CRITERIA FOR UTILIZATION OF BY-PRODUCTS FROM THE FERRO-ALLOY INDUSTRY

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ABSTRACT

Authorities that regulate environmental issues pertaining to industrial wastes in South Africa regard landfill disposal as the only effective environmental management option for slag and other inorganic by-products from the ferro-alloy industry. Metallurgical slags are widely utilised in civil engineering and construction applications in other countries in the world and in line with the overall philosophy of conserving mineral and other natural resources, these materials should be assessed for the possibility of resource recovery, recycling, reclamation, direct re-use or alternative uses.

This presentation describes a risk-based approach for the assessment of by-products from the ferro-alloy industry for alternative use. Once a by-product from an industrial process has been identified for alternative use, its intended use would be defined, but it will not be possible to control its actual use or misuse in society, nor will it be possible to control its fate during the application life cycle. In the interest of protection of human health and the environment, potential risks associated with the handling and uses of a material throughout its life cycle therefore have to be quantified. The assessment has to include both human health and ecological risks and must cover the entire life cycle of a product, from its production up to its end-of-life disposal. The presentation introduces the concept of tiered risk assessment and demonstrates how this applies in the overall assessment of by-products from metallurgical industry sector for safe use in society.

1. INTRODUCTION

A range of inorganic by-products is generated in processes that are used for the production and recovery of metals. Of these, metallurgical slag is the major by-product. Authorities that regulate environmental issues pertaining to industrial wastes in South Africa regard landfill disposal as the only effective environmental management option for slag and other inorganic by-products from the ferro-alloy industry.

A major point of dispute is the fact that by-products from the ferro-alloy industry are classified as probably hazardous waste, irrespective of their potential for use in other sectors of industry and irrespective of the intention for use.

Administrative procedures may be pursued in accordance with the regulatory guidelines to release these materials for alternative use, but the procedures that are required lack clear scientific guidance and are not helpful for assessing the potential impacts that these materials may have on human health and the environment. Landfill disposal of slag and other inorganic by-products should not be the primary focus of environmental management programmes in the metallurgical industry sector. In line with the overall philosophy of conserving mineral and other natural resources, these materials should be assessed for the possibility of resource recovery, recycling, reclamation, direct re-use or alternative uses.

Metallurgical slags are widely utilised in civil engineering and construction applications in other countries in the world and several international slag associations promote their value[1-6]. Alternative use applications are not limited to slag, but may include other inorganic by-products from the ferro-alloy industry. Landfill disposal should be considered only in cases where no options for utilisation are available. Opportunities for alternative use of materials and by-products from the ferro-alloy industry have however been hampered as a result of the absence of official criteria for assessment.

Evaluating hazardous properties of alternative products or applications of by-products requires a risk-based approach to decide which properties would be relevant in relation to potential human health risks and environmental impacts. This would determine which types of tests are appropriate to assess the intended use of the material and further through the various steps of its life cycle. This assessment is particularly relevant for situations where the same material may be applied under different circumstances, which may have different human health and environmental impacts.

This document presents a risk-based framework and criteria for the assessment of by-products from the ferro-alloy industry for utilisation in other sectors of industry and society. A risk assessment paradigm for consideration of potential impacts on human health and ecological receptors is provided.

2. FUNDAMENTALS OF THE RISK-BASED APPROACH

Risk assessment is a conceptual framework that provides the mechanism for a structured review of relevant information for the purpose of estimating health or environmental outcomes. A holistic risk assessment strategy is an inclusive paradigm that expands beyond the traditional human health risk assessment paradigm in that it views humans and ecological systems as one overall interacting system.

Figure 1 illustrates a risk-based decision support framework for the assessment and management of environmental risk issues. The risk assessment component is supported by an extensive science database, involving several scientific disciplines in the risk quantification process. Government Policy must not be in conflict with the underlying science, and expectations and responsibilities of industry must be aligned with both Government Policy and the scientific decision framework. The principles outlined in Figure 1 are applicable to the assessment of utilisation opportunities for by-products from the ferro-alloy industry, as well as in the consideration of factors relating to disposal of waste.

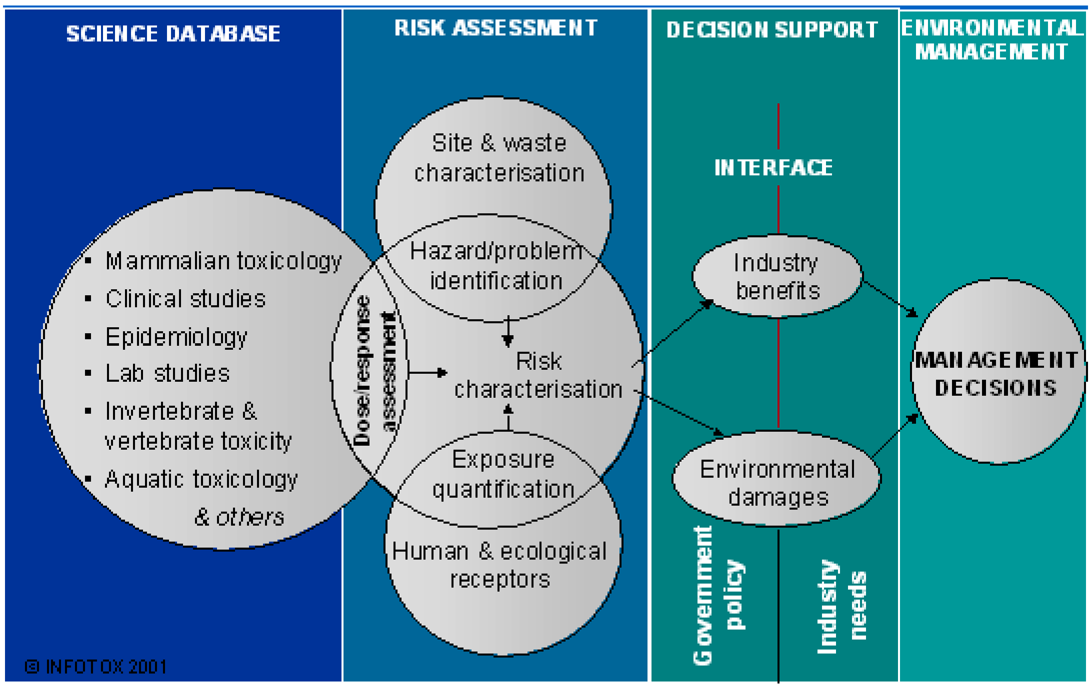

Figure 1: Decision support framework for risk-based development of submissions for authorisation of alternative use of by-products and waste disposal facilities[7]

Throughout the scientific, socioeconomic and political interactions in the decision framework, the precautionary principle should be foremost in the assessment of potential risk to human health and the environment. The precautionary principle should, however, be distinguished from the intention of risk assessment techniques that are designed deliberately to overestimate rather than underestimate risk. In the risk assessment framework, large margins of safety are applied. The approach is not based on how much exposure can be tolerated, but rather, the overall philosophy provides for large margins of safety. The approach thus provides sufficient confidence in the risk information to facilitate decision-making. In such cases, application of the precautionary principle is uncalled for. The precautionary principle should be invoked only when the level of scientific uncertainty about the consequences or likelihood of the risk is such that the best available scientific advice cannot assess the risk with sufficient confidence to support decision-making[8].

The intent is to have the underlying philosophy that a balance must always exist between costs and benefits in decisions relating to protection of human health and the environment. In this endeavour, there is a commitment to use risk assessment to assist in identifying the most appropriate management strategy, with emphasis on flexibility to allow the most cost effective solution to be selected and implemented.

3. THE PARADIGM FOR HUMAN HEALTH RISK ASSESSMENT

The original paradigm for regulatory human health risk assessment in the USA was developed by the National Research Council[9]. This model has been adopted and refined by the US Environmental Protection Agency (USEPA) and other agencies in the world as published under the International Programme on Chemical Safety[10], and is widely used for quantitative health risk assessments. The paradigm essentially divides human health risk assessment into a number of logical steps, as is outlined below.

Hazard assessment is the identification of chemical and biological contaminants suspected to pose hazards and a description of the types of toxicity that they may evoke.

Dose-response assessment (toxicological assessment) addresses the relationship between levels of biological exposure and the manifestation of adverse health effects in humans, and/or how humans can be expected to respond to different doses or concentrations of contaminants. This is a quantitative assessment that distinguishes between carcinogens and non-carcinogens.

Exposure assessment includes a description of the environmental pathways and distribution of hazardous substances, identification of potentially exposed individuals or communities, the routes of direct and indirect exposure, and an estimate of concentrations and duration of the exposure. Total chemical analyses and leach tests provide essential information for exposure quantification. Determination of the intake of a substance (i.e. dose), expressed in mg per kg body weight per day (mg/kg-day) is the critical outcome of an exposure assessment.

Risk characterisation involves the integration of the components described above, with the purpose of determining whether specific exposures to an individual or a community might lead to adverse health effects.

Uncertainty analysis identifies the nature and, when possible, the magnitude of the uncertainty and variability inherent in the characterisation of risks. The results of any risk assessment reflect scientific uncertainty associated with limitations in available data and assumptions that are made in the absence of such data, and the variability in exposure and toxicological response expected, given the diversity within the human population. The assumptions and limitations that form part of all risk characterisations should be explicitly discussed. Uncertainty analysis demonstrates the level of confidence in the outcome of the risk assessment and indicates whether additional data might be required, or whether elements of the precautionary principle should be applied.

4. THE PARADIGM FOR ECOLOGICAL RISK ASSESSMENT

In parallel with human health risk assessment, the risk-based approach considers assessment of potential impacts on aquatic ecosystems[11, 12, 13]. It should be taken into account that certain substances that have low importance in human health risk assessment might have serious impacts on aquatic ecosystems and it is essential that such substances not be removed from the list of chemicals of potential concern in the assessment.

Ecological risk assessments differ from human health risk assessments in the sense that whereas the assessment of risk to humans consider individuals, ecological risk assessments, also referred to as ecological impact assessments, focus on risks to communities of all species in an ecosystem. In its simplest form, ecological risk assessment refers to the probability of an adverse effect occurring in an ecological system. The philosophy underpinning the use of toxicological data in resource protection is that ecosystems have thresholds that allow them to withstand and assimilate stressors based on their unique physical, chemical, and biological properties. Toxic events can adversely affect the aquatic environment where thresholds are exceeded or where multiple stressors are prevalent. As per general risk assessment methodology, ecological risk assessment includes the estimations of hazard and exposure due to an environmental stressor[14]. The methodology also includes uncertainty analysis. The following terms are pertinent to ecological risk assessment:

Stressor refers to a substance, circumstance, or energy field that causes impacts, either positive or negative, upon a biological system. Stressors can be as wide ranging as chemical effects, ionising radiation, or rapid changes in temperature.

Hazard refers to the potential of a stressor to cause particular effects upon a biological system. Hazard assessment does not take exposure into account and is not probabilistic in nature;

Exposure is a measure of the concentrations or persistence of a stressor within the defined system. In aquatic ecotoxicology, this is normally measured as a concentration in water. Only complete exposure pathways are considered in the assessment of risk. An exposure pathway is incomplete where an ecological hazard has been identified but no significant receptors exist, or in cases where the contaminant cannot reach any identified potential receptors. Unless enough of a stressor interacts with biological systems, no effects can occur;

Risk results from a combination of exposure and effects expressed as a probability. Hence, risk assessment defines the probability of an undesired effect, expressed in the context of associated uncertainties.

5. TIERED RISK ASSESSMENT METHODOLOGY

The concept of a tiered risk assessment approach originated in the USA in the determination of cleanup objectives for contaminated land at underground petroleum storage tanks, based on risks to human health[15]. Subsequently, the concept of tiered risk assessment has also been applied to assess impacts on ecosystems.

The tiered risk assessment methodology is designed to reduce uncertainties in risk assessment in a stepwise approach. The level of risk assessment does not at all affect the level of actual risk. It merely relates to the level of detail in which the assessment is conducted. Each subsequent tier requires a more in-depth investigation of the factors that would affect risk, thereby reducing uncertainties in assumptions and increasing the scientific information base. As confidence in the assessment increases in the higher tiers, the need for accommodating large safety factors into the assessment is reduced. Without affecting risk, this approach has the potential to make waste management practices more practicable and may significantly reduce the costs of waste management.

Total chemical analysis of materials serves as the first step in the assessment, identifying elements of potential concern for human health and ecological receptors. Leach tests are used to estimate the release potential of constituents from materials and wastes over a range of possible management activities, which may include recycling or reuse, assessing the efficacy of waste treatment processes and during storage and disposal. Leach tests are also used for the assessment of criteria for the utilisation of by-products.

Tier-1 and Tier-2 risk assessments are essentially backwards risk assessments, in which measured or predicted concentrations of contaminants in environmental media (e.g. soil, water and air) are assessed against guideline concentrations. For human health risk assessment, these guidelines are health-risk based concentrations, derived from generic intake and target risk levels. Exposures to carcinogens and noncarcinogens are assessed separately according to protocols that have been accepted internationally[9, 10, 16, 17].

For ecological risk assessment it is unrealistic to generate toxicity data representing all species present in the environment. Hence, data extrapolation methods have and currently are being used to extrapolate a limited set of data to represent a distribution of species of varying tolerances. These approaches, known as species sensitivity distributions (SSDs), assume that the measured variability in sensitivities among species is a function of inherent differences in species sensitivity and in environmental (exposure) conditions that can be described by an appropriate statistical distribution. The Australian and New Zealand Water Quality Guidelines (ANZWQG) for toxicants are recommended as guidelines, because these represent some of the latest developments in the derivation of water quality guidelines for the protection of aquatic ecosystems[18].

Substances that are present in environmental media at concentrations below the guideline values can be removed from the list of substances of potential concern. A primary purpose of the Tier-1 assessment is to screen out non-issues, so that the assessment can focus on the real concerns. Care should however be taken that substances with low human toxicity are not screened out in these steps without considering potential impacts on aquatic ecosystems.

The Tier-2 assessment differs from the Tier-1 level in that some of the exposure parameters may be scenario-specific, and the concentrations that are compared against the guideline concentrations would reflect the better-defined exposure concentrations. In the assessment of landfill disposal sites, the Tier-2 assessment typically takes into account the effectiveness of containment (liner systems) in combination with attenuation of contaminants in the unsaturated soil underneath the footprint of the site. The guideline concentrations for the Tier-2 assessment apply to concentrations of contaminants underneath the site at the point of entry into the underlying aquifer and are the same as those used in the Tier-1 assessment. The Tier-2 assessment is still generic in that it does not take into account any specific location or potentially affected community.

The Tier-3 risk assessment is a full quantitative risk assessment in which well-defined exposure information is used to quantify cancer and non-cancer risks to humans. The procedures require in-depth investigation of exposure scenarios and relevant epidemiological and toxicological literature, thereby reducing uncertainties in assumptions and increasing the scientific information base. Similarly, ecological impacts are considered in the actual environmental setting, taking into consideration the ecological nature and status of the receiving environment.

A similar tiered approach can be followed in setting criteria for potential impacts of by-products from the ferro-alloy industry on human health and the environment, during their normal use and for end-of-life scenarios. Once a material or by-product is released into society, the risk assessment has to be based on scenarios of use and generally the assessment would not be site specific. It is not known where materials or by-products will be used in society and the end-of-life disposal scenarios are undefined. It is therefore not possible to conduct risk assessments for alternative use of by-products on a Tier-3 level and assessment on a Tier-2 level has to be based on conservative generic assumptions of potential exposure of members of the public and ecological receptors.

6. RISK-BASED ASSESSMENT FOR ALTERNATIVE PRODUCTS AND UTILISATION SCENARIOS

Figure 2 illustrates the generic process for the assessment of by-products from the ferro-alloy industry for alternative use[7]. When products derived from these by-products are introduced into society, or when direct use of such materials for useful applications is allowed, the potential for exposure of a wide spectrum of members of the community has to be considered. Generic exposure scenarios have to be constructed to assess potential risks associated with these alternative products and utilisation scenarios. Figure 3 illustrates a typical exposure assessment flow diagram[7].

Once a by-product from an industrial process has been identified for alternative use, its intended use would be defined, but it will not be possible to control its actual use or misuse in society, nor will it be possible to control its fate during the application life cycle. In the interest of protection of human health and the environment, potential risks associated with the handling and uses of a material throughout its life cycle therefore have to be quantified.

The diagram in Figure 2 shows a number of logical steps that have to be followed. Every possible step in the life cycle of a material or product has to be assessed including, amongst others, the product manufacturing stage (covering potential occupational and environmental risks), transport, storage, and end-of-life fate. Both human and ecological risk assessments have to be performed. It may be possible that products could be modified to comply with the risk objectives. However, if a product cannot meet the human or ecological risk criteria, the material or by-product has to be disposed of as waste. The focus then will shift to a risk-based assessment for its safe disposal.

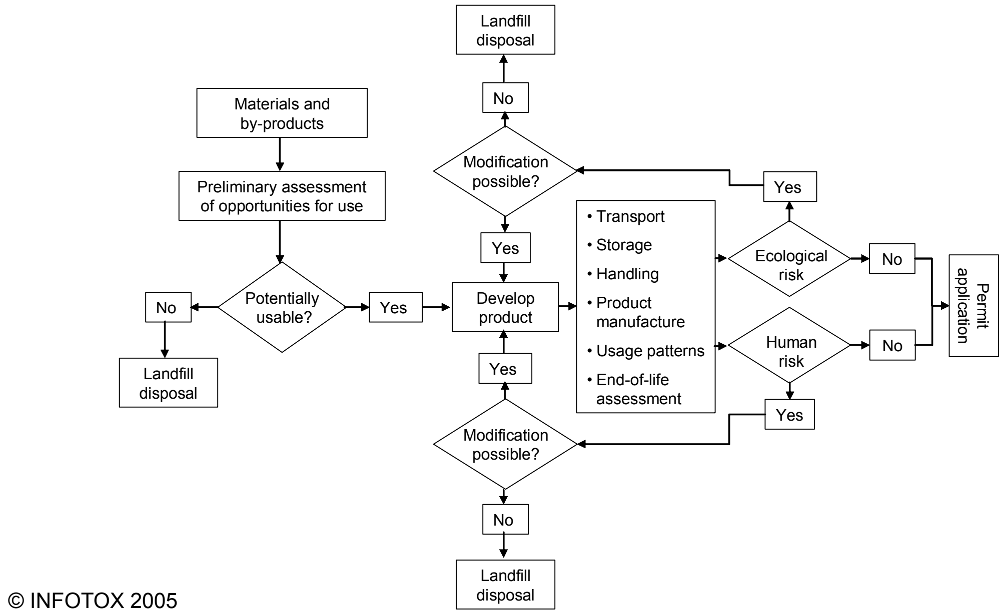

Figure 2: Risk-based assessment of materials and by-products for alternative use[7]

The initial characterisation process requires full chemical analysis of the by-products, which allows the risk assessment to focus on *chemicals of potential concern*. The assessment is qualitative and is aimed at the identification of substances that might contribute significantly to health and environmental risks. It also serves to identify substances that have characteristic leaching properties under various pH conditions that differ from the majority of substances. For example, most metals are mobilised at low pH, but hexavalent chromium leaches to a greater extent at high pH. Furthermore, the analytical information would provide an initial indication of the presence of substances that might render a material unacceptable for the intended use. For example, high chloride content is unacceptable in cement and high manganese content of a product might cause an unacceptable human health risk through inhalation of its dust. High concentrations of salts are likely to leach into groundwater and surface water, potentially causing high risks to aquatic ecosystems.

In the example, a hypothetical product manufactured from a ferro-alloy by-product, which originally might have been classified as a waste, is submitted for assessment. The product's life cycle may include recycling, but the eventual fate may be that it will be discarded in the environment. Each product or potential application has to be taken through an exposure assessment similar to the example in Figure 3. This scenario development has to be considered in each phase of the entire life cycle of the material ("cradle-to-grave").

Substances that have the potential to leach in significant amounts from the product matrix in alternative use scenarios are of pertinent interest. This would determine which types of tests are appropriate to assess the environmental impact as close as possible to the intended use of the material or by-product and further

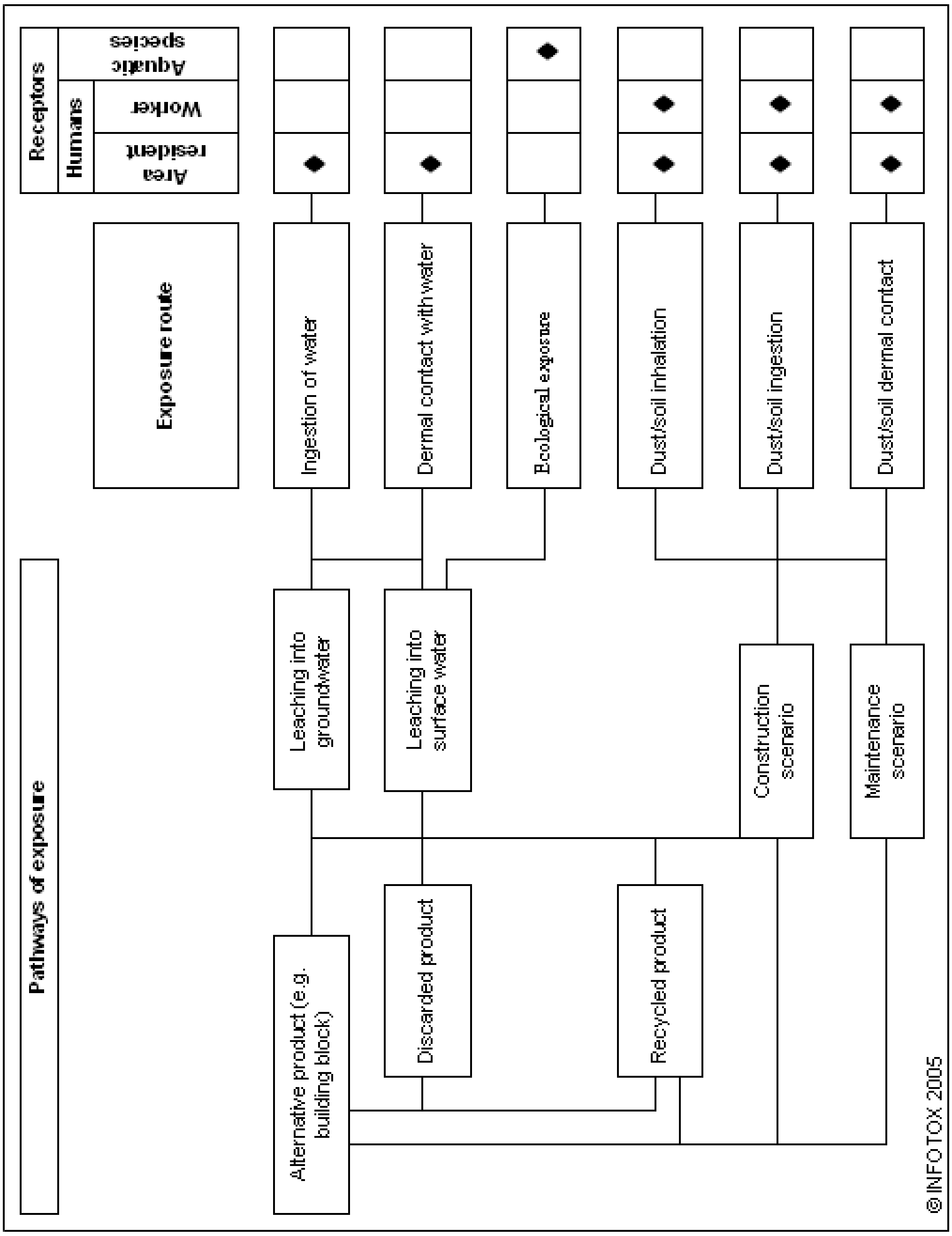

Figure 3: Potential exposure scenarios for the life cycle of alternative products

through its life cycle. Certain occupational exposures during construction or maintenance activities that involve these products or utilisation scenarios are also important considerations. All of these have to be considered in the assessment of potential risk associated with alternative use of materials from the ferro-alloy industry.

7. QUANTIFICATION OF EXPOSURE

Because scenarios of alternative use of by-products from the ferro-alloy industry cannot be related to site-specific conditions, the risk assessment has to be limited to generic, conservative conditions. A large margin of safety is thus accommodated in the assessment.

7.1 Dust Generation

Occupational exposure

Crushing operations and manufacturing of monolithic products may generate dust that would contain the metal and non-metal constituents of the original material or by-product. Usage of products such as bricks would also contain the constituents of the original metallurgical by-products, which would become airborne during cutting and grinding operations. If the material or by-product is mixed with other materials (e.g. Portland cement) in the process of manufacturing of products (e.g. building blocks or water pipes), the production process, installation, maintenance and end-of-life disposal have to be assessed for potential occupational risks. All routes of exposure (inhalation, ingestion and dermal contact) have to be considered.

For exposure to contaminants through inhalation, a Tier-1 occupational health risk assessment is essentially conducted as an exposure assessment. Ambient air concentrations are assessed against guideline concentrations defined as occupational exposure limits (OELs)[19, 20], recommended exposure limits (RELs)[21, 22], or threshold limit values (TLVs)[23]. The guidelines account for acute-duration as well as for chronic-duration exposures. The listed references and technical background documents relating to the various occupational exposure limits provide extensive guidelines for measuring exposure and assessment of associated risks.

Occupational exposure through routes other than inhalation requires quantification of cancer and noncancer risks. Exposure parameters that are relevant to occupational scenarios have to be selected[24]. These steps provide for intermittent and less-than-lifetime exposure and may distinguish between various intensities of physical activity.

Community exposure

Similar to occupational exposure, members of the community may be exposed to dust and hazardous constituents originating from the material or waste during manufacturing of products, crushing operations and alternative usage scenarios. These dust releases may disperse from the source areas into off-site areas where members of the public could be exposed.

The approach for community health risk assessment associated with exposure to airborne substances follows standard procedures for exposure quantification and risk characterisation[16,17,25,26].

7.2 Groundwater and Surface Water Pathways

The mechanisms that control the release of contaminants from a material into water bodies can be described as being either equilibrium controlled or mass-transfer rate controlled[27].

Equilibrium controlled release occurs for slow percolation through porous or granular materials, which is the case in applications such as for granular road base material. Solubility control occurs when the solution in contact with a material is saturated with respect to the constituent species of interest. This condition is prevalent at low liquid-to-solid (L/S) ratios.

Mass transfer rate controlled release occurs when flow is predominantly at the exterior boundary of monolithic materials (e.g. building blocks) or where percolation is very rapid relative to the mass transfer rate of constituent release to the percolating water (e.g. construction debris used as fill material).

A generic leaching characterisation approach can be employed for all fine and coarse granular metallurgical materials, to cover a wide range of potential uses of such materials, with or without treatment. Similarly, a generic characterisation approach can be developed for all products manufactured from metallurgical materials, which during their service life have a monolithic character (e.g. building blocks). Widely different materials can be tested with the same basic procedures. Leachate concentrations of substances provide a conservative estimate of concentrations to which humans and ecological receptors could be exposed during various scenarios in the life cycle of an alternative product.

8. QUANTIFICATION OF RISK

Risk assessment for both percolation-controlled and mass-transfer controlled leaching scenarios is conducted in accordance with the risk assessment paradigms described in this document.

As has been outlined above, the primary purpose of a Tier-1 assessment is to screen out substances that are non-issues with regard to risk, so that the assessment can focus on the real concerns. Substances that cannot be screened out in the Tier-1 assessment have to be considered in a Tier-2 approach. In the assessment of risks associated with the various use and disposal scenarios in the life cycle of a material or a product that contains material from the ferro-alloy industry, site-specific factors cannot be considered. A Tier-3 risk assessment is therefore not possible, because the materials and products can be utilised or discarded at any possible location and under many different conditions.

Following the Tier-1 assessment and focusing on substances of potential concern, a Tier-2 risk assessment has to rely on certain reasonable generic assumptions. The primary consideration relates to potential impacts of substances that may leach into groundwater and through surface run-off or through migration from groundwater into surface water. Groundwater has to be considered in groundwater use areas, assuming reasonable yield. For surface water, the assessment has to assume a situation of reasonable habitat, which requires certain minimum flow conditions.

It is reasonable to assume a dilution and attenuation factor (DAF) of 10 to 20 in groundwater use areas. Professional judgement has to be applied to ensure that the assessment is on the side of caution. The nature of the materials and products that could be discarded would determine the likely size of a contaminant source, which would affect the magnitude of the DAF. The concentrations of substances determined in leach tests have to be divided by the generic DAF to be compared against the risk-based concentrations for human and ecological receptors.

In the assessment of impact on ecological receptors, based on application of aquatic ecotoxicity parameters of substances of potential concern, a dilution and attenuation factor would consist of a term that accounts for the groundwater-to-surface water dilution factor and another term for dilution in the receiving surface water body. A combined DAF of 100 is reasonable to assume. This would also account for surface run-off and associated dilution through stormwater.

9. CONCLUSIONS

This presentation has described a risk-based approach for the assessment of by-products from the ferro-alloy industry for alternative use. Once a by-product from an industrial process has been identified for alternative use, its intended use would be defined, but it will not be possible to control its actual use or misuse in society, nor will it be possible to control its fate during the application life cycle. In the interest of protection of human health and the environment, potential risks associated with the handling and use of a material throughout its life cycle, therefore, have to be quantified. The assessment has to include both human health and ecological risks and must cover the entire life cycle of a product, from its production up to its end-of-life disposal. The presentation has introduced the concept of tiered risk assessment and demonstrated how this applies in the overall assessment of by-products from metallurgical industry sector for safe use in society.

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