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Bioaccumulation

'Bioaccumulation' is often used as a general term to describe the process whereby a substance is taken up by living organisms from their environment and diet and stored in the body. It is typically seen as an unwanted phenomenon, particularly in relation to man-made chemicals, because of the possibility that some substances could progressively 'build up' to levels that could be harmful.

On the other hand, bioaccumulation is an essential process that allows animals to take up and store certain substances that are vital for their survival – various vitamins, trace elements, fats and amino acids for example.

Whether bioaccumulation of a given substance may have adverse effects depends on the toxicity and on the levels reached, and these levels in turn depend on the rates at which the substance is taken up, distributed in the organism, metabolised and/or excreted.

A particular concern attaches to substances that might 'biomagnify', such that the levels steadily increase in food webs from prey to predator (secondary poisoning) so the highest levels are found in animals at the top of the food chain (including humans). Complicating factors in the assessment of biomagnification are the increasing lipid content of higher organisms and changing lipid content of organisms over the year.

Identifying substances that could pose a real risk through bioaccumulation and especially biomagnification is a very important task for industry and regulators. But it is also a difficult task because confirming that bioaccumulation to harmful levels, or biomagnification, is likely to happen in the real environment, such that the risks can be managed or eliminated, requires substantial field studies. There are numerous substances in commercial use and many different kinds of organisms and environments to be considered. It is often possible, however, to 'screen' substances on the basis of some simple physical and chemical properties, or using computer modelling, to exclude the majority of substances from further consideration as they clearly do not have any potential to bioaccumulate, or to prioritise substances which appear to have the greatest potential to pose a risk.

Regulatory approaches to identifying and controlling potentially problematic bioaccumulative substances have been put in place in various countries and regions, though over the 30 years since this began, the scientific understanding of the relevant processes has been improving. Currently, these regulatory approaches differ markedly, but proposals to improve these approaches have recently been made in a specially convened international

workshop of experts from academia, industry and government for a framework for applying the best science and techniques[1].

Concepts, Definitions and Measurements

In most instances of bioaccumulation, substances are taken up and stored in organisms in fatty tissues. Consequently substances that are highly hydrophobic (lipophilic) i.e. that partition strongly into fats as opposed to water, are potentially bioaccumulative. Whether they will build up to significant levels in such tissues, however, depends not only on exposure (e.g. the concentration in the environment or diet) but critically on the extent to which they are metabolised in the body and the extent to which they are excreted.

The level of bioaccumulation can also vary between species: it may be broadly similar across species with similar constitutions (e.g. lipid content) and metabolisms but be quite different in other cases. For example, some substances will bioaccumulate in aquatic organisms and not in land animals, and vice versa.

Although bioaccumulation is used as a general term as explained above, it also has a more specific meaning. There are numerous other useful terms and concepts that are valuable for understanding and measuring the processes and behaviour of substances in relation to potential risk through bioaccumulation. These are outlined below:

- **The octanol/water partition coefficient** is an important bioaccumulation parameter that can be used as a surrogate measure to indicate or exclude the intrinsic potential of an organic substance to be taken up in fatty tissues. This parameter estimates the affinity of a substance for fat in terms of the partition coefficient between octanol (representing fat) and water.
  The parameter is expressed as the logarithm of the partition coefficient i.e. **log K_{ow}**. It should be noted that the log K_{ow} is only valid for organic substances.
  More recently the **log K_{oa}** has been introduced which is the partition coefficient between octanol and air. This can be used as an indicator for bioaccumulation in the terrestrial food chain.
- **Bioconcentration** refers specifically to uptake of a substance from the water in which an organism lives. The **Bioconcentration Factor (BCF)** is determined in controlled laboratory experiments in which the substance is present in the water but not in the diet or other source: it is the ratio of the concentration in the organism to that in the water once a steady state has been reached.
  The typical standard test to determine bioconcentration is the OECD 305 test which is widely known and applied. For aquatic organisms most uptake is normally from the water rather than diet or surroundings: even for sediment dwelling organisms uptake from the water in the pores in the sediment is normally more important than uptake from ingested contaminated sediment.
- The **Bioaccumulation Factor (BAF)** for a substance is the ratio of the concentration of the substance within the organism compared to the concentration in an environmental compartment. This is the ratio of the concentration of the substance in the organism to the concentration in the water it lives in, under conditions where it can take up the substance by multiple routes including from the water, surrounding sediment and its diet. It is often determined from field (real world) experiments.
- **Biomagnification** refers to the process through which a substance becomes stored at higher concentrations in predator organisms than in their prey, and is expressed as the Biomagnification **Factor (BMF)**. This is the ratio of the concentration of the substance in the predator compared to the prey. **BMFs** can be determined by either laboratory or field experiments, though laboratory values reflect exposure of organisms only via the diet and not via water or air.
- **Trophic magnification** describes the situation where a substance tends to be present at steadily increasing levels through a food web, through a series of prey/predator steps. This

represents the situation of greatest concern. The **Trophic Magnification Factor (TMF)** is derived from the slope of the line reflecting log normalised concentrations in organisms in relation to their 'trophic level' or hierarchical position in the food web.

Using bioaccumulation measurements and data to assess and manage risks

Today, there are a range of techniques to measure or estimate absorption, distribution, metabolism and excretion (ADME), not only for single organisms, but also to model biomagnification and trophic magnification across aquatic and terrestrial food webs. It should be realised that technological advancements in analytical techniques are allowing us to detect ever smaller concentrations of substances, sometimes below any likely level of concern.

However, the identification and control of substances that may pose a risk of secondary poisoning through bioaccumulation began to be put in place over 30 years ago before such techniques and the detailed scientific understanding had been developed. Regulations in various parts of the world thus frequently consider substances to be bioaccumulative, and subject to control measures, based only on bioaccumulation or bioconcentration factors, or even simply partition coefficients, with little or no consideration of distribution, metabolism and excretion, nor of the likelihood of biomagnification.

Sometimes, factors that apply only to aquatic or to terrestrial eco-systems are inappropriately applied to both. There are also cases where the screening criteria regularly used fail to identify potentially problematic substances, for example, bioaccumulative substances which have no affinity for lipids but do bind to proteins.

Improving regulatory approaches to bioaccumulation

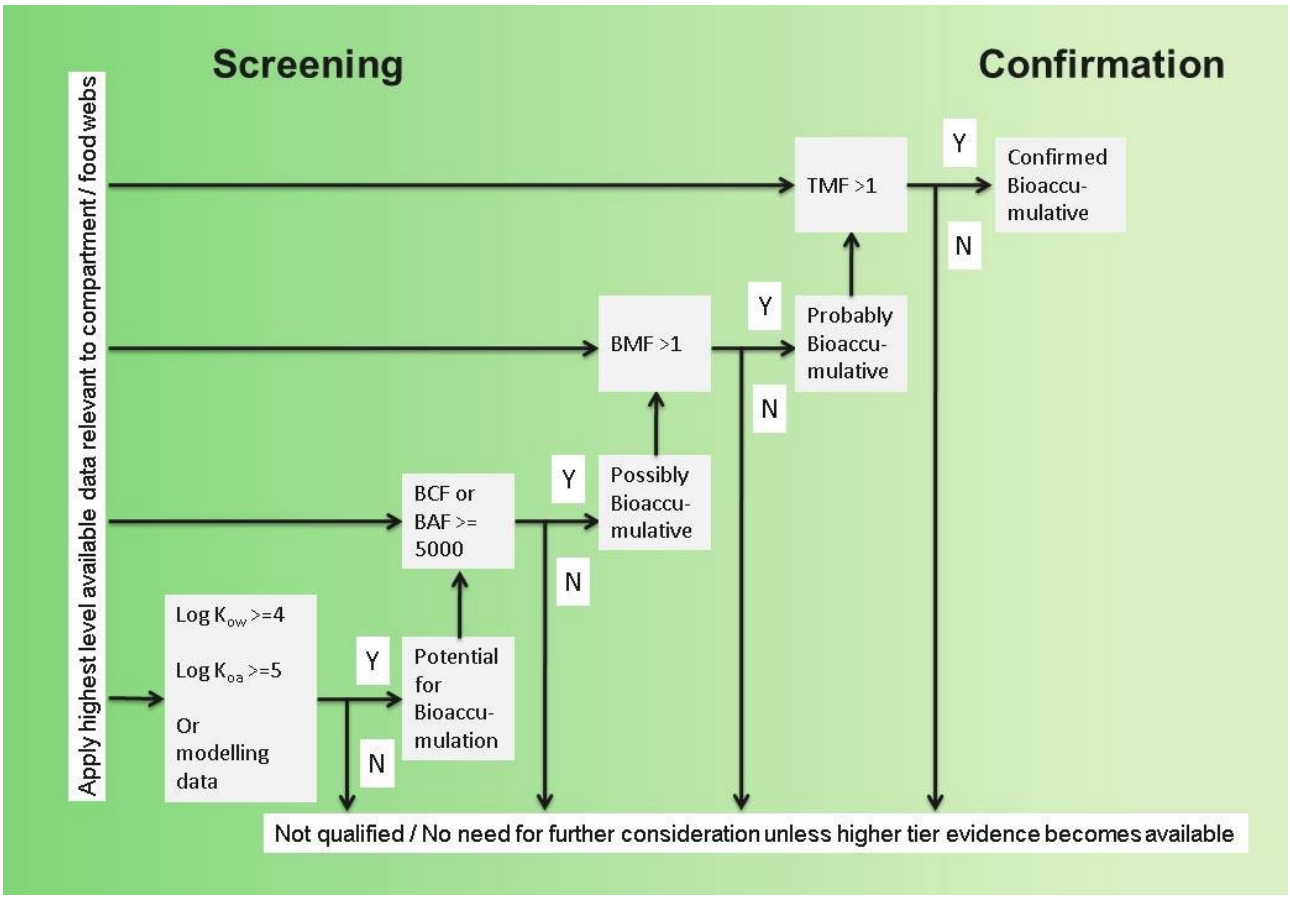
Recently, the whole approach to identifying substances that may cause a problem through bioaccumulation has been discussed in depth in expert workshops involving scientists from academia, from government and from industry. They concluded that the way in which factors and parameters are currently used in regulation to assess bioaccumulation is often inappropriate or inadequate for the purpose. In particular, in the context of control of POP(s) and PBT(s), they felt that a key barrier to progress and harmonisation was the lack of a common definition of a 'bioaccumulative substance'. Accordingly they proposed the following definition for a bioaccumulative substance: "a substance is considered bioaccumulative if it biomagnifies in food chains".

The expert workshop also produced a consensus proposal for a tiered framework that could be used to apply relevant data more consistently leading to more efficient and reliable identification, prioritisation, assessment, and control of problem bioaccumulative substances.

The **chart on the next page** illustrates how such an approach could be used both for screening of large numbers of chemicals, (in a bottom up approach starting with readily available data) and for confirmation and consideration of control measures (in a top down approach using the most definitive data that can be acquired). The framework supports an approach to reach a final decision which is an important part of identifying PBTs or POPs as chemical s of concern.

References

1. Gobas et al. (2009). Revisiting Bioaccumulation Criteria for POPs and PBT Assessments. Integrated Environmental Assessment and Management, 5(4), 624. This issue of Integrated Environmental Assessment and Management summarises the results of the SETAC Pellston Workshop, convened to discuss the issues surrounding POPs/PBTs. It can be accessed free of charge at http://onlinelibrary.wiley.com/doi/10.1002/ieam.v5:4/issuetoc.



The chlorine industry in Europe

Euro Chlor represents chlor-alkali producers in the EU and EFTA regions employing about 39,000 people at 69 manufacturing locations. Almost 2,000,000 jobs in Europe are directly or indirectly related to chlorine and its co-product caustic soda (sodium hydroxide). These two key chemical building blocks underpin 55% of European chemical industry turnover (2007: € 740 billion).

Focus on Chlorine Science

This Focus on Chlorine Science (FOCS) is part of a series of leaflets aiming to clarify and consolidate scientific research in the field of chlorine industry. With the FOCS series, we want to facilitate the knowledge gathering of scientists, regulators and key decision makers. For further Euro chlor science publications, please consult http://www.eurochlor.org/communications-corner/science-publications.aspx

Euro Chlor

Euro Chlor provides a focal point for the chlor-alkali industry's drive to achieve a sustainable future through economically and environmentally-sound manufacture and use of its products. Based in Brussels, at the heart of the European Union, this business association works with national, European and international authorities to ensure that legislation affecting the industry is workable, efficient and effective.

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