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Playing with fire: the global threat presented by brominated flame retardants justifies urgent substitution

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Abstract

Few would now deny that the use of organobromine compounds to achieve fire retardancy in a diverse array of products and materials has led to contamination of the ecosphere on a widespread scale. This environmental prevalence and persistence of the brominated flame retardants, coupled with growing evidence of their potential for harm, present all too familiar parallels with the previous generation of persistent organic pollutants. Indeed, given the intrinsic properties of these brominated chemicals, the nature and extent of the current problem could well have been predicted in advance. The question is then whether we are prepared to let history repeat itself once more or to take precautionary action now to switch to more sustainable alternatives. The choice facing society is not between brominated flame retardants and unsafe products, but between fire safety leading to global contamination or fire safety achieved in less polluting ways. If we look beyond options for simple chemical-for-chemical substitution to alternative materials and designs, many of the solutions are already available. The remainder could undoubtedly be developed given the incentives to do so. However, a strong and clear policy approach, backed by legislative phase-outs within specified (and challenging) timeframes, will be necessary to break our current dependency on organobromine chemistry. This paper presents the justification for such an approach, reviews those initiatives already underway to replace brominated flame retardants and identifies pathways to the use of more sustainable products in the service of society.

Keywords: Brominated flame retardants; Organic pollutants; Fire safety

1. Introduction: a growing problem, a growing understanding

It is fair to say that the widespread distribution of brominated flame retardants in the environment, their appearance in human and wildlife tissues and their complex modes of toxicity are emerging issues and that our understanding of their fate and effects remains limited. Prior to the mid-1990s, for example, very little had been published on this diverse group of environmental contaminants. Early reports such as that of Anderson and Blomkist (1981) generated some interest, although the issue remained very much related to specific industrial point sources. It was not until later in the 1980s that the wider geographical spread of polybrominated biphenyls and diphenylethers (PBBs, PBDEs) was first noted, with residues detected in seals and seabirds from the Baltic, North Sea and Arctic (Jansson et al., 1987).

Despite these early warnings, research interest in these compounds has really only taken off within the last 5 years, probably reflecting in part the development of analytical techniques with the necessary sensitivity and reproducibility to allow coordinated international research (see e.g. de Boer et al., 2001). Even now, our knowledge of the environmental behaviour of brominated flame retardants remains restricted to only a very few compounds among the plethora reportedly in use (see e.g. Jansson, 2001). Since 1997, the number of research publications describing the distribution, accumulation and toxicity of various brominated flame retardants, especially the PBDEs, has grown exponentially. Their widespread distribution, including their detection in remote areas such as the Arctic and the deep oceans (e.g. Sellström et al., 1993; de Boer et al., 1998) has captured the attention not just of the scientific community, but also of governments and the public. A number of recent scientific symposia have been devoted to discussion of this compound group (most notably the 2nd International Workshop on Brominated Flame Retardants held in Stockholm in May 2001) or have dedicated special sessions to the issue (such as the annual Dioxin conferences, most recently docu-

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mented in Volume 52 of Organohalogen Compounds). Indeed, the production of this current volume, along with other extensive reviews which precede it (most recently the special issue of Chemosphere, Vol. 46, No. 5, published in February 2002), provide an illustration in themselves of the seriousness and urgency with which this relatively new field of research is being addressed.

There are a number of excellent review papers summarising the rapidly growing databases of information on the sources, distribution, fate and effects of brominated flame retardants (Bergman, 2000; de Boer et al., 2000; Watanabe and Sakai, 2001; Alaee and Wenning, 2002; de Wit, 2002). Together with many of the papers in the current volume, these reviews illustrate the substantial concerns that exist regarding the ubiquitous and global distribution of brominated flame retardants, as well as their environmental persistence, ability (in many cases) to accumulate through food chains and chronic toxicity. To a large extent, these properties and characteristics mirror those of other, better known, persistent organic pollutants, including the PCBs and chlorinated dioxins. Although detailed source inventories for environmental releases of brominated flame retardants are not currently available, it is likely that substantial releases arise during all stages of the lifecycle, i.e. chemical manufacture, incorporation into products, use of such products and their ultimate disposal or recycling. As is the case for all persistent hazardous chemicals, once organobromine compounds have been included as components in end-products, they have effectively become diffuse sources of contamination; their environmental release is only a matter of time. Their role as precursors in the formation of polybrominated dioxins and furans, particularly during high temperature waste disposal and recycling operations, has also been well documented (IPCS, 1998; Söderström and Marklund, 2002).

2. Brominated flame retardants as ubiquitous and pervasive contaminants

Several very recent studies reinforce the extent of the problem and the legitimacy of concerns. For example, Christensen et al. (2002) provide the first evidence of the presence of PBDEs in Greenland, reporting part per billion (ng/g fresh weight) levels of tetra- and penta-bromodiphenyl ether (TeBDE and PeBDE) in fish and mussel tissue. Using archived tissue samples, Ikonomou et al. (2002) describe an exponential increase in concentrations of PBDEs in Canadian arctic wildlife, notably in ringed seals. Although levels of PBDEs are still lower than those of PCBs in the seals, the authors stress that the balance could well be reversed if current trends continue.

In terms of human exposure, studies by Jakobsson et al. (2002) and Thomsen et al. (2002) provide further evidence of the pervasive nature of human tissue contamination with PBDEs, tribromophenol (TriBP) and tetrabromobisphenol-A (TBBP-A). Blood serum concentrations of PBDEs in Norwegian men and women increased more than sixfold in the period 1977 to 1999; concentrations in infants (0–4 years old) appear to be particularly high (Thomsen et al., 2002). Concentrations of TBBP-A also appear to have increased from 1986 to present. Ohta et al. (2002) provide one of the few studies to date on concentrations of PBDEs in foodstuffs and resulting intake, with a focus on nursing mothers in Japan. Work on the global distribution of various brominated flame retardants in other foodstuffs, such as butter (Jones et al., 2001) is ongoing. Widespread occurrence, and sometimes relatively high levels (mg/kg, parts per million), of PBDEs and hexabromocyclododecane (HBCD) have also been reported for dust samples from the indoor environment (Bergman et al., 1997; Leonards et al., 2001), a further possible source of exposure. Most recently, Öberg et al. (2002) report the widespread presence of PBDEs and TBBP-A in sewage sludge from treatment plants in Sweden, identifying congener patterns specific to three different commercial formulations (including DeBDE).

Perhaps most significantly, the findings of several recent studies challenge some of the fundamental assumptions underpinning arguments for the alleged safety and inert nature of brominated flame retardants. Reports by Sellström et al. (2001) and Jakobsson et al. (2002) illustrate the bioavailability of the highly brominated decabromodiphenylether (DeBDE or BDE-209) through demonstrated presence in the eggs of peregrine falcons and in the blood of people working with computers. Its presence in human tissues reaffirms the earlier findings of Klasson-Wehler et al. (1997) and Sjödin et al. (1999) and dismisses claims that molecules of DeBDE are simply too large to pass through biological membranes. The behavioural neurotoxicity of DeBDE, as well as other PBDEs, was highlighted by Eriksson et al. (2001), suggesting significant toxicity of the parent compound, especially during early stages of development. Other studies have demonstrated the propensity for DeBDE to debrominate in the environment (Tysklind et al., 2001), a potential contributory source of some of the more bioaccumulative congeners commonly found in wildlife. Furthermore, PBDEs form hydroxylated metabolites following ingestion (Mörck and Klasson-Wehler, 2001), metabolites which may, in some cases, be more potent toxins than the parent PBDEs themselves (Meerts et al., 2001).

Jakobsson et al. (2002) report the presence of TBBP-A in the blood of computer technicians, indicating that this compound may also be bioavailable simply through contact with computer hardware during use. Moreover, the experiments of Wichmann et al. (2002) challenge the long-held assumption that the covalent binding of TBBP-A to polymer matrices sterically hinders the formation of brominated dioxins and furans during combustion.

Still relatively little information is available relating to another brominated flame retardant in common use, namely hexabromocyclododecane (HBCD). To some degree, the paucity of data for this compound is now beginning to be addressed through the development of new analytical techniques capable of distinguishing a number of distinct isomers (Allchin and Morris, 2002). Recently, van Leeuwen (2002) reported for the first time the presence of HBCD (51 ppb) in the tissues of mussels collected downstream from a flame-retardant production plant in the Netherlands. Other emerging data indicate that this compound may also be widely distributed through the environment (Allchin and Morris, 2002). Future research will need to take account also of the various organobromine compounds which commonly appear as unidentified components in extracts of environmental samples (Jansson, 2001), as these could provide further early warnings of compounds of significance.

3. Learning the lessons of the past?

In summary, the weight of emerging evidence points increasingly to a contamination problem of widespread, perhaps global, proportions, involving chemicals which are inherently toxic, persistent and bioavailable. We are exposed to them through our food, through the air and through contact with dust, as well as through ordinary use of the wide-range of consumer products in which they are incorporated. What limited trend data are available point to significant, in some cases substantial, increases in concentration in the environment over the last two decades, including in the tissues of wildlife and humans. Our knowledge of possible health effects may still be in its infancy, but the findings of developmental defects, interference with thyroid hormone systems (e.g. Meerts et al., 1998) and dioxin-like toxicity are all too familiar warning signs and provide clear cause for concern.

Given the significant parallels between the current situation regarding PBDEs and historic trends relating, for example, to the PCBs, it is reasonable to ask the question "could we have predicted the emergence of the current problems with brominated flame retardants from their intrinsic chemical nature?" In other words, given our regrettable experience with (and ongoing legacy of) the PCBs and various persistent chlorinated pesticides, should we be at all surprised that the widespread, open use of persistent organobromine chemicals has similarly resulted in widespread and increasing contamination of the biosphere? There is a strong sense that history is repeating itself, despite the fact that even some of the basic, intrinsic properties of polybrominated organic compounds could have given sufficient warning as to what was to come. Indeed, as a case example of the application of a multistage chemical assessment methodology, Palm et al. (2002) conclude that, despite significant data gaps relating to environmental fate and effects, the intrinsic properties of PBDEs are sufficient alone to predict environmental concern. Similarly, Jansson et al. (1987) interpreted their findings of PBBs and PBDEs in wildlife in Northern Europe and the Arctic as illustrative of a more generic risk in the use of "polyhalogenated hydrocarbons."

If we pose the question "do we know for certain that ongoing use and release of brominated flame retardants will cause adverse effects in humans and/or wildlife?", the honest answer would have to be that we do not. Uncertainty is a universal characteristic of our state of knowledge and understanding of ecosystem structure and function and of the manner in which chemical agents are transported through, and interact with, natural systems. Further research will undoubtedly reduce some of the uncertainty, but a proportion (and an unknown proportion at that) will remain irreducible, either because the factors in question are not amenable to analytical reduction or because we simply remain ignorant of their existence. We are, therefore, inevitably presented with the need to take decisions to protect the environment and human health in the face of incomplete information and substantial uncertainty (Stirling, 1999; Santillo and Johnston, 2001). Even if further research may ultimately allow for more confident judgements, the time required must be balanced against the potential during that time for further, possibly irreversible, harm to occur.

A more responsible question is then "despite the knowledge gaps and uncertainties, do we nevertheless know enough already to give serious cause for concern regarding the fate and effects of brominated flame retardants?" The answer must surely be that we do. Indeed, at this stage we probably already know more about the distribution and effects of brominated flame retardants, particularly the PBDEs, than was known about PCBs at the time at which the first restrictions and bans were coming in to force.

Should we not therefore take action to avoid, as far and as soon as possible, further releases of brominated flame retardants to the environment in order to begin to reverse the current worrying trends in distribution and exposure? Can we not learn from the lessons of the past that, even if we have not yet documented specific adverse impacts in humans and wildlife, this is likely to be simply a matter of time? In short, given the hazardous properties they possess, should we not conclude that the widespread presence of brominated flame retardants in the environment is fundamentally undesirable? The recent European Environment Agency report "Late Lessons from Early Warnings" (EEA, 2001) documents numerous examples in which failure to apply precaution at an early stage, despite warning signs or even (in some cases) prior knowledge of a chemical's propensity to cause harm, has led to environmental and/or health impacts which could have been minimised or even avoided.

4. Legislative developments: recognising the unsustainability of hazardous chemicals

It is increasingly being recognised that there are certain intrinsic physico-chemical properties, especially high persistence, toxicity and liability to long-range transport and bioaccumulation, which render the use and inevitable release of chemicals which possess them fundamentally unsustainable. For example, the Stockholm Convention (2001) on persistent organic pollutants (POPs) established for the first time a global mechanism for the elimination of some of the most problematic synthetic chemicals (UNEP, 2001). Although the number of individual chemicals or groups currently covered by the POPs Convention is fairly small (12), criteria have been established which should, in future, lead to the addition, and eventual elimination, of further chemicals with similar or equivalent hazardous properties. Similar provisions exist under the UNECE POPs Protocol (part of the Convention on Long-Range Transboundary Air Pollution, LRTAP) (Lerche et al., 2002). Being a global instrument, developments of the Stockholm Convention will undoubtedly take time. The Nordic Council of Ministers has, however, already begun an initiative to identify new candidate substances. A detailed case study on the commercially important flame retardant pentabromodiphenylether (PeBDE), conducted under this initiative, highlights the fact that this chemical shares many of the undesirable properties associated with those POPs already targeted for elimination (Peltola and Yla-Mononen, 2001).

On a more regional basis, political recognition of the problems presented by intrinsically hazardous substances, including the brominated flame retardants, is not a new phenomenon. Indeed, when Ministers at the 4th North Sea Conference held in Esbjerg (Denmark) in 1995 established for the first time the "one generation" (25 year) target for the cessation of releases of hazardous substances to the marine environment, brominated flame retardants were listed among several groups of chemicals requiring particular attention. The "one generation" goal arising from the Esbjerg Declaration was later formalised for the whole North East Atlantic region by adoption of the target for cessation of discharges, emissions and losses of hazardous substances by the year 2020 under the 1998 Hazardous Substances Strategy for the OSPAR Convention (1992) (OSPAR, 1998a). In a similar manner to the POPs Convention, the OSPAR Strategy includes criteria on the basis of which chemicals or groups are identified as hazardous. These criteria are understandably broader than the very restrictive criteria applied under the Stockholm Convention, though once again they are based primarily on the intrinsic hazards of chemicals as an indication of likelihood of harm, should the chemical reach the marine environment. Brominated flame retardants, as a group, were included on the initial list of 15 substances (or groups) requiring priority action to meet the cessation target, and remain as priority substances.

Since 1998, work has proceeded within OSPAR to document the concerns for the marine environment presented by several of the most commercially important brominated flame retardants, notably the PBDEs, HBCD and TBBP-A. A background document identifying those concerns is already available for the PBDEs and HBCD (OSPAR, 2001), and this reaffirms the importance of meeting the 2020 cessation target. The OSPAR document recognises that risk assessments are already underway (in the case of PeBDE, completed) at EU level for some of these compounds, under the Existing Substances legislative programme, and proposes to await the outcome of these assessments and consequent deliberations before deciding what further action (if any) will need to be taken by OSPAR to meet its cessation target. The OSPAR background document for TBBP-A is still in preparation, being developed in parallel with the EU risk assessment itself.

The EU risk assessment for PeBDE identified a need to reduce risks on the basis of threat to the environment and the particular concerns raised by increasing levels in human breast milk. These concerns led to the proposal from the European Commission to ban the marketing and use of PeBDE throughout the EU (CEC, 2001a), a proposal which has since been accepted by the institutions of the European Parliament and Council of Ministers. At the same time, the European Parliament has taken the position that the ban on marketing and use should, on a precautionary basis justified by the balance of emerging evidence, be extended to include both octabromodiphenylether (OcBDE) and DeBDE, the two other widely used PBDE formulations in the European market. Inevitably, there is substantial opposition to this proposal, both from the bromine industry, which has a clear commercial interest to defend, and from the European Commission, which views such an approach as pre-empting the outcomes of the ongoing risk assessments for these two chemicals.

Nevertheless, it may be seen from the introductory discussion above that the more precautionary stance maintained by the European Parliament has clear and sufficient justification. A national target for the phase-out of all PBDEs (and PBBs, though in practice, this has largely already been achieved) was adopted within Sweden several years ago, based on the same concerns and a recognition of the need for greater precaution and responsibility in the use and release of chemicals (the latter more recently captured in Sweden's commitments to a non-toxic environment, supported by development of non-hazardous products, SCNGCP, 2000).

The EU assessment for OcBDE is now nearing completion, and a ban on its marketing and use might also be proposed. If this is the case, it would be difficult to see how the continued use of DeBDE could be justified, given the apparent ease with which DeBDE can be debrominated to form lower-brominated congeners. The outcome, however, and the future for PBDEs in Europe remain in the balance. It also remains to be seen whether the EU ban on marketing and use of PeBDE, already a minor commercial concern in the region, has any impact on its use in other parts of the world. For example, Hale et al. (2002) have highlighted the massive scale of ongoing use of PeBDE formulations within the US markets, and the consequently ever increasing environmental burden. As She et al. (2002) report, levels of PBDEs in human breast tissue in parts of the USA are by far the highest recorded to date.

Within Europe, concerns have also focused on the significance of brominated flame retardants as precursors for the formation of highly toxic brominated dioxins and furans during the high temperature recycling and thermal destruction (incineration) of wastes. Regulatory concerns have so far focused specifically on electrical and electronic wastes. Already in 1998, UNEP and the World Health Organisation (under the joint International Programme for Chemical Safety, IPCS, 1998) recommended that the use of brominated flame retardants should be avoided wherever possible precisely because of their contribution to brominated dioxin and furan production when flame retardant treated products were combusted. During its development of a new Directive to tackle waste electrical and electronic equipment (the so-called WEEE Directive), the European Commission also recognised the inescapable need to avoid the use of certain hazardous substances in such equipment from the outset. Hence the WEEE Directive, which focuses on mechanisms and targets for separation and recycling, was supplemented by Restrictions On Hazardous Substances (ROHS), requiring the phase-out of a number of hazardous chemicals from new electrical and electronic appliances, including PBBs and PBDEs. Following debate at the European Parliament, the final measure sets a deadline of 2006 for the phase-out to be achieved within this broad product group (EC, 2002).

5. Substitution as a duty of care

There are, therefore, already a number of regulatory initiatives and decisions at the regional level which will require the substitution of some or all brominated flame retardants, especially some PBDEs, with less hazardous and more sustainable alternatives. The development of measures to address hazardous substances at the European level has overall, however, been a painfully slow and largely ineffective process to date. In the mean time, continued unrestricted production, marketing and use of intrinsically hazardous substances, until such time as lengthy (and all too often inconclusive) assessments of "risk" have been completed, has allowed a worsening of the problems.

We have reviewed in more detail elsewhere the problems inherent in the current EU chemicals legislation, and suggested an alternative, more precautionary approach to chemicals regulation (Santillo et al., 1999). It was recognition of some of these same problems that led to the initial decision by EU Environment Ministers in 1998 to overhaul existing chemicals regulation and develop a new approach to chemicals policy. The European Commission finally published a White Paper outlining the elements of the new approach in February 2001 (CEC, 2001b). Greenpeace welcomed the new policy as a sea-change in thinking and stressed that the development of detailed legislation to put the policy into practice provided an essential opportunity to realise the commitments within the EU Treaty to provide a high level of protection for human health and the environment from hazardous chemicals (Santillo and Johnston, 2001).

One of the central elements of the proposed new policy is the so-called Registration, Evaluation and Authorisation of CHemicals (REACH) system. Under REACH, chemicals presenting a certain level of intrinsic hazard (the level still to be agreed) would not be permitted for continued use except in clearly justified cases (e.g. where the chemical serves an essential societal role and there are currently no effective alternatives). This introduces to EU legislation for the first time the concept that inherent hazardous properties may render the continued use of a particular chemical undesirable. This presumption against the marketing and use of so-called "chemicals of very high concern" (unless by justified derogation) implies a duty for producers and users to substitute these hazardous chemicals with safer alternatives wherever possible. As noted above, the criteria by which chemicals of very high concern will be selected remain to be finalised. Ultimately, these criteria will determine which chemicals and groups are captured by the positive authorisation system.

6. Substitution of brominated flame retardants: a justifiable goal?

In the light of the preceding discussions concerning the hazardous and undesirable properties associated with the various brominated flame retardants studied to date, and the emergence of new approaches to chemical regulation, one could ask a number of important questions:

1. Does the existing body of evidence provide adequate justification to identify these brominated flame retardants as priority candidates for substitution with safer alternatives?
2. If so, do effective alternatives (chemicals, materials, designs) already exist for some or all of the current applications for which these brominated flame retardants are used?
3. In cases in which no effective alternatives can currently be identified, is this a justification for continued indefinite use of the brominated products, or rather a signal to redouble efforts to identify and/or develop such alternatives?

The answer to the first of these questions should be clear from the discussion above. Although agreement on the need to phase-out these brominated flame retardants, or at least greatly restrict their use, is far from universal, it is by no means a view held only by environmental NGOs that the balance of evidence already justifies their replacement with less hazardous (and preferably non-hazardous) alternatives.

The bromine industry continues to advocate their inherent safety, though this position is becoming increasingly untenable.

By extension, one could reasonably ask whether there is already sufficient knowledge to justify the substitution of brominated flame retardants as an entire group. It must be recognised that those compounds addressed specifically in the discussion above represent only a fraction of the range of brominated flame retardants reportedly in use, though they undoubtedly predominate in terms of market volume. Estimates vary, but it is generally thought that around 70–75 brominated compounds are registered for use as fire retardants world-wide (Lassen et al., 1999; Arias, 2001). Unfortunately, information on properties and uses of the vast majority remains scarce.

At the same time, research on environmental distribution and health effects has understandably focused on the limited range of brominated flame retardants in common use (de Wit, 2002). Even for these, analytical techniques remain under development. It seems highly unlikely that the capacity to screen reliably for a wider range of the brominated compounds in current use will exist for some time to come. Already, however, some studies have reported the appearance of as yet unidentified brominated compounds in tissues and other environmental samples, an aspect about which, as Jansson (2001) stresses, we should remain vigilant. This will become even more vital if restrictions on some commonly used flame retardants result in increased use of other brominated chemicals as alternatives.

At present, however, it is clear that knowledge regarding the distribution and hazards of brominated flame retardants other than brominated diphenyl ethers, bisphenols and cyclododecanes (and perhaps the now obsolete brominated biphenyls, PBBs) is extremely limited. It is also clear that we are many years, if not decades, from a complete description and understanding of the threats posed by the other brominated flame retardants, during which time their use, and our consequent exposure, will inevitably continue. The question is then whether the benefit of the substantial doubt surrounding the impacts of these chemicals, many of which are likely (given their chemical structure) to be environmentally persistent, should be given to the producers or to the protection of the environment and human health from chemical exposure. In this regard, the recent precautionary decision of the State Council of the Netherlands to prohibit the marketing of a new brominated flame retardant (bis(2,3-dibromopropyl) tetrabromobisphenol-A, FR-720), on the grounds that available information was insufficient to demonstrate safety (Raad van State, 2003), is an interesting development, and one which may serve as a precedent for similar actions in the future.

In short, even in the absence of proof of harm for the majority, existing knowledge of the problems posed by those brominated flame retardants which *have* been well characterised could be seen as a reasonable basis for seeking non-brominated solutions to fire-safety on a more generic basis. Moreover, irrespective of the level of hazard presented by each individual chemical during production and use, all brominated flame retardants share the common characteristic of acting as a source of bromine to the waste stream. It was this aspect, and the potential for the formation of brominated dioxins and furans during incineration, which lay behind the World Health Organisation's recommendation to avoid the use of brominated flame retardants wherever possible (IPCS, 1998). Addressing these concerns will inevitably necessitate broader substitution of brominated products.

7. Substitution of brominated flame retardants: an achievable goal?

Without doubt, society does not yet have the means to replace all current uses of brominated compounds for fire retardancy, and, even where effective substitutes do exist, their introduction clearly cannot happen overnight. Nevertheless, these should not be seen as reasons to prevent what progress *can* already be made towards the replacement of brominated flame retardants, nor more generally to accept that exposure to these hazardous chemicals is an inevitable price to pay for fire safety in a modern world. Indeed, if society is serious about achieving high levels of protection for the environment and human health (as, for example, is enshrined within the EU Treaty), we must acknowledge that necessary fire safety standards must be achieved in more sustainable ways.

Aside from defending the safety of the brominated chemicals, the bromine industry frequently relies upon accident statistics, specifically deaths or injuries caused by electrical equipment which was not properly fire-proofed, to support its claims (Spiegelstein, 2000; Alaee and Wenning, 2002). While the statistics they present provide clear evidence (should any be necessary) of the vital importance of fire safety and use of intrinsically non-combustible products, this is not a fundamental justification for the use of organobromine chemicals to achieve fire safety standards. Theirs is, in many ways, a disingenuous argument, but one which is often used to dismiss supporters of brominated flame retardant substitution, coupled with accusations that alternative approaches inevitably compromise fire safety. For the products in which they are incorporated, brominated flame retardants are undoubtedly fulfilling an essential societal need, but this need is for fire safety and this may well be achievable through other more sustainable means. As the Swedish Rescue Services Agency points out, achieving fire safety standards and avoiding casualties is about much more than chemical additives in products (Albinson, 2001).

So are we to accept the bromine industry's arguments that there are very few effective alternatives to organobromine chemicals for fire retardancy? Evidence such as that collated for the Danish EPA's assessment of alternatives

(Lassen et al., 1999) indicates that, for a large proportion of applications, non-brominated alternatives are already commercially available. Solutions range from the use of an alternative, non-brominated chemical additive, through to material substitution and even to changes in design and construction to render products inherently less flammable. Construction of television sets with greater spacing or metallic barriers between components, or which use lower voltage components, are examples of the latter. Although some alternative chemical additives may carry hazards of their own, such that further innovation and development may be necessary ultimately to replace these also, arguments that organobromine chemicals are the only viable option are clearly indefensible. The wide availability of effective substitutes is further supported in a very practical sense by the ability of a number of manufacturers and retailers to have ceased the use of brominated compounds as fire retardants, or at least to provide consumers with an informed choice. Unfortunately, information identifying which companies provide bromine-free fire-retarded products is still not widely available, although the database of electronic goods available in Denmark, maintained by the Danish "Green Information Centre", is a useful example of what can be done.[1] Unfortunately, commitments made in 1998 by Environment Ministers in the North East Atlantic (OSPAR) region to provide consumers with information on the presence of hazardous substances in products (OSPAR, 1998b) have yet to be put into practice.

8. The role of responsible and precautionary governance

In short, while it is undoubtedly the case that alternatives are not readily available for all applications, these applications may well be the exceptions rather than the rule. The existence of specific examples for which substitution is not possible should not be seen to cast doubt on the wisdom of the principle of substitution as a whole. For those applications for which effective, less-hazardous alternatives are available, they should be introduced without further delay. For those that cannot be substituted immediately, continued use may be permitted for a specific, time-limited period, during which the manufacturer and/or user must demonstrate that they are actively seeking or developing alternatives. Such an approach would be entirely consistent with the developing REACH system within the EU, i.e. a presumption against continued use of brominated flame retardants and a duty to substitute with less hazardous alternatives, with the possibility of derogations for those essential uses for which alternatives are not currently available.

Of course, in the absence of legislative pressure, a few progressive companies have voluntarily phased-out brominated flame retardants from their products. While this demonstrates what is achievable, the small number of pioneering companies also illustrates the inertia within many sectors to switch from what are cost-competitive and effective brominated products to alternatives on the basis of what are frequently portrayed as "unproven" environmental or human health concerns. In their study for the Danish EPA, Lassen et al. (1999) note that many bromine-free alternative flame retardant systems are more expensive than brominated systems, though in most cases the difference is not large. It is unlikely, therefore, that the market for fire retardant systems will shift substantially away from brominated compounds without substantial policy and public pressure or incentives to do so. Clearly, decisions to prohibit the continued use of one or more hazardous chemicals provide the most effective regulatory pressure. Indeed, coupled with efforts to enable consumers to make informed selections of non-brominated products, a clear and consistent policy position that brominated flame retardants must be phased-out within a realistic, but challenging, timeframe would likely produce a remarkably rapid shift in the balance of the market.

It seems inevitable, even in the absence of precautionary regulatory or policy pressure, that brominated flame retardants would eventually cease to be used, though in this case only after rapidly escalating environmental levels had resulted in demonstrable harm to wildlife and/or humans. The challenge for governments, therefore, is to have the confidence and responsibility to take early action both to push and encourage substitution with effective alternatives.

9. Precaution as a stimulus for innovation

In this sense, the outcome of the more recent 5th North Sea Ministerial Conference (Bergen, Norway, March 2002) carries substantial significance (NSC, 2002). In addition to agreeing that the issue of hazardous substances in consumer products must be addressed as a priority in the reform of the EU chemicals policy and in the development of the EU integrated product policy, North Sea Ministers emphasized the vital role to be played by the principle of substitution and the need for new initiatives to promote its application. More specifically, Ministers stressed that such initiatives should:

(i) "in addition to industry, involve all other relevant stakeholders, environmental non-governmental organisations and representatives of consumers;
(ii) address both processes and products with regard to their full lifecycle;
(iii) ensure availability to users, including consumers, of information on the hazards and risks presented to human health and the environment by hazardous

[1] See http://www.greeninfo.dk/artikel.asp?artikelID=3754&kategoriID=281.

substances, and to the presence of such substances in consumer products so that they are in a position to make an informed choice;

(iv) be based on applying an integrated product policy to minimize hazards and risks throughout the production, use and disposal of products (including waste minimisation and increased re-use or recycling);

(v) request industry to seek for safer alternatives to hazardous substances; and

(vi) promote and facilitate the identification and development of such safer and preferably non-hazardous alternatives where they do not currently exist.''

This progressive statement of intent captures several of the key concepts discussed above. Furthermore, a number of other important elements emerge from this declaration. Firstly, in order to evaluate properly the availability of alternatives, e.g. to brominated flame retardants, it will be necessary to engage a broader section of ''industry'' than is commonly represented by the various federations of chemical producers. Although many of the solutions already exist, they are unlikely to be readily identified by those with a direct commercial interest in production or marketing of brominated compounds. Moreover, experience has frequently shown the valuable contribution that can be gained from the inclusion of the retail sector in such discussions, as retailers have a much more direct connection, and responsibility, to the consumer.

Secondly, the final indent of the extract above illustrates the importance of innovating to find solutions where they do not currently exist, rather than simply accepting the status quo. In this sense, the application of a precautionary approach requiring a shift away from brominated flame retardants would necessarily stimulate innovation, not stifle it as many opponents of precaution often argue (e.g. Holm and Harris, 1999). Indeed, innovation to achieve progressive reduction in overall human impact on the environment was an important (though generally overlooked) component of the original formulations of the principle of precautionary action (Santillo and Johnston, 1999). As Tickner (2001) notes, one result of a strong policy decision to substitute can be a much greater (and more productive) focus on identifying appropriate solutions and less emphasis on trying to disprove that the problem exists in the first place.

10. Conclusions: achieving fire safety more sustainably

Whether or not it is right to target brominated flame retardants for substitution with safer alternatives depends on how far one is prepared to accept their ever increasing presence as contaminants in remote environments and in human breast milk and blood, and the threat they present with regard to their inherent toxicity, particularly when their use is already avoidable. In our minds, at least, and in the minds of many others, the evidence is already more than sufficient to warrant precautionary action to phase-out this ''new generation'' of persistent organic pollutants. Indeed, the systematic accumulation in the biosphere documented for many brominated flame retardants contravenes one of the basic first order principles of sustainability (Cairns, 1997).

The common presentation to society of a choice between accepting brominated flame retardants or accepting unsafe products is misleading, disingenuous and unhelpful. The public, and indeed the policy-makers, should be made aware that the real choice is between fire safety achieved using toxic and persistent organobromine compounds which will inevitably escape to our environment, or fire safety achieved in more innovative, holistic and sustainable ways.

In some cases, substitution is likely to be a straightforward issue of selecting an alternative which is already available. In other cases, it will probably not be this simple, particularly if one or more of the potential alternatives possess significant hazards of their own. It is possible, however, to establish certain guiding principles for decision-making in such cases, e.g.:

- always seek to select the alternative possessing the least hazardous properties, and re-evaluate the selection on an ongoing or periodic basis;
- as far as possible, avoid alternatives which possess similar or equivalent undesirable properties to the chemical being substituted;
- have the confidence to target hazardous substances for ultimate substitution even if alternatives have yet to be identified, in order to stimulate the development of solutions;
- be prepared to take further precautionary decisions as necessary on the basis of emerging information which may indicate previously unidentified hazards.

Contrary to what some might wish us to believe, the contamination of the global environment with persistent organobromine compounds is not an inevitable and inescapable consequence of providing a high level of fire safety in a modern world. Ultimately, we must hope that humanity has the foresight and ingenuity to arrive at better solutions. After all, we owe it not only to ourselves, but also to future generations to do so.

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