Assessing the public exposure related to the use of NORM in new types of building materials

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Abstract. For a safe reuse of Naturally Occurring Radioactive Materials (NORMs) in construction, it is of great importance to evaluate the radiological aspects of the reuse in addition to chemical, environmental, economic… aspects before the construction materials are introduced on the market. This is of particular importance for new types of construction materials, such as alkali activated materials, that allow the reuse of a large faction (wt%.) of residues. The Euratom BSS (basic safety standards) sets the requirement of the radiological evaluation of building materials that incorporate specific residues from NORM related industries. In the period 2014-2017, the COST Action Tu1301 NORM4Building initiated a lot of research on the radiological evaluation of new types of construction material that are currently in the research state. In the course of the NORM4Building project a radiological database on NORM & building materials was developed. In addition, new dosimetrical tools were developed for a more realistic evaluate of the gamma dose related to the reuse of NORM in construction. These dosimetrical tools provide a more realistic radiological screening of the reuse of building materials in addition to the Activity Concentration Index (ACI) that is proposed by the EU-BSS as screening tool. In the current paper and linked presentation, the contents of the NORM4Building database will be presented next to the newly developed dosimetrical tools for the evaluation of the public exposure to gamma radiation from different types of building materials. The NORM4Building database is available via www.norm4building.org.

KEYWORDS Natural occurring radioactive materials, building materials, database, concrete, by-products, Euratom Basic Safety Standards

1. INTRODUCTION

Turning waste into resources is a key step on the Roadmap to a Resource Efficient Europe [1]. The recycled materials can however contain a measurable amount of natural occurring radionuclides such as ^{238}U, ^{232}Th and their decay products and ^{40}K and this aspect needs to be considered, particularly when the residues are included in building materials. Several industries that need to consider the precences of naturally occurring radioactive materials (NORMs) are listed in Annex VI of Council Directive 2013/59/Euratom [2]. An enhanced content of natural occuring radionuclides can be an issue for by-products such as fly ash from coal, peat and heavy oil fired power plants, phosphogypsum from phosphate industry, phosphorous slag from thermal phosphorus production, copper and tin slags from primary and secondary production, red mud from aluminium production and some residues from steel production. For the use of these by-products in building materials, the Council Directive 2013/59/Euratom (Euratom Basic Safety Standards; EU-BSS) [2] sets the requirement of the radiological evaluation of the produced building materials. In the EU-BSS, a screening parameter, the activity concentration index (ACI), is defined for the initial screening of the building materials incorporating NORM residues however the real criterion that determines if the use of the considered residues in building materials is acceptable or not is the reference level of 1 mSv/year.

In the concrete industries, the considered residues are used in increased amounts as supplementary cementitious materials (SCMs) (as partial cement replacement or as mineral additions in concrete) and as aggregates [3]. In the ceramic industries metal smelting slags can be used as aggregates in clay-based ceramics [4]. In the bond system of clay ceramics residues, such as red mud, can be used [4]. Alternatives for cement and concrete using Alkali-Activated Materials (AAMs) are being developed. AAMs contain calcium silicate or a more aluminosilicate-rich precursor such as a fly or bottam ash, metallurgical slag or natural pozzolan, as solid aluminosilicate source [5].

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2. SCENARIOS FOR INCORPORATION OF A BY-PRODUCT IN CONCRETE

Table 1 lists the compositions which were used to model the use of by-products in specific types of concrete.

Table 1 Description of concrete compositions used in the model compositions

Scenario ID	**Construction Material**	**Composition (kg/m³)**			
		Cement	**By-product**	**Aggregates**	**Water**
1	Reference concrete	400		1850	150
2	High volume fly ash (HVFA) concrete	160	220 (fly ash (FA))	1700	140
3	Concrete with FA as partial replacement of cement and sand’	320	130 (FA)	1750	150
4	Concrete with FA as partial replacement of sand	360	90 (FA)	1800	150
5	Concrete with slag as partial replacement of cement and aggregates’	80	720 (slag)	1850	150
6	Concrete with slag as partial replacement of cement	80	320 (slag)	1850	150
7	Concrete with slag as partial replacement of aggregates’	400	400 (slag)	1450	150
8	Alkali activated concrete containing red mud as partial replacement of cement and aggregates		1800 (red mud)	450	150

The activity concentration index (equation 1) [6] was calculated for several types of concrete using the compositions listed in table 1.

$$I - index = \frac{Ac_{226Ra}}{300\ Bq/kg} + \frac{Ac_{232Th}}{200\ Bq/kg} + \frac{Ac_{40K}}{3000\ Bq/kg} \quad (1)$$

With Ac the activity concentration of the mentioned radionuclide expressed in Bq/kg. The average values of 0.38 and 0.45 were used in the calculations as I-indexes for respectively cement and soil/aggregates [7]. The results of the I-index calculation using the concentrations listed in Table 1 are described in detail in [8].

3. DATABASES TO ASSESS THE USE OF NORM IN CONSTRUCTION

During the course of the COST Action NORM4Building several stategies to data collection and the verification of the collected were explored and efforts were initiated to merge databases that contain data on NORM and the use of NORM in construction materials.

A lot of data on natural radioactivity in European building materials was collected by Trevisi et al. [7]. Recently, this dataset that mainly contained data on ^{226}Ra, ^{232}Th and ^{40}K activity concentrations of building materials in Europe was further enlarged and expanded with radon emanation and exhalation rates [9]. The data collection for the construction of this database and the verification of the collected results involved an extremely labour intensive process.

A new approach to data collection was developed in order to semi-automatically collect data from scientific publications. This appoach that relies on automated data mining via natural language processing and text link analysis is further described in [8]. This approach has important advantages: (1) hundreds of publications can be processed automatically at a monthly basis; (2) the approach allows a continuous (automated) search for newly published literature and is therefore very useful for keeping an inventory up to date; (3) the data search can be expanded or modified using different key-words which allows the construction of a more detailed and expanded database. In its current form, the approach has several limitations: (1) data from graphical images (eg.: histograms) is not collected; (2) the licence for datamining software is very expensive; (3) the reliability of the collected data is strongly dependent of the reliability of the included publications, an aspect that cannot be assessed by the automated datamining program, and therefore the validation of the results requires a labour intensive verification step; (4) the included publications enclose both papers that reported averaged results and papers that reported individual measurements in more detail. A drawback of this fact is that only a limited amount of statistical analysis can be applied on the collected data. On the basis of this approach the NORM4Building database was constructed and this database is available via www.norm4building.org. A large set of the data that is collected in this database is described in detail in [8] and [10].

To allow a more in-depth statistical analysis, a database that is purely based on individual measurement entries and not on average results reported in literature was constructed by Sas et al. [11] ('By-BM database'). This database allows many interesting analysis and visualisation options. A future aim is to step by step investigate the data reported in the previously mentioned databases and to track the underlying 'individual measurement results' (if they can be found) and to incorporated these, after a verification step, in the By-BM database. The combination of the described approaches and databases can provide important added value especially if automated data collection can be combined with more in-depth statistical analysis options. The By-BM database is accessible online via http://bybmproject.com/ and the data included was discussed in [11].

4. EXPANDED SET OF SCREENING TOOLS FOR GAMMA DOSE ASSESSMENT

For the assessment of gamma ray exposure from building materials several methods have been developed ranging from simple indices to more sophisticated Monte Carlo simulations [2][12][13][14]. In the dose assessment calculations based on gamma ray attenuation and build-up factors the density and wall thickness were identified as very critical parameters [15][16][17]. The approach implemented by the EU-BSS uses an Activity Concentration Index (ACI) [2] that does not include the density and wall thickness as modifiable parameters. Technical guide Radiation Protection (RP)-112 [6] describes the index, originally developed by Markkanen [18], in more detail. The index described in RP-112 assumes a standard room with dimensions 400 cm x 500 cm x 280 cm, uses the density of concrete (2350 kg/m^3) and assumes a thickness of 20 cm for walls, floors and ceilings. A screening method that takes into consideration density an thickness via a density and thickness corrected index I(ρd) was proposed by Nuccetelli et al. [19] Complementary to the methodology proposed by the EU-BSS, the technical report CEN/TR 17113:2017, potentially a precursor for the development of a harmonized European Standard, also included a more elaborate index that allows modifying the density and the thickness [20].

A new study described by Croymans et al. [21] provided a dose calculation assessment using the original dose calculation of Markkanen with an expanded set of gamma lines and a higher total gamma intensity. The developed model by Croymans et al. [21] that uses an expanded set of gamma lines is complementary to the existing ACI model, proposed in the EU-BSS and the density and thickness corrected assessments proposed by Nuccetelli et al. [19] and CEN/TR 17113:2017 [20]. An initial screening can be based on the ACI proposed by the EU-BSS, especially useful in case that the building materials are thinner than 20 cm or lighter than 2350 kg/m^3. For building materials thicker than 20 cm or heavier than 2350 kg/m^3 it is advisable to use a density corrected assessment tool, especially useful for standard room sizes. The expanded gamma dose assessment method, allowing the assessment of non-standard rooms, can be used in specific cases. This model also allows considering the presence of doors and windows in the considered model.

5. CONCLUSSION & OUTLOOK

A semi-automated database for screening, identifying materials of concern from a radiological perspective was set-up by the COST-Action NORM4Building. More realistic scenarios are proposed for assessing the impact of the use of NORM in building materials. Complementary tools for the evaluation of the gamma dose related to the use of NORM in building materials were developed.

The NORM4Building network joint forces with the EAN-NORM & EU-NORM networks to form the European NORM Association (ENA). Future aims involve the further integration of the developed databases and implementing the developed tools for gamma dose assessment in the online database.

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