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Abstract

To get a better insight into the radiological features of industrial by-products that can be reused in building materials a review of the reported scientific data can be very useful. The current study is based on the continuously growing database of the By-BM (H2020-MSCA-IF-2015) project (By-products for Building Materials). Currently, the By-BM database contains individual data of about 431 by-products and 1095 building and raw materials. It was found that in case of the building materials the natural radionuclide content varied widely (Ra-226: <DL-27851 Bq/kg; Th-232: <DL-906 Bq/kg, K-40: <DL-17922 Bq/kg), more so than for the by-products (Ra-226: 7-3152 Bq/kg; Th-232: <DL-1350 Bq/kg, K-40: <DL-3001 Bq/kg). The average Ra-226, Th-232 and K-40 contents of the reported by-products were respectively 2.52, 2.35 and 0.39 times higher than the building materials. The gamma exposure of bulk building products was calculated according to IAEA Specific Safety Guide No. SSG-32 and the European Commission Radiation Protection 112 based I-index (EU BSS). It was found that in most cases the I-index without density consideration provides a significant overestimation in excess effective dose.

Introduction

Generally, the minerals contain natural origin terrestrial radionuclides (U-238 and Th-232 series, furthermore K-40) which do not cause significantly higher radiation exposure in excess to the normal background levels. The current worldwide average activity concentration is 412 Bq/kg for K-40, 33 Bq/kg for U-238, 32 Bq/kg for Ra-226 and 45 Bq/kg for Th-232 [1]. In case of the building materials the reported world average values are 500 Bq/kg, 50 Bq/kg, 50 Bq/kg of K-40, Ra-226 and Th-232, respectively [2].

Although, the reported activity concentrations are relatively low, large variation can be found in case of specific areas. Occasionally, anomalies can occur. Elevated levels of radionuclides can be found in natural materials. In so many cases these materials were applied as building material. This is the reason why the determination of the natural radionuclide content in building materials is important to assess the exposure on residents because most individuals spend 80% or even more of their time under indoor condition. The chronic exposure of low doses from ionizing radiation can increase the risk of health damage to individuals, which may occur decades after the exposure [3].

Building materials can be produced directly from natural materials e.g. rocks, granite, clay, etc. or reuse of additional materials of industrial by-products, such as fly ash, bottom ash, steel slag, red mud, etc. The urgent investigation of reuse of by-products is essential to enabling new materials to be safely and efficiently integrated into new and refurbished buildings. To get an insight into the radiological features of potentially reusable by-products a review of the reported scientific data is necessary. This study is based on the continuously growing database of the By-BM (H2020-MSCA-IF-2015) project. The aim of this project is to characterize the mechanical and radiological parameters of constituents and prepared By-BM geopolymers made from industrial by-products. This project is connected to, and provides information to the NORM database of COST TU 1301 NORM4Building Action.

Materials and methods

In order to draw conclusions from scientific reported data embedded into By-BM database unified selection criteria was laid down:

- To get an overview about the gathered scientific reported data only individually reported sample information about the Ra-226, Th-232 and K-40 were obtained by gamma spectrometry was used. i.e. the range of activity concentration was usually not imported into the database. It was necessary to make the statistical analysis possible after datamining.
- Average results of certain materials were used only if the investigated material originated from the same site, e.g. quarries, mines, reservoirs. In the case of commercial building materials, the brand and the type of the samples had to be clearly mentioned in the reference to fulfil selection criteria. Furthermore, the range of the data was also checked and the mean was used only if the minimum and maximum values were within 20% of the mean.
- In several cases the U-238 activity concentration values were published. In those cases, the reported data was imported into the database only if the results were obtained from the Rn-222 progenies (Bi-214, Pb-214) to avoid the disequilibrium in the decay chain

Generally, to limit gamma exposure originated from building materials the widely used I-index – defined in RP112 [4] – is applied. The I-index can be calculated by the following equation:

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

Where C_{Ra-226}, C_{Th-232} and C_{K-40} are, respectively, the Ra-226, Th-232 and K-40 activity concentrations in Bq/kg. The calculation method, the I-index is based on the model of Markkanen [5] with fixed parameters of concrete building (density and thickness of the walls are 2350 kg/m^3 and 20 cm, respectively). The I-index value of 1.0 can be used as a conservative screening tool for identifying materials that during their use would cause doses exceeding the reference level (1 mSv/y excess in addition to outdoor exposure) in the case of bulk amount inbuilt. In the European Union [6] to control the gamma exposure originated from building materials the I-index is recommended for the member states to screen them.

The Council Directive [6] allows the dilution and mixing of construction materials as long as the final building product itself is below the activity concentration index value of 1.0, which makes possible the mixing of by-products with low activity level raw materials. The calculation of dose 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) to get precise dose estimation on residents.

The density and the thickness of modelled concrete room are constant parameter. In the case of the International Atomic Energy Agency (IAEA) released No. SSG-32 (Specific Safety Guide) the simplified calculation method is based on the same model of Markkanen [4] but the thickness and the density of the building material are taken into consideration during the calculation.

Results and discussion

The current version of the By-BM database contains individual data about Ra-226, Th-232, K-40 activity concentration of 30 different materials (23 building materials, 7 by-products, Table 1). Altogether, information about 431 by-products, 1095 building material and raw materials were collected from 48 countries.

The worldwide distribution and the number of data are illustrated in Fig. 1. It was found that in case of the building materials the natural isotope content varied widely (Ra-226: <DL-27851 Bq/kg; Th-232: <DL-906 Bq/kg, K-40: <DL-17922 Bq/kg), more so than the by-products (Ra-226: 7-3152 Bq/kg; Th-232: <DL-1350 Bq/kg, K-40: <DL-3001 Bq/kg). But the mean value of Ra-226, Th-232 and K-40 content of the reported by-products as respectively 2.52, 2.35 and 0.39 times higher in case of the by-products than the building materials.

This is the reason why generally the radionuclide content cannot be ignored since the by-products can cause increased radiological risk.

Table 1: The worldwide distribution and the number of data

Material name	#	Density	Material type	Material name	#	Density	Material type
		kg/m^3	BM/BP			kg/m^3	BM/BP
Aggregate	9	1900	BM	**Sandstone**	14	2323	BM
Basalt	3	3000	BM	**Serizzo**	5	2650	BM
Brick	243	1900	BM	**Sienite**	5	2700	BM
Cement	87	1500	BM	**Asbestos tile**	4	1750	BM
Ceramics	94	2400	BM	**Travertine**	9	2300	BM
Concrete	63	2350	BM	**Tuff**	10	2100	BM
Gas concrete	37	700	BM	**Volcanic**	7	1800	BM
Granite	297	2600	BM	**Bottom ash**	59	700	BP
Gypsum	66	865	BM	**Fly ash**	145	720	BP
Limestone	16	2600	BM	**Manganese clay**	44	2800	BP
Marble	72	2550	BM	**Phosphogypsum**	45	1500	BP
Pumice	3	650	BM	**Red mud**	92	1600	BP
Rock	31	2300	BM	**Steel slag**	41	2600	BP
Sand	19	1500	BM	**Residue of TiO_2**	5	4300	BP

In this study the absorbed gamma dose rate of a model room with 20 cm wall thickness with various density as calculated applying dose conversion factors of RP-112 without density consideration and the IAEA No. SSG-32, respectively. The data about Ra-226, Th-232 and K-40 activity concentration of the building materials were collected from worldwide scientific reported sources. The I-indexes of the building materials were also calculated and compared with the absorbed gamma dose rates of the 2 different calculation methods.

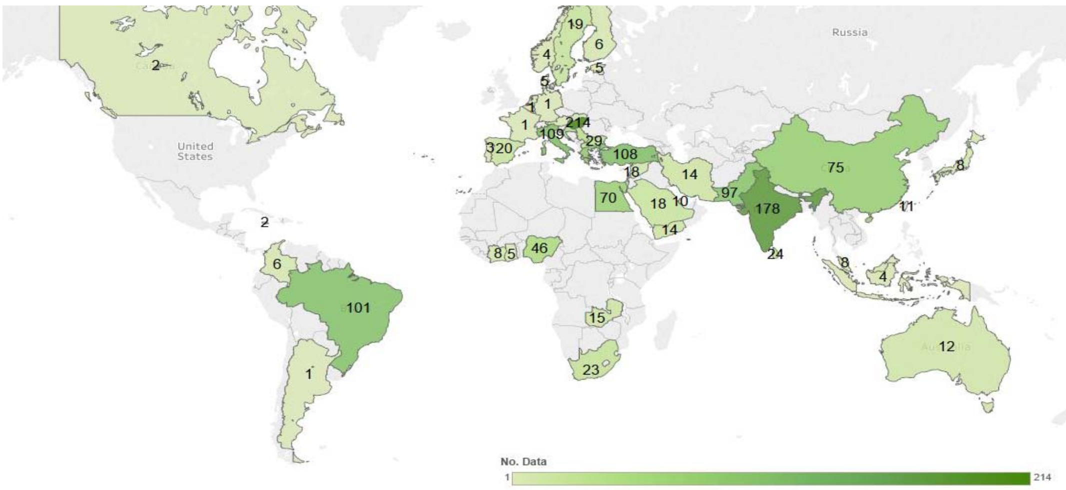

Fig. 1: The worldwide distribution and the number of data

The absorbed gamma dose rates results were compared and clearly proved that without density consideration the calculated dose rate is significantly higher in the case of low density building materials (Fig. 2a). Under 1000 kg/m^3 even 60-70% higher dose rate can be estimated. This is the reason why with density consideration the calculated I-indexes belong to lower dose rate which clearly proves the overestimation of I-index in connection with generated dose rate (Fig 2b).

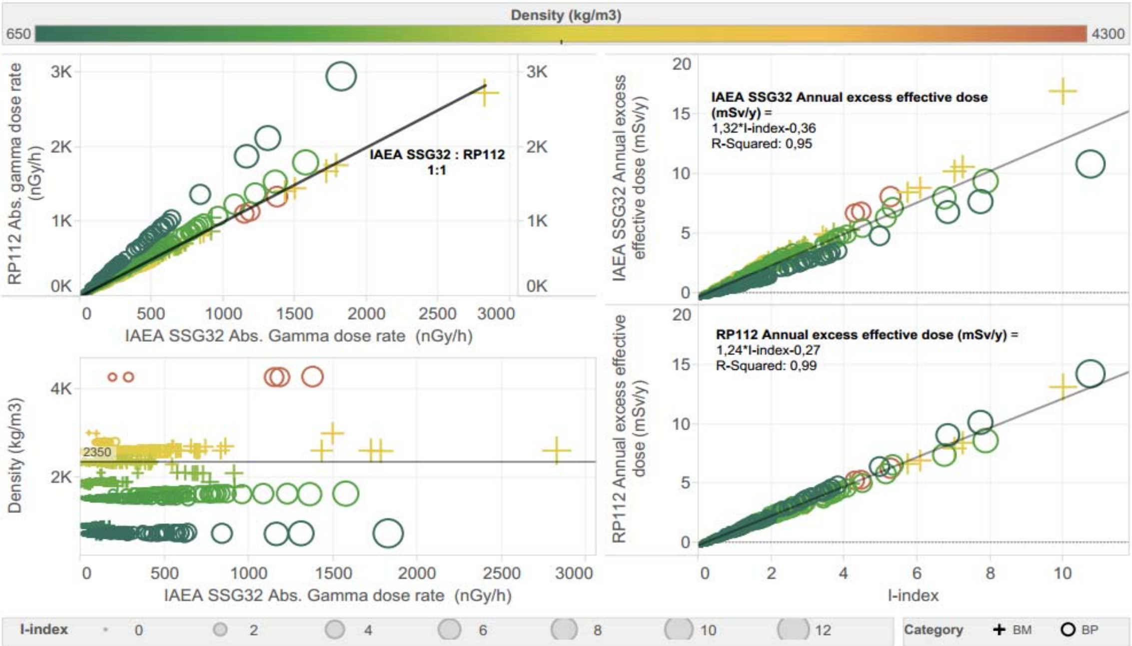

Fig. 2a: Overestimation without density consideration of absorbed dose

Fig. 2b: Annual dose excess calculated with different methods in the function of I-index

Conclusion

It was found that in most cases the application of I-index without density consideration provides a significant overestimation in excess effective dose originated from building materials. It means the I-index provides a conservative and superficial approximation. In the case of building materials with low density e.g. commonly used perforated bricks, this can make significant overestimation and unnecessary restriction in the case of certain low density building materials.

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