Differential stimulation and suppression of phytoplankton growth by ammonium enrichment in eutrophic hardwater lakes over 16 years

Swarbrick, V. J., Simpson, G. L., Gilbert, P. M., & Leavitt, P. (2018). Differential stimulation and suppression of phytoplankton growth by ammonium enrichment in eutrophic hardwater lakes over 16 years. *Limnology and Oceanography*. https://doi.org/10.1002/lno.11093

Published in:
Limnology and Oceanography

**Document Version:**
Publisher's PDF, also known as Version of record

**Queen's University Belfast - Research Portal:**
Link to publication record in Queen's University Belfast Research Portal

**Publisher rights**
Copyright 2018 the authors.
This is an open access article published under a Creative Commons Attribution License (https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution and reproduction in any medium, provided the author and source are cited.

**General rights**
Copyright for the publications made accessible via the Queen's University Belfast Research Portal is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

**Take down policy**
The Research Portal is Queen's institutional repository that provides access to Queen's research output. Every effort has been made to ensure that content in the Research Portal does not infringe any person's rights, or applicable UK laws. If you discover content in the Research Portal that you believe breaches copyright or violates any law, please contact openaccess@qub.ac.uk.

Download date: 27. Jun. 2020
RADIOLOGICAL RISKS ASSOCIATED WITH BUILDING MATERIALS AND INDUSTRIAL BY-PRODUCTS

Z. SAS1,* , W. SCHROEYERS2, G. BATOR3, M. SOUTSOS1, W. SHA1, R. DOHERTY1 AND T. KOVACS3

1School of Natural and Built Environment, Queen's University Belfast, David Keir Bldg., 39-123 Stranmillis Rd, Belfast BT9 5AG, United Kingdom
z.sas@qub.ac.uk

2Faculty of Engineering Technology, Hasselt University, Campus Diepenbeek, Agoralaan Bldg. H, Diepenbeek B-3590, Belgium

3Institute of Radiochemistry and Radioecology, University of Pannonia, 10 Egyetem str, Veszprem H-8200, Hungary

Abstract

To get a better insight into the radiological features of natural raw materials and industrial by-products that can be used 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 on 1095 raw materials and 431 industrial by-products used for building. It was found that radionuclide concentrations in the raw materials varied widely — from less than detection levels up to 27 851 Bq/kg for Ra-226, 906 Bq/kg for Th-232 and 17 922 Bq/kg for K-40 — while the radionuclide content of the by-products varied less widely — from 7 to 3152 Bq/kg for Ra-226 and from less than the detection limit up to 1350 and 3001 Bq/kg for Th-232 and K-40, respectively. The average Ra-226, Th-232 and K-40 concentrations in the industrial by-products were, respectively, 2.52, 2.35 and 0.39 times those in the building materials. Gamma exposure arising from bulk building products was calculated (i) using the ‘I-index’ approach described in the European Commission publication Radiation Protection 112, based on a single, fixed value for the material density and (ii) as described in IAEA Safety Standards Series No. SSG-32 using measured values of material density. It was found that in most cases the I-index approach (without consideration of the material density) resulted in a significant overestimation of effective dose.

Introduction

Radiation exposures due to minerals containing radionuclides of natural, terrestrial origin (238 U decay series, Th-232 decay series and K-40) are generally not significantly higher than normal background levels. Average worldwide activity concentrations are currently 33, 32, 45 and 412 Bq/kg for U-238, Ra-226, Th-232 and K-40, respectively [1]. In the case of building materials, average worldwide values are 50 Bq/kg for Ra-226, 50 Bq/kg for Th-232 and 500 Bq/kg for K-40 [2]. Although, these average activity concentrations are relatively low, large variations can be found and, as a result of the occurrence of anomalies, elevated concentrations can be found in some natural materials. In many cases, these materials with elevated concentrations have been used as building material. The determination of the radionuclide content of building materials and assessment of indoor exposure is therefore important because most individuals spend 80% or more of their time indoors. Chronic exposure involving moderate doses of 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 such as rocks, granite and clay or from industrial by-products such as fly-ash, bottom ash, steel slag and bauxite tailings (‘red mud’). It is important to investigate the use of such materials in order to allow them to be safely and efficiently integrated into new and refurbished buildings. To get an insight into the radiological features of potentially
usable industrial 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 for, the NORM database COST TU 1301 NORM4Building Action.

**Materials and methods**

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

(a) To establish an overview of the scientific data, individually reported sample data for Ra-226, Th-232 and K-40 obtained by gamma spectrometry were used — the ranges of activity concentrations were not usually imported into the database. After extracting the data, criteria were applied to ensure a meaningful statistical analysis.

(b) Average concentration values for certain materials were used only if the investigated material originated from the same site, e.g. a quarry, mine or reservoir. In the case of commercial building material, the brand and type of each sample 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.

(c) U-238 activity concentrations were imported into the database only if the results were obtained from the measurement of the concentrations of Rn-222 progeny (Bi-214 and Pb-214) to avoid errors due to decay chain disequilibrium.

The so-called ‘I-index’ is widely used for evaluating building materials with respect to gamma exposure [4]. The index is calculated using equation (1).

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

(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 becquerels per kilogram. This calculation method is based on a model described in Ref. [5] for a building constructed from concrete with a density of 2350 kg/m$^3$ and a wall thickness of 20 cm. An I-index of 1 is specified in Ref. [6] as a conservative screening criterion for identifying materials that, when incorporated into a building in bulk quantities, might give rise to an individual dose of more than 1 mSv above background. In terms of Ref. [6], the dilution and mixing of construction materials is permitted as long as the index of the final building product itself is below a value of 1, which makes possible the mixing of by-products with low activity level raw materials.

In order to determine the dose more precisely, the actual density and thickness of the material (rather than the fixed values specified above), as well as factors relating to the type of building and the intended use of the material (bulk or superficial) need to be taken into account. In Ref. [7], the dose modelling used in Ref. [4] is again applied, but this time using the actual density and thickness of the building material.

**Results and discussion**

The current version of the By-BM database contains data on 1095 natural materials used for building and 431 industrial by-products, gathered from 48 countries. The worldwide distribution of data sources and information on material density and type are shown in Fig. 1 and Tables 1 and 2.
FIG. 1. Worldwide distribution of data sources for building materials.

| Material name                  | Number of data sources | Density (kg/m³) |
|-------------------------------|------------------------|-----------------|
| Aggregate                     | 9                      | 1900            |
| Basalt                        | 3                      | 3000            |
| Brick                         | 243                    | 1900            |
| Cement                        | 87                     | 1500            |
| Ceramics                      | 94                     | 2400            |
| Concrete                      | 63                     | 2350            |
| Cellular lightweight concrete | 37                     | 700             |
| Granite                       | 297                    | 2600            |
| Gypsum                        | 66                     | 865             |
| Limestone                     | 16                     | 2600            |
| Marble                        | 72                     | 2550            |
| Pumice                        | 3                      | 650             |
| Rock                          | 31                     | 2300            |
| Sand                          | 19                     | 1500            |
| Sandstone                     | 14                     | 2323            |
| Serizzo                       | 5                      | 2650            |
| Sienite                       | 5                      | 2700            |
| Asbestos tile                 | 4                      | 1750            |
| Travertine                    | 9                      | 2300            |
| Tuff                          | 10                     | 2100            |
| Volcanic                      | 7                      | 1800            |
Individual data on Ra-226, Th-232 and K-40 activity concentrations are available for 30 different materials (23 raw materials used for building and 7 industrial by-products). In the case of the raw materials used for building, it was found that radionuclide concentrations varied widely — from less than detection levels up to 27,851 Bq/kg for Ra-226, 906 Bq/kg for Th-232 and 17,922 Bq/kg for K-40 — while the radionuclide content of the industrial by-products varied less widely — from 7 to 3152 Bq/kg for Ra-226 and from less than the detection limit up to 1350 and 3001 Bq/kg for Th-232 and K-40, respectively. The average Ra-226, Th-232 and K-40 concentrations in the industrial by-products were, respectively, 2.52, 2.35 and 0.39 times those in the raw materials — this illustrates why, when considering possible radiation exposure, the radionuclide content of such by-products generally cannot be ignored.

In this study, the absorbed gamma dose rate received by an individual was calculated using a model room with a 20 cm wall thickness and with various densities of material, using activity concentration data for Ra-226, Th-232 and K-40 obtained from the database. The dose calculation was carried out using (i) a fixed density of 2350 kg/m³ in accordance with the modelling method adopted in Ref. [4] and (ii) the actual densities obtained from the database in accordance with the modelling method adopted in Ref. [7]. The I-indices of the building materials were also calculated and compared with the absorbed gamma doses determined using the two different calculation methods. The absorbed gamma doses were compared and clearly showed that without density consideration the calculated dose is significantly higher in the case of low density building materials (see Fig. 2(a)). For densities less than 1000 kg/m³, the overestimation can be as high as 60–70%. This is the reason why, with density consideration, the calculated I-indices correspond to a lower dose rate, which clearly proves the overestimation of I-index in connection with generated dose rate (see Fig 2(b)).

### TABLE 2. INDUSTRIAL BY-PRODUCTS

| Material name                     | Number of data sources | Density (kg/m³) |
|-----------------------------------|------------------------|-----------------|
| Bottom ash                        | 59                     | 700             |
| Fly ash                           | 145                    | 720             |
| Manganese clay                    | 44                     | 2800            |
| Phosphogypsum                     | 45                     | 1500            |
| Bauxite tailings (Red mud)        | 92                     | 1600            |
| Steel slag                        | 41                     | 2600            |
| Residue of TiO₂                    | 5                      | 4300            |
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 the I-index approach without density consideration provides a significant overestimation of the dose arising from building materials. It means that the I-index provides a conservative and superficial approximation. In the case of building materials with low density, such as commonly used cellular lightweight concrete bricks, this can result in a significant overestimation of dose and an unnecessary restriction on their use.

**Acknowledgement**

The project leading to this application has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 701932. The authors would like to acknowledge networking support by the COST Action TU1301. www.norm4building.org.

**References**

[1] UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION, Sources and Effects of Ionizing Radiation, UNSCEAR 2008 Report to the General Assembly, Scientific Annexes A and B, Vol. I, United Nations, New York (2010).

[2] UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION, Sources and Effects of Ionizing Radiation, UNSCEAR 1993 Report to the General Assembly, with Scientific Annexes, United Nations, New York (1993).

[3] INTERNATIONAL COMMISSION ON RADIOPHYSICAL PROTECTION, 1990 Recommendations of the International Commission on Radiological Protection, Publication 60, Pergamon Press, Oxford and New York (1991).

[4] EUROPEAN COMMISSION, Radiological Protection Principles Concerning the Natural Radioactivity of Building Materials, Radiation Protection 112, Office for Official Publications of
the European Communities, Luxembourg (1999),
http://ec.europa.eu/energy/nuclear/radiation_protection/doc/publication/112.pdf.

[5] MARKKANEN, M., Radiation Dose Assessments for Materials with Elevated Natural Radioactivity, Rep. STUK-B-STO 32, Finnish Centre for Radiation and Nuclear Safety, Helsinki (1995).

[6] THE COUNCIL OF THE EUROPEAN UNION, Council Directive 2013/59/Euratom of 5 Dec. 2013 Laying Down Basic Safety Standards for Protection against the Dangers Arising from Exposure to Ionising Radiation, L13, vol. 57 (2014).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, WORLD HEALTH ORGANIZATION, Protection of the Public against Exposure Indoors due to Radon and Other Natural Sources of Radiation, IAEA Safety Standards Series No. SSG-32, IAEA, Vienna (2015).