COST Project NORM4BUILDING

On site measurement strategies for NORM and Building materials

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COST – network ‘NORM4Building’
(Research and Technological development Framework Program)

• ORGANIZATION OF MEETINGS (2016):
  – Linked to the Terrestrial Radionuclides in Environment symposium in Veszprém, Hungary (May 17-18, 2016)
  – Linked to: Rilem materials-System conference, Copenhagen, Denmark (Aug 21-24, 2016)

• SHORT-TERM SCIENTIFIC MISSIONS

• TRAINING SCHOOLS
  – Athens (September 12-16\textsuperscript{th}, 2016)

• PUBLICATIONS and DISSEMINATION
  \text{www.norm4building.org}
Main objective ‘NORM4BUILDING’

• Exchange of multidisciplinary knowledge and experiences (radiological, technical, economical, legislative, ecological, ...)

Stimulate the reuse of NORM residues in new tailor-made sustainable building materials (focus on concrete, cement and ceramics)

while considering exposure to external gamma radiation and the resulting indoor air quality.
## Secondary raw materials

<table>
<thead>
<tr>
<th>NORM residues (with interesting properties for reuse in building materials)</th>
<th>Codification EU-Waste Catalogue?</th>
<th>Estimated production (Milion Tons/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>coal fly-ash</td>
<td>001 02 or 10 01 16</td>
<td>44 (2003, EU 15) ¹</td>
</tr>
<tr>
<td>slag and bottom ash from a coal-fired power plant</td>
<td>10 01 01 or 10 01 14</td>
<td>8 (2003, EU 15) ¹</td>
</tr>
<tr>
<td>phosphorous slag from thermal phosphorus production</td>
<td>06 09 02</td>
<td>-</td>
</tr>
<tr>
<td>phosphogypsum from phosphoric acid production,</td>
<td>-</td>
<td>180 (2003, World) ²</td>
</tr>
<tr>
<td>red-mud, (bauxite residue), from alumina production</td>
<td>01 03 07</td>
<td>120 (2003, World) ³</td>
</tr>
<tr>
<td>unprocessed slag from primary iron production</td>
<td>10 02 02</td>
<td>260-310 (2011, World) ⁴</td>
</tr>
<tr>
<td>steel or stainless steel, lead slags</td>
<td>10 04 01</td>
<td>130-210 (2011, World) ⁴</td>
</tr>
<tr>
<td>copper slags, from primary and secondary production.</td>
<td>10 06 01</td>
<td>24,6 (2009, World) ⁵</td>
</tr>
<tr>
<td>tin slags from primary and secondary production</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>specific residues originating from pyro- and hydro-metallurgies producing platinum group metals or rare earth elements</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

¹ Ecoba - SPECIAL PRINT CPI 04/06  
³ www.redmud.org/Disposal.html  
NORM processing industries (New EU-BSS ANNEX VI)

- extraction of rare earths from monazite;
- production of thorium compounds and manufacture of thorium-containing products;
- processing of niobium/tantalum ore;
- oil and gas production;
- geothermal energy production;
- TiO$_2$ pigment production;
- thermal phosphorus production;
- zircon and zirconium industry;
- production of phosphate fertilisers;
- cement production, maintenance of clinker ovens;
- coal-fired power plants, maintenance of boilers;
- phosphoric acid production;
- primary iron production;
- tin/lead/copper smelting;
- ground water filtration facilities;
- mining of ores other than uranium ore.

Including relevant secondary processes
Member States can add other relevant activities
*European list NORM-industries for strict regulation:

Natural occurring radionuclides:

- $^{238}\text{U}$ & decay products
- $^{232}\text{Th}$ & decay products
- $^{40}\text{K}$

**Notification if**

- $> 1 \text{ Bq/g}$
- $> 10 \text{ Bq/g}$
New Euratom-BSS in addition to CPR

Residues of NORM processing industry to be recycled in building materials?

BSS Art. 75.2 + Indicative list in Annex XI + CPR

Yes

\[
ACI = \frac{C_{Ra226}}{300} \frac{Bq}{kg} + \frac{C_{Th232}}{200} \frac{Bq}{kg} + \frac{C_{K40}}{3000} \frac{Bq}{kg}
\]

Index ≤ 1?

Results may be requested by the regulatory authority

TS 351014 + CPR art. 18 + BSS Annex VII & VIII

Yes

No regulatory control

BSS Art. 26 & 30 and Annex VII Table A part 2

No

BSS Art. 75
Specific national requirements or restrictions taking into account:
Density; thickness of the material; factors relating to materials and intended use of it (bulk or superficial)

\((\text{Gamma})\) Dose estimate < 1 mSv/year
"Declaration of performance"
CE marking + classification to be made available to the consumers

CPR Art. 4, 8.2, 8.3, 11, 24
+ EU harmonized standards
CEN-TG 32

Based on a presentation by Stéphane Calpéna (EC-DG-ENER-D4), EU-NORM 2, Prague (2014)
Art. 74.1
National Reference Levels shall not exceed:

300 Bq/m³  Effective dose 18 mSv/year (ICRP)

Art. 74.2
Member States shall promote action to identify dwellings with radon concentration (as an annual average) exceeding the reference level and encourage, where appropriate, by technical or financial means, radon concentration-reducing measures in these dwellings.

Art. 74.3
...local and national information to be made available...

Based on a presentation by Stéphane Calpéna (EC-DG-ENER-D4), EU-NORM 2, Prague (2014)
NORM in building materials
(New European Directives, Annex XI)

- Materials including by-products or residues from NORM industries such as
  - fly ash,
  - phosphogypsum,
  - phosphorous slag
  - tin slag
  - copper slag
  - red mud (residue from aluminium production)
  - residues from steel production
Scientific focus working groups

Working Group 1
1. Studying **state of the art** in the reuse of NORM residues in building materials
2. Development of a **data base with good practices**

Working Group 2
1. Develop **new options** for tailor-made building materials to incorporate NORM residues.

Working Group 3
1. Improve **measurement capacity** for NORM containing building materials
2. **Standardization** of measurement protocols and development of (pre-)standards.

Working Group 4
1. Improving **dosimetric models** for a number of building scenarios.
2. Investigating the influence of different **legislative radioprotection scenarios**.
Norm4Building Database

a) **Criteria** for evaluation of practices were set.
b) Gathering information on NORMs currently used for building materials
c) Including **representative national surveys**

### Information per entry

**General information:**
- By-product name; Industrial sector
- Country
- Total amount of by-product [Mt], Number of surveyed samples
- References

**Radiological features**
- Activity concentration (terrestrial isotopes: Ra-226; Th-232, K-40)
- Activity concentration index
- Emanation and exhalation features

**Non-radiological features**

<table>
<thead>
<tr>
<th>*Density [kg/m³]</th>
<th>Particle size distribution</th>
<th>H₂O [wt%]</th>
<th>SiO₂ [wt%]</th>
<th>Al₂O₃ [wt%]</th>
<th>CaO [wt%]</th>
<th>Fe₂O₃ [wt%]</th>
<th>C [wt%]</th>
<th>Na₂O [wt%]</th>
<th>SO₄²⁻ [wt%]</th>
<th>MgO [wt%]</th>
<th>Cl [wt%]</th>
<th>P₂O₅ [wt%]</th>
<th>LOI %</th>
<th>loss on ignition [wt%]</th>
<th>pH</th>
</tr>
</thead>
</table>

*Density [kg/m³] is a crucial parameter for understanding the physical properties of the materials. The particle size distribution is also important, as it affects the material's behavior and performance. The table includes a variety of chemical and physical characteristics, such as water content, silica, alumina, calcium oxide, iron oxide, carbon, sodium oxide, sulfur, magnesium, chlorine, phosphorus, and loss on ignition. The pH value is also provided, which is relevant for understanding the material's reaction with other substances.

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[European Commission Logo]
Working Group 1
‘Data base with good practices’

Norm4Building Database

- **Criteria** for evaluation of practices were set.
- Gathering information on NORMs currently used for building materials
- Including representative national surveys

Evaluation of practices

- Collaboration with industry to **evaluate the application in construction materials**
- **Cost-benefit and SWOT analysis**

Output

- **Updating ‘Activity Concentration Index’ (ACI) database**
- Update information for the **European Waste Catalogue**
- **Dissemination plan**

Impact:
- NORM aspects are taken into account for reuse
- ‘Good practices database’ as guideline for reuse for industry
Status database  (total 792 entries, 9/10/2015)
Working Group 2
‘Options for new tailor-made building materials’

Study new develop options

a) Analytical model with relation between % of virgin raw materials substituted and radiological content

b) Recommendations on use secondary raw materials in alkali activated cements considering the radiological content.
Most important: Designing materials that are fit for purpose!
Working Group 2
‘Options for new tailor-made building materials’

Study new develop options

a) Analytical model with relation between % of virgin raw materials substituted and radiological content
b) Recommendations on use secondary raw materials in alkali activated cements considering the radiological content.

Radiological content linked to...

a) Pretreatment of the raw materials
b) Development and application of the building material
c) Effect of inherent and engineered properties
Many aspects determine the eventual reuse of ‘byproducts’

- **Size of the byproduct stream**
- **Properties of the byproduct**
- **Environmental and health issues**
- **Potential market and acceptance/perception aspects**
- **Cost** aspects throughout the chain
- **Competition** with other byproducts
- **CE marking and other certification aspects**
- …
Validated (on-site) measurement protocols for

a) Activity Concentration Index
b) Radon (possibly thoron) emanation and exhalation rate

Intercomparisons using several measurements protocols and instruments
Metal processing: how radionuclides (U-238 decay chain) can behave during smelting?

(similar for decay chain of Th-232)
Approaches to in-situ measurements to determine the activity concentration

• conventional approach:
  1. **Spectra analysis calibrating broad spectral windows** during the analysis for the main natural isotopes
     • Activity concentration is determined from the net content of the window around individual peaks
     • Typical energy windows used to estimate the activity concentration for in-situ measurements:

          | Radionuclide | Energy (keV) | Window (keV) |
          |--------------|-------------|-------------|
          | Potassium ($^{40}$K) | $^{40}$K | 1460 | 1370-1570 |
          | Uranium ($^{238}$U) | $^{214}$Bi | 1765 | 1660-1860 |
          | Thorium ($^{232}$Th) | $^{208}$Tl | 2614 | 2410-2810 |

IAEA 2003
1. Spectra analysis calibrating broad spectral windows

   Problems:
   
   • Blind to any unexpected signal (anthropic radionuclides).
   • Low accuracy for short time acquisitions
   • Physical restriction of poor intrinsic energetic resolution of the (mostly used) NaI(Tl) detector.
   • Assumption of secular equilibrium

   Not valid
2. Full spectrum analysis method

- The total spectrum is `unfolded' into the spectra for the individual radionuclides (the so-called standard spectra) and a background spectrum.
- Standard spectra (of each investigated radionuclide) derived from the calibration procedure.
Many problems related to the measurement of NORM and NORM containing building materials

• **Disequilibrium** in decay chains

• **Big variation and heterogeneity** of the materials / components / matrices

• **Many radionuclides** (peaks) in one sample (spectrum)
  – Need for corrections for overlapping peaks
  – Some natural radionuclides have no gamma emission or very weak emission probability (e.g. Th-232, U-238, U-234, ...)
$^{238}\text{U}$ decay chain

$^{238}\text{U}$ decay through a series of alpha and beta decay to $^{206}\text{Pb}$ (stable)

$^{238}\text{U} \rightarrow ^{206}\text{Pb} + 8\frac{4}{2}\text{He} + 6e^- + 6\bar{\nu}_e$
$^{232}\text{Th}$ decay chain

$^{232}\text{Th}$ decay through a series of alpha and beta decay to $^{208}\text{Pb}$ (stable)

$^{232}\text{Th} \rightarrow ^{208}\text{Pb} + 6^4_2\text{He} + 4e^- + 4\bar{\nu}_e$
Many problems related to measurement of NORM and NORM containing building materials

- High level of **expertise & instrumentations** required e.g. HPGe, alpha spectrometry
  - **Sample preparation** for alpha spectrometry

- Sampling uncertainties

- Need of fast measurement results for taking **fast decisions** e.g. compliance of raw material feed in an industrial process
  - → role of on-site methods as screening tool
Problems related to measurement of NORM and NORM containing building materials

- **When can we allow the use of on-site methods?**
  - Only use them for specific, well defined applications (**screening tools**)
    - When the measured value (taking into account the uncertainty) is significantly below the screening level
  - Measure material in **well defined geometries** (big bags)
  - If possible measure **larger quantities** of material for a **longer time**
  - Need to **validate** the use of on-site methods
  - Use of **newer scintillation detectors** which generally show better energy resolutions,
    - LaBr$_3$:Ce, CeBr$_3$, BGO (Bismuth germanate), CdWO$_4$, PbWO$_4$
Validated *on-site* measurement protocols for

- Activity Concentration Index
- Radon (possibly thoron) emanation and exhalation rate

**Towards standardisation**

- Proposal for a *calibration procedure*
- Steps in the development of pre-standard materials

**Problem:** good standards are missing
Validated (on-site) measurement protocols for

- Activity Concentration Index
- Radon (possibly thoron) emanation and exhalation rate

Intercomparisons using several measurements protocols and instruments

Towards standardisation

- Proposal for a calibration procedure
- Steps in the development of pre-standard materials

Towards certification

- Factsheet for unified certification procedure of construction materials.

MetroNORM

Metrology for processing materials with high natural radioactivity
# COST network: Intercomparison exercise

## Countries and Labs

<table>
<thead>
<tr>
<th>Country</th>
<th>Organization/Institute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albania</td>
<td>Institute of Applied Nuclear Physics, University of Tirana</td>
</tr>
<tr>
<td>Belgium</td>
<td>Nuclear Technology - Faculty of Engineering Technology, University of Hasselt</td>
</tr>
<tr>
<td>Belgium</td>
<td>SCK CEN Belgian Nuclear Research Centre</td>
</tr>
<tr>
<td>Croatia</td>
<td>Institute for Medical research and occupational Health Radiation Protection Unit</td>
</tr>
<tr>
<td>Denmark</td>
<td>DTU Nutech, Technical University of Denmark</td>
</tr>
<tr>
<td>Estonia</td>
<td>Institute of Physics, University of Tartu</td>
</tr>
<tr>
<td>France</td>
<td>IRSN Institut de Radioprotection et de Sureté Nucléaire</td>
</tr>
<tr>
<td>Germany</td>
<td>IAF - Radioökologie GmbH</td>
</tr>
<tr>
<td>Greece</td>
<td>National Technical University of Athens</td>
</tr>
<tr>
<td>Hungary</td>
<td>Institute of Radiochemistry and Radioecology, University of Pannonia</td>
</tr>
<tr>
<td>Hungary</td>
<td>Social Organization for Radio-ecological Cleanliness</td>
</tr>
<tr>
<td>Italy</td>
<td>University of Ferrara, Department of Physics and Earth Science</td>
</tr>
<tr>
<td>Italy</td>
<td>Instituto Superiore di Santà</td>
</tr>
<tr>
<td>Netherlands</td>
<td>NRG</td>
</tr>
<tr>
<td>Poland</td>
<td>Silesian Centre for Environmental Radioactivity, GIG</td>
</tr>
<tr>
<td>Portugal</td>
<td>Instituto Superior Técnico (IST), Campus Tecnologico e Nuclear (CTN), Universidade de Lisboa</td>
</tr>
<tr>
<td>Slovenia</td>
<td>ZVD Zavod za varstvo pri delu d.o.o.</td>
</tr>
<tr>
<td>Spain</td>
<td>CIEMAT-Servicio de Protección Radiológica</td>
</tr>
<tr>
<td>Spain</td>
<td>CIEMAT-Unidad de Radiactividad Ambiental y Vigilancia Radiológica</td>
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<tr>
<td>Spain</td>
<td>University of Huelva</td>
</tr>
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<td>Spain</td>
<td>University of Salamanca</td>
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<td>Spain</td>
<td>University Autonoma de Barcelona</td>
</tr>
<tr>
<td>Spain</td>
<td>University Autonoma de Barcelona</td>
</tr>
<tr>
<td>USA</td>
<td>Nuclear Engineering Teaching Lab, University of Texas</td>
</tr>
</tbody>
</table>

16 Countries
23 Labs
Improved (more realistic) dosimetrical models

For use of NORMs in
a) Cement
b) Concrete
c) Ceramics

Specific focus on use of NORMs in alkali activated cements.
Improved (more realistic) dosimetrical models

For use of NORMs in
a) Cement
b) Concrete
c) Ceramics

Specific focus on use of NORMs in alkali activated cements.

Evaluation of implementation on market.

a) Round table discussions with all stakeholders
b) End-of-Life?
   - Leachability?
WG4: evaluation of reuse of NORM in building materials

- Experimental building material related parameters
  ➔ modeling of impact building materials
    1. Gamma dose modelling
    2. Rn (and Tn) dose modelling
    3. Leachability/breakdown modelling of radiological and chemical impact

Too be published soon: NORM4Building the book…
Working Group 4
‘Improving dosimetrical models’

**Improved (more realistic) dosimetrical models**

For use of NORMs in
a) Cement
b) Concrete
c) Ceramics

Specific focus on use of NORMs in **alkali activated cements**.

**Evaluation of implementation on market.**

a) Round table discussions with all stakeholders
b) End-of-Life?
   • Leachability?

**Evaluation of legislation**

a) Impact EU-BSS
b) Comparison of alternative national (EU-BSS based) legislative scenarios
And then the Belgians came...

- FANC Decree of March 2013
  - Addition treatment of NORM to work activities: "processing, valorisation and recycling of residues with an activity concentration > RP 122 II"

- Submits NORM residue treatment facilities to notification

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Activity concentration (Bq/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U-238sec (incl. U-235sec)</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>0.1 (mono-landfill)</td>
</tr>
<tr>
<td>U nat</td>
<td>5</td>
</tr>
<tr>
<td>Th-230</td>
<td>10</td>
</tr>
<tr>
<td>Ra-226+</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>0.1 (mono-landfill)</td>
</tr>
<tr>
<td>Pb-210+</td>
<td>5</td>
</tr>
<tr>
<td>Po-210</td>
<td>5</td>
</tr>
<tr>
<td>Th-232sec</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>0.1 (mono-landfill)</td>
</tr>
<tr>
<td>Th-232</td>
<td>5</td>
</tr>
<tr>
<td>Ra-228+</td>
<td>1</td>
</tr>
<tr>
<td>Th-228+</td>
<td>0.5</td>
</tr>
<tr>
<td>K-40</td>
<td>5</td>
</tr>
</tbody>
</table>
Acceptance Criteria dependent on type of treatment (Belgium, FANC)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Activity Concentration</th>
<th>Input (Waste producer)</th>
<th>Output (Waste Processor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building Materials</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$C_{\text{exemption}}$</td>
<td></td>
<td>$\text{RP 122 II}$</td>
<td>Monitoring residues</td>
</tr>
<tr>
<td>$C_{\text{max}}$</td>
<td></td>
<td>$10 \text{ Bq/g}$</td>
<td>- Activity index (buildings)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- RP 122 II (roads)</td>
</tr>
</tbody>
</table>
Interested?  
**www.norm4building.org**

Contact:  
**COST@uhasselt.be**