INCORPORATING THE RADIOLOGICAL EFFECTS AND ENVIRONMENTAL IMPACT ASSESSMENT OF NATURALLY OCCURRING RADIOACTIVE MATERIALS (NORM) INTO THE LIFE CYCLE ENVIRONMENTAL OPTIMISATION OF BAUXITE RESIDUE (BR) VALORISATION

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Abstract

Bauxite Residue (BR) is a potentially valuable source of metals and construction materials, which the ETN REDMUD project aims to develop technologies to exploit. Bauxite contains low levels of Naturally Occurring Radioactive Materials (NORM), which are concentrated in BR, and could potentially be released during BR valorisation, or further concentrated in novel products resulting from BR valorisation. Life Cycle Assessment (LCA) is a well-established and standardised methodology to quantify the potential impacts arising from the life cycle of products and services, however it is not currently possible use it to assess the radiological impacts of NORM. The inclusion of NORM exposure in LCA is an important step to avoid burden shifting in the environmental optimisation of BR valorisation.

Introduction

Radioactive isotopes occur naturally within many minerals in the earth's crust,[1] including bauxite. Human activities can increase the exposure of both humans and ecosystems to Naturally Occurring Radioactive Materials (NORM) and the resulting increased exposure to ionising radiation has the potential to lead to adverse impacts upon these receptors.

In many cases, in particular that of the valorisation of bauxite residue (BR), the radiological impacts of the NORM in these materials are likely to manifest themselves at a place and a time other than that of their original processing. That is, at another stage in their life-cycle. Life Cycle Assessment (LCA) is a standardised and internationally recognised method to quantify and assess the whole life cycle impact of products and services across a variety of impact categories. The aim is to gain a holistic view of the potential effects of the human actions required in order to achieve the provision of these products. This has the potential to tell us not only the likely magnitude of the impact, but where in the life cycle of a product the greatest impacts are likely to occur and what is causing them. In the case of the radiological impacts of NORM resulting from BR valorisation, this could potentially yield valuable insights into the significance of NORM, and highlight, at an early stage, potential ways in which to optimise the valorisation process through the mitigation of radiological risks.

Life Cycle Assessment (LCA)

Humans operate within our own constructed system of products and processes. We demand, purchase and use manufactured items, and we use natural resources to produce and supply these items. In LCA this is referred to as the 'technosphere'. These products and processes exchange substances and energy with the environment. This may take the form of acquiring or sequestering raw materials from the environment, such as the aluminium atoms contained within bauxite, or releasing substances back to environment, for example the emission of carbon dioxide through the burning of fossil fuels. In LCA these exchanges are modelled and quantified across the life cycle of a given item, compiling them into a so-called Life Cycle Inventory (LCI). This is achieved by establishing the 'unit processes' that make up the life cycle of the item (from raw material extraction, through production, distribution, use and eventual disposal), quantifying the environmental exchanges that result from these processes, and scaling them according to the amount of the item in question that is being assessed.

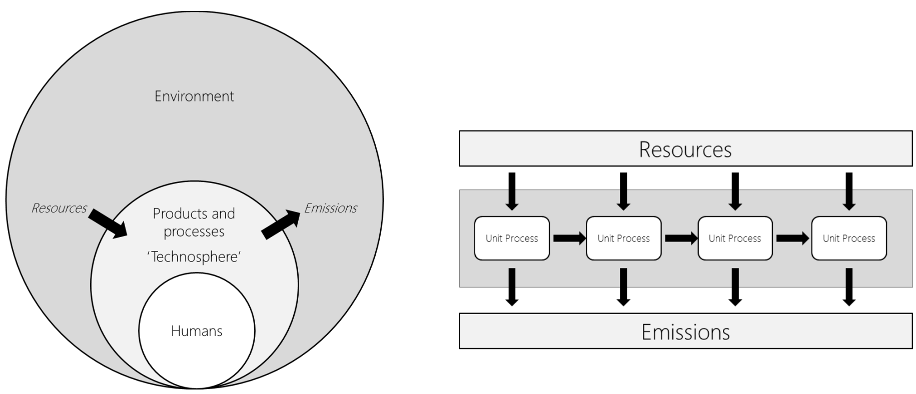

Figure 1: Environmental exchanges quantified in LCA, at a global level (left) and in the context of an LCA model (right)

Once these exchanges have been established and inventoried, they can be characterised according to their potential impact within a defined 'impact category' on the basis of cause-effect relationships. For example, the emission of greenhouse gases to the environment contributes to the greenhouse effect by virtue of the radiative forcing effect of their molecules preventing energy from leaving the atmosphere. The degree of radiative forcing caused over a given time scale varies between gases, for example over a 100 year period methane has a 25 times greater effect than carbon dioxide. By characterising all greenhouse gases emitted to the atmosphere in terms of their radiative forcing effect relative to carbon dioxide, the exchanges of these gases recorded in the LCI can be aggregated under a single unit of 'impact' (CO_2 equivalents), to yield the life cycle climate change impact of that item, more commonly referred to as its 'carbon footprint'.

Characterisation methods exist for multiple impacts (including non-renewable resource depletion – based on removal of raw materials from the environment, terrestrial acidification – based on the emission of acid gases and their precursors to the environment, and chemical toxicity – based on emissions of toxic substances to the environment) and can be developed for any impact where a robust cause-effect relationship between the exchange of a substance with the environment and an adverse consequence can be established and modelled. At present, no characterisation method exists for the assessment of radiological impacts caused by NORM.

Exposure to NORM Radionuclides as a Result of BR Valorisation

Natural Occurring Radioactive Materials (NORMs) are present in the earth crust in low quantities. Human activities such as mining bring these materials to the earth surface and radionuclides may be released to the environment or the workers might be subjected to ionising radiation during ore processing and utilisation. Alternatively these radionuclides may remain associated with, and be concentrated in, useful products (e.g. granite building materials) or in process wastes (e.g. bauxite residue). These materials, containing increased concentrations of radionuclides, are referred to as Technologically Enhanced NORM (TENORM). Both environmental releases of NORM radionuclides and the utilisation of TENORM have the potential to lead to radiological exposure pathways to human and non-human biota that would not otherwise exist. Natural radiation serves as a source of cancer risk for both humans and fauna. In terms of human exposure, the risk of radiation induced cancer is documented in epidemiological studies. The mortality rate from all types of cancer per 1 man.Sv excessive exposure is estimated to be 0.05.[2]

When NORM radionuclides are released as emissions to air and water, they are subsequently dispersed and transported through the environment, and, via various mechanisms (e.g. deposition, translocation, ingestion and bioaccumulation[3]), can end up in proximity to human and non-human biota, resulting in exposure to ionising radiation.

One particular area of focus for BR valorisation is its application in building materials. While many hazardous substances are effectively immobilised in these products,[4] the ionising radiation potential of the radionuclides is not affected. Standard building materials will of course contain certain levels of naturally occurring radionuclides, which will vary by geography.[5] The incorporation of TENORM into building material however has the potential to lead to exposure above that of the average building material.

The International Commission on Radiological Protection[6] has set an exposure limit for the general public of 1 mSv above background radiation, above which there is a risk of adverse effects. The use of TENORM in building materials has the potential to have a significant effect on increasing radiation exposure levels above background. Experimental buildings built in Jamaica using bricks containing bauxite residue were recorded as increasing radiation exposure above background by 0.58 mSv and 1.21 mSv for bricks made from 50 % and 100 % BR respectively.[7] It is worth noting that these increased doses are from building materials using unprocessed BR. The ETN REDMUD project aims to extract useful materials from BR prior to its use in building materials, with the potential to further concentrate NORM in the resulting materials.

Towards the Inclusion of NORM in LCA

In order to include NORM within LCA, the dose received by human and non-human receptors must be modelled, based on inventoriable flows. This requires that a number of existing models are reviewed, to assess their suitability and potential adaptability to the problem of NORM. These include environmental fate models, which estimate the environmental fate of given releases to the environment, radon release models, which estimate the amount of radon released into a given space from the NORM in the wall material, and dose models for the gamma emitters in building materials.

The dose received by the receptors can potentially be utilised as a midpoint indicator within LCA, this is the point at which different sources of the same impact can be quantified in the same unit, from which the amount of damage that occurs can be quantified.

From the midpoint indicator it may be possible to extend the impact assessment method to assess this damage. This requires models of dose response to be reviewed and assessed for suitability. Concepts such as Disability Adjusted Life Years (DALYs),[2] and Screening Level Ecological Risk Assessment (SLERA)[8] are among the potential candidates for damage analysis.

Benefits of NORM Assessment to the Red Mud Project

In order for the valorisation technologies for BR developed as part of the Red Mud project to be successfully adopted at sufficient scale, it is important that they are optimised in terms of technology, economy and the environment. LCA offers the most comprehensive and holistic way to assess the true environmental impacts of both the current 'Business as Usual' situation and BR valorisation. It also allows potential 'hotspots' of impact in the life cycle of BR valorisation to be identified at an early stage. These hotspots can then be further investigated to ascertain whether technical solutions exist to further optimise the environmental profile of BR valorisation.

In order for environmental optimisation to be fully effective however, burden shifting must be avoided. Burden shifting refers situations where actions taken to reduce a particular environmental impact inadvertently cause an increase in impact elsewhere in the life-cycle and/or in another impact category. In order to ensure burdens are not shifted into an impact category that is not considered in a given LCA, it is important that a suitable set of impacts are considered for the system concerned. For BR valorisation, the known presence of elevated levels of NORM raises the spectre of burden shifting to radiological impact. For example, increasing the BR content of building materials may lead to a decrease in carbon footprint, either through reduced processing requirements or through increased displacement of virgin materials. Use of these materials may however lead to an unacceptable increase in exposure to radiation. A suitable impact category to assess NORM impact is therefore vital for any LCA of BR valorisation, in order to avoid this eventuality.

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