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ТОКСИКОЛОГИЧНИ АСПЕКТИ НА СТРОИТЕЛНИТЕ МАТЕРИАЛИ, ОЦЕНЯВАНИ В EPD И PEF СЕРТИФИКАТИ

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TOXICOLOGICAL ASPECTS OF CONSTRUCTION MATERIALS TREATED IN EPDs AND PEFs

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Abstract:
Modern buildings face various and interdependent challenges in terms of innovation, design, energy and resource efficiency, sustainable materials and construction, durability and potential for waste recovery and recycling. Construction materials play an important role in the assessment of building's sustainability and their significance is recognised by the intensive development and use of the methodology for environmental product declarations (EPDs).In addition to that, the European commission provides guidance on product environmental footprint assessment (PEFs). This paper discusses the health-related indicators in EPDs and PEFs and their application to some construction materials. An overview is done on the nature of these indicators and the approaches for their assessment and applicability in EPDs and PEFs. While EPDs of construction products are prepared based on well-developed methodology and specific standard (EN 15804) that act as core product category rules (PCR) for all types of products, PEF guidelines treat each product separately and their scope is quite limited in terms of construction materials.
This study outlines both the common features of both approaches for assessment eco-toxicity and human health and provides a discussion on their relevant fields of application, including on construction and demolition waste (CDW) management.

Keywords:
Construction materials, toxicity, particulate matter, ionising radiation,

1. INTRODUCTION

Modern building materials need to respond to various requirement for technical qualities, economic feasibility and environmental performance and sustainability. They also need to be suitable for reuse/recycling from CDW management point of view. The environmental impacts of materials are assessed by various indicators: CO_2 emissions, ozone depletion, smog creation, eutrophication, acidification, radiation, toxicity, etc. and the primary impacts are known to be occurring during the manufacturing stage. The use of resources is a significant issue for construction materials since around 50% of all extracted natural resources are transformed and consumed by the construction industry [1]. This determines the huge and various types of CDW –

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more than a third of all generated waste in the EU (EC) and underlines the need for proper attitude towards this waste by exploiting the potential for reuse, recycling and recovery.

Furthermore, Regulation 305 [2] lists toxicological aspects under the 3rd requirement that must be controlled before launching a product on the market. The requirement for hygiene, health and the environment treats emissions of toxic gases; **dangerous substances; volatile organic compounds (VOC), greenhouse gases or dangerous particles** into indoor or outdoor air; **dangerous radiation**; release of **dangerous substances** to water/soil, etc.

Whether we consider the material itself during production and use or the waste formed by this material when the building is demolished, the issue with toxicity to humans and natural habitats needs to be addressed because homes contain a large amount of chemicals and heavy metals that can be released at different stages of the life cycle. Toxicity of construction materials can be presented and declared either by an environmental production declaration (EPD) or by a certificate of the product environmental footprint (PEF).

This paper provides a summarised overview on the methodologies for toxicity evaluation used in EPDs and PEFs, and their relevance to construction materials and CDW. The better understanding of toxicological mechanisms can help us outline potential hotspots in the health-related issues of construction materials and recovery of CDW.

2. EPDs AND PEFs

2.1. Environmental Product Declarations (EPDs)

An environmental product declaration (EPD) is defined by EN 15804 [3] as a type III declaration that provides "quantified environmental data using predetermined indicators and, where relevant, additional environmental information" about products. EPDs are based on the life-cycle assessment approach (LCA) standardised in the ISO 14000 series. The information in EPDs can be considered a substantial source of information for assessment of the whole building. Type III EPDs cover all life stages of a building: product stage, construction (installation, assembly), use and end-of-life stage. Each stage is described by modules representing specific sub-stages and processes in a general building. At present, EN 15804 allows omittance of some stages because of uncertain scenarios, lack of reliable data or because of irrelevance to the environmental performance. The mandatory scope of an EPD covers the product stage (modules A1-A3), end-of-life processes (modules C1-C4 in regards with deconstruction/demolition and CDW management) and relationships to other product systems through recovery/recycling activities (module D).

EPDs of type III are verified by independent bodies and published by program operators. The peer-review process guarantees transparency and completeness of the assessment which is why they are widely used and required by green building certification schemes, public procurements, organisation, etc. From this standpoint, EPDs is a valuable source of information about a number of environmental indicators grouped as core environmental impacts, additional environmental impacts (toxicity), resource use and output (waste) flows. In order to encompass in broad sense, the vast variety of materials and products, EN 15804 serves as a core product category rules (PCRs) establishing the framework for construction products and outlining the evaluation methodologies for the impact categories and indicators. Despite the common methodological basis, the EPDs cannot serve as a comparison basis between products because certain cut-offs in assessed data are allows and declared life cycle stages may vary from EPD to EPD.

2.2. PEFs

The product environmental footprint (PEF) is another life cycle-based method for measuring environmental performance developed and recommended by the European Commission [4]. PEF is defined as a "general method to measure and communicate the potential life cycle environmental impact of a product". The emergence of PEF aims at providing a single unified method for substantiating the environmental aspects of products and enabling a green market for all kind of products. The PEF initiative is the proposal of the EC to overcome eventual misleading claims of certain green labels by establishing a reliable framework. Product Environmental Footprint Category Rules Guidance [5] is published as a result from the pilot stage of the PEF project (2013-2018). Like EPDs, PEFs follow the modular approach and uses the same life cycle stages structure. The PEFCR resembles the function of EN 15804 as a core category rules document. It describes the procedure for PEF development and technical specifications (scope, impact assessment categories, modelling of specific aspects and stages, etc.). The difference between PEFCR and EN 15804 is that PEFCR targets all kinds of products, while EN 15804 is focused only on construction materials.

The PEFCR Guidance [5] requires sixteen indicators to be evaluated and they correspond to the core and additional (toxicity) environmental impacts categories in EN 15804. PEF in general should cover the whole life cycle of the product with possible exceptions for specific products. Because of the vast complexity of products in the human life, PEFCR are expected to be developed for representative products (non-existing products based on a combination of existing technologies). Nineteen PEFCRs for various product groups (e.g. foods, drinks, clothes, paper, metal sheets, pipe systems, IT equipment, etc.) are published during the pilot phase and are valid until the end of 2021. From the available PEFCRs only few are relevant to construction - for decorative paints, hot and cold water supply systems, metal sheets and some thermal insulation products (cellulose insulation, EPS, PU and foamed glass). New PEFCR are expected to be developed [6].

The PEFCR proposes specific scenarios about the end-of-life stage regarding dismantling/demolition, transport of waste, treatment activities, energy recovery and landfill rates per country. E.g., for non-mineral insulation products in Bulgaria it is assumed that 0% of the thermal insulation would be recycled, 7% would be subjected to energy recovery and 93% would be landfilled, while mineral insulations are considered to be directed for landfilling in full [7]. In contrast, the scenarios for countries with well-developed CDW recovery practices (Austria, Belgium, Denmark, Germany) state that 100% of the insulation would be subjected to energy recovery.

3. TOXICITY CATEGORIES IN EPDs AND PEFs

3.1. Human toxicity and ecotoxicity

USEtox model is used to characterise direct human toxicological and ecotoxicological impacts in the LCA. It is developed under the UNEP -SETAC Life Cycle Initiative [8, 9, 10] and its aim is to provide a scientific basis for a “comparative assessment of chemicals based on their impacts on human health and on ecosystems” [8]. The model describes the environmental distribution, exposure of humans and ecosystem populations, and toxicity-related effects from this exposure by using data from existing databases and peer reviewed sources. The characterisation factors (CFs) in USEtox vary widely and there are vast differences from substance to substance (up to 12 orders of magnitude) determined by the variations in production, emittance, distribution mechanisms, fraction intake by humans and/or ecosystem species and differences in the sensitivity to the different compounds [10]. The number of contributing flows is very high – around 1000 substances for human toxicity and more than 2500 substances for aquatic ecotoxicity [8]. USEtox allows for distinguishing between products with negligible and products with higher toxicity impact potentials by analysing even a large number of chemicals – more than 30000 different substances are frequently used in products [11] most of which pose potential risk of toxicological effects on humans and ecosystems.

The methodology considers three receiving compartments of the contaminants – 1) indoor air, urban and rural areas, 2) continental freshwater and 3) agricultural soils. The purpose of the estimation is to classify and provide basis for comparison between chemicals. The impact scores of chemical compounds are calculated using estimated emitted mass in the different compartments. Both human toxicity and ecotoxicity are expressed in comparative toxic units (CTUs) which indicates the comparative character of this approach. CTU for human toxicity represents "the estimated increase in morbidity in the total human population per unit mass of a contaminant emitted, assuming equal weighting between cancer and non-cancer effects: [CTUh per kg emitted] = [disease cases per kg emitted]", and for freshwater ecotoxicity, the CF "provides an estimate of the potentially affected fraction of species (PAF) integrated over time and volume per unit mass of a chemical emitted": [CTUe per kg emitted]= [PAF m^3 d per kg emitted] [8].

The USEtox model calculates the CF of each substance as a combination of a fate factor (FC), exposure factor (XF) and effect factor (EF):

$$CF = FF \times XF \times EF \quad (1)$$

FF calculates how the substance is dispersed in the environment (describing degradation and inter-compartment transfer) and represents the persistence of a chemical in the environment over certain period of time (e.g. days). XF quantifies the human and/or ecological system contact with environmental media and is represented by the fraction of the chemical transferred to the receptor population in a specific period (a day).

Toxicity of construction materials is a broad problem because of their complex chemical composition. A variety of stabilizers, plasticisers, pigments, etc. substances are added to a wide range of construction products (concrete, mortars, plastics, wood preservatives, finishing materials, materials for chemical treatment, sealants, paints, etc.). Toxicological impacts can arise from various products at various stages in the life cycle – e.g persistent bio-accumulative and toxic chemicals (PTBs), chemicals that mimic or block the action of hormones (endocrine disruptors – ECDs), leachate of vinyl chloride monomer (e.g. from PVC pipes), phthalates (found in home dust emitted from PVC products); formaldehyde and volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), heavy metals and compounds (from pigments, fillers, UV stabilizers, and flame retardants); organic and inorganic substances in wood preservatives (copper compounds, chromium, boron compounds, arsenic, , etc); asbestos, moulds, fungi and algae, etc. The following scheme (Figure 1) shows the various sources of toxicological effects from construction materials.

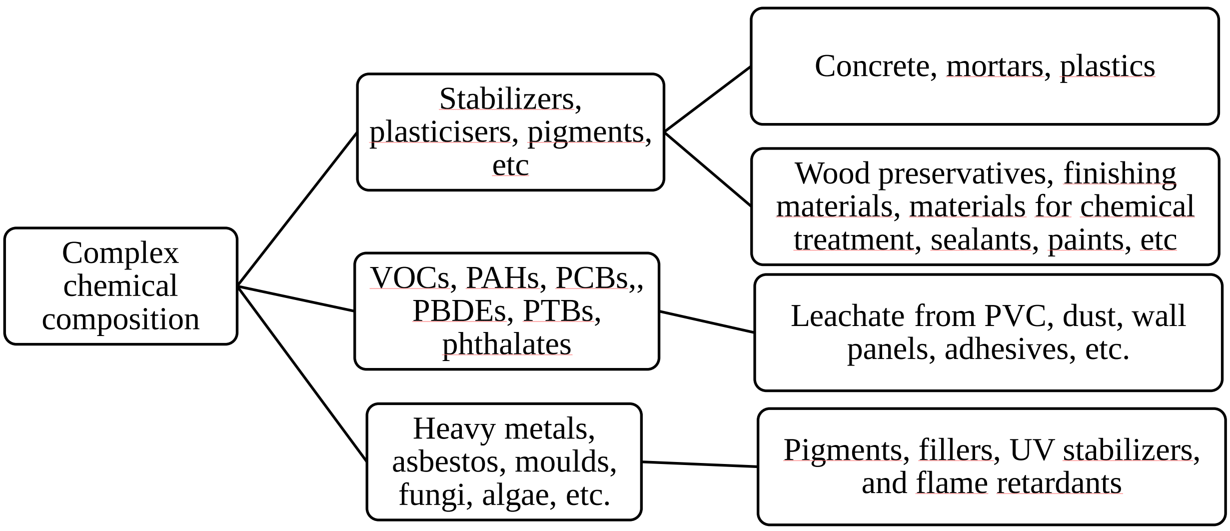

Figure 1. Sources of toxicity from construction materials.

Paints are one of the most widespread sources of VOCs because they contain organic solvents and at reduced ventilation of the premises, VOCs might be released. A number of cancerogenic substances are identified in paints that are summarized below [12]

Table 1. Cancerogenic substances in paints

Compound	**Likely sourse**
Chromates	Primers, paints
Cadmium	Pigments
Benzene	Solvents
Methylene chloride	Paint strippers
Styrene	Organic solvents
Nikel compounds	Pigments
Dichlorobenzidine	Pigments
Lead	Primers, dryers, pigments
Antimony oxide	Some pigments
Nitropropane	Organic solvent
Tetrachloroethylene	Organic solvent

Wood impregnating materials are another underrated source of toxicity because in the past impregnating substances included creosote or others based on salt impregnation like copper, chrome and arsenic, which are highly toxic and bio-accumulative and can be leached by rainwater. This makes them a significant hazard both for humans and for ecosystems [12]. It is found that wood used in railway cross ties has a high content of creosote [13] so they must be classified as hazardous wastes and they must be properly immobilised and no longer reused [14].

Another issue with materials is that some of them can release toxic gases during fire, e.g. some thermal insulating materials like polyethylene or polyurethane foam have very high toxicity index [12]. One way to limit or prevent this effect is the use of non-combustible surface treatment of the insulating layer or to add flame-reducing additives.

3.2. Particulate matter

The methodology used to calculate this impact is adopted by [15] in the Global Guidance for Life Cycle Impact Assessment Indicators by SETAC-UNEP. To characterise the impacts, the emissions are expressed as mass of $PM_{2.5}$ and their advective distribution and transformation within air (indoors and outdoors) is modelled to assess the concentration of $PM_{2.5}$. A fraction of this mass is later inhaled by exposed population and the cumulative population risk is measured in disease incidences among the exposed population. Disease incidences are transformed into a metric of damage by accounting for disease severity. The Harvard Six Cities study [16] is the first to investigate the effects of PM on human health, showing that mortality rates were approximately 30% higher in the dirtiest city (Steubenville, Ohio) compared to the cleanest city (Portage, Wisconsin), “suggesting that for every 1 $\mu g/m^3$ levels, mortality rates increased by approximately 1.5%” [14]. Other sources [17] indicate that a 1 mg/m^3 increase in $PM_{2.5}$ leads to 0.6% increase in all-cause mortality, and 1.1% increase in cardiovascular mortality (with certain variability).

Inhalation intake fraction (iF) suggested by [18] provides a suitable measure to account for $PM_{2.5}$ impacts and is adopted in PEFCR and EN 15804:

$$iF = \frac{Cumulative\ inhalation\ intake\ by\ population, kg}{Mass\ released\ into\ the\ environment, kg} \quad (2)$$

Several factors can influence iF, a summary for $PM_{2.5}$ outdoor and indoor origin is presented in table 2:

Table 2: Factors influencing the iF for $PM_{2.5}$ [15]

Outdoor origin	Indoor origin
- Population density - Breathing rate - Wind speed - Mixing height - Source-to-recipient distance - Infiltration (leaks in building envelope, active filtration by ventilation system, deposition within the room)	- Building air exchange rate - Building volume - Inter- and intra-zonal air flows and mixing - $PM_{2.5}$ removal mechanisms (deposition to surfaces and filtration in HVAC systems that recirculate air) - Breathing rate - Time spent in indoor environments

The CFs for $PM_{2.5}$ health impacts are calculated using a similar approach as in modelling human toxicity and ecotoxicity. The model combines fate (transfer and losses in compartments), exposure (daily fraction of air inhaled), exposure-response slope (change in all-cause mortality) and severity (change in human health damage). CFs are expressed as change in disease incidences per kg emissions of $PM_{2.5}$ or precursors [deaths/kg emitted] for premature all-cause mortality.

Emissions of $PM_{2.5}$ can be found in activities using machine operations or during concrete mixing and casting. Dust emissions are very often generated from repair works and during dismantling or demolition of buildings as these processes require intensive drilling, crushing, cutting, etc. of building elements.

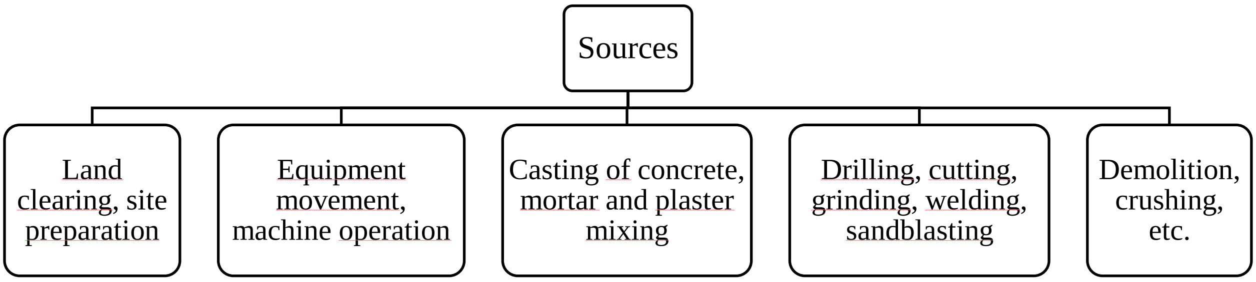

Figure 2. Origin of particulate matter from construction materials.

The magnitude of dust emissions depends on the type of material and the moisture content. Silica dust is commonly emitted from activities with materials that contain silica or hydrosilicates – e.g. concrete and mortars [19]. In such cases it is recommended the materials to be preliminary moistened or washed as the particles consolidate and the aerosol matter dispersed is much less [20].

3.3. Ionizing radiation

Currently, information on impacts from ionising radiation for some construction materials is provided as part of the data safety sheets. The model adopted in PEFs and EPDs for assessing the impact on human health from ionising radiation is developed by Dreicer, et al. [21] and updated by Frischknecht, et al. [22]. The human health effects are described related to the routine releases of radioactive material to the environment, e.g. from man-made source such as nuclear and coal power plants, phosphate rock extraction, oil and gas extraction.

The discharge and distribution of radioactive materials in different media (atmosphere, rivers, lakes, the ocean and soil) is modelled. The health effects (cancer and severe hereditary effects) are calculated statistically, and their severity is weighted using the concept of disability adjusted life years (DALY) which calculates disability adjusted life years and years lived disabled.

Health effects from radiation are typically classified as deterministic or stochastic. Deterministic effects describe direct effect of radiation, e.g. radiation burns on the human body, while stochastic effects take into account the cancerogenic and hereditary effects. In general construction materials are not classified as potential sources of radiation. However, the utilisation of industrial by-products may increase the risk significantly. For example, phosphogypsum, some blast furnace slags and some fly ashes used as mineral additives for concrete can contain heavy metals and radioactive elements such as radium (^{226}Ra), lead (^{210}Pb) and uranium (^{238}U, ^{234}U) originating from phosphate rocks [12].

Demolition of specific buildings where radioactive materials are used– factories, power plants, etc. may also pose risk or ionising radiation – e.g. during jack hammering of concrete when radioactive substances (radon) from the aggregates may be aerosolised [19].

4. CONCLUSION

The paper provides an overview of the impact categories and indicators assessing toxicological effects for humans and aquatic ecosystems as well as other health-related issues. The models describing and estimating these impacts are the outcome of continuous research, so they have strong scientific background and their reliability is claimed sufficient. The inclusion of toxicological impacts in EPDs, even as optional indicators, allows for a more comprehensive application of the assessment methods and would help improving the calculation procedures. This, combined with the expected launching of new PEFCRs for construction products over the next few years would probably define the mandatory status of these indicators in time.

The setting of uniform prerequisites for various products under the same PEFCR makes the study largely controlled but, on the other hand, it sets the ground for possible comparisons of products because the differences would be mostly in the sourcing of raw materials and production process. Nevertheless, there would still be limitations to comparisons of construction products by their PEFs because it would only be relevant at building level when the product is part of a system. In this case, a reasonable basis for comparison demands a suitable reference about the application which means that PEFs would hardly be used as a direct comparison basis soon.

It is important to emphasise that the purpose of health-related impacts is to allow relative comparisons between products rather than being used to extrapolate and calculate health risk and potential disease occurrence. The assessment of toxicity and other health and ecosystem indicators is a serious step forward to drawing the attention to the hazardous substances in construction materials and to the accumulation and dispersion processes. This is particularly significant for the characterisation procedure of CDW so that end-of-life activities can be responsibly and safely implemented.

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