TOWARDS A HOLISTIC APPROACH FOR RISK ASSESSMENT WHEN REUSING SLAG WITH ENHANCED NORM CONTENT IN BUILDING MATERIALS

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Introduction

The depleting of energy resources and raw materials requires an increasing sustainable use of materials and energy. In this context, the reuse of (waste) residue streams to develop new synthetic building materials for the construction sector is highly relevant.

Slag and bottom ash from coal-fired power plants, phosphorous slag from thermal phosphorus production, unprocessed slag from primary iron production and lead, copper and tin slags from primary and secondary production can, dependent on the origin of the ores and the used industrial process, contain enhanced concentrations of naturally occurring radioactive materials (NORM) [1]. These types of residues can have very interesting properties for the cement industry as alternative raw materials and supplementary cementitious materials (SCMs) or, in the case of residues with a high calorific value, they can be introduced as an alternative fuel where the remaining ash is typically incorporated in the cement clinker [2, 3]. In the concrete industries, the residues are used or studied for use in increased amounts as SCMs (as partial cement replacement or as mineral additions in concrete) and as aggregates [4]. In the ceramic industry, slags from various types of metal smelting were used or investigated for use in clay based ceramics as aggregate [5]. Alternatively other types of NORM containing residues (such as red mud from the Bayer process) can be used in the bond system of clay ceramics [5]. An emerging field in the building industry is the development of Alkali-Activated Materials (AAMs). The AAMs can contain calcium silicate or a more aluminosilicate-rich precursor such as a metallurgical slag, natural pozzolan, fly ash or bottom ash as solid aluminosilicate source [6].

On the 5th of December 2013, the council of the European Union has adopted the new directive 2013/59/EURATOM (Euratom Basic Safety Standards, EU-BSS) [7] that specifically addresses the topic of the use of residues from NORM processing industries in building materials. The EU-BSS sets the requirement of a radiological screening and further characterisation of building materials that incorporate specific residues (considered are among others fly ash; phosphogypsum; phosphorus, tin and copper slag; red mud and residues from steel production) from NORM processing industries before the they can be distributed on the market. The current European recommendation concerning natural radioactivity in building materials is based on RP 112 [8]. RP 112 uses a model for building materials including the effects related to the presence of all natural radionuclides from ^{238}U and ^{232}Th decay series and ^{40}K. In the model secular equilibrium among all radionuclides constituting decay series is assumed. This assumption is more or less valid in case of construction material of natural origin. However when NORMs are considered quite opposite assumption should be made. Lack of equilibrium impacts the model of risk scenarios and implies application of more accurate measurement methods.

Upon studying environmental aspects of (waste) residue based building materials it is advisable to opt for a holistic material flow analysis covering relevant environmental and safety issues related to radiological, chemical and leaching properties of the (secondary) raw materials as well as final products based on these raw materials. Attention has already been given to the radiological properties for several of these secondary resources [8]. Newly developed building materials can contain a larger fraction of residues. For these building materials, the radiological aspect is still not fully investigated. To cover this aspect the new EU sponsored COST Action Tu1301 'NORM4BUILDING' was initiated in January 2014.

Objectives

The main objective of COST action Tu1301 'NORM4BUILDING' is the exchange of multidisciplinary knowledge and experiences (radiological, technical, economical, legislative, ecological) to stimulate the reuse of NORM residues in new tailor-made sustainable building materials in the construction sector while considering the impact on both external gamma exposure of building occupants and indoor air quality. The COST network consists out of four working groups and the aims for each working group are given in figure 1.

The recasting of the EU-BSS by the European Commission can have a large impact on reuse options for NORM in building materials. The new COST action aims at providing scientific support and solutions for industry regarding the reuse of slag materials in building materials compatible with the requirements of the new EU-BSS.

By improving dosimetrical models [9] for the reuse of NORM residues in building materials the new COST action aims at further stimulating justified uses of NORM residues in different types of newly developed building materials. Based on these models, the COST Action aims at investigating realistic legislative scenarios so that the authorities can allow reuse pathways for NORM that can be accepted from a radioprotection point of view in concordance with the Lead Marked Initiative (LMI) and sustainable construction.

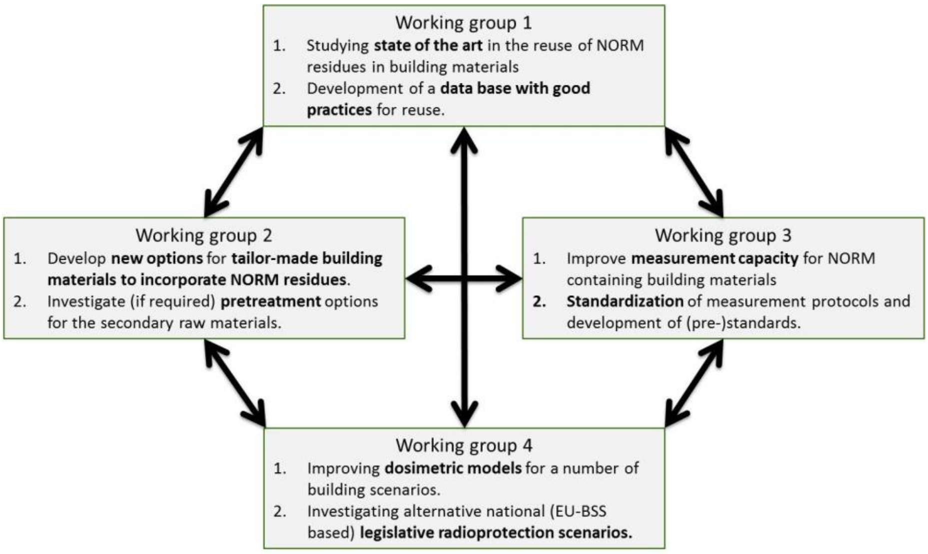

Figure 1: Aims of the four working groups of the 'NORM4Building' network.

Scientific approach and current status

The NORM4Building COST action develops strategies for the reuse of NORM residues in ceramics, concrete and cement with a focus on the reuse of NORM residues in emerging building materials, in particular geopolymers/inorganic polymers.

The new database that currently is being developed by working groups 1 and 2 serves to combine information on different aspects (technical, chemical, radiological…) of the NORM residues and the (residue based) building materials. The gathered data can be used as input for a more holistic evaluation of the reuse options.

Working group 3 investigates industrially useful methodology/protocols for the determination of the activity concentration index (Annex VIII of the EU-BSS [7]) to assess the applicability of the newly developed building materials for the European building market. Specifically to further support the industry in their search for cost-efficient measurement solutions, the applicability of *on-site* measurement methodology is investigated [10, 11]. Working group 3 organizes intercomparisons between different institutes using several measurement protocols and instruments.

Working group 4 targets the challenges in modelling and modelling tools specifically for scenarios using the newly developed construction materials containing NORM residues. Research on several computational methodologies - room models [12] - and *on-site* techniques [9,13,14] is available to evaluate and predict the indoor gamma dose rate and the radon and thoron indoor concentrations on the basis of the radioactivity content and other characteristics of newly developed building materials. It was found that modelling of doses due to natural radionuclides in building materials is an effective tool for optimization of radiation protection. Such modelling cannot be done for each building material, however in case the activity concentration index is higher than 1, the modelling might be helpful in deciding if the construction materials under consideration might be used.

Working group 4 uses three different modelling approaches: (1) Gamma dose modelling, (2) Radon (and Thoron) dose modelling and (3) modelling of the leaching of radionuclides and metals. Gamma dose modeling uses ^{226}Ra, ^{232}Th and ^{40}K concentrations, the density, thickness and other information on structure of dwellings as input parameters to model the activity concentration index accounting for density and thickness. Results on gamma dose modeling are in publication [15]. The activity concentration index will be further developed in order to consider the actual structure of dwellings. Radon (and thoron) dose modelling uses the ^{226}Ra activity concentration and the radon (thoron) exhalation as input parameters for Rn exhalation modeling for real life circumstances and important properties of building materials (decomposition, crack generation, porosity…). The Rn activity is further modelled to account for e.g. ventilation, dwelling size and convection. For further dose estimation working group 4 is awaiting the new recommendations of the ICRP. As experimental input for the modelling of the leaching behavior, method 1313 [16-18], to study the pH dependence, and method 1314 [17-19], to study the end of life aspects by means of a percolation tests, were proposed. Modeling of the leaching behavior further includes important properties (mixtures, materials with different layers, carbonation, oxidation,…) of building materials.

The NORM4Building network currently consists out of more than 90 researchers from 24 different European countries and is open for further international collaboration. Figure 2 depicts the institutes and countries involved in the network. More information regarding the COST action is available at www.norm4building.org.

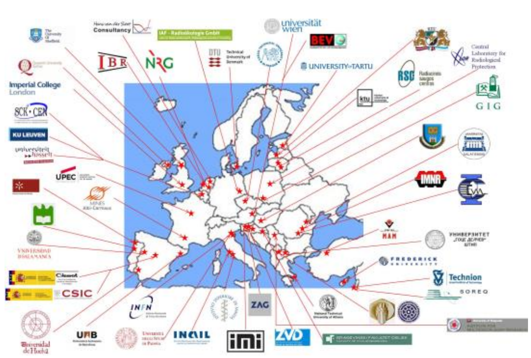

Figure 2: Institutes participating in the 'NORM4Building' network (December 2014)

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