

Environmental Problems Caused by Fires and Fire-Fighting Agents

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ABSTRACT

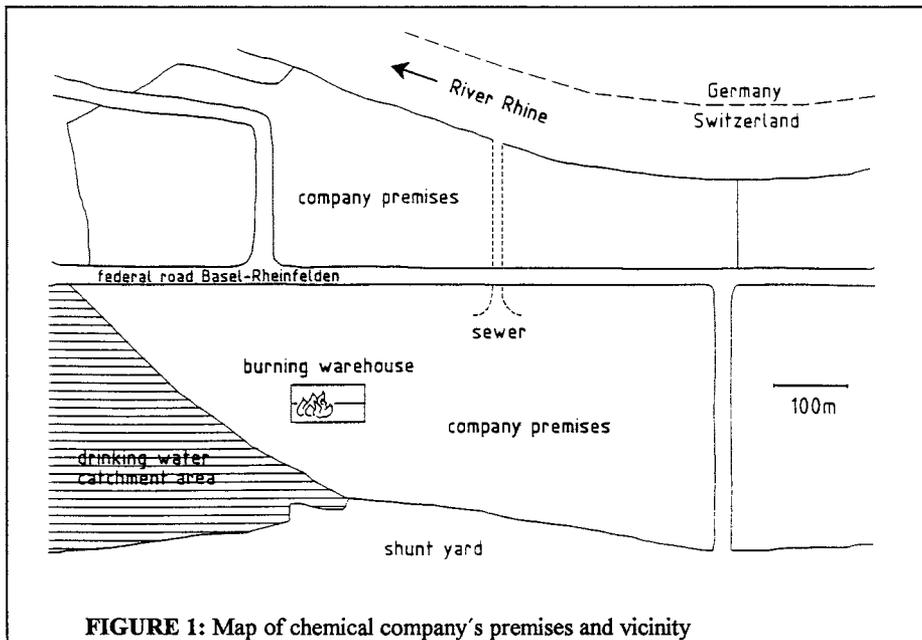
For fire safety engineering, a new responsibility - to avoid environmental damage - arises besides the traditional tasks, which in the first line are the protection of life and property. An increasing awareness focusses on the environmental impacts of fire suppression activities. The global dimensions of environmental pollution originating from major incidents as well as from natural fires, are depicted. The banning of Halons because of their ozone depleting potential is explained. Initiated by a fire in a chemical warehouse Central Europe's interest concentrates on the retention of contaminated extinguishing water. Finally, remediation strategies for fire-related environmental pollution are discussed.

KEYWORDS: atmospheric trace gases, biomass burning, environmental pollution, extinguishing water retention, Halon ban, oil well fires, remediation of firegrounds, surface waters pollution.

1 INTRODUCTION

On the 1st November 1986 a major blaze burnt down a warehouse for chemicals in Schweizerhalle near the city of Basel, Switzerland. This major incident caused one of the largest environmental pollutions in Central Europe. It was neither the fire itself, nor explosions nor the smoke cloud but the extinguishing water that ran off the fire-ground that had a tremendous impact on the environment. Approximately 20,000 m³ of extinguishing water, contaminated with pesticides and a very toxic water soluble mercury compound ran into the River Rhine or seeped down into the ground [1]. In the upper reaches of the Rhine all eels and many micro-organisms died [2, 3]. The pollution wave ran downstream and was detected and monitored by analytical methods, since on the Rhine a water quality monitoring system had been installed long before. The polluted water passed border between Germany and The Netherlands on 13th November [4]. Water-works that take their water from the Rhine had to interrupt the withdrawal of water temporarily. Moreover, everyone could easily recognize the

polluter! Together with the extinguishing water, a red colour was washing down the River Rhine. Figure 1 gives an overall view of the company's premises and its vicinity.



This disaster led to a shock throughout a population, which had become far more sensitive to environmental problems than before. In the years after World War II the growth of industrial activities, and especially the growth of the chemical industry, and their release of hazardous waste had caused an extreme pollution in many rivers. Great efforts had been made to reduce these pollutions and to remediate the rivers. But in 1986 only one fire or the mistake of the fire brigade seemed to have destroyed all the efforts of so many years.

There were other, more psychological effects concerned with this incident. For the German population, the Rhine is not just another river. The Rhine is rather a national symbol that evokes many emotions. Furthermore, politics was involved because the River Rhine near the city of Basel forms the border between Switzerland and Germany, and between France and Germany. Diplomatic ill-feelings arose between the German and the Swiss government because information on the disaster was given hesitantly.

On the one hand, in Germany and in the neighbouring countries, this accident created a general awareness of the environmental dangers of fires. On the other hand, the accident initiated hectic activities to reduce the risks that arise from extinguishing water that runs off burning stores with hazardous goods. Nevertheless, there are only few serious activities to reduce the possible environmental impact of fires. Until today there is only little knowledge about the equilibrium between the environmental pollution resulting from the fire itself and that of fighting the fire. In other words: The environmental management of fires is in its beginning stages.

2 GENERAL

The various aspects of possible environmental pollution caused by fires and by fire-fighting agents are shown in figure 2. The substances released by a working fire have an influence on the atmosphere, the vicinity of the burning object, the soil, the ground water, and the surface waters in very diverse manners. I shall only discuss the chemical aspects of pollution. My report does not include other dangers to the environment, such as the heat of a fire, bursting tanks, vapour cloud explosions, etc.

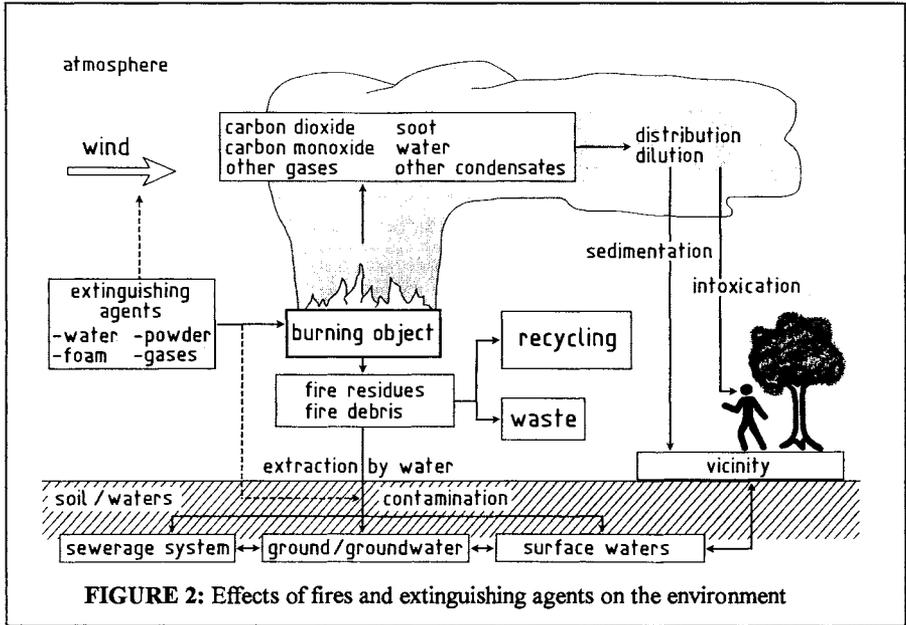


FIGURE 2: Effects of fires and extinguishing agents on the environment

In contrast to a chemical reaction in a chemical reactor, under a set of controlled conditions, a fire is an uncontrolled chaotic process, in which hundreds of chemical compounds are produced. In the first line, these are water and carbon dioxide. Many other released substances have a high toxic potential to men, flora, and fauna. Wood and many synthetic polymers begin to decompose when they are exposed to prolonged heating with temperatures of little more than 100 °C. The subsets of combustion products which are developed during pyrolytic processes or de-novo syntheses depend much on the composition of the burning system, its ventilation conditions, and temperature. Another influencing factor is the type of combustion, such as smouldering or flaming fire. Table 1 shows an approximate split of compounds produced by a fire under different temperature margins.

Gases, soot, and condensates are transported into the fire's vicinity by the ascending convection current. There are a lot of models that aim at describing the spread of smoke plumes in the atmosphere [11, 12]. The local concentration of air pollutants in the smoke is reduced significantly due to dilution and distribution. In most cases there is only little danger of people being actually poisoned by volatile combustion products, even in close vicinity to major

blazes, unless they are trapped in compartment fires [7, 13]. But it has to be pointed out that some of the most toxic combustion products, such as PAHs, PCDDs, and PCDFs, are bound to and transported by soot particles [14]. It is of high interest how much people are endangered when they have come into contact with these substances once or frequently. Many questions of fixing exposure limits are unanswered yet [15].

TABLE 1: Typical volatile products of fire.

Temperature margins	Typical volatile products of fire
100 - 300 °C	HX, HCN, H ₂ S, Monomers
300 - 400 °C	NO _x , CH ₄ , C ₂ H ₄ , CH ₃ OH, C ₂ H ₅ OH, HCOOH, CH ₃ COOH, H ₂ CO, CH ₂ =CH-CHO, Furans, Ketons
400 - 500 °C	Hydrocarbons C ₇ - C ₁₀ , Chlorinated Hydrocarbons
500 - 600 °C	Hydrocarbons C ₁₀ - C ₃₀ , BTX, PAH Chlorinated Aromatic Compounds, PCDD, PCDF
> 300 °C	NO _x , Soot
for all margins	H ₂ O, CO ₂ , CO, SO ₂

Toxic and in other ways dangerous substances are brought into the soil of the fireground by the fire brigade's activities. If the fire brigade succeeds and provides a sudden quenching of the hot fuel with cold water this will stop the chemical chain reactions at once. In a fire which is subject to a sudden fall in temperature and change of reaction medium as a result of the application of a fire-fighting agent, a chemical cocktail with an indefinite composition is created. There are only few rules that help to estimate what kind or spectrum of chemicals are produced and in what concentration they can be expected.

What remains after a fire can be divided into three categories: Waste, extracted water and residue that is suitable for re-use or recycling. The waste itself includes normal rubbish and debris which are contaminated with toxic compounds. The contaminated waste has to be disposed of on a hazardous waste dump. The remediation of fire-damaged premises is an emerging, very profitable business. In Germany, there are some 250 companies involved in the restoration of buildings or factories which are damaged by fire or contaminated by combustion products [16].

The retention of polluted water running off the fireground is another problem of its own. Extracted water flows into the sewerage system and into surface waters or seeps away into the soil or deeper into the ground water as can be seen in figure 2. The disaster in Schweizerhalle in 1986 resulted in a lot of regulations in Germany and other European countries about installations to collect the extinguishing water (part 4.2 of my report) [17].

Sometimes paradoxical situations arise. A simple wood fire produces so much of acetic and other acids that the pH-value can be very low. By law it is prohibited to discharge such acidic water into the sewerage system. In a particular instance the fire brigade extinguished a fire in a wickerwork factory. A part of the run-off water was collected in a basement car park. A fire-fighter had the idea to measure the pH. The result of this measurement was a very low pH so that the water had to be pumped into tanks and de-acidified before discharging it into the sewerage system [18].

The assessment of an environmental pollution is a highly political question, too. The regulations governing the handling of the residue and debris of a fire may vary widely between the different countries. Obviously, in countries with a very dense population like in Central Europe, stringent regulations for environmental protection are necessary. Public awareness leads to synergistic effects and sometimes people tend to exaggerate their fear of dangerous environmental conditions.

The problems culminate when it comes to fires in stores or transportation units of hazardous goods (see introduction). Toxic compounds are not only produced by thermal decomposition or syntheses. Furthermore, the stored and by the fire itself unaffected toxic substances are partially extracted and washed out by the extinguishing water [19]. In Germany, it is not allowed to build a store for dangerous goods without a reservoir for the fire-fighting run-off water. Existing stores have to be upgraded with such reservoirs [17].

3 ENVIRONMENTAL PROBLEMS RELATED TO VERY LARGE FIRES

3.1 Oil well fires during the Gulf war

It seems to be evident that the larger a fire or the class of fire is, the more extensive are the effects on the environment. People were afraid of global pollution coming from the fires in Kuwait during and after the Gulf war.

The Iraqis ignited the oil well fires as from the 20th February 1991. The last of 725 burning wells was extinguished on the 6th November 1991 [20]. After the end of the war, the oil losses were estimated to 1,500,000 Barrels per day (220,000 t/d) [21]. If we calculate on a basis of a regressive decline of burning oil due to the extinguishing activities from July through November 1991, the result is that 300,000,000 Barrels (43,000,000 t) of oil were lost. A large fraction of the oil was lost in the fires. Another part presumably vaporised and a third part ran off the oil fields and formed lakes or flowed into the Persian Gulf [22]. There are great differences between several estimations of the single quantities.

Clouds of smoke with a width of 15 - 150 km were reported in a distance of up to 1,000 km in lee of Kuwait [23]. Table 2 shows some estimated and controversial values of pollution coming from these fires. Black snow was observed at a slope in the mountains of the Himalayas [24]. The injection height of the smoke into the atmosphere was at no time higher than 6,000 m [23]. If an altitude of 10,000 m had been exceeded, the possibility of a stratospherical pollution with consequences to the climate of the World would have been possible. In the cities near the Gulf region no considerable increase of air pollutants, such as ozone, nitrogen oxides, carbon monoxide, or PAHs ($1 \mu\text{g} / \text{m}^3$) was measured [23]. But in an area of 15,000,000 to 30,000,000 km^2 (Iran, Iraq, Saudi-Arabia, parts of Turkey, Armenia, and

Azerbaijan) a sedimentation of 250 mg / m² · a of soot was estimated [25]. In 1992 in Kuwait and parts of Saudi-Arabia, vegetation losses were recognized by washing pollutants (PAHs and heavy metals) out of the atmosphere [23].

In many cases, serious environmental damage is not caused by the fires themselves but by the circumstances accompanying them. The oil lakes covered an area of between 80 and 100 km². The average depth of these lakes was 20 to 100 cm. Furthermore, oil soaked the soil 40 to 100 cm deep [22]. Only 2,000,000 Barrels were collected again. Another part spilled into the sea and formed an oil carpet of 1,500 km² south of Kuwait on the western coast of the Persian Gulf [26].

An unknown quantity of the swimming liquid oil was biodegradable. Another part sank to the bottom of the sea and covers now an unknown area. A 770-km-long strip of the coast was polluted by a two-km-wide bitumen-like hard substance. Approximately 30,000 seabirds died. 20 per cent of the coral-reefs are irreversibly damaged. At a cost of 500 to 550 Mill US\$ it is possible to remediate only a part of the beach [23].

TABLE 2:
Atmospheric pollution caused by the burning of oil wells following the Kuwait-conflict in 1991

Soot	11,550 t/d	[25]
	1,370 - 2,740 t/d	[27]
NO _x	2,900 - 4,600 t/d	[27]
SO ₂	14,500 - 27,000 t/d	[27]
	8,800 t/d	[25]

3.2 Large forest fires

To speak about forest fires in the capital of Canada is like taking coals to Newcastle. I will only refer to a few aspects that are relevant to the atmosphere in a global scale.

A large fraction of the trace gases (CO₂, CO, CH₄, NMHC, NO_x, SO₂, COS, etc.) and aerosols, that influence the climate and are emitted into the atmosphere, are released during the combustion of tropical biomass. Estimations of the emitted quantities vary within a wide range.

Particularly the countries in the tropical and sub-tropical hemisphere as well as the new states emerging from the former Soviet Union lack reliable data and statistics on the annual destruction of forest due to natural or anthropogenic fires. Data that is gained by satellite monitoring is not satisfactory either. Some satellites lack the necessary sensing devices whereas other satellites do not provide sufficient observation time or frequency. My comments are based on data and calculations by Crutzen, Andreae, and Goldammer [28, 29].

Per year approximately the following quantities of carbon are released in tropical and non-tropical areas [29]:

deforestation	$1.08 * 10^{15} \text{ t}$
savannah fires	$1.66 * 10^{15} \text{ t}$
fire wood	$0.88 * 10^{15} \text{ t}$
agricultural waste (straw etc.)	$0.38 * 10^{15} \text{ t}$
charcoal production	$0.08 * 10^{15} \text{ t}$

This amounts to $4.08 * 10^{15}$ tons of emitted carbon through biomass burning. The overall quantity of carbon dioxide is approximately $13.28 * 10^{15} \text{ t}$, about 40 per cent of which is generated during combustion of biomass and fossil fuel. Carbon that is not oxidised to carbon dioxide is bound in CO, CH₄, NMHC, and COS, as well as in soot and aerosols [29].

Carbon dioxide, which has so far been regarded as being of major relevance for anthropogenic changes of climate, is only one amongst other trace gases that influence the atmosphere. Except for FCFCs, these gases also come from biomass burning, though in smaller quantities. The earth warming potential of methane is 3.7 higher than that of carbon dioxide, and that of Dinitrogen oxide is 180 times higher [30].

Furthermore tropical biomass burning produces photochemical smog, consisting of CO, NO_x and various hydrocarbons. Through a chemical reaction chain, which will not be discussed here, ozone is generated. In January 1991 a concentration of approximately 95 ppb ozone was measured at an altitude of 2000 m above an African savannah area. Even higher concentrations were found above the East Atlantic. It is expected that these high concentrations can be traced to the frequent savannah fires in West Africa [31].

3.3 Other fires with global consequences

It is believed that during the fire storms, which were consequences of the bombardments of Japanese and German urban areas in World War II and certain meteorological conditions, combustion products were injected into the stratosphere [32]. If it comes to military confrontations that lead to the use of nuclear weapons this will result in tremendous fire storms and the transportation of huge amounts of soot and other air-pollutants into the atmosphere and the stratosphere.

Drastic change of climate would have to be faced. The nuclear winter is not a topic issue at the moment but this potential nightmare should not be forgotten about [33].

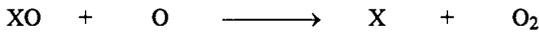
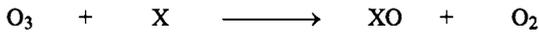
4 ENVIRONMENTAL PROBLEMS DUE TO FIRE FIGHTING AGENTS

Fire fighting is basically an activity that aims at reducing further damage to the environment. The current production of air-pollutants is stopped. The introductory example has shown that certain properties of fire-fighting agents and the great solubility of toxic substances in water can result in great damage to the environment. Foam is occasionally washed into rivers, disturbs the oxygen access through the water surface and thus causes the death of fish.

4.1 Halons

The discussion concerning Halons, which together with the FCFCs are regarded as being responsible for the destruction of the ozone layer in the stratosphere, shows how environmental problems with a very efficient fire-fighting agent can take a global dimension. The regulations governing the renunciation of Halons as fire-fighting agents are in some countries already more stringent than the Montreal Protocol, on which they are based. In Germany, apart from very few exceptions (aircraft, submarines, and chemical laboratories with individual licences) Halons are prohibited since 1st January 1994 [34, 35].

The equilibrium concentration of ozone in the stratosphere is already subject to a wide range of variation resulting from natural processes. The natural ozone destruction is being augmented by anthropogenic causes and the equilibrium concentration is decreasing. Particularly halogen radicals, which are generated in the stratosphere by cracking of the fluorinated and chlorinated hydrocarbons or the brominated hydrocarbons, act as catalysts in the process of ozone destruction [36]. One of the reaction mechanisms follows this scheme:



where X represents Cl or Br.

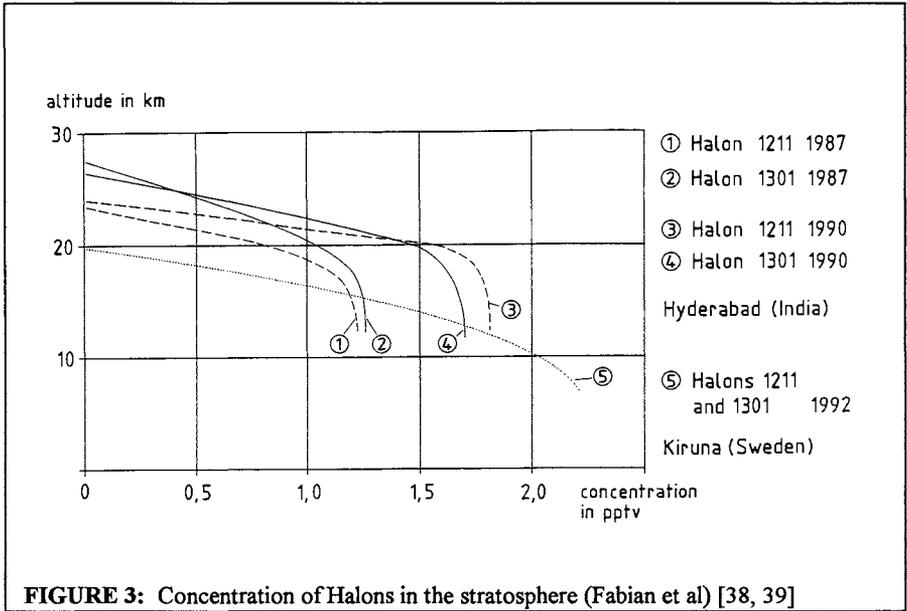
Not only the ozone molecules are cracked but also the oxygen atoms, which are necessary for the ozone generation, are eliminated:



Since the halogen radicals are always re-generated, the X can participate in the destruction process repeatedly. Only if the Cl becomes a component in longer living molecules, as in ClNO₂ (chloronitrate), the ozone destruction terminates. A similar energy sink as for chlorine in chloronitrate does not exist for bromine. Consequently, the bromine resp. bromine oxide radicals have an ozone depleting potential (ODP) which is 40 to 50 times that of chlorine [37].

What is the current bromine concentration in the stratosphere? Figure 3 shows graphs that represent measurements of Halon 1211 and 1301 at altitudes of 10 to 30 km. The results were obtained by freezing out the Halons in gas traps, which were brought into the stratosphere by balloons. The advantage of this method is that a vertical profile of the ozone layer is obtained. By frequent measuring it was found out that the Halon concentration rises by the factor 1.1 to 1.2 per year [38]. Altogether, about 10 to 30 per cent of ozone destruction induced by halogen radicals are believed to have originated from brominated compounds [37].

Only approximately one sixth of all brominated substances can be traced to Halons. Another source of bromine is BrCH₃ in the first line. BrCH₃ is produced by seaweed. BrCH₃ is a less stable compound than the Halons and most of it is destructed already in the atmosphere. Overall, the Halons contribute about 3 to 5 per cent to the ozone destruction.



4.2 Extinguishing water retention

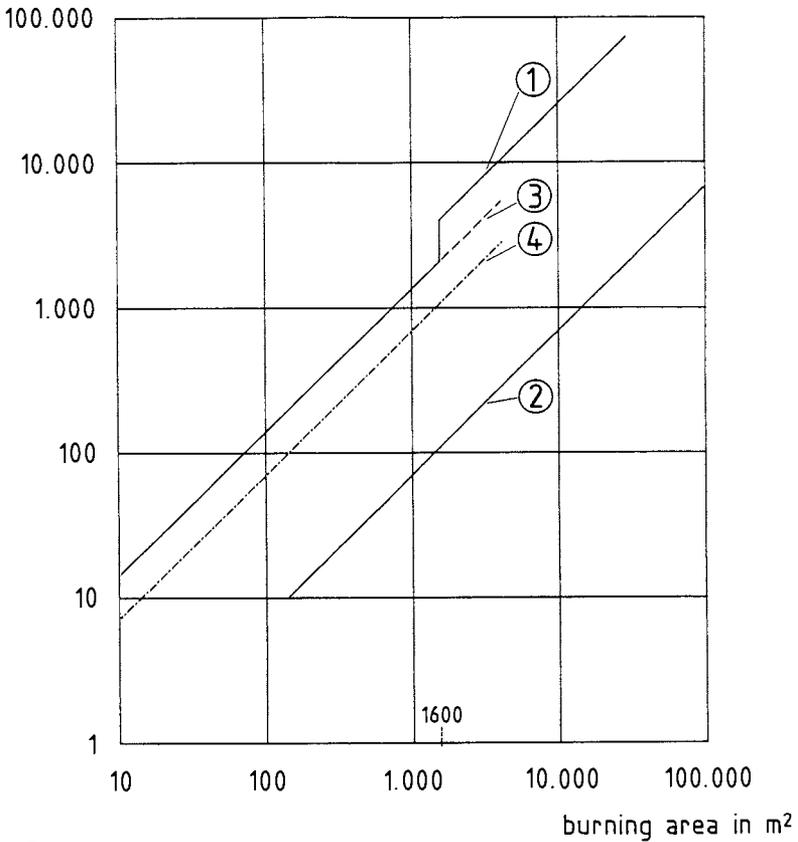
I already mentioned that, particularly after the fire at Schweizerhalle, many activities were started to prevent from the repetition of such catastrophes. But it is very difficult to develop calculation schemes for realistic dimensions of the necessary capacities of extinguishing water retention systems. The quantity of used extinguishing water is basically never measured, especially not at major incidents.

Other working groups [40], as well as we [41] have tried to gather information about the quantities of used water from well documented incidents. The results of this research are shown in figure 4. The variation of the obtained data is rather wide, as had been expected. The maximum limits of the used extinguishing water are about in the same range. If firegrounds larger than 1,600 m² are affected there is a significant larger quantity of extinguishing water.

The water delivered to the working fire can be divided into four subsets:

1. water that is vaporised by the heat of the fire (vaporised water)
2. water that is absorbed by the fuel (absorbed water)
3. water that runs off the fuel and might be contaminated with combustion products (waste water)
4. water that is sprayed on adjacent objects to protect them from radiant heat (protection water)

quantity of extinguishing
water in m³



- ① Consumption of extinguishing water, upper limit
 LW_0 [m³] = 1,5 * burning area [m²], for burning areas ≤ 1,600 m²
 LW_0' [m³] = 2,5 * burning area [m²], for burning areas > 1,600 m²
- ② Consumption of extinguishing water, lower limit
 LW_U [m³] = 0,075 * burning area [m²]
 90 per cent of evaluations are estimated to vary between ① and ②
- ③ Quantity of extinguishing water according to Günther (AGBF-Research)
 LW_0 [m³] = 1,5 * burning area [m²]
- ④ Quantity of extinguishing run-off water (waste water) according to Günther (AGBF-Research)
 SW [m³] = 0,75 * burning area [m²]

FIGURE 4: Consumption of extinguishing water at large fires [40, 41].

The latter does not need to be taken into consideration if it has not mixed with any contaminated water. Only the so-called waste water has to be collected. Its quantity is estimated as half the amount of extinguishing water. (see graph 4 in figure 4).

In order to come to terms with extinguishing water retention some criteria were established. A concept of the insurance industry (VdS, CEA) [42, 43] categorizes certain classes of fire hazards and their potential to emit toxic and eco-toxic compounds. Some other regulations, of which public authorities are rather fond of [44], consider the aquatic hazard classes (Wassergefährdungsklassen, abbreviated "WGK") of the stored goods as determinants, where WGK 0 means "not aquatic hazardous" and the highest, WGK 3 "severely aquatic hazardous". If only goods rated as WGK 0 are stored no extinguishing water retention system has to be provided.

TABLE 3: Capacities of extinguishing water retention systems [44].

Store compartment area [m ²]	Required capacity of extinguishing water retention systems [m ³] for stack height less than 12 m					
	K1 / K2			K3 / K4		
	WGK 1	WGK 2	WGK 3	WGK 1	WGK 2	WGK 3
25	6.0	9.0	12.0	6.0	9.0	12.0
50	12.0	18.0	24.0	12.0	18.0	24.0
75	18.0	27.0	36.0	18.0	27.0	36.0
100	25.0	37.5	50.0	25.0	37.5	50.0
150	45.0	67.5	90.0	40.0	60.0	80.0
200	70.0	105.0	140.0	55.0	82.5	110.0
250	100.0	150.0	200.0	70.0	105.0	140.0
300	135.0	202.5	270.0	90.0	135.0	180.0
400	200.0	300.0	400.0	125.0	187.5	250.0
500	250.0	375.0	500.0	150.0	225.0	300.0
600	300.0	450.0	600.0	150.0	225.0	300.0
700	350.0	525.0	700.0	150.0	225.0	300.0
800	400.0	600.0	800.0	150.0	225.0	300.0
900	450.0	675.0	900.0	150.0	225.0	300.0
≥ 1000	500.0	750.0	1,000.0	150.0	225.0	300.0

A safety category (Sicherheitskategorie, abbreviated "K") is determined according to the precautions for fire detection and fire suppression. K 1 comprises the minimum requirements (public fire brigade, no further requirements concerning fire detection) and in K 4 the highest level of precautions is required (public fire brigade or industrial fire brigade, automatic fire detection and suppression system). The safety categories rule allowable quantities of goods, maximum area and stack resp. rack dimensions and minimum capacity of the extinguishing water retention system.

5 SALVAGE OPERATIONS AND FIREGROUND REMEDIATION

So far I depicted the problems that arise during the "hot phase" of a fire and during the application of fire-extinguishing agents. Other problems are caused by the "cold fireground" which might be contaminated by combustion products [5]. Because of the higher level of public awareness of environmental matters, there are more and more demands for the removal of contaminants before the beginning of re-construction. The removal concerns the fireground as well as its vicinity. The fire at Schweizerhalle caused a lot of environmental problems. On the other end, it was a challenge for the affected company and third parties to provide proper relief of the hazards and dangers related to the local release of highly toxic substances. During that process a lot of experience was gained - though the price was rather high.

Top priority was given to the cleaning of the river [45]. Already in November 1986 the worst polluted area of the river-bed was vacuumed by SCUBA divers. This was where most of the extinguishing water had flown into the river. The next step was to clean several thousand m² of river floor upstream of a dam where the Rhine is used as a power plant's water reservoir. These activities terminated already on 19th December 1989 and prevented the river-bed from being polluted to a greater extent. Altogether more than 1,000 kg of contaminants, mainly insecticides, had been extracted from the river.

Fortunately, most of the self-cleaning capacity of the river withstood the disaster. This meant that the remaining contamination could be degraded in the biological way. Only eight months after the fire - on the 1st July 1987 - the fishing ban in the Basel area was lifted again [2]. After the wave of pollution had passed, bank-filtered water without a loss in its quality could be used by the water-works again. Altogether, the Rhine is back in a stable condition [46].

Parallel to the Rhine cleaning activities, the remediation of the fireground's soil was kicked-off. First order was to secure the premises and to conduct measurements. In order to prevent further soaking of the contaminants into the soil the area was covered and a tent was erected to protect the remainders of the damaged store from rain. In a second tent the debris and residue were collected and decontaminated before disposal. The contents of each container and drum, damaged or not, had to be analysed, poured into safe storing devices and prepared for transportation and disposal.

The most difficult and time-consuming task was the decontamination of the soil underneath and around the warehouse. The drinking water catchment area of Basel city was in close proximity to the storage area. It was feared that the large quantities of extinguishing water would cause the ground water's current to revert and thus spoil the whole water supply. By massive pumping on the chemical company's premises the ground water level was lowered and thus the threat eliminated. The public authorities demanded that the water outside the chemical company's premises had to maintain drinking water quality. This could be achieved.

Several thousand soil samples were analysed and the results displayed in a pollution grid. Then the soil was removed by digging down to a depth of 11 m. 40,000 t of soil with a for that region typical mixture of clay, gravel, and sand had to be excavated. 15,000 t of the soil material were decontaminated in a special flotation process, which had been modified for soil remediation. By this 90 to 95 per cent of the contaminants could be removed. The cleaned gravel was used to re-fill the excavated area. The remaining, contaminated sludge (3 to 5 per

cent of the former quantity) had to be disposed of on a hazardous waste landfill. This work was terminated in the autumn of 1992. Finally the surface area was covered and sealed to immobilise traces of contaminants in the soil. New construction on these grounds is not intended [45].

5.2 Remediation of fire-related environmental damage

In the previous section I took the Schweizerhalle fire as an example to explain a few key aspects that are relevant for the remediation of fire-related damage [16]. The first step is to inform the insurer and responsible public authorities so that a joint committee can assess fire loss and potential hazards on site. In accordance with the scope of the destruction, experts have to gather samples for analysis. The results of the analysis will give information about the toxicological potential of the situation. Then aims and strategy of the remediation work will have to be determined [47].

In Germany, the German Association of Property Insurers (Verband der Sachversicherer, VdS), together with the Federal Hygiene and Health Authority, has lately issued a new "Guideline for the Restoration of Firegrounds" [48]. This is a step in a new direction, since it is the first time that a policy paper of property insurers focuses on aspects of occupational health and safety.

This guideline also comprises a documentation of the mutual co-operation between insurers, public authorities, experts, and salvage companies in Germany and Switzerland, which has worked out well. Environmental damage is reduced drastically if first measures are taken immediately and if the salvage work is begun as soon as possible. This of course requires the insurer to be informed without delay.

A balanced public relation policy is of vital importance. In the German public there is an ever-present fear and headlines like "plastics on fire ... PVC on fire ... dioxins ... Seveso" are linked too easily. If during or after incidents experts, who are able to cope with the questions of the Press or other media, are not at hand, no one has to wonder about citizen's increasing fears.

In the Guidelines of the German Association of Property Insurers the fire-related environmental pollution is categorized in hazardous areas (Gefährdungsbereiche, abbreviated "GB"): GB 0 comprises small fires with limited dimensions (waste-bin, stove), where the pollution does not exceed the seat of the fire. Here household-like cleaning will suffice. The potential of larger damage is classified as follows: GB 1: fires in living quarters, offices, public buildings, workshops without large quantities of halogenated organic compounds or little hazardous contamination; GB 2: fires involving large quantities of halogenated organic compounds and more contaminants; and finally GB 3 involving trade and industrial premises and presence of toxic substances. Category GB 3 also includes fires involving pesticides, polychlorinated biphenyls (PCBs) and pentachlorophenols (PCPs) because the latter can contribute to the synthesis of 2,3,7,8-TCCD/F.

Depending on the endangered structure efforts and measures for the removal of debris, restoration of the fire site, and the disposal of the residue are estimated. A separation of the residue components is strongly recommended in order to re-use or recycle as much as possible and to keep the quantity of heavily contaminated waste as small as possible [49]. Some

devices might be re-useable after cleaning. The voluminous structural debris should be decontaminated if at all possible because the disposal is very expensive. Material that is not decontaminable and remaining residue has to be disposed of on hazardous waste dumps or through incinerators. If the vicinity of the fireground is spoiled or contaminated with hazardous materials it will require sanitation, too. The progress of decontamination measures has to be monitored and documented with analytical methods.

Aspects of occupational health and safety have a magnitude of importance for the employees working on the decontamination site. If necessary, disposable overgarments, entry procedures, shower facilities and the such have to be provided. Adequate personal protective equipment (i. e. respiratory protection) might have to be worn at all times.

Besides fires in chemical stores the public as well as scientists focus on the dioxins (PCDD/F), which are generated in large quantities during combustion, more than on polyaromatic hydrocarbons. Both compound families are synthesised during every combustion process, in residential heating systems, too [50].

Particularly the concentration of dioxins is slightly increasing world-wide. In some areas the concentration reaches already the proximity of the harmless ceiling level. For this reason it is important to determine the background concentration of contaminants at the remediation site [51]. The removal of dioxins has already become a routine procedure. For their extraction it is of advantage that dioxins are always adsorbed at soot particles, distributed by the smoke and can be removed by washing off the soot. Without giving further details I shall just mention that there are new techniques to restore chlorine-spoiled concrete [52].

6 CONCLUSION

I have tried to give an overall view of the complex and heterogeneous environmental problems that are caused by fires and of the measures of extinguishing the fire. Fire seems to be only a peripheral problem of environmental engineering. In a well-respected German publication on environmental engineering, fire is not mentioned at all [53]. The event "fire" is certainly of major relevance when regarded as one amongst another types of incidents that have a negative impact on the environment. If one adds the various fire scenarios that rule certain areas of the World in the form of forest fires, savannah fires, and deforestation activities, then the global influence of "fire ecology" on our environment is obvious.

REFERENCES

- 1 Brandverhütungsdienst für Industrie und Gewerbe (BvD), "Der Brand im Lagerhaus Sandoz AG in Muttenz vom 1.11.86 - Das Ereignis und seine Lehren", Zürich, 1987.
- 2 "Schweizerhalle - Der Brand vom 1. November 1986 und seine Folgen", ed. Sandoz AG, CH-4002 Basel, 1987.
- 3 Such, W., "Der Sandoz-Chemieunfall, Auswirkungen und Folgerungen", *Zivilverteidigung*, 11, 5 - 15, 1987.
- 4 Landesamt für Abwasser und Abfall NRW, "Brand bei Sandoz und die Folgen für den Rhein in NRW", *LWA-Sonderbericht*, Düsseldorf, 1986.

- 5 Wirts, H. D., "Gefahrstoffe nach Bränden und deren Auswirkungen", VdS-Seminar, 25./26.1.1994, Cologne.
- 6 Drysdale, D., An Introduction to Fire Dynamics, pp. 1 - 33, J. Wiley and Sons, Chichester - New York - Brisbane - Toronto - Singapore, 1985.
- 7 Prager, F. H., "Sicherheitskonzept für die brandschutztechnische Bewertung der Rauchgastoxizität", thesis, University of Aachen (RWTH), 1986.
- 8 Aseeva, R. M. and Zaikov, G. E., Combustion of Polymer Materials, Hanser Verlag, München, Wien, New York, 1985.
- 9 Lundgren, B. and Stridh, "Chemical Analysis of Fire Effluents", "Fire and Polymers", "Hazard Identification and Prevention", ACS Symposium Series No. 425, Washington D. C., 1990.
- 10 Bußmann, B., Einbroth, H. J., Sasse, H. R., Prager, F. H., Evaluation of Fires by Establishing the Characteristics of Smoke Fumes, Journal of Fire Sciences, 10, 411 - 431, 1992.
- 11 Petersen, G., Eppel, D., Lautenschlager, M. and Müller, A., "Initialization of the Euler Model MODIS with Field Data from the 'Epri Plume Validation Project'", presented at the 15th International Technical Meeting on Air Pollution and its Application, Plenum Publishing Co., New York, 1985.
- 12 Bigalke, K., Schatzmann, M., Berechnung der Anfangsbedingungen für den Stofftransport in mesoskaligen Zirkulationsmodellen, GKSS-Bericht 89/E/24, 1984.
- 13 Friedrich, D., Helsenich, G., "Ausbreitungsmodelle zur Beurteilung von Schadstoffwolken", Brandschutz, 47: 8, 564 - 569, 1993.
- 14 Weiß, A., "Dioxine und Brandschäden", VFDB-Zeitschrift, 37: 3, 122 - 128, 1988.
- 15 NATO/CCMS (1988), International Toxicity Equivalency Factor (I-TEF), Method of Risk Assessment for Complex Mixtures of Dioxins and Related Compounds, Pilot Study on International Information Exchange on Dioxins and Related Compounds, Report No. 176, NATO/Committee on Challenges of Modern Society, August 1988.
- 16 Esser, A., "Sanierungspraxis: Tendenzen und Entwicklungen", Sanierung von Brandschäden, VdS-Fachtagung 25./26.1.1994, Cologne.
- 17 Kerkloh, G., "Löschwasserrückhaltung - Richtlinien, Konzepte und technische Ausführung", diploma thesis, University of Wuppertal (BUGHW), 1993.
- 18 Jeziorek, T., "Umweltfolgeschäden bei Bränden und deren Vermeidung", semester thesis, University of Wuppertal (BUGHW), 1988.
- 19 Kettrup, A., "Ökologische Auswirkungen im Brandfall auf die Gewässer", ed. Verband der Chemischen Industrie, Brände und ihre Vermeidung, 1/1987, Frankfurt am Main, 1987.
- 20 Höpner, Th., "Die Ökokatastrophe am Golf", Umweltwissenschaften und Schadstoff-Forschung, 3: 6, 354 - 361, 1991.
- 21 Zellner, R., "Auswirkungen von Ölbränden auf die Chemie der Atmosphäre", Universität Hannover, Institut für Physikalische Chemie und Elektrochemie.

- 22 Höpner, Th., "Öl als Waffe ökologischer Kriegführung", Ärzte gegen den Atomkrieg, 39: 10, 34 - 39, 1992.
- 23 United Nations, "Updated Scientific Report on the Environmental Effects of the Conflict between Iraq and Kuwait", Report of the Executive Director of the Governing Council of the United Nations Environment Programme, document no. UNEP/GC.17/Inf.9, 8 March 1993.
- 24 Anonym, "Rauch breitet sich weiter aus", Der Spiegel, 13 / 91 (25.3.1991)
- 25 Hahn, J., Schröder, P., Seiler, W., "Stellungnahme zum Fragenkatalog des Deutschen Bundestages für die Anhörung zum Thema 'Auswirkungen des Golfkrieges': Umweltauswirkungen des Golfkrieges und die Möglichkeiten der Bundesrepublik Deutschland bei der Beseitigung dieser Kriegsfolgen", Fraunhofer Institut für atmosphärische Umweltforschung, 1991.
- 26 Höpner, Th., Berthe-Corti, L., Harder, H., Michaelsen, M., "Fertigwerden mit einem GAU? Biologischer Ölabbau nach dem Golfkrieg", Einblicke - Forschung an der Universität Oldenburg, 7: 13, 8 - 12, 1991.
- 27 Bach, W., "Stellungnahme zum Fragenkatalog des Deutschen Bundestages für die Anhörung zum Thema 'Auswirkungen des Golfkrieges': Umweltauswirkungen des Golfkrieges und Möglichkeiten der Bundesrepublik Deutschland zur Mitwirkung bei der Beseitigung dieser Kriegsfolgen", Westfälische-Wilhelms-Universität, Inst. für Geographie, Abt. für Klima und Energieforschung, Münster, 1991.
- 28 Crutzen, J. P., Andreae, M. O., "Biomass burning in the tropics: Impact on atmospheric chemistry and biochemical cycles", Science, 250, 1669 - 1678, 1990.
- 29 Andreae, M. O., Goldammer, J. G., "Tropical wildland fires and other biomass burning: Environmental impacts and implications for land-use and fire management", Abidjan conference on West Africa's forest environment, ed.: The World Bank, Washington (in press).
- 30 Lashof, D. A., Ahuja, D. R., "Relative contributions of greenhouse gas emissions to global warming", Nature, 344, 529 - 531, 1990.
- 31 Goldammer, J. G., Feuer in Waldökosystemen der Tropen und der Subtropen, Birkhäuser Verlag, Basel - Boston - Berlin, 1993.
- 32 Besson, W., "Der Feuersturm", VFDB-Zeitschrift, 9, 5 - 12, 1969.
- 33 Thompson, S. L., Schneider, S. H., "The Nuclear Winter Debate: Comment and Correspondence", Foreign Affairs, 65: 1, 171 - 178, 1986.
- 34 Montrealer Protokoll über Stoffe, die zu einem Abbau der Ozonschicht führen (deutsche Fassung), 16.9.1987
- 35 "Verordnung zum Verbot von bestimmten, die Ozonschicht abbauenden Halogenkohlenwasserstoffen" (FCKW-Halon-Verbotsverordnung), vom 6.5.1991, BGBl. I, 1090.
- 36 Schweitzer, O., "Halon als Umweltproblem!? - Das Feuerlöschmittel Halon und seine Auswirkungen auf die Umwelt", semester thesis, University of Wuppertal (BUGHW), 1991.
- 37 Singh, O. N., Borchers, R., Lal, S., Subbarya, B. H., Krüger, B. C.; Fabian, P., "1990 vertical distribution profile of two important halons - F-12B1 and F-13B1 - in the tropics", Proceedings of the Quadrennial Ozone Symposium, June 4 - 13, 1992, University of Virginia, Charlottesville, USA (in print).

- 38 Fabian, P., Borchers, R., Kourtidis, K., "Bromine-containing source gases during eases", Geophysical Research Letters (in print).
- 39 Fabian, P., Singh, O. N., Borchers, R., Lal, S., Subbarya, "Measurements of atmospheric BrO_x radicals in the tropical and mid latitude atmosphere", Nature 334, No. 6182, 11, 1988.
- 40 Günther, K.-P., Thon, W., "Löschwasserrückhaltung als Beitrag zum Umweltschutz", VFDB-Zeitschrift 39, 36 - 38, 1990.
- 41 Schweitzer, O., "Ermittlung des Löschwasserverbrauches durch die Auswertung von Brandberichten im Hinblick auf erforderliche Löschwasservolumina", diploma thesis, University of Wuppertal (BUGHW), 1991.
- 42 Verband der Sachversicherer, "Richtlinien für den Brandschutz für Lager mit gefährlichen Stoffen", VdS-Richtlinie 2218, Köln, 1988.
- 43 Comité Européen des Assurances, "Empfehlungen für den Brandschutz für Lager mit gefährlichen Stoffen", Zürich, 1992.
- 44 Richtlinie zur Bemessung von Löschwasserrückhalteinrichtungen beim Lagern wassergefährdender Stoffe - Löschwasserrückhalterrichtlinie (LöRiLi) in der Fassung vom 20.11.1992, MBI NW 1719, 1922.
- 45 Heusser, M., Kauser, P., "Die Entsorgung von kontaminierten Brandrückständen", VFDB-Zeitschrift, 39, 28 - 30, 1990.
- 46 Deutsche Kommission zur Reinhaltung des Rheins, "2. Deutsche Bericht zum Sandoz-Unfall - Zustand des Rheins 'Ein Jahr danach' ", 1988.
- 47 Fiedler, H., "Toxikologische Gefährdungseinschätzung, Expositions- und Risikoanalyse", VdS-Seminar, 25./26.1.1994, Cologne.
- 48 Ibing, P., "VdS-Leitlinie zur Brandschadensanierung: Entwurf", VdS-Seminar, 25./26.1.1994, Cologne.
- 49 Rackwitz, D., "Brandschutt - wohin damit?", VdS-Seminar, 25./26.1.1994, Cologne.
- 50 Bröker, G., Geuecke, K.-J., Hiester, E., Niesenhaus, H., Emission polychlorierter Dibenzop-dioxine und -furan aus Hausbrand-Feuerungen, Landesamt für Immissionschutz Nordrhein-Westfalen, LIS-Bericht Nr. 103, 1992
- 51 Ihme, W., "Allgemeines Modell zur Quantifizierung der Exposition des Menschen durch kontaminierte Böden", thesis, University of Wuppertal (BUGHW), 1992.
- 52 Bernardt, H., "Elektrosanierung von Stahlbeton", VdS-Seminar, 25./26.1.1994, Cologne.
- 53 Förstner, U., Umweltschutztechnik, 4. Aufl., Springer Verlag, Berlin - Heidelberg - New York, 1993.

