gy^{-1} x 7 000 h a^{-1}

=> C_{Ra} = 510 Bq kg^{-1}

The factor for thorium:

Dose criterion 0.3 mSv a^{-1} = $0.3 \cdot 10^{-3}$ Sv a^{-1} = $0.14 x C_{Th} \cdot 10^{-9}$ Gy h^{-1} x 0.7 Sv Gy^{-1} x 7 000 h a^{-1}

=> C_{Th} = 437 Bq kg^{-1}

The factor for potassium:

Dose criterion 0.3 mSv a^{-1} = $0.3 \cdot 10^{-3}$ Sv a^{-1} = $0.0096 x C_{K} \cdot 10^{-9}$ Gy h^{-1} x 0.7 Sv Gy^{-1} x 7 000 h a^{-1}

=> C_{K} = 6378 Bq kg^{-1}

The same activity index as earlier can be used by setting its limit value at 2 instead of 1.

The corresponding factors for a dose criterion of 1 mSv a^{-1} are 1701 Bq kg^{-1}, 1458 Bq kg^{-1} and 21259 Bq kg^{-1} for radium, thorium and potassium, respectively. Once again, the same activity concentration index can be used by setting its limit value at 6 instead of 1.

Notice that there is no subtraction of background because the thin layers of superficial material do not reduce significantly the background dose.

ANNEX II: A SAMPLE DOSE ASSESSMENT

Gamma exposure in a concrete room

The walls, floor and ceiling of the model room (Table 3) are of concrete having the following activity concentrations:

^{226}Ra	80 Bq kg^{-1}
^{232}Th	70 Bq kg^{-1}
^{40}K	800 Bq kg^{-1}

The absorbed dose rate in air in the room can be calculated by using the specific dose rates given in Table 3:

Dose rate indoors = $(0.92 \cdot 80 + 1.1 \cdot 70 + 0.08 \cdot 800)$ nGy h^{-1} = 215 nGy h^{-1} = 0.215 μGy h^{-1}

The annual effective dose to an occupant from the gamma radiation originating from the concrete is 0.7 Sv Gy^{-1} x 7 000 h x 0.215 μGy h^{-1} = 1054 μSv = 1.1 mSv.

This is not, however, the excess exposure from building materials because concrete structures shield against gamma radiation from the undisturbed earth's crust. Using the average value of 50 nGy h^{-1} for the background, the excess dose rate in the room is therefore (0.215 - 0.050) μGy h^{-1} = 0.165 μGy h^{-1} and the annual excess effective dose to the occupant is 0.7 Sv Gy^{-1} x 7 000 h x 0.165 μGy h^{-1} = 809 μSv = 0.8 mSv.

As a comparison, the value of the activity concentration index (paragraph 21) is

I = 80/300 + 70/200 + 800/3000 = 0.88,

which is less than 1, indicating that the annual effective dose is less than 1 mSv, which the assessment also showed.

Notice that the value of the activity concentration index is not directly an estimate for the effective dose because the background dose is considered directly in the factors of the activity concentration index. The only case where the index has the same numerical value as the assessed effective dose in mSv, is the limit value of 1.