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

5th European IRPA Congress, June 4-8 (2018)

**Wouter Schroeyers**, Tom Croymans, Zoltan Sas, Rosabianca Trevisi, Cristina Nuccetelli, Federica Leonardi, Tibor Kovacs, Sonja Schreurs

UHASSELT
KNOWLEDGE IN ACTION

NORM4BUILDING

cost

# Outline

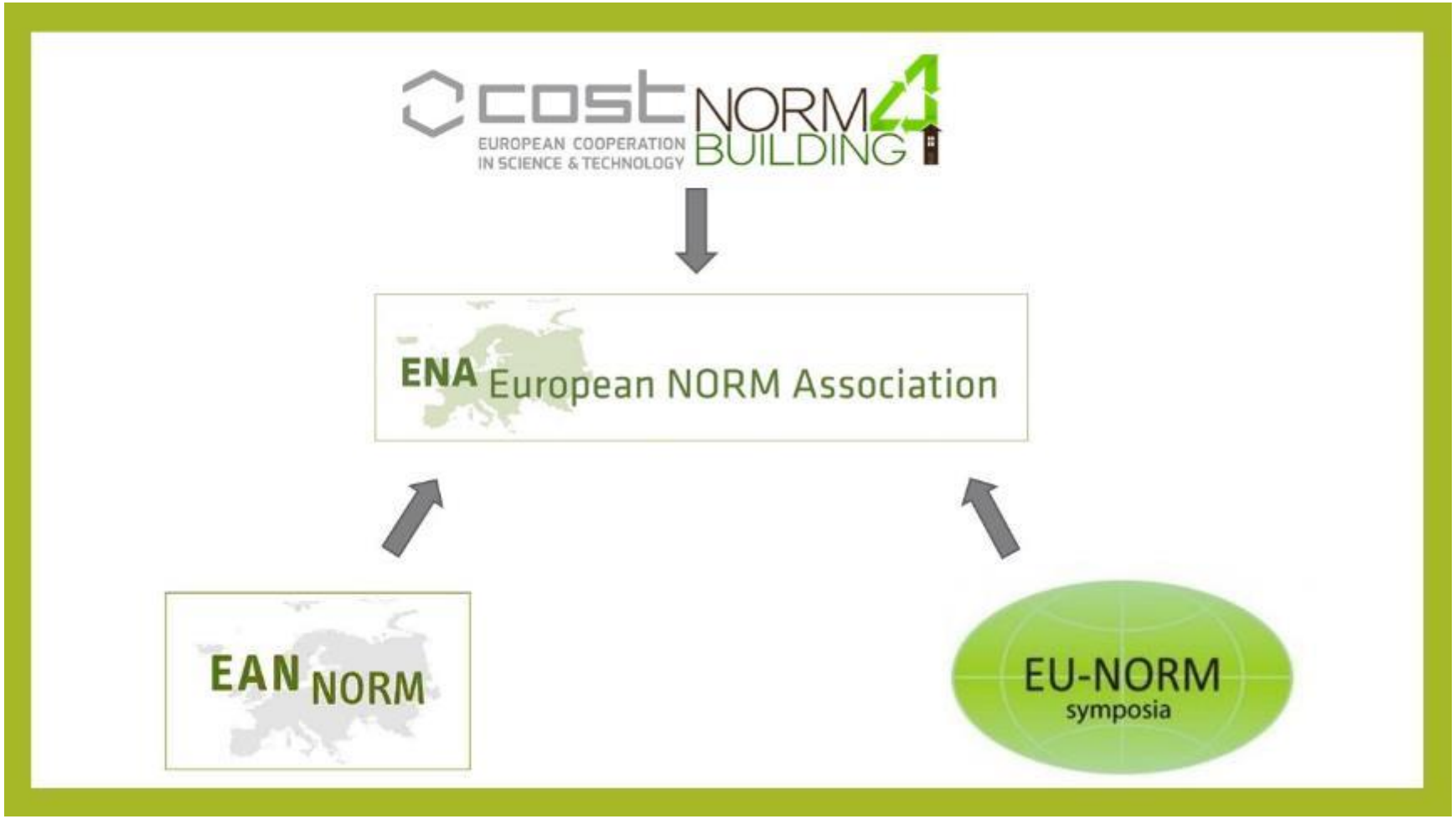
- **Introduction**
- Methodology:
  - A database to screen the potential impact of NORM
  - Screening tools for gamma dose assessment
- Results & discussion
  - By-products
  - Building materials
  - Expanded set of tools for gamma dose assessment
- Conclusion

# The NORM4Building Network (2014-2017)

- Exchange of multidisciplinary knowledge and experiences (radiological, technical, economical, legislative, ecological, …)
- NORM (Naturally Occurring Radioactive Materials)

| Stimulate the **use of by-products in new tailor-made sustainable building materials** | While **assuring (radiation) protection of the population / environment** |
|---|---|

# European NORM Association



# Research @ NuTeC (Uhasselt) - MTM (KULeuven)

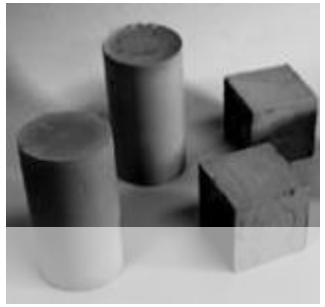

Fly ash


Red mud


Phosphogypsum

**By-products (NORM)**

Alkali activation



Use in publicly accessible environment

Use in nuclear safety applications

- Gamma dose evaluation


Tom.Croymans

- Radon exhalation
- Leaching


Katrijn.Gijbels


Zoltan Sas

- Leaching


Niels Vandevenne

- Durability prediction in gamma radiation field


Bram Mast

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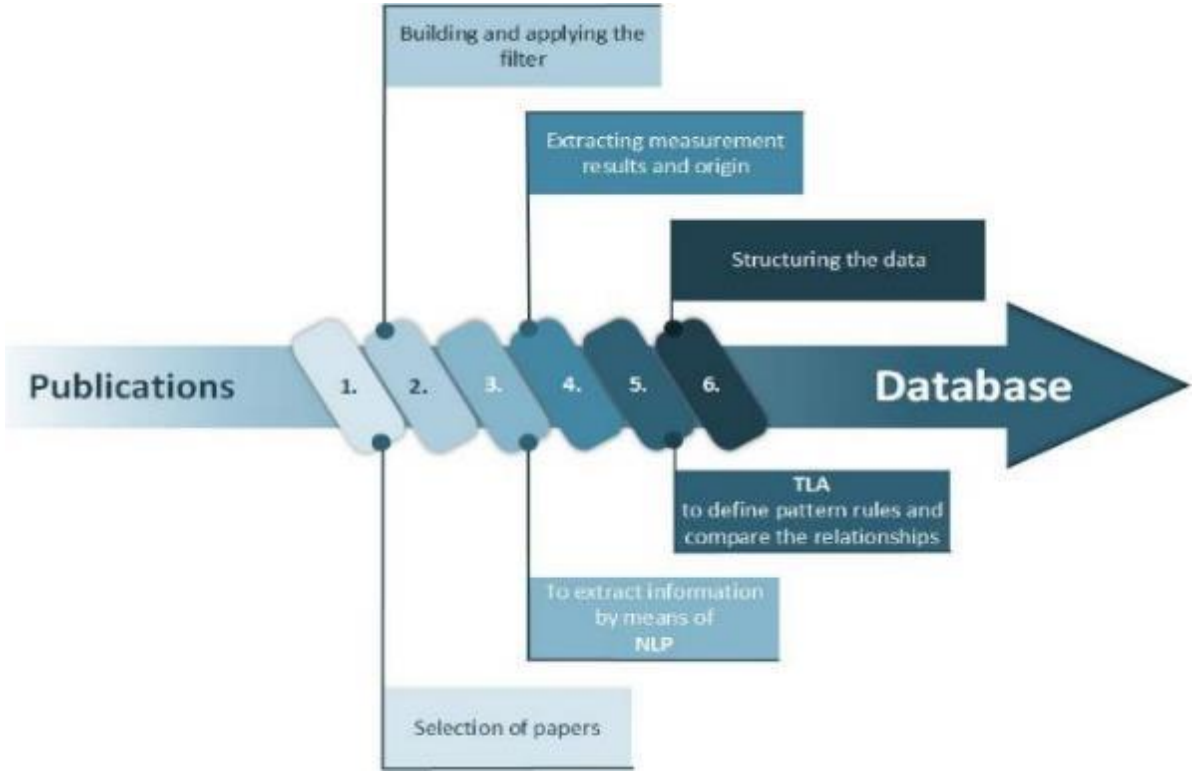
# NORM4Building database

www.norm4building.org




**Database team:**
Tibor Kovacs
Gergo Bator
Zoltan Sas

**Verification team:**
Cristina Nuccetelli
Rosabianca Trevisi
Federica Leonardi

- **Semi-automatic approach for data collection**
  - >68.000 publications processed (from Science Direct, Web of Science, etc…)
  - Manual validation of entries (so far 1452 entries validated:



Schroeyers et al.
Construction and Building Materials 159 (2018) 755–767

# Scenarios for evaluation use of by-products: technical properties determine use

| Scenario ID | Construction Material | Composition (kg/m$^3$) | | | |
|---|---|---|---|---|---|
| | | 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 |



Schroeyers et al.
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# I-index calculations

$$I - index = \frac{Ac_{226Ra}}{300\ B\ q/k\ g} + \frac{Ac_{232Th}}{200\ B\ q/k\ g} + \frac{Ac_{40K}}{3000\ B\ q/k\ g}$$

Euratom-BSS, 2013

- First screening to verify if I-index < 1 to assess which materials need further investigation
- **Only used for building materials** (or for their constituents if the constituents are also building materials)
- Values used in calculations:
  - Cement: I-index 0,38 (*)
  - Soil/aggregates: I-index 0,45 (*)



(*) Trevisi et al.
J. Environ. Radioact. 105 (2012) 11–20.

# The room model of Markkanen

- Absorbed dose rate in air:

$$D_A = 5.77\text{x}10^{-7}\,\frac{AC\,\boldsymbol{\rho}}{4\pi}\sum\gamma_i\left(\frac{\mu_{en}}{\rho}\right)_i E_i\int \boldsymbol{B_i}\,\frac{\mathrm{e}^{-\boldsymbol{\mu_i s}}}{\boldsymbol{l}^2}\,\mathbf{dV}$$

| Nuclide | Averaged values used in calculations | | | | | |
|---|---|---|---|---|---|---|
| | Energy | γ | μ | $\mu_e/\rho$ | C | D |
| | keV | | $cm^{-1}$ | $10^{-5}\ cm^2g^{-1}$ | | |
| $^{238}U$ | 810 | 2.12 | 0.166 | 0.0285 | 1.161 | 0.144 |
| $^{232}Th$ | 587 | 2.05 | 0.193 | 0.0295 | 1.279 | 0.190 |
| $^{232}Th$ | 2 615 | 0.356 | 0.0927 | 0.0217 | 0.734 | 0.0234 |
| $^{40}K$ | 1 461 | 0.107 | 0.124 | 0.0257 | 0.946 | 0.0755 |
| $^{137}Cs$ | 662 | 0.852 | 0.183 | 0.0293 | 1.237 | 0.1737 |

(coefficients C and D are included in the build-up factors)



Markkanen,
Finish Cent, Radiat. Nucl. Saf. Rep. STUK-B-STO 32 (1995) 1–41.

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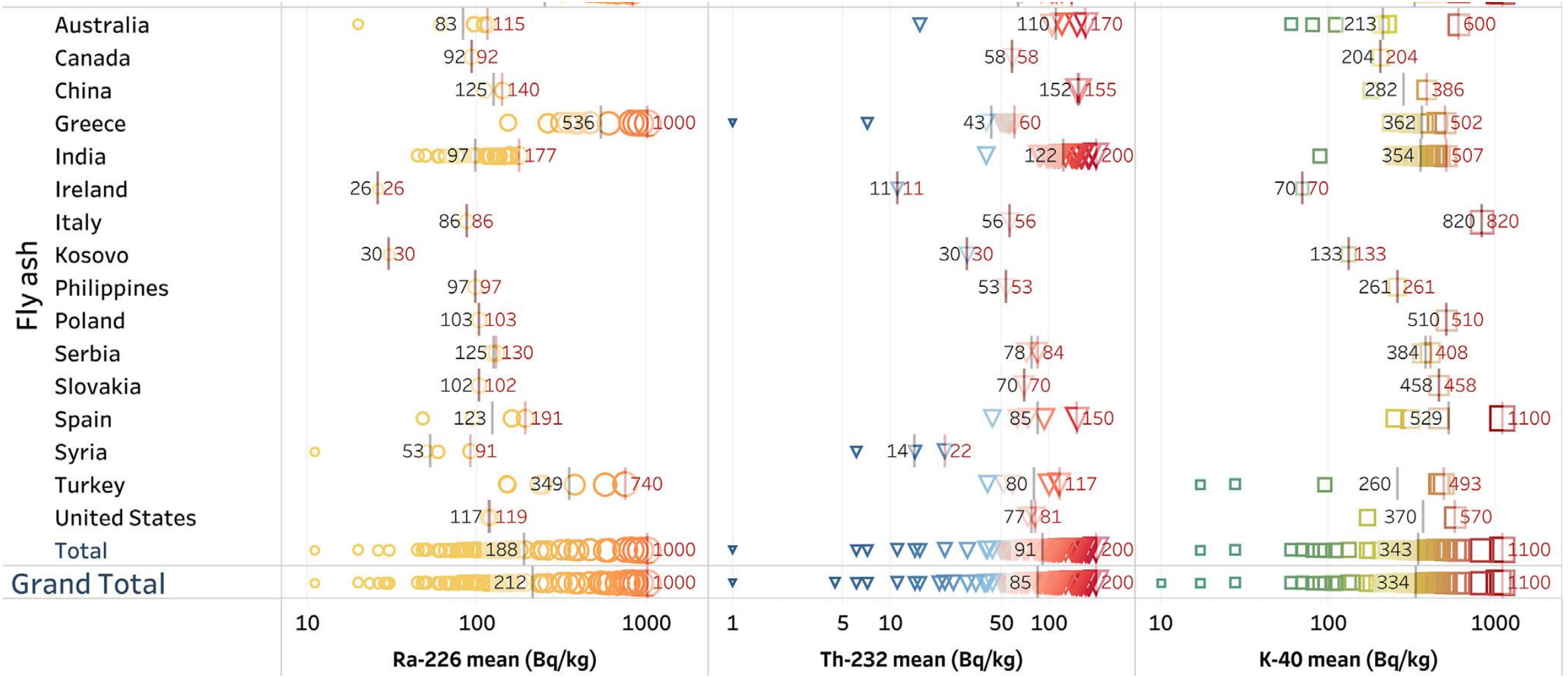
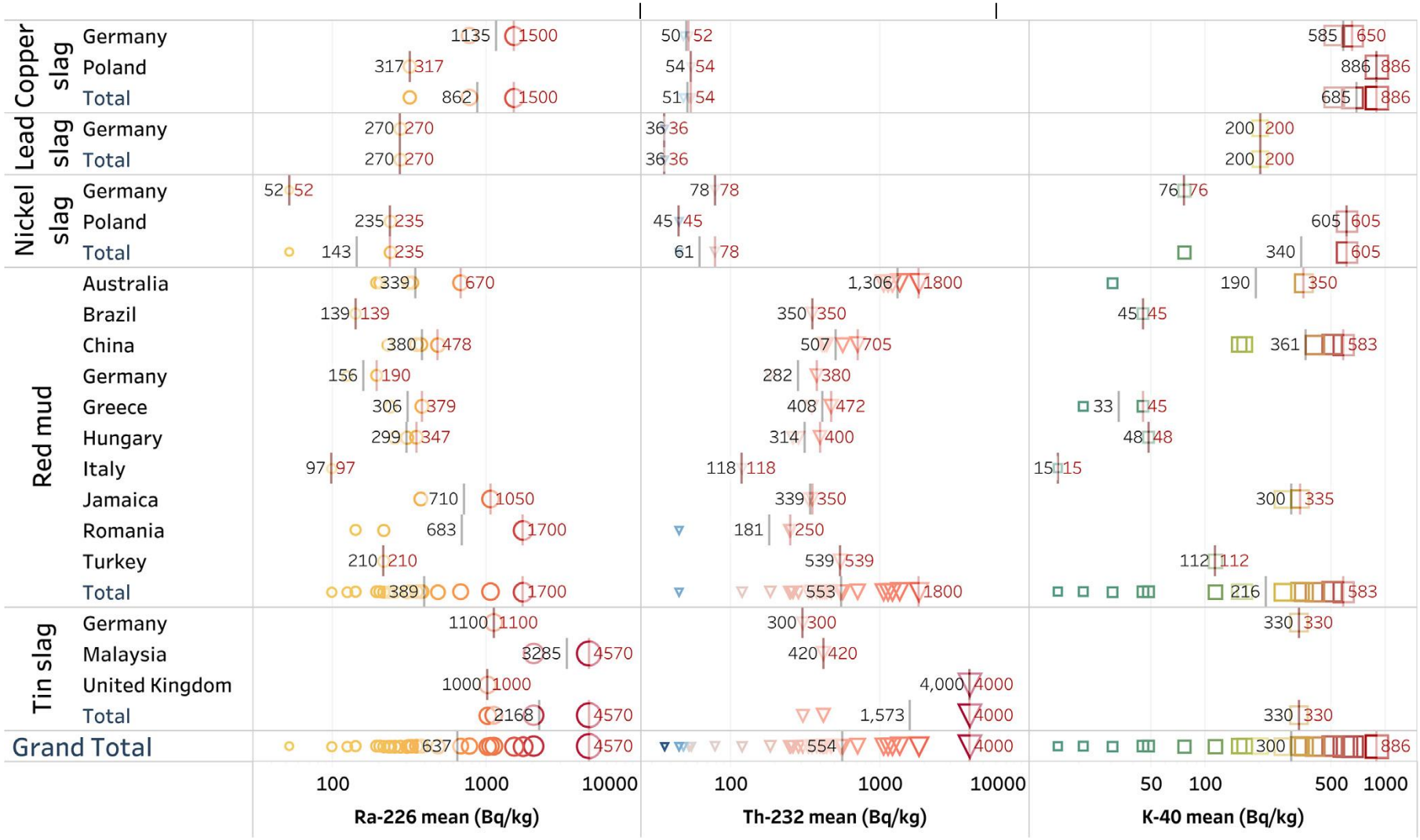
# Fly ash from coal, peat and heavy oil fired power plants






Schroeyers et al.
Construction and Building Materials 159 (2018) 755–767

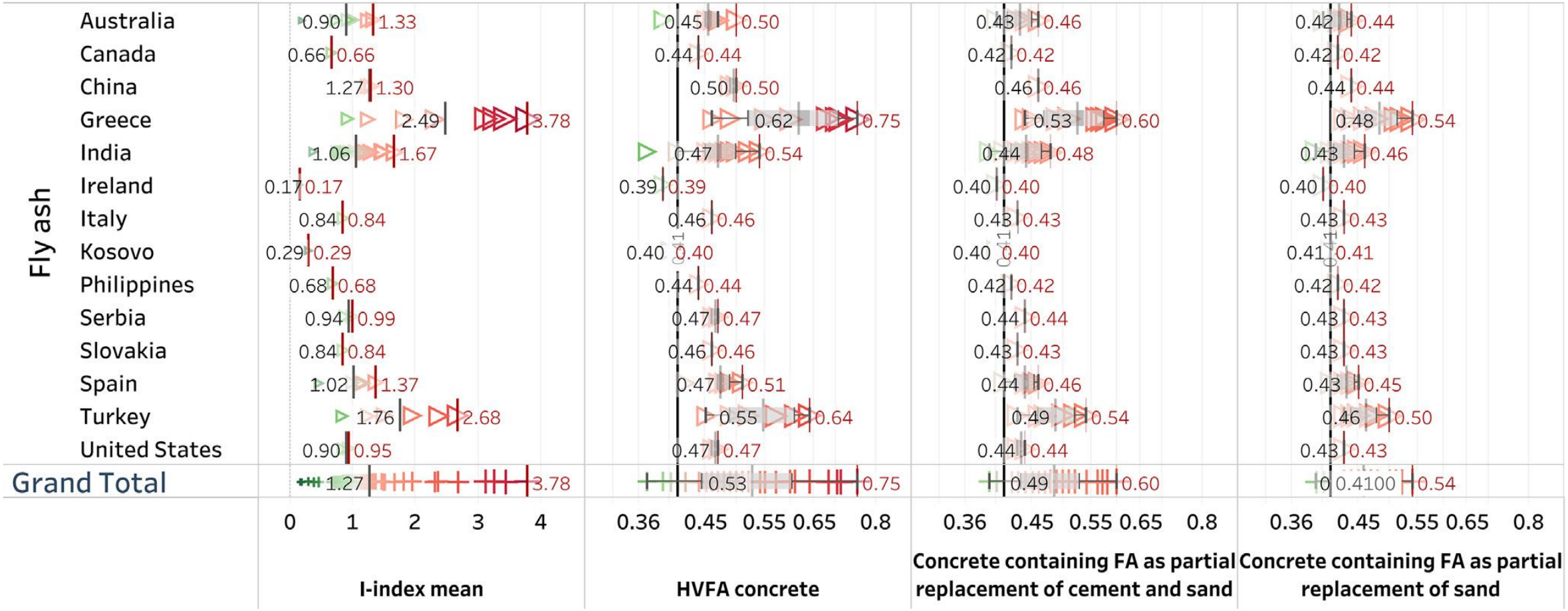
# By-products from non-ferrous industry






Schroeyers et al.
Construction and Building Materials 159 (2018) 755–767

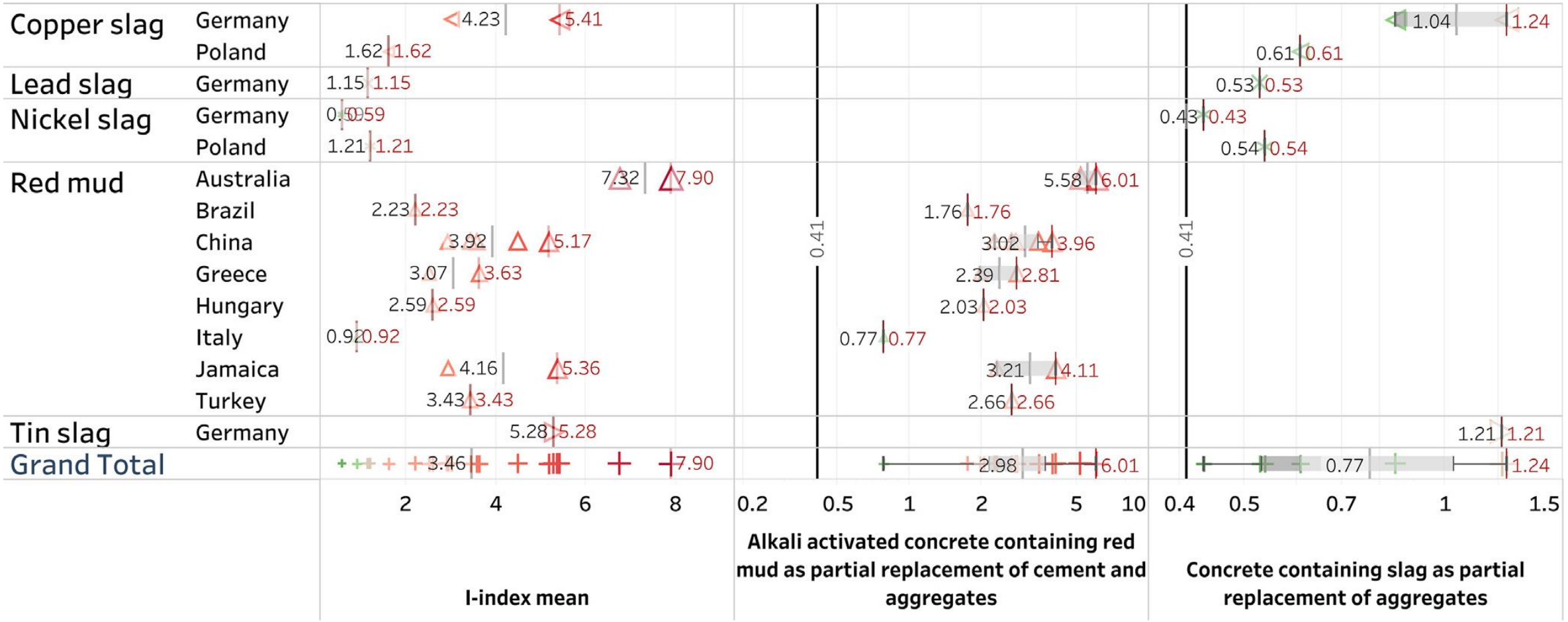
# I-index concrete containing fly ash






Schroeyers et al.
Construction and Building Materials 159 (2018) 755–767

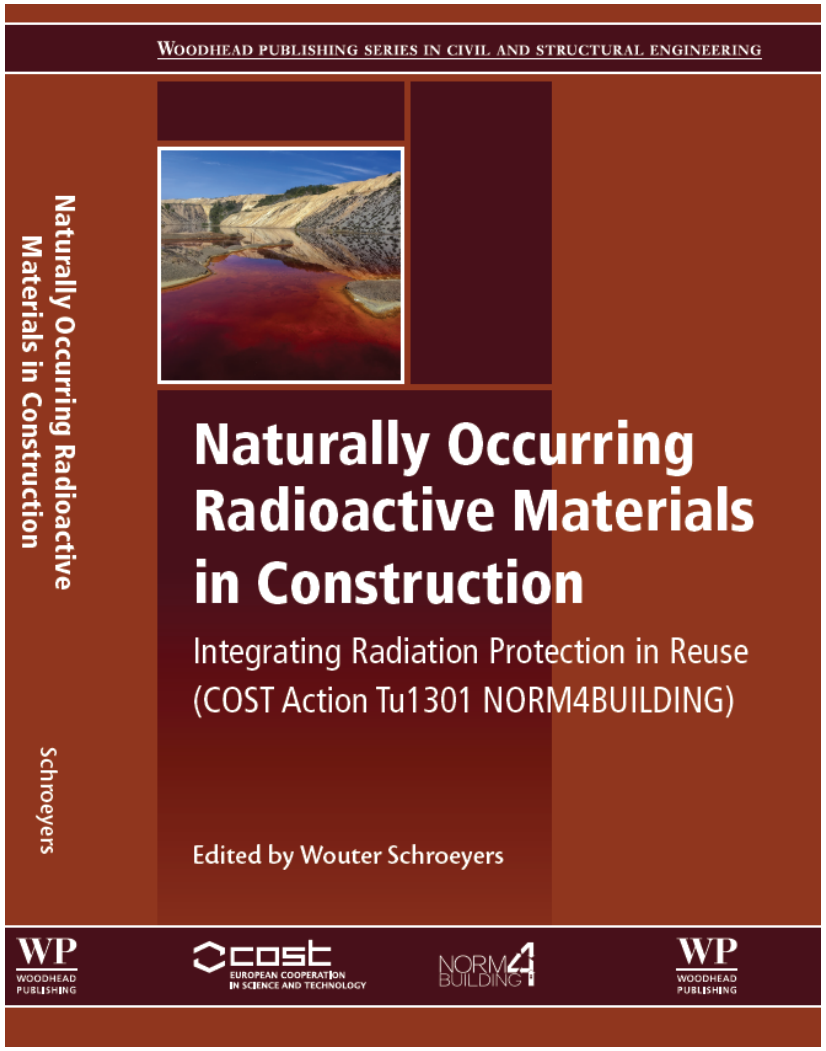
# I-index concrete containing non-ferrous slag and red mud as replacement aggregates






Schroeyers et al.
Construction and Building Materials 159 (2018) 755–767

# “NORM4Building, the book”: detailled assessement of impact of use of NORM in construction




1. Objectives
2. Introduction
3. Basic aspects of natural radioactivity
4. Legislative aspects
5. Measurement of NORM
6. From raw materials to NORM by-products
7. From NORM by-products to building materials
8. Leaching assessment
9. Nontechnical aspects
10. General conclusion and the way forward

# Discussion: evaluating datamining approach

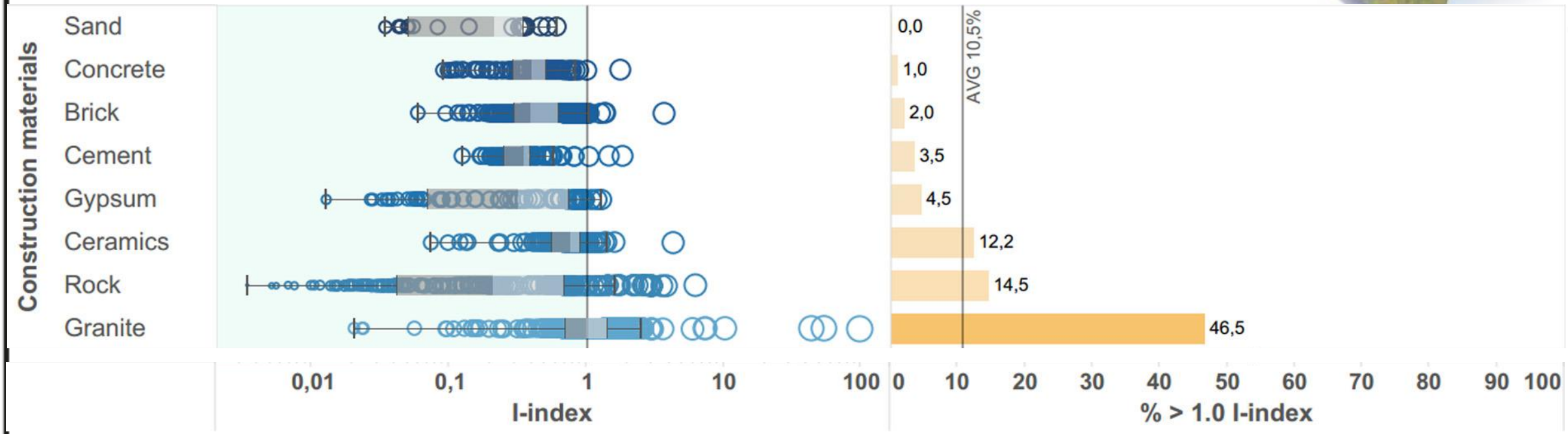
- Strength:
  - **Hundreds of publications** can be **processed monthly**
  - Finds data **accurately**
  - Allows **continuous (automated) search** for new data: useful for keeping inventory up to date
  - Can run again on collected data using **different key-words**

- Limitations:
  - Reliability of the data is strongly dependent of the **reliability of the published results:**
  - Validation is a **labour intensive step**
  - Data from **graphical images** (eg.: histograms) is currently not collected
  - Licence for datamining software is **expensive**
  - **Industrially relevant?**
    - **There is a need** to filter out publications according to date, insert **more data from national surveys**



Schroeyers et al.
Construction and Building Materials 159 (2018) 755–767

# New database based on individual measurement entries: **By-BM Database**




http://bybmproject.com/



Sas et al.
Construction and Building Materials 150 (2017) 227–237

H2020-MSCA-IF-2015 By-BM

MARIE CURIE ACTIONS

Queen's University Belfast

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KNOWLEDGE IN ACTION

# Room for further improving the screening of building materials?

$$I - index = \frac{Ac_{226Ra}}{300\ B\ q/k\ g} + \frac{Ac_{232Th}}{200\ B\ q/k\ g} + \frac{Ac_{40K}}{3000\ B\ q/k\ g}$$

- Including the density and thickness dependence?

| | Dose (mSv/y) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Model** | **Markkanen - ACI** | **D(ρd)** | | | | | | |
| **Thickness (cm)** | **20** | **10** | **10** | **18** | **20** | **25** | **40** | **40** |
| **Density (kg/m³)** | **2350** | **1400** | **3000** | **3000** | **2350** | **1400** | **1400** | **3000** |
| **Furnace slags** | 0.726 | 0.238 | 0.549 | 0.745 | 0.704 | 0.606 | 0.755 | 0.916 |
| **Bottom ash and fly ash** | 1.293 | 0.521 | 1.017 | 1.329 | 1.264 | 1.108 | 1.346 | 1.604 |
| **Phosphogypsum** | 1.592 | 0.659 | 1.237 | 1.595 | 1.521 | 1.342 | 1.614 | 1.905 |
| **Bauxite residue** | 3.825 | 1.841 | 3.190 | 4.043 | 3.865 | 3.437 | 4.087 | 4.796 |
| **Cement** | 0.206 | -0.019 | 0.128 | 0.222 | 0.202 | 0.155 | 0.227 | 0.304 |

$$D(\rho d) = \left[\frac{Ac_{Ra226}(\rho d)^2}{170[(\rho d)^2 + 156(\rho d) + 11477]}\right. + \frac{Ac_{Th232}(\rho d)^2}{130[(\rho d)^2 + 173(\rho d) + 11226]} + \frac{Ac_{K40}(\rho d)^2}{1870[(\rho d)^2 + 194(\rho d) + 11610]} - 0.245$$

Yellow: Markkanen – ACI overestimates

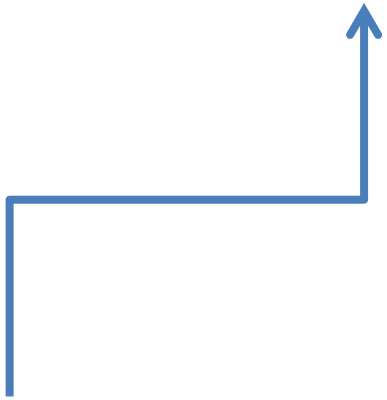
Red: Markkanen – ACI underestimates



Nuccetelli et al.
Journal of Environmental Radioactivity 143 (2015) 70-75

# Room for further improving the model?

- The room model of Markkanen
  - Absorbed dose rate in air: $D_A = 5.77\text{x}10^{-7} \frac{AC\,\rho}{4\pi} \sum \gamma_i \left(\frac{\mu_{en}}{\rho}\right)_i E_i \int B_i \frac{e^{-\mu_i s}}{l^2} dV$



<u>Expanded Gamma Dose Assessment:</u>

1845 gamma lines of $^{238}U$, $^{235}U$ and $^{232}Th$ decay series and $^{40}K$



Croymans et al.
Construction and Building Materials 159 (2018) 768–778

# Expanded Gamma Dose Assessment

| | Dose D(ρd) (mSv/y) | | | | | | |
|---|---|---|---|---|---|---|---|
| **Thickness (cm)** | **10** | **10** | **18** | **20** | **25** | **40** | **40** |
| **Density (kg/m³)** | **1400** | **3000** | **3000** | **2350** | **1400** | **1400** | **3000** |
| **Furnace slags** | 0.238 | 0.549 | 0.745 | 0.704 | 0.606 | 0.755 | 0.916 |
| **Bottom ash and fly ash** | 0.521 | 1.017 | 1.329 | 1.264 | 1.108 | 1.346 | 1.604 |
| **Phosphogypsum** | 0.659 | 1.237 | 1.595 | 1.521 | 1.342 | 1.614 | 1.905 |
| **Bauxite residue** | 1.841 | 3.190 | 4.043 | 3.865 | 3.437 | 4.087 | 4.796 |
| **Cement** | -0.019 | 0.128 | 0.222 | 0.202 | 0.155 | 0.227 | 0.304 |
| | **Dose EGDA+ (mSv/y)** | | | | | | |
| **Thickness (cm)** | **10** | **10** | **18** | **20** | **25** | **40** | **40** |
| **Density (kg/m³)** | **1400** | **3000** | **3000** | **2350** | **1400** | **1400** | **3000** |
| **Furnace slags** | 0.239 | 0.558 | 0.738 | 0.698 | 0.592 | 0.714 | 0.813 |
| **Bottom ash and fly ash** | 0.522 | 1.031 | 1.319 | 1.256 | 1.085 | 1.281 | 1.442 |
| **Phosphogypsum** | 0.664 | 1.256 | 1.580 | 1.510 | 1.317 | 1.536 | 1.711 |
| **Bauxite residue** | 1.830 | 3.199 | 3.976 | 3.804 | 3.343 | 3.873 | 4.325 |
| **Cement** | -0.019 | 0.132 | 0.219 | 0.200 | 0.148 | 0.207 | 0.257 |

Red: D(pd) underestimates

Yellow: D(pd) overestimates



Croymans et al.
Construction and Building Materials 159 (2018) 768–778

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# Conclusion - outlook

- Expanded **database** for screening, identifying materials of concern from a radiological perspective
- More **realistic scenarios** were used for assessing the impact
- An expanded sets of tools for evaluation of the (absorbed) **gamma dose** was developed
  - ➔ taking **adequate measures**
- Outlook:
  - Combining several databases
  - Including the **individual measurement entries** (entries should contain adequate information on the measurement technique used, type of sample analysed,…)
  - Including the **date of measurement/study as a relevant parameter**
  - Including the **different tools for gamma dose assessment** in the online database

ENA European NORM Association

https://ena-norm.eu/

# The 1st ENA Workshop

## Katowice, Upper Silesia, POLAND

19-23 November 2018

Main topics:

1. **NORM and environment** – challenges due to the release of formation/process water
2. **NORM in building materials** –practical approaches to control radioactivity
3. **NORM in the industry** - look beyond oil and gas, phosphorite and red mud.

GIG

**Silesian Centre for Environmental Radioactivity**,

Central Mining Institute (GIG), Plac Gwarków 1, Katowice, Poland

# Training school on ‘NORM Inventories’
# Environet NORM Project

**International case studies** and **technical visits**

The making of an **inventory of NORM in specific industrial sectors:**

- **Phosphate industry, rare earth and metal processing, oil and gas industry…**

Timing: **26-30 November 2018**

Location: **Hasselt University, Belgium**

Contact: wouter.schroeyers@uhasselt.be