# ENVIRONMENTAL CONCERNS OF FIRES : FACTS, FIGURES, QUESTIONS AND NEW CHALLENGES FOR THE FUTURE

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## ABSTRACT

*The effect of fires on the environment has been increasingly in the public eye since the chemical warehouse accident in the Sandoz facility in Schweizerhalle in November 1986. This paper presents a discussion of this accident together with a representative sample of other environmentally important case studies related to fires. Modes of interaction with the environment and potential transfer mechanisms are discussed. The impact of fire effluents in both the short and long terms and activities on the quantification of the environmental effect of fires are also presented. Some of the current environmental debates that are interacting with fire prevention and fire firefighting techniques are also discussed, outlining challenging remaining issues.*

*Finally, insight on international action in response to these incidents and related standardisation activities under progress is presented.*

KEY WORDS: fire, environment, emissions, organic pollutants

## INTRODUCTION

Community awareness of the fact that large fires may present dramatic and persistent adverse effects on the environment has been accentuated by a number of high impact incidents over the past half century, as indicated by a few review papers [1,2,3,4,5]. Perhaps the most instructive example of these was the chemical fire in an industrial warehouse near Basel Switzerland in November 1986, best described in references [6,7,8]. This fire presented major challenges in terms of fire fighting tactics, emergency response management, crisis communication with concerned nearby countries (France and Germany), air pollution in a highly urbanised area, and water pollution. Large amounts of extinguishing water contaminated by pesticides and other toxic chemicals ran off directly into the river Rhine, killing aquatic life for several hundreds of kilometres. Moreover, the environmental problems caused by fires go far beyond pollution by run-off waters as stated as early as 1994 by Hölemann[3].

The serious consequences of these disasters have confirmed that the environmental impact of fires is a real threat that urgently needs to be treated by a more systemic approach. In particular, the hazard from the emission and re-deposition in the environment of some fire effluent components having carcinogenic or mutagenic properties, and sub-lethal exposures to toxic compounds are a matter of intensive debate. Hölemann[3] previously pointed out some of the difficulties associated with this problem and the size of appropriate mitigation measures. However, we need to better understand the relationship between these phenomena, and develop scientifically sound tools for identification of the hazard, the assessment of risk, and the implementation of fire prevention and protection measures. Such work is just beginning within ISO/TC92/SC3 under its mandate to consider not just the local effect of fire effluent on people but also its effect on the environment [9]. A very limited number of papers have focussed on the environmental issues of fires until recently [10].

On the one hand, environmental issues of fires can be somewhat negatively summarised by reporting them

in terms of a history of conflict among fire safety, health and environment quality conservation [11]. This view is largely supported by several examples such as the long term use of asbestos, or decades of use of fire resistant PCBs (polychlorobiphenyls) in electric transformers followed by PCBs being progressively phased out, fire fighter training on abandoned houses, soil contamination at fire training academies, wildland fire management, hazardous material incident responses, water conservation measures, halon replacements that are greenhouse gases, fire retardant chemicals that are used in furniture, cables and appliances, alternative fuels and increased use of plastic materials in the automotive industry. On the other hand, remaining "old problems" (such as contaminated water runoff) and emerging ones (determination of the degree to which fire effluents contribute to POPs, persistent organic pollutant, -production) need to be clearly identified, weighted and treated in the most relevant way.
The challenge in the future is not to raise public awareness of the environmental impact of fires or the importance of fire prevention or mitigation ; but to improve the interaction between these facets of fire science to ensure that toxicity, eco-toxicity and fire safety are dealt with together in a single holistic approach. It is only through such an approach that we can optimise any fire related situation to ensure that neither is fire safety obtained at an unacceptable cost to the environment, nor is environmental safety obtained at an unacceptable cost to fire safety. This paper will provide some background to this discussion based on experience from some environmentally significant fire accidents, important modes of environmental impact and relevant legislation and standardisation activities.

## THE SANDOZ FIRE LEGACY

On the 1st November, 1986, at 00.19 hours a fire was discovered in the Sandoz warehouse (B956) in Schweizerhalle near Basel in Switzerland, simultaneously by traffic police and a Sandoz Ltd employee. Although the commander of the Sandoz fire brigade and several fire fighters were on the scene within minutes, the fire had already engulfed approximately one quarter of the warehouse and was spreading rapidly. Reinforcements were quickly brought in and one hour later 15 fire brigades and 200 firemen were in action. The warehouse contained some 1300 tons of organic chemicals, largely for agricultural use. Initial efforts were focussed on preventing the fire from spreading to neighbouring buildings and an adjacent open air barrel storage facility. Attempts to extinguish the fire with foam were ineffective and large quantities of water were used (up to 25 $m^3$/min being directed towards the central warehouse building). In total an estimated 20 000 $m^3$ of water were used in the mitigation and extinguishment activities. This water, highly contaminated with organic compounds, was then able to drain into the Rhine (through drains) and to seep into surrounding soil.
Numerous studies have been made of this catastrophic warehouse fire and it is often cited as the first major fire to receive significant publicity focussed largely on its effect on the surrounding environment. This is no doubt due to a combination of factors, both scientific and political. The fire in itself did not cause significant air pollution over and above the levels of air pollution from other sources on a typical winter day, but did cause significant pollution of the Rhine river and the land surrounding the warehouse site. While the Rhine is an important central European river its pollution would perhaps not have received such international attention had it not served as the border between several countries.
Thus, the environmental effects of an accident in Switzerland had immediate consequences for its neighbours (Germany and France) and subsequent consequences even for neighbours downstream. (Polluted water reached The Netherlands on the 13th November). Indeed, all drinking water extraction downstream from the accident to the North Sea had to be temporarily shut down. This international aspect of the disaster has almost certainly heightened awareness of the accident and interest in monitoring its consequences. To understand all the environmental implications of that fire, the best reference is likely to be the special issue of *Chemosphere*[8]. Worth noting is that the fire occurred in a highly urbanised area justifying some interesting screening investigation of sub-lethal exposure to carcinogenic and mutagenic species that could have been emitted by the fire, owing to the chemicals in storage. No evidence of such a threat was reported as the main conclusion in that particular case.
While the recovery of the Rhine was possible within about 5 years its devastation during the initial period after the fire was significant. Several changes were made to German legislation as a direct result of this accident requiring the installation of catchment basins for run-off water surrounding large chemical storage facilities. Further, several European-funded research projects were initiated specifically to investigate the products from combustion of chemicals in storage facilities, in terms of emissions to the

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air, water and soil [e.g., the STEP, Toxfire and Mistral projects [12]].
Perhaps the single most important and positive results of the Sandoz fire, however, is the role it is playing in raising international awareness of the importance of fires as significant point sources of pollution to the air, water and soil. This has, in turn, promoted useful safety storage guidance documents that address such techniques as incompatible chemical segregation principles, limitation of stored quantities and requirements for fire water containment[13, 14].

## CASE STUDIES

A large number of fire catastrophes have occurred historically which have had a significant effect on the environment. The present presentation does not aim at an exhaustive collation of these accidents. Rather a small number of representative fires are discussed to illustrate the international nature of this issue and the ubiquitous nature of the environmental effects. Table 1 contains a summary of the fires briefly discussed.

**Table 1: A selection of important case histories with established environmental outcomes.**

| Date | Place | Comments |
|---|---|---|
| 1962 | Centralia, USA | Coal mine fire, burning continuously since 1962. At that time the local population was some 1100 most of them had to relocate progressively.[4] |
| Nov. 1986 | Basle, Switzerland | The chemical warehouse fire that was referred to worldwide[4,5], initiated debate of the environmental issues of fires, and was a source of progress in the area (see dedicated section). 10 years after this ecological disaster, eels that were restocked the Rhine were still not consumable. |
| Oct.1987 | Nantes, France | A chemical warehouse storing inorganic fertilisers suffered a major blaze due to self-sustained decomposition of 20 t of N-P-K products, releasing a massive toxic plume that eventually dispersed over the ocean[5]. 15,000 people were evacuated as a precaution. Afterwards, an experimental assessment of the plume toxicity confirmed the toxicity of the effluents[47]. |
| June 1987 | Ohio, USA | Sherwin-Williams paint warehouse fire in environmentally sensitive area (see dedicated section) [18] |
| June 1988 | Near Tours, France | Known as the *Protex* fire, that chemical fire spread vigorously due to close proximity of flammable and toxic products. The plume zone was some 30 km long and 12 km large (fire plume zone) and provoked a major pollution of the river Brenne. |
| Feb. 1990 & May 1990 | Hagerville, Ontario, Saint-Amable, Quebec, Canada | Two of the numerous large-scale tire waste fires that have taken place in North America [15]. Tire fires last several days to several months. They lead to massive air, soil and water pollution and to extreme difficulties in fire fighting. Evacuation of people is required in some cases, and fresh water is sometimes disrupted for long periods. Lessons learned led to the production of useful guidelines in Europe and North America [15,17]. |
| 1991 | Kuwait | As a result of the Iraqi invasion of Kuwait, oil wells were systematically damaged with explosives resulting in uncontrolled gas and oil blowout fires of some 700 wells. The environment contamination by both oil leakage and fire gases was severe, in relation with the tremendously important and long lasting releases of pollutants that have affected air and soils (equivalent to some 7,400,000 bbls/day), according to NIST evaluation reported in 1994 [3, 46] |
| July 1992 | South Bradford (UK) | A major pollution of the aquatic environment resulted from the runoff of some 16,000 $m^3$ of contaminated water used to fight the fire in the plant of a chemical manufacturer named Allied Colloid in Bradford : the UK reference in matter of pollution by contaminated water run-off in fresh water streams. The origin was the proximity of storage of incompatible chemicals. |
| Oct. 1995 | Wilton (UK) | Polypropylene warehouse fire on a BASF chemical complex, raging for 12 hours, due to fault in the lighting system. |

**Table 1 A selection of important case histories with established environmental outcomes (cont'd)**

| Date | Place | Comments |
|---|---|---|

| | | |
|---|---|---|
| Dec. 1995 | Somerset West, South Africa | Massive fire of a sulphur stockpile used by three different companies in industrial applications in the era of the South African embargo[19]. A unique proof that fire toxicity may be a lethal threat, even in the open environment |
| June 2001 | Venizel, France | Paper mill containing PCB transformers. An fire accident with considerable difficulties in the emergency response management, that required the medical survey over 1 year of some 100 people (including journalists), liable to have suffered some exposure to PCDDs (dioxines) and PAHs (polycyclic aromatic hydrocarbons). A case study that reveals that until the phase out of a banned product is fully effective, the threat is remains. A very instructive report was produced on the aftermath of that fire and made public by the French Authorities[22] |
| Jan 2002 | Murcia (Spain) | Large release of toxic effluents arose from warehouse storing inorganic fertilisers (NPK), a quite similar scenario to the one which occurred in Nantes (1987)[5] |
| 1990s to 2000s | Wildland fires | Significant concerns worldwide, massive fires lasting weeks long, inducing multiple fire deaths and large property losses in urbanised areas, or causing sanitary problems or temporary closures of airports due to large levels of pollutants emitted on long periods (USA, Australia, Indonesia, Southern Europe...) |

Many of the events reported briefly in table 1 have been the subject of detailed studies reported in the open literature, following the fire investigations. This paper provides additional description of two of these, the Sulphur fire at Somerset West and the Sherman Williams Paint Warehouse Fire in Dayton, as they illustrate particularly well some of the specific issues of the environmental dimension of large fires.

**The Sulphur fire at Somerset West (Western Cape Province in South Africa, December 1995)[2,19,20,21]**
This massive fire hit an impressive stockpile of sulphur, the size of which was a consequence of the local government's response to the anti-Apartheid sanctions. The raw material was a key product for three major companies producing munitions and fertilisers. Surprisingly, this fire has remained relatively unknown in the fire literature except on the local level, where the Ministry of the Environment [20] made the full enquiry report available to the public (Commission DESAI report). Indeed, this accident provides some important lessons for the fire community. In particular it reinforces the idea that industrial fires of non-hydrocarbon combustibles (i.e., those containing a significant amount of hetero-atoms in the organic chemicals involved or involving non-organic materials) may behave quite differently from hydrocarbon fires in terms of the nature of emissions and how they threaten the environment. In the early stages of this incident, the fire was wrongly identified as a bush fire, yet it emitted some 14,000 t of sulphur dioxide [21]. The fire was a tragic demonstration of shortcomings in hazard management and emergency response, leading to :

- disorganised evacuation, in a panic, of several thousands of people,
- congestion of all emergency services and transportation routes,
- agricultural impacts that ranged over a broad area extending to 30 km from the fire site,
- and last, but not least, $SO_2$ levels in the nearby Macassar town (30,000 inhabitants), that far exceeded the safety threshold over 20 h of exposure, resulting in multiple deaths in the open environment at distances quite remote from the fire site. Although the actual number of deaths attributed to this incident is controversial this does present a unique reference to such a threat, to our knowledge.

**The Sherwin Williams Paint Warehouse Fire (Dayton, Ohio May 27 1987) [1,18]**
This major chemical blaze had to be faced by the concerned fire services and local authorities only 6 months after the Sandoz case, pioneering after a time of hesitation the use of the still controversial 'let it burn option'. The fire brigades were confronted with a fully engulfed fire, raging in a warehouse containing over 6 million litres of paint and other toxic chemicals located over the aquifer. The local source of fresh water was supplying one third of the 400,000 people living in the countryside. Due to the absence of any capacity for water containment, it was agreed that the environmental threat would have been more severe (in terms of deep water pollution) if extinguishing operations were used instead of allowing the fire to consume all combustible material and release pollutant emissions into the air. The property itself was estimated to be a total loss before this strategic decision was taken in full agreement

with all stakeholders.

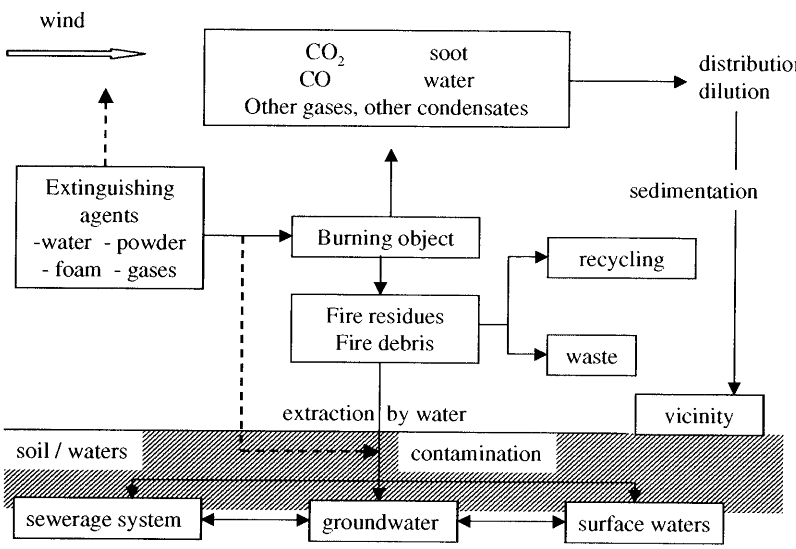
## FIRE EMISSIONS AND TRANSFER MECHANISMS

The interaction between a fire and its surroundings or environment is best illustrated in Figure 1. This figure shows how fires effect the environment through:

- Direct gaseous and particulate emissions to the atmosphere (fire plume)
- Spread of atmospheric emissions
- Deposition of atmospheric emissions
- Soil contamination
- Aquifer contamination

This contamination can be due to emissions of numerous, time and product dependant effluents from the fire itself (primarily source term) or those associated with the fire brigade activities that may even influence the nature of airborne emissions [23].

**Figure 1: Emission pathways from fires.**




The effect of these various emissions depends in part on the transfer mechanism (i.e., atmospheric emission of gaseous species or soil and aquifer contamination) and on the specific species (i.e., small gaseous compounds, large particles and the range of species in between). A wide variety of toxic effluents are generally emitted in fires. These effluents may follow a number of pathways to impact human and ecological receptors. Risk assessments may not be possible for all potential impacts but contingency planning should take account of appropriate "worst-case" scenarios. In assessing the potential environmental impacts of toxic releases from fires, the following major zones of impact are generally considered.

### Fire zone

This area is defined by the direct fire damage and the corresponding emergency response. The primary response generally relates to preserving the health and safety of individuals who may be within this zone, with secondary consideration for the structure and its contents. The environmental impacts are typically less critical with minor exceptions.

### Fire plume zone

The fire plume zone is an area over which the smoke/vapour plume from the fire disperses. Within this zone there is the potential for harm from inhalation of and surface exposure to the airborne toxic gases and

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particles within the plume. For intense plumes, there is also the potential for decreased visibility, although this is generally of little environment significance. PM10, airborne particles with a mass median aerodynamic diameter under 10μm present an important potential environmental problem both due to their direct effect on the respiratory system and due to their transport of other potentially carcinogenic organic species (e.g., polycyclic aromatic hydrocarbons, dioxins and furanes).

Both local topography and meteorological conditions (wind speed and air stability characteristics) have an influence on the characteristics of dispersion and the extent of the fire plume zone. Short-term environmental impacts are most significant in this zone. Valleys, basins, high buildings and street canyons, adjacent to or surrounding the fire can effect the dispersion of the plume. Low wind speed, temperature inversion and conditions that promote rapid plume grounding all limit plume dispersion. The combined effects of topographical features and meteorological conditions that result in restricted dispersion are generally additive and result in higher air pollutant concentrations within the fire plume.
As stated by Gann et al.[34], in homes fires, far more occupants are likely to be exposed to fire smoke than those actually suffering consequences, either immediate to the fire incident or afterwards. Thus it might appear that single smoke exposures outside the immediate fire vicinity (see fig. 1) might seem inconsequential. However, single exposure to the plumes from atypical fuels (e.g. chemical fires involving pesticides[42], high sulphur content materials, fertilisers, pool chemicals, etc) poses special risks and repeated exposure to sub-lethal concentrations of fire gases have been reported as potentially responsible for chronic diseases or specific pathologies among firemen populations [35].

**Plume deposition zone**

The fire plume is affected by complex thermal, mechanical and chemical transfers that leads in turn to final sedimentation processes as mentioned in figure 1.
Atmospheric releases may thus also affect terrestrial and aquatic environments through deposition of pollutants from the fire generated plume. Many thermal degradation products can condense on, or be adsorbed by, the soot particles and be transported with the smoke. There may also be deposition on structures, leading to corrosion, particularly from acidic decomposition products. These effects on building materials, machinery and electrotechnical equipment are much like those from acid rain. Health and ecological damage can arise from exposure to deposited pollutants through a variety of pathways including aerial deposition to water and land and accumulation in the food chain and subsequent consumption of contaminated food.

**Water runoff zone**

As exemplified in a number of case studies, fire-fighting water runoff presents the major potential threat to the aquatic environment from toxic releases from fires in the short term although some threat to the aquatic environment is present through deposition of airborne pollutants into aquatic receptors. The threat from fire-fighting water runoff is strongest where runoff waters directly enter aquatic habitats in surface waters (e.g., rivers, streams, ditches), within the immediate vicinity of the site, and where levels of toxic releases are particularly high.

Short-term impacts may arise where fire-water runoff infiltrates drinking-water supplies during or immediately following a fire. The risk is higher local to the fire, where the runoff water is potentially most highly contaminated with ash / soot / decomposition products, and relatively undiluted. The likelihood of such water being directly ingested is limited, but such surface water bodies do represent a potential hazard. Impact on the aquatic environment will be exacerbated where the contours of the land are such that runoff is conducted directly to surface waters (non-contained) and where dilution effects are limited (low flows, small water volumes within the receptor, and a short source-to-receptor pathway). Toxic, carcinogenic, and exotic organic compounds in surface waters can directly affect freshwater habitats and species. Marine habitats and species may also be affected, though owing to dilution, the impacts are likely to be diminished.
The assessment of the level and area of contamination of the various eco-systems as a follow up of any accidental emissions is a quite complex procedure and thus it is rare that such studies have been performed so far in the fields. Reference [36] provides good reference material concerning this aspect.

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## ENVIRONMENTAL IMPACT OF FIRE FIGHTING TACTICS AND FIRE PREVENTION

Challenging issues as regard fire safety and the fast growing environmental concerns have sharply increased since the early 1990s. Several of the major activities are discussed below:

### The progressive phase out of halons

Since the 1950s, there had been great expansion of the use of the halon (halogenated hydrocarbon fire extinguishing fluids. These chemicals quench flames with high efficiency, low toxicity, and no residue. They thus became the agent of choice for protecting sensitive (e.g., computer rooms) and valuable (e.g., aircraft) properties.. The most prevalent fire suppressant halons are also potent depleters of stratospheric ozone. They are no longer in production and their use has been restricted to those few applications where no alternative yet exists. Replacements have been developed for most applications. These generally dilute and cool the flame environment below the flame-propagation limit, without the strong chemical action of the halons. . They are either mixtures of inerting gases ($N_2/Ar/CO_2$), or single gases interfering with the combustion reactions like $C_3HF_7$ (HFC 227 ea), $CHF_3$ (HFC 23) or $C_4F_{10}$ (FC 3-1-10)[48].

Significant problems were anticipated and mitigated to foster the sustainable protection of property without compromising fire protection primary goals. Indeed, existing alternatives to halons no longer contribute to the ozone depletion process, i.e., their ozone depletion values (ODP) are zero. However, they are contributors to global warming and may present other adverse potential effects to the environment due to their environmental persistence. (See table 2.)

**Table 2 : halon 1301 and some commercial alternatives : environmental parameters**

| | ODP | GWP (100 years vs CO2) | Atmospheric lifetime (years) |
|---|---|---|---|
| Halon 1301 | 16 | 4900 | 77 |
| HFC 227ea | 0 | 2050 | 31 |
| FC 3-1-10 | 0 | 5500 | 2600 |
| HFC 23 | 0 | 9000 | 280 |

### Water containment basins

The problem of water basins for run-off water in the event of a fire is internationally recognized and some industrial countries such as Switzerland, Germany, France, the Netherlands, and the UK, as well as some international groups of experts from the chemical industry, insurance and fire service and administration sectors have provided useful guidelines, and sometime controversial recommendations. In particular the sizing of the containment basins as well as the overall design and management of containment systems have received attention in some countries (e.g., references. [43, 44, 45]), although in a quite diverse manner.

Many industrial sites in the chemical industry are equipped with containment basins. However, to date, existing regulatory texts (the existence of which is patchy at best) are based largely on "magic" compliance rules as no universally recognized fire engineering technique has been made available. This has resulted in, as exemplified by Vandonkelaar [7], sizing rules giving containment basin capacity characteristics that vary by up a factor of 10 for a given industrial facility, according to location of the facility. France has initiated a number of initiatives to update current technical knowledge to promote a more engineering sound approach, both on a National and international level.

### Fire fighting foams

On 16th May 2000, 3M™ Corporation, in agreement with the US Environmental Protection Agency (EPA), announced officially its decision to cease marketing its AFFF series of firefighting foams, a fact which illustrates the voluntary code of practice more popular in the US. The decision was justified by the potential long term environmental impact of a single substance PFOS, perfluorooocanyl sulfonate, a manufacturing process intermediate bound to the so-called Simons' electro-fluorination method.[25]

Useful updates on the environmental issues of all firefighting foams (including FP/FFFP and AFFF) have been published by R. Harman [26] and W. H. Ruppert et al [27], together with the regulatory frameworks pertaining in this matter in Europe and the US. This decision by the manufacturer has created a void for those applications (e.g., liquid fuel fires on airport runways, ship decks) where these foams are used.

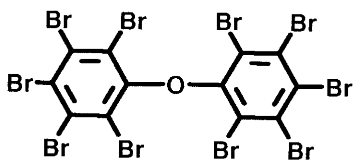
It is now clear that in summary one can make the following statements :

- The water polluting effects of a firefighting foam must be considered as a condition for its use. Indeed, none of the available firefighting foam can to be considered as environmentally benign
- Due care should be taken when running training operations with foams, to avoid their release into the environment
- It is clear that fire protection/suppression benefits are too great (in particular for type B fires) to phase out foams
- Environmental impacts of foams must be mitigated, new formulations are desirable to fill the void, but will not be the complete answer.

**Flame retardants and the environmental issues**

Over several decades, a variety of flame retardant (FR) chemicals have been developed to lower the ignitability and flame spread performance of both plastics and natural materials used in construction and furnishings. The widespread use of these chemicals has led to significant reduction in the number and severity of unwanted fires, and thus sustainable development of flame retardants production and use remains a key issue. However, concerns have been raised concerning a variety of FR chemicals (e.g., halogenated -brominated as well as chlorinated- FRs, antimony trioxide, etc). Recently both the State of California and the European Union have announced required phase-outs of two brominated flame retardant (BFR) groups : pentabromodiphenyl ethers and octabromodiphenyl ethers. Belonging to the same family of BFRs, Decabrominated diphenyl ether (see figure 2), which is fully brominated is currently extensively used in the cable industry, in particular in North America. It is also under consideration for restriction. There is at present no consensus regarding any health and environment significant issues with this FR, justifying the additional studies that are underway to clarify remaining uncertainties[30,31].

**Figure 2 : Structure of Deca bromodiphenyl ether, one of the PBDEs in extensive use**




Much of the debate surrounding BFRs has originated from massive accidental (and non-fire related) exposure to PBBs in 1973 [2] through the food chain, that occurred in Michigan (USA). A useful document[28] was recently published that provides a good overview of technical and societal aspects pertaining to FR chemicals, in general. A more scientific overview of the current understanding issues and remaining challenges on current BFRs in use has been provided in the special issue of Chemosphere [2]. Other papers of interest are those of E.Harimann et al[31] and G. L. Nelson[32], both presented at a recent FPRF symposium.

Extensive reviews of toxicological properties of several flame retardants are underway, in particular in Europe, as a result of the legislation. Figure 3 illustrates the complexity of appropriately addressing the question of effective exposure to chemicals in our environment and in particular flame retardants, reflecting the whole life-cycle of the product, including the accidental exposure through fires.

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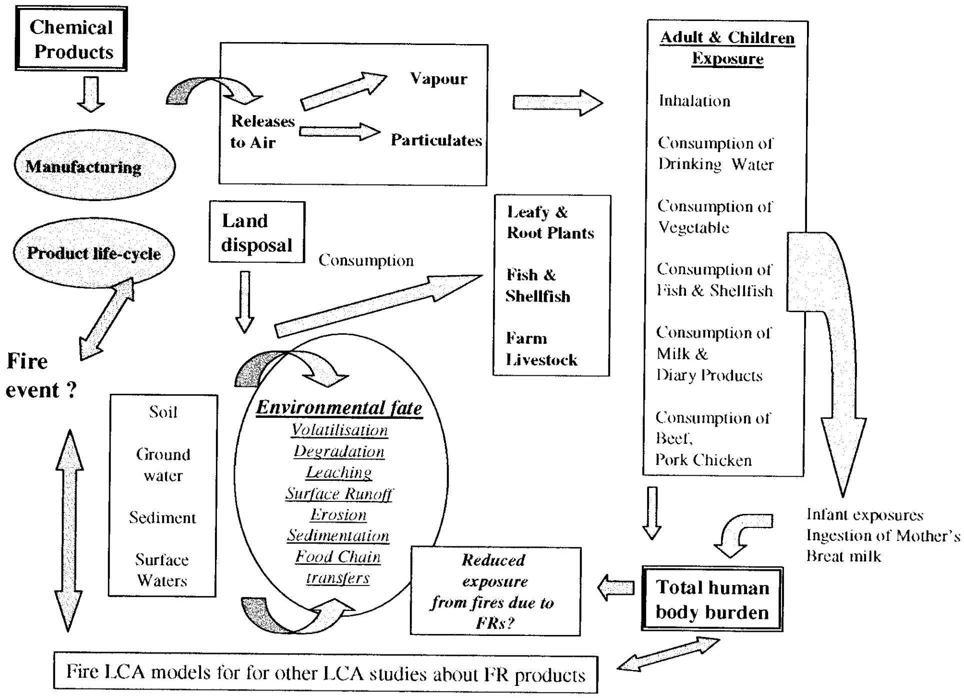
**Figure 3 : A Holistic approach for the assessment of human body exposure to chemicals (adapted from Wenning's paper [30])**




From the extensive discussion preceding and following this legislation, it is clear that addressing the environmental health and safety issues of flame retardants while maintaining high fire safety performance is no simple and straightforward process. Unfortunately, much of the debate has been politicised and little information was initially available to make a quantitative comparison between flame retardants that were questioned and alternatives (whether these were alternative flame retardants or entailed a reduction in the fire performance of the material used in specific products).

In 1998 the first attempt was made to define a quantitative model to establish the environmental impact of choosing between high fire performance or low fire performance products, or between different flame retardants[40]. The Fire-LCA model is based on a holistic approach to calculating the environmental impact of fires using a life-cycle assessment model supplemented by emissions from fires and the cost of replacement of products involved in fires[41]. The model has been applied in three separate case studies and shows the importance of including the environmental impact of fires when calculating the environmental impact of the use of flame retardants. Indeed, a product's impact on the environment in a general way must be considered for its entire life cycle, as stated by Ahrens et al[4].

## EXAMPLES OF THE TECHNICAL AND REGULATORY FRAMEWORK THAT AFFECTS THE FIRE PROBLEM

### The Stockholm Convention on Persistent Organic Pollutants (POPs).

The Stockholm Convention is a global treaty to protect human health and the environment from POPs, which are described as chemicals that remain intact in the environment for long periods, become widely distributed geographically, accumulate in the fatty tissue of living organisms and are toxic to humans and wildlife. POPs circulate globally and can cause damage wherever they travel. In implementing the Convention, governments will take measures to eliminate or reduce the release of POPs into the environment.

### UN Convention on the Transboundary Effects of Industrial Accidents

Since the early 1990s the United Nations Economic Commission for Europe has concentrated its efforts on

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preventing industrial accidents and especially their transboundary effects.
Major accidents at Seveso in Italy in 1976 and Basel in Switzerland in 1986 caused significant environmental damage. In Seveso, the release of dioxin contaminated the surrounding area, and in Basel, the pollution of the Rhine -- in France and Germany, as well as in Switzerland -- following a fire at a chemical warehouse killed thousands of fish.
The objectives of this global convention are to protect human health and the environment from persistent organic pollutants. The Convention contains six annexes which form an integral part of the document. Annex C lists POPs which may be produced and released unintentionally as the result of combustion processes.

**Seveso II Directive (96/082/EEC)**
The Seveso II Directive applies to a wide range of activities including the storage, use and manufacture of large quantities of dangerous chemicals. It places additional responsibility on operators of establishments to document their major-accident prevention policy and to ensure that it is properly implemented. Operators are also required to produce a safety report to document those procedures put in place to prevent major accidents or, in those instances where accidents have occurred, to limit their consequence for man and the environment. Such safety reports shall be made publicly available.

**Montreal Protocol**
The Montreal Protocol on Substances That Deplete the Ozone Layer is a landmark international agreement designed to protect the stratospheric ozone layer. The treaty was originally signed in 1987 and substantially amended in 1990 and 1992. The Montreal Protocol stipulates that the production and consumption of compounds that deplete ozone in the stratosphere--chlorofluorocarbons (CFCs), halons, carbon tetrachloride, and methyl chloroform--are to be phased out by 2000 (2005 for methyl chloroform). Some 180 countries have ratified the Protocol at this time.

**Precautionary Principle**
The Precautionary Principle is generally defined in terms of the 1998 Wingspread Statement: "When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause-and-effect relationships are not fully established scientifically."

One of the most important expressions of the precautionary principle internationally is the Rio Declaration from the 1992 United Nations Conference on Environment and Development, also known as Agenda 21. The declaration stated that in order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation. Nonetheless, the subjective nature of this principle hampers its uniform and egalitarian application.

**EPA reglations 40 CFR Part 82, subpart A, Subpart E, Subpart G and Subpart H[39]**
These texts, in accordance with the Clean air Act, sets the rules as regards the problem of the ozone depletion process (e.g. phase out of halons)

**STANDARDISATION ACTIVITIES**

**BS 7982**
In response to several incidents in the UK in the 1990's (in particular the Cleveland warehouse fire in 1995) the British Standards Institution (BSI) committee responsible for developing standards on the burning behaviour of plastics initiated[37] the development of a standard to categorise the environmental impact of such events. The first version of the standard (BS7982) was made available for public comment in 2000 and all comments were taken into account before a final version was published in September 2001. This standard is intended to be a ready reference both on information and guidance pertaining to large scale fires involving plastics. It does not provide any guidance on how to quantify the environmental impact any given fire has had after the fact.

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**ISO TC92 SC3**

Traditionally ISO/TC92/SC3 has focussed on the effect of fires on humans. This is leading to the creation of several standards determining and defining the toxic effect of fire effluents, and using that information in a fire hazard or risk analysis. Recently [9], the mandate of this sub-committee was extended to include the effect of fires on the environment. In October 2002 a workshop was held at SP Swedish National Testing and Research Institute in Borås entitled: "Fire Threat to the Environment"[38]. In this workshop the delegates identified some general principles to guide possible ISO TC92 standardisation activity in the field.

- The focus should be on the consequences of large unwanted fires, such as in industrial buildings and other large occupancies, rather than the consequences of small individual fires and combustion in incinerators or power stations.
- While fires may effect the environment in many ways SC3 can only be concerned with aspects of this environmental effect that are appropriate for standardisation.

After the meeting in Borås a Task Group (TG1) was set up and commissioned to bring forward one or more topics for further development. This Task Group has met on two occasions in conjunction with TC92/SC3 meetings to define the best path forward. Presently work is ongoing in two specific areas: a) the creation of a Guidance Document on the Environmental Impact of Fires; and b) the creation of a Guidance Document on the Sizing of Water Basins. It is expected that these will lead to new work items within a year, resulting in Technical Specifications or Technical Standards.

## CONCLUSIONS

Environmental concerns arising from human activities have long been identified in many areas. Fires and fire safety issues are no exception. The scientific knowledge to support decision making processes in the trade-offs between local safety and global environmental preservation is still limited and requires further and urgent attention.

As is evident from the information presented in this paper, potential environmental concerns associated with fires are diverse. Some control over the environmental effect of fires has been obtained with variable success through national and/or international regulation and voluntary codes of practice.

Since some of the fire-generated environmental effects cross national boundaries, there is a real challenge in the field for international standardisation committees, such as ISO, to establish consensual approaches and appropriate tools to address these issues. Such an effort is now underway in ISO TC 92 SC3, Fire threat to People and the Environment.

## REFERENCES


[1] CFPA, Europe, "Fire and its environmental Impact, A guide to good practice produced by the Confederation of Fire Protection Association Europe, London, 1990, 2.1.5

[2] Fowles J. et al, "The ecotoxicity of Fire Water Runoff – Part I : Review of the Literature", ESR, Fire Research Report, NZ Fire Service Commission Research Report 17, ISBN 0-908920-60-1, August 2001

[3] Hölemann H., "Environmental Problems Caused by Fire and Fire-Fighting Agents," Fire Safety Science –Fourth International Symposium, Proceedings, 1994, p61-p77.

[4] Ahrens M., and Rohr K.D., , "Fire and the Environment: Issues and Events," in *Proceedings of the Fire Risk and Hazard Assessment Research Application Symposium*, The Fire Protection Research Foundation, Quincy MA, USA, p309-p320, 2003.

[5] Tewarson A. & Marlair G., "Liquids and chemicals", Chapter 8 in C. Harper's (Ed) 'Handbook of building materials for fire protection', Mc Graw Hill, ISBN 0071388915, 2003, p8.1 – p8.43

[6] Aresu de Seui H. , "Instructive Fire", Sandoz in Schweizerhalle (Switzerland) (In French), Revue Belge du feu,

[redacted]

n°84, Febr. 1987, pp 8 – 13

[7] Van Donkelaar P., "protecting waterways from the run-off pollution", Fire International, Winter 1995, p18-p22

[8] Suter K.E., et al. (Guest editors), "Analytical and Toxicological Investigations of Respiratory Filters and Building Ventilation Filters Exposed to Combustion Gases of the Chemical Warehouse Fire in Schweizerhalle," *Chemosphere*, vol 19, n°7, ISSN 0045-6535, 1989.

[9] Cox G. , "Developments on the Standardisation of Fire Safety within ISO," Interflam'99, Proceedings, 1999, pp. 843-851.

[10] FPRF, Proceedings of 'Fire Risk and Hazard Assessment Research Application Symposium', held in Baltimore, July 2003 (see session devoted to Fire Risk, Hazard and the Environment) pp 309-379

[11] Lowman R., see paper in ref. 10, p328-p343

[12] See for instance the proceedings of "Industrial Fire III Workshop, Riso, Denmark, September 1996, EUR 17477 EN, ISBN 87-550-2287-1.

[13] Sandoz Corporate Safety and Environmental Protection, "Warehousing – Guideline for Plant Safety n°28", Edition 4/1991

[14] CEA, "Fire Protection in Warehousing of Hazardous Materials", Edition 1994

[15] Poole S;L., , "Scrap and shredded tire fires – Special report", USFA, Technical report series, Stambbaugh & Banks (Eds), report 093, Dec. 1998.

[16] HMSO, "Fire Safety for Tyre Sites", Home Office Publication, 1995, ISBN 011 3411510

[17] IAFC, "Guidelines for the outside storage of scrap tire fires", 1994

[18] Copeland T.D., & Schaenman P., "Sherwin-Williams Paint Warehouse Fire, Dayton Ohio. With supplement on Sandoz Chemical Plant Fire Basel, Switzerland", United State Fire Administration – Technical Report Series, Federal Emergency Management Agency – USFA – Report 009 (contract EMW6866c62277), 1987

[19] Munnik H., "South African sulfur fire", Fire International, September 1996, p14-p16

[20] Desai Commission (01997). Report of the Commission of Inquiry into the sulphur fire at Somerset West, Republic of South Africa, June 28

[21] Batterman S.A. et al, "Estimation and Evaluation of Exposures from Large Sulfur Fire in South Africa", Environmental Resear ch Section A8, 316-333 (1999)

[22] Gabler W., "Unseen hazards of firefighting", Fire International, May 1999, p29-p32
"Guidance on assessing the environmental effect on fire effluent", document N7 (in draft) supporting work in progress in TG1 group on environmental issues of fires, March 2004

[23] Sarthou S. et al, "Toxic risks relating to exposure to polychlorobiphenyls - A study of the fire at the paper plant in Venizel – Operations – Measures implemented for medical monitoring, and risk assessment" (In French)", Joint report of the Prefecture de l'Aisne, DRASS Nord-Pas-de-Calais and Institut de Veille Sanitaire, December 2002

[24] Health and Safety Executive, "The fire at Allied Colloids Limited. A Report of the HSE's investigation into the fire at Allied Colloids Ltd, Low Moor, Bradford on 21 July 1992', ISBN 0 71 760 707 0, 1993

[25] Klein R., "Are you using the right foam concentrate ?", Industrial Fire Journal, September 2000, 69-74

[26] Harman R., "Focus on foam", Fire Engineering Journal & Fire Prevention, June 2003 p21-p23

[27] Ruppert W.H. et al, "Environmental Impacts of Fire Fighting Foams", FPRF Symposium, Baltimore July 9-11, 2003, Proceedings p364-p371

[28] Beard A. (Ed), "Flame Retardants – FAQs", a brochure of the European Flame Retardants Association, January 2004 (see www.cefic-efra.com)

[29] de Witt C. A., "An Overview of brominated flame retardants in the environment", Chemosphere 46 (2002) p583-p624.

[30] Wenning R. J. , "Uncertainties and data needs in risk assessment of three commercial PBEs: probabilistic exposure analysis and comparison with European Commission Results", Chemosphere, 46 (202) p779-p796

[31] Harriman E. et al, "Environmental Challenges and Materials Restrictions in Coated Wire and Cable", Fire Risk and Hazard Assessment Research Application Symposium, Fire Protection Research Foundation, Baltimore, July 2003, Proceedings p358-p363

[32] Nelson G. L. , "Fire, plastic and the environment", Fire Risk and Hazard Assessment Research Application

[redacted]

Symposium, Fire Protection Research Foundation, Baltimore, July 2003, Proceedings p344-p357

[33] Rahman F., Langford K. H., Scrimshaw M.D., Lester J.N., "Review, Polybrominated diphenyl ether (PBDE) flame retardants", The Science of Total Environment 275 (2001) p1-p17

[34] Gann R. G. et al, "Sublethal effects of smoke on survival and health", Human Behaviour in Fire, Proceedings of the 2nd Int. Symposium, MIT, Cambridge, USA, 26-28 March 2001, p285-p296

[35] Rechenbach P., "Fires today : risks and protection for fire-fighters", Flame Retardants 2000, London Feb. 2000, Proceedings Interscience Comm. Ltd, p171-p184.

[36] DETR, "Environmental Follow-up of Industrial Accidents – A report prepared by the Institute of Terrestrial Ecology", October 1997, ISBN 0 11 753457 9

[37] Purser D., "Assessment of Environmental Hazards from Fires and Draft Guidance in British Standards", FPRF Symposium : Fire Risk and Hazard Assessment Research Application Symposium : Baltimore (USA) 20-22 June 2001

[38] Gann R. G., "The ISO TC 92 SC3 Initiative on Fire Threat to the Environment", Proceedings of the Fire Risk and Hazard Assessment Research Application Symposium, (Fire Protection Research Foundation), Baltimore, July 9-11, 2003 (p231-p327)

[39] Voluntary Code of practice for the reduction of Emissions HFC& PFC Fire Protection Agents, FEMA- FSSA-HARC- NAFED-EPA developed and endorsed document, March 2002

[40] Simonson M., Stripple H., "The incorporation of fire considerations in the life-cycle assessment of polymeric composite materials : a preparatory study", Interlam'99, Proceedings Interscience Communication, p885-p895

[41] Simonson M., Andersson P., Emanuelsson V., Stripple H., "a life-cycle assessment (LCA) model for cables based on the fire-LCA model, Fire and Materials, 2003 : 27, p71-p89

[42] Marlair G., Marlière F., Desmet S., Costa C., Leck M. & Siegried W., "Experimental Evaluation of the Fire Hazard of Organophosphorous Insecticides by use of Various Test Methods", Industrial Fires III, Riso, Denmark, 17-18 September 1996, Workshop Proceedings EUR 17477 EN, ISBN 87550-2287-1, p93-p110

[43] NSW Hazardous Materials Policy Co-ordinating Committee, "Best Practice Guidelines for Contaminated Water Retention and Treatment Systems", July 1994, ISBN 0-7310-8994-4

[44] Mason P., "Design of containment systems for the prevention of water pollution", CIRIA report 164, 1997 ISSN 0305 408X

[45] VCI, "Fire Protection Concept for chemical warehouses with regard to water protection", Verband der Chemischen Industrie e.V. (VCI), November 1988, English Version January. 1989

[46] Evans D.D., Madrzykowski D & Haynes G. A., "Flame Heights and Heat release Rates of 1991 Kuwait Oil Field Fires", Fire Safety Science –Fourth International Symposium, Proceedings, 1994, p 1279-p1289

[47] Marlair G., Cwiklinski C., Marlière F., Breulet H & Costa, C., "A Review of Large-Scale Fire Testing Focusing on the Fire Behaviour of Chemicals", Interflam'96, Cambridge 26-28 March 1996, Proceedings p 371-p3382

[48] NFPA 2001, "Standard for Clean Agent Fire Extinguishing Systems", 2000 edition