NRRC Specific Regulations

Reference Levels of Natural Occurring Radioactive Materials in Construction and Building Materials

NRRC-R-01-SR08
2023

هيئة الرقابة النووية والإشعاعية
Nuclear and Radiological Regulatory Commission

Specific Regulation

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Preamble

In accordance with the provisions of the Radiation Safety Regulation (NRRC-R-01), approved by the NRRC's Board of Directors in resolution No. (R/1/1/2022), dated 20 April 2022, chapter (4) section (19) article 52(c), this specific regulation provides detailed requirements for the implementation of the requirements stated in the Radiation Safety Regulation. This specific regulation has been prepared on the basis of International Atomic Energy Agency (IAEA) standards, as well as the international best practices and the experiences of similar international regulatory bodies, and in accordance with the Kingdom's international commitments, and it has been approved by the NRRC's CEO resolution No. 1095, dated 22/3/2023.

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Chapter 1: Objective, Scope and Definitions

Section 1: Objective

1. This specific regulation is to provide the regulatory requirements on import, excavation, and manufacturing considering radiation safety for using construction and building materials for the purpose of protection of the public and the environment from harmful effects of radiation exposure to these products in the Kingdom.

Section 2: Scope

2. This specific regulation shall apply to all inorganic bulk building materials (crushed stone, gravel, sand, cement, gypsum, etc.) and building products (facing, decorative and other products made of natural stone, bricks and wall stones), as well as industrial residues used directly as building materials or as raw materials for their production.

3. This specific regulation prohibits intentional addition of radionuclides to building materials and importing or exporting building materials that have intentionally added radionuclides.

4. This specific regulation is not intended to be applicable in case of nuclear and radiological emergency resulted to radioactive contamination of construction and building materials.

Section 3: Definition

Building material

Any construction product for incorporation in a permanent manner in a

building or parts thereof and the performance of which has an effect on the performance of the building with regard to exposure of its occupants to ionizing radiation.

Exposure (X)

Is a measure of ionization produced by radiation in air. X is measured by the conventional unit of roentgen (R) and the SI unit is coulomb per kilogram (C kg^{-1}).

External exposure

Exposure to radiation from a source outside the body.

Natural radioactivity

Is a radioactivity produced by sources of ionizing radiation that are of natural sources from uranium series ^{238}U, thorium series ^{232}Th, and potassium ^{40}K.

Artificial radioactivity

Is a radioactivity produced by sources of ionizing radiation that are of man-made or not of natural origin.

Chapter 2: Approach for Assessing Public Health Risk from Building Materials

Section 4: Radiation risk factors and dose criterion for building materials

5. Different amounts of radioactive nuclides can be found naturally in building materials. Mostly these materials derived from rock and soil mainly contain natural radionuclides of the uranium series ^{238}U, thorium series ^{232}Th, and potassium ^{40}K. Their emissions from building materials represent one of the major sources of radioactivity exposure, which contributes to the total annual effective dose of humans.

6. Radiation exposure due to building materials can be divided into external and internal exposure:

    a. The external exposure is caused by the direct gamma radiation.

    b. The internal exposure is caused by the inhalation of radon and its progenies. Radon is a part of the radioactive decay series of uranium and thorium series, which are present in building materials.

7. Safety requirements for building materials are issued in order to minimize the radiation exposure from the content of these materials. For the external exposure, the safety requirements are set in terms of annual effective dose of 1 mSv per year, in addition to outdoor external exposure, either for workers or inhabitants of dwellings.

8. The inhalation dose from radon is not considered in the reference level of 1 mSv per year. The radon from building materials and soil is

regulated by a separate reference level for indoor radon concentration. When gamma doses are limited to levels below 1 mSv per year, the ^{226}Ra concentrations in the materials are limited, in practice, to levels which are unlikely to cause indoor radon concentrations exceeding 200 Bq m^{-3}. In many cases, the radon indoors predominantly originates from the ground, and not from the building material.

Section 5: Classification of Construction and Building Materials

9. Building material can be classified in two different ways:

   a. According to building material's origin:

      i. Natural building materials are those unprocessed or minimally processed materials such as: wood, soil (mud, clay, sand... etc.), stone (marble, gravels... etc.), rock (granite, quartzite, dolomite... etc.), and fibrous plant.

      ii. Synthetic building materials are those processed materials without any intentional addition of radionuclides such as: steel, plastics, cement, concrete, glass, gypsum, sanitary appliances, tiles, petroleum-based paints, blocks, fabric, ceramic, bricks, and their products.

   b. According to building material's uses as:

      i. Houses and public buildings (internal uses, external uses).

      ii. Roads, playgrounds, and other civil engineering uses.

Section 6: Compliance to the Reference Level

10. In the case of building materials used in building construction: For building materials of concern from a radiation protection point of view (see Annex I), whether from natural origin or from those in which specific residues from identified NORM industries have been incorporated, the final gamma dose from the building and its compliance with the reference level of 1 mSv per year (in addition to outdoor external exposure) must be verified prior to the marketing of such materials. In any case, the application of an Activity Indexes (I_n) as a conservative screening tool is required as the initial step.

11. In the case of building materials used in roads, playgrounds, and other civil engineering:

    The reference level for the radiation dose of the public due to the gamma radiation caused by materials used in road, street, yard, and related construction work is 0.1 mSv per year.

Section 7: Activity Index

12. Activity Indexes (I_n) are screening tools that used to assess the compliance to the reference level. They are used to assess whether or not the reference level is exceeded. The activity index is calculated from activity concentration measurements (Bq kg^{-1}) of the material.

13. When activity indexes are calculated, radium (^{226}Ra) in the uranium decay series, thorium (^{232}Th) in the thorium decay series, potassium (^{40}K) and cesium (^{137}Cs) from global fallout are considered. Other nuclides may need to be taken into consideration in special cases.

14. The activity concentrations of these radionuclides must be determined according to the approved standard methods.

Section 8: Assessment of Radiation Doses

15. Materials used in building construction:

    a. For building materials mentioned in Section 6 of this specific regulation, the activity concentrations of the radionuclides specified in Section 7 are determined.

    The activity index "I" for final building materials intended for use in building construction is:

$$I_1 = \frac{C_{^{226}Ra}}{300} + \frac{C_{^{232}Th}}{200} + \frac{C_{^{40}K}}{3000}$$

    where $C_{^{232}Th}$, $C_{^{226}Ra}$ and $C_{^{40}K}$ are the activity concentration values of ^{232}Th, ^{226}Ra and ^{40}K in the final product expressed in Bq kg $^{-1}$.

    b. The index relates to the gamma radiation dose in excess of typical outdoor exposure inside a building constructed with a specific building material. The index applies to the building material, not to its constituents except when those constituents are building materials themselves and are separately assessed as such. For application of the index to such constituents, in particular residues from industries processing naturally occurring radioactive material recycled into building materials, an appropriate partitioning factor must be applied. When industrial by-products are incorporated in building materials, 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, further nuclides beyond ^{226}Ra, ^{232}Th and ^{40}K shall be considered. The index I should be applied to the final product.

c. The activity concentration index value of 1 can be used as a conservative screening tool for identifying materials that may cause the reference level laid down in Section 6 to be exceeded. If the activity index "I_1" is 1 or less than 1, the material can be used as building material, so far as radioactivity is concerned, without restriction. In the other case, the estimation of dose shall be required. Dose assessment should be based on scenarios where the material is used in a typical way for the type of material in question and needs to take into account other factors such as density, thickness of the material as well as factors relating to the type of building and the intended use of the material (bulk or superficial).

16. Materials used in road, street, and related construction work:

a. The activity index "I_2" for materials used in road, street and related construction work as defined as:

$$I_2 = \frac{C_{226Ra}}{700} + \frac{C_{232Th}}{500} + \frac{C_{40K}}{8000} + \frac{C_{137Cs}}{2000}$$

b. If the activity index "I_2" is 1 or less than 1, the material can be used, so far as radioactivity is concerned, without restriction.

c. In case of materials with a restricted use (such as usual paving stones or paving tiles), no separate investigation is required if the activity index (I_2) of the material is equal to or less than 1.5.

Chapter 3: Regulatory Control

Section 9: Reference Levels

17. The reference level applying to indoor external exposure to gamma radiation emitted by building materials, in addition to outdoor external exposure, shall be 1 mSv per year or less.

18. The reference level for the radiation dose of the public due to the gamma radiation caused by materials used in road, street, yard, and related construction work is 0.1 mSv per year or less.

19. For the determination of the Index I, at least the activity concentration of nuclides listed in Table (1) shall be measured. Other nuclides may need to be taken into consideration in special cases.

Table 1: List of the nuclides of interest that shall be measured to calculate the index I_n

Type of Use	Nuclides of Interest			
Houses and Public Build-ings	^{226}Ra	^{232}Th	^{40}K	
Road, Street, and Related Construction Work	^{226}Ra	^{232}Th	^{40}K	^{137}Cs*

* Only ^{137}Cs resulted from global fallout due to the nuclear tests or nuclear accidents in other countries shall be considered, and it is not acceptable to be present in houses and public buildings.

20. For use without restriction the radioactive contents of building materials, according to their uses, shall provide an activity concentration Index (I_n) as defined in "Section 6", that complies with the listed relations in Table(2).

Table 2: Values of Index (I_n) for building materials and any products that may be used without any restriction for construction purposes.

Type of Use	Nuclides of Interest	
Houses and Public Buildings	$I_1 = \frac{C_{^{226}Ra}}{300} + \frac{C_{^{232}Th}}{200} + \frac{C_{^{40}K}}{3000} \leq 1$	
Road, Street, and Related Construction Work	Bulk use	$I_2 = \frac{C_{^{226}Ra}}{700} + \frac{C_{^{232}Th}}{500} + \frac{C_{^{40}K}}{8000} + \frac{C_{^{137}Cs}}{2000} \leq 1$
	Superficial use	$I_2 = \frac{C_{^{226}Ra}}{700} + \frac{C_{^{232}Th}}{500} + \frac{C_{^{40}K}}{8000} + \frac{C_{^{137}Cs}}{2000} \leq 1.5$

21. If the activity index exceeds 1, the responsible party shall calculate the dose from external exposure to gamma radiation that would arise from the use of the building materials and verify the compliance to the reference level. Such an assessment shall be based on scenarios where the material is used in a typical way for the type of material in question. The dose assessment shall allow for the background levels of external exposure outdoors due to radionuclides of natural origin in undisturbed soil. Examples for calculating doses from external exposure to gamma radiation from building materials provided in Annex II.

22. For the building materials requiring dose assessment, the calculated annual effective dose "ED" from external exposure to gamma radiation due to the building material should be compared to the reference level. If the calculated effective dose is less than the reference level of 1 mSv, the building material should not be subject to restrictions on its use. If the calculated annual effective dose exceeds the reference level of 1 mSv, appropriate corrective measures should be taken, which may include setting specific restrictions on the uses envisaged for such building materials.

Section 10: Methodologies of Measurements

23. All measurements shall be taken prior to the use of building materials.

24. Measurements of activity concentrations in building materials should be made with appropriate equipment, which has undergone approved calibration and quality assurance programs.

25. Detection and quantification of the presence of specific radionuclides (Section 7, Table (1)) is usually made by laboratory analysis of representative samples. Gamma spectrometry is the preferred test method.

26. If a disequilibrium between the nuclides of a given chain can be assumed, it is recommended to use the maximum concentration for typifying the whole chain, keeping in mind that this approach may overestimate the dose.

Section 11: Obligations of the Responsible Party

27. The responsible party shall ensure that all aspects of radiation safety regarding production, use, handling and disposal of ash and materials are met. Furthermore, the responsible party shall ensure that all safety-related investigations and measurements are conducted.

28. The producers and distributors of such materials are all required to inform consumers of the level of radioactivity contained in the material.

Annex I: List of Types of Building Materials

Indicative list of types of building materials considered with regard to their emitted gamma radia-tion as referred in "Section 6" is shown below:

1. Natural materials

a. Alum-shale.

b. Building materials or additives of natural igneous origin, such as:

i. Granitoids (such as granites, syenite and orthogneiss),

ii. Porphyries;

iii. Tuff;

iv. Pozzolana (pozzolanic ash).

2. Materials incorporating residues from industries processing naturally occurring radioactive material, such as:

i. Fly ash;

ii. Phosphogypsum;

iii. Phosphorus slag;

iv. Tin slag;

v. Copper slag;

vi. Red mud (residue from aluminum production);

vii. Residues from steel production.

Annex II: Examples of Method Used for Assessment of Doses from Building Materials

- This Annex provides a dose assessment methodology for emitted gamma radiation from building and construction materials. This approach is needed for building materials and construction products if the index (I) exceeds (1) as stated in section 8 of this specific regulation.

- To prospectively assess indoor external gamma doses resulting from the use of a given building material, mathematical models need to be used. For that purpose, the activity concentrations of the radionuclides of interest have to be known, and a series of assumptions needs to be made regarding the room model including shape and size of the room, thickness and densities of the walls, existence of door and windows, etc.).

- In this annex, a room with dimension of 4m x 3m x 2.5 m without door and windows.

- The main contributors to the gamma dose are ^{226}Ra, ^{232}Th and their progeny, and ^{40}K. The activity concentrations of these radionuclides can be determined according to the approved standard methods as stated in section 7.

- In regard to building materials (construction products) used in their intended use as a final product in a permanent manner within a building or parts thereof, the procedure for the assessment of indoor gamma exposure of concern is summarized in the following flowchart:

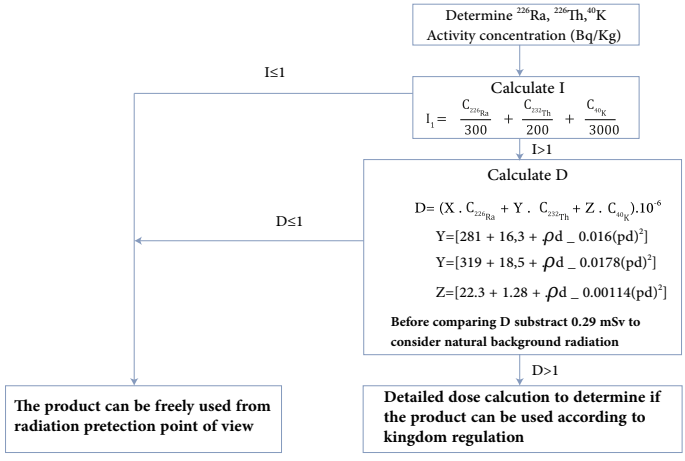

Figure 1: The procedure for the assessment of indoor gamma exposure of concern flowchart

This calculation was performed using an occupancy factor of 7000 hours and considering the building material used as bulk material. The proposed formula (eq. 1) calculate dose (D) (in mSv/y) is valid for a material with unit mass per area up to 500 kg m^{-2} due to self-attenuation phenomena.

$$Dose\ (mSv.y^{-1}) = \begin{bmatrix} [281 + 16.3\rho d - 0.0161(\rho d)^2] \cdot & C_{226_{Ra}} \\ +[319 + 18.5\rho d - 0.0178(\rho d)^2] \cdot & C_{232_{Th}} \\ +[22.3 + 1.28\rho d - 0.00114(\rho d)^2] \cdot & C_{40_K} \end{bmatrix} \cdot 10^{-6} \qquad (1)$$

The calculated dose (D), despite its correction for surface density (ρ) and thickness (d) of the material, remains a conservative estimate and is not necessarily representative for the product's dose under real conditions. Its restricted representation under real conditions is embedded in the selection of assumptions, such as ignoring doors and windows, assuming a room constructed from a single building product, and disregarding alternative room dimensions.

Example 1: The case when the index (I) is less than (1)
For a standard room of concrete and having the flowing measurements:

Density (kg/m^3)	2350
Thickness (cm)	20
^{226}Ra (Bq/kg)	60
^{232}Th (Bq/kg)	60
^{40}K (Bq/kg)	1200

$$I = \left(\frac{C_{226_{Ra}}}{300} + \frac{C_{232_{Th}}}{200} + \frac{C_{40_K}}{3000}\right) = \left(\frac{60}{300} + \frac{60}{200} + \frac{1200}{3000}\right) = 0.9$$

The Index (I) is less than (1), so material can be freely used.

Example 2: The case when the index (I) is greater than (1), but the dose is less than 1 mSv.y^{-1} For a standard room of concrete and having the following measurements:

Density (kg/m^3)	1350
Thickness (cm)	20
^{226}Ra (Bq/kg)	110
^{232}Th (Bq/kg)	80
^{40}K (Bq/kg)	1200
Background (mSv.y^{-1})	0.2

$$I_2 = \left(\frac{C_{226_{Ra}}}{300} + \frac{C_{232_{Th}}}{200} + \frac{C_{40_K}}{3000}\right) = \left(\frac{180}{300} + \frac{90}{200} + \frac{700}{3000}\right) = 1.17$$

Index (I) is higher than 1, the dose has to be assessed

$$D = \begin{bmatrix} [281 + 16.3\rho d - 0.0161(\rho d)^2] \cdot & C_{226_{Ra}} \\ +[319 + 18.5\rho d - 0.0178(\rho d)^2] \cdot & C_{232_{Th}} \\ +[22.3 + 1.28\rho d - 0.00114(\rho d)^2] \cdot & C_{40_K} \end{bmatrix} \cdot 10^{-6} =$$

$$= (3508 \cdot 110 + 4016 \cdot 80 + 285 \cdot 1200) \cdot 10^{-6} = 1.05\ mSv.y^{-1}$$

The dose is 1.05 mSv.y^{-1}, after the subtraction of a background of 0.2 mSv.y^{-1} the dose will be 0.85 mSv.y^{-1}, which is less than 1 mSv.y^{-1}, so the material can be freely used.

Example 3: The case when the index (I) is greater than (1), the dose is also greater than 1 mSv.y^{-1}

For a standard room of concrete and having the following measurements:

Density (kg/m^3)	2350
Thickness (m)	20
^{226}Ra (Bq/kg)	120
^{232}Th (Bq/kg)	90
^{40}K (Bq/kg)	1500
Background (mSv.y^{-1})	0.2

$$I = \left(\frac{C_{226Ra}}{300} + \frac{C_{232Th}}{200} + \frac{C_{40K}}{3000}\right) = \left(\frac{120}{300} + \frac{90}{200} + \frac{1500}{3000}\right) = 1.35$$

Index I is higher than 1, the dose has to be assessed

$$D = \begin{bmatrix} [281 + 16.3\rho d - 0.0161(\rho d)^2] \cdot & C_{226Ra} \\ +[319 + 18.5\rho d - 0.0178(\rho d)^2] \cdot & C_{232Th} \\ +[22.3 + 1.28\rho d - 0.00114(\rho d)^2] \cdot & C_{40K} \end{bmatrix} \cdot 10^{-6}$$

$$= (4386 \cdot 120 + 5082 \cdot 90 + 372 \cdot 1500) \cdot 10^{-6} = 1.54\ mSv.y^{-1}$$

The dose is 1.54 mSv.y^{-1}, after the subtraction of a background of 0.2 mSv.y^{-1} the dose is 1.34 mSv.y^{-1}. In this case, a more detailed dose assessment is required by the radiation protection expert, considering for example different room model.

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