Environmental Review of Fire Fighting Foams with particular emphasis on their Fluorosurfactant Content

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R&D Technical Report P6-012/14/TR

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This report summarises the progress made to date in reviewing the environmental data on fire fighting foams marketed and used in the UK, with particular reference to their fluorosurfactant content. It is to be used by the Environment Agency project board to assess the progress of the project and to formulate a project plan for the completion of the remaining tasks.

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FOREWORD

This report reviews the environmental fate and behaviour of UK fire fighting foams and their constituents. It details the environmental impacts of fluorosurfactants and provides information on the regulatory frameworks underwhich fire fighting foams could be controlled. It is produced for the Environment Agency as an update and furtherance to the National Rivers Authority R&D Note 339.

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EXECUTIVE SUMMARY

This report updates a previous NRA R&D Note 339 on the prioritisation of fire fighting foams for EQS development. It provides a detailed review of the environmental fate and effects of UK fire fighting foams and their constituents in aquatic ecosystems. In addition it gives a comprehensive account of the environmental risk of fluorosurfactants, known to be persistent and bioaccumulative constituents of fire fighting foams. The report also evaluates methods of reducing the impacts of fire fighting foams at training grounds and provides a review of containment and treatment procedures for foam run-off. It concludes with a summary of the environmental legislation that applies to the use and disposal of fire fighting foams. All UK formulated foams were considered in this review, as well as a number of foams produced by overseas formulators.

Investigations into the aquatic toxicity of foam concentrates indicated that, in general, fire-fighting foams are of low acute toxicity. Exceptions were the Synthetic Detergent foams that are of moderate toxicity. However, as the available data related to the foam concentrate as sold and not to the finished foam as used operationally, it is expected that the toxicity of the finished foams is likely to be lower (less toxic) than the concentrate due to the effects of dilution with water.

Foam concentrates are also not expected to be highly persistent. Although most fire fighting foam concentrates would not be regarded as readily biodegradable (according to the CHIP classification HSE, 1994), the majority of foams did biodegrade appreciably within 28 days. However, a quarter of the foams (11 of 40) did degrade rapidly (BOD/COD ratio of >50% within 5 days) and as such these foams may have a negative effect on aquatic systems due to the depletion of oxygen. This may be a particular problem under conditions of low dilution in receiving waters, particularly in summer months.

Environmental data collected for the specific chemical constituents of foams highlighted by the formulators MSDSs indicated that, unlike the parent foam products, a number of the constituents of the foams were toxic, persistent and possibly bioaccumulative. The anionic surfactants, biocides and the metal salts were of particular concern due to their high toxicities when compared to other constituents. Although they are present at low levels in the finished foams and may not pose an acute hazard, the persistent nature of some of these constituents could lead to their accumulation to toxic levels in the environment.

The fluorosurfactant content of foams is also of environmental concern due to their persistence and bioaccumulative properties. All perfluorinated surfactants will degrade to very persistent fluorocarbons with or without a functional group attached (depending on the parent compound), that will remain in the environment for years. Perfluorinated sulphonyl compounds (such as PFOS) have been shown to accumulate in the liver of mammals up to mg/kg levels. However, perfluorinated substances that do not contain the sulphonate group (e.g. PFOA) do not appear to bioaccumulate to the same degree. PFOS is toxic to mammals when dosed at the low mg/kg/day rate. However, the toxicity of other perfluorinated compounds with functional groups other than sulphonyl has not been investigated.

In terms of dealing with fire fighting foam run-off at training grounds there are three main components within the run-off that require addressing, namely:

- the hydrocarbon content where kerosene is used as a fuel for practise fires;

- the BOD or oxygen depleting potential of the foam solution, and;
- the persistent components of foams e.g. fluorosurfactants and metals

There are currently only limited procedures in place at fire training facilities to treat the negative effects of fire fighting foam run-off. The impacts of foams are typically reduced by storage and release to waste water drain and public sewer. However, there are methods that could be put into place that may further reduce the impacts of foam run-off. These include reed beds to ameliorate BOD, activated carbon to remove the persistent constituents of foams such as the fluorosurfactants and separation of the hydrocarbon elements.

The control of fire-fighting foams in the UK is not covered by any specific regulation. However, there are a number of legal sources that apply to the general release of substances to the environment that are relevant to the release of fire-fighting foams, particularly in training exercises. The two most relevant pieces of legislation in relation to discharges of fire fighting foam run-off from training exercises are the Water Resources Act and the Groundwater Directive. However, without detailed knowledge of the substances used in the production of fire-fighting foam concentrates it is not possible to give a definitive guide to the legislation that needs to be complied with in any given situation.

Due to the lack of detailed information on the foam constituents available on product MSDSs and the unwillingness of foam formulators to disclose this information, a prioritisation of the foam constituents and subsequently the foam products in terms of their environmental impacts could not be achieved.

KEY WORDS

Fire fighting foams, aquatic toxicity, biodegradation, persistence, fluorosurfactant, environmental impact, regulation.

1. INTRODUCTION

1.1 Background

Fire fighting foams are used to save lives and to protect property in emergency situations. They were developed for use on flammable liquid fires and are one of the most important and effective tools for dealing with fires involving such liquids. For obvious reasons, foam development and purchase has historically been driven by fire fighting properties rather than environmental effects. However, because of the episodic large-scale and unpredictable nature of their usage in fire fighting situations and their repeated confined discharge in training situations, fire fighting foams have the potential to have a pronounced effect on the environment.

Recently interest in and concern over fire fighting foams has been renewed due to research indicating wide environmental dispersal and persistence of some of their constituents and breakdown products, particularly fluorosurfactants (Renner, 2001). As a result of research on fluorosurfactants the 3M Company announced a total phase out of their fire fighting foam products. This unprecedented move was based on concerns regarding perfluoro-octanol sulphonate (PFOS) a metabolite of an important intermediate, produced in the 3M fluorosurfactant manufacturing process (Klein, 2000). 3M were the only company to produce perfluoro compounds with a sulphonate end group and as a result theirs was the only product range from which PFOS could be produced as a breakdown product of their foams. PFOS had been shown to be widely dispersed and persistent in the environment. Measurable concentrations were also reported in the blood and tissues of wildlife and humans (Renner, 2001).

All other manufacturers produce fluorosurfactants with carboxylate end groups. However these chemicals have the same basic molecular shape and properties as PFOS. Consequently there is now a growing realisation that the carboxylate surfactant products might breakdown to produce substances with similar persistence and fate properties as PFOS.

1.2 Objectives

WRc have been contracted by the Environment Agency to review the ecotoxicity and environmental fate of fire fighting foams and their constituents, particularly fluorosurfactants. This report is intended for use in the formulation of Agency policy and specific guidance for emergency services, in order to minimise environmental harm arising from the use of fire fighting foams, particularly in training situations.

There are three major UK formulators of fire fighting foams (Croda Kerr, Chubb Fire and Angus Fire) producing approximately eighty fire fighting foam products between them. There are also a number of overseas formulators that market and sell their foams in the UK. Schmitz (Germany) Bio Ex (France) and Auxquima S.A. (Spain), producing seven foams between them, that were highlighted as of interest to the UK market.

Publicly available data from MSDSs have been reviewed on the toxicity, persistence and bioaccumulation of all eighty-seven foams and their constituents.

This report also reviews the following information:

- The environmental fate and effects of fluorosurfactants and the impact they have on the environment.
- The use and treatment of 'spent' fire-fighting foams.
- The regulatory frameworks under which fire fighting foam storage, use and disposal could be controlled.

1.3 Key points - Section 1

- There are three major UK formulators of fire fighting foams (Angus Fire, Croda Kerr, and Chubb Fire).
- They produce approximately eighty fire fighting foam products between them.
- There are also a number of overseas formulators that market and sell their foams in the UK. Schmitz (Germany), Bio Ex (France) and Auxquima S.A. (Spain) were highlighted as of interest to the UK market.
- Seven foams produced by these overseas companies were highlighted as of interest to this report.

2. BRIEF OVERVIEW OF FIRE FIGHTING FOAMS

2.1 General

Fires can be categorised into a number of classes depending on the type of combustible material involved. Class A fires involve ordinary combustibles, such as wood, cloth, and paper. Class B fires involve the combustion of liquids or liquifiable solids and Class C and D fires involve gases and metals such as magnesium, titanium, zirconium, sodium, and potassium, respectively.

In most circumstances water is used to extinguish fires. However, water is ineffective when fighting Class B fires involving flammable liquids. This is due to the density of water. It has a specific gravity higher than that of most flammable liquids and consequently it sinks below the burning fuel. Consequently, it has little effect in extinguishing the fire and can even cause the flammable liquid to spill out of its contained area. For this reason fire fighting foams were developed. These are produced by a combination of foam concentrate and water, which is then mixed with air (aspirated). The resulting foam forms a low-density blanket that floats on the flammable liquids, suffocating and extinguishing the fire. The main features of fire fighting foams are:

- Expansion volume – the volume of foam produced from a foam solution after it has been put through foam-making machinery.
- Stability in use – the ability of a foam blanket to retain its liquid content and properties, such as the number, size and shape of its bubbles.
- Fluidity in use and over flammable liquids – the ability of the foam to be projected on to and to then flow across fires.
- Contamination resistance to flammable liquids – the ability of the foam to resist contamination from the flammable fuel it is applied to.
- Sealing and resealing of foam blanket – the ability of the foam to seal and reseal over flammable liquids and to seal against hot and irregular shaped objects.
- Knockdown and extinction of fires – the ability of the foam blanket to extinguish and control fires.
- Burn-back resistance to thermal breakdown – the ability of the foam to stay intact on the fuel when subjected to heat and/or flame.

Fire fighting foams extinguish liquid fuel fires in the following ways (HM Fire Service Inspectorate 2000):

- By excluding air form the surface of the fuel.
- By separating the flames and the fuel.

- By reducing the release of flammable vapour from the fuel.

- By forming a radiant heat barrier, which reduces the feedback of heat from the flames to the fuel and therefore reduces the production of flammable vapour.

- By cooling the fuel surface as the foam solution drains out of the foam blanket. This also produces steam, which dilutes the oxygen around the fire.

Foams are stored as 'concentrates'. When mixed with water they become a 'solution', and when aspirated with air they become 'finished foam'. Concentrates are available in different strengths (1, 3 and 6%). A 3% concentrate is twice as strong as 6% concentrate (only half the amount of 3% concentrate is needed to make full strength solution), and 1% concentrate is six times as strong as 6% concentrate. At low concentrations some foam concentrates may also be used as wetting agents. In such circumstances the concentrates are not used to produce foams but to reduce the surface tension of water and increase its spreading and penetrating abilities.

Finished foams can generally be classified as high, medium or low expansion. The expansion ratio of a foam indicates the ratio of the volume of a finished foam to the volume of the foam solution used to produce it (e.g. if 2000 litres of foam were produced by aspirating 100 litres of foam solution the ratio would be 20:1). High expansion foams have ratios of >200:1, medium expansion foams have ratios of >20:1 and low expansion foams have ratios of $\leq$ 20:1.

The expansion ratio of a foam will influence the types of fires which it can be used to extinguish. Low expansion foams can be projected over long distances and heights and, as such, are suitable for fires involving large storage tanks, traffic accidents, flammable liquid spills and aircraft crash rescues. Medium expansion foams can only be projected over small distances, but they have the ability to flow easily and cover large areas quickly. Medium expansion foams are suitable for vapour suppression, fires in small cable ducts and transformers and to control small fires after road traffic accidents. High expansion foams cannot be projected any appreciable distance, but the large quantity of foam produced can quickly fill very large enclosures. Consequently, high-density foams are very useful in fighting fires in warehouses, aircraft hangers and mineshafts. They can also be used to suppress vapour, including fires involving cryogenic liquids such as Liquefied Natural Gas (LNG) and Liquefied Petroleum Gas (LPG).

2.2 Foam Types

There are approximately seven different types of fire fighting foams, based on the classifications given in the Fire Service Technical Manual on fire fighting foams (HM Fire Service Inspectorate 2000). These seven types fit into two generic families:

- <u>hydrolysed protein based foams</u>

    - Protein (P)

    - Fluoroprotein (FP)

- Film-forming fluoroprotein (FFFP)
- Alcohol resistant FFFP (AR-FFFP)

- synthetic based foams
  - synthetic detergents (SYNDET)
  - Aqueous film forming foam (AFFF)
  - Alcohol resistant AFFF (AR-AFFF)

There are also a small number of specialised foam concentrates. Those that are of relevance to this review are:

- Hazmat foam concentrates – which suppress toxic and odorous vapours and/or flammable liquids;
- Class A foam concentrates – which are for use on class A fires, such as forest fires.

Developments of both protein based and synthetic based foams have been directed towards similar goals: fast knockdown, good security and wide usefulness (particularly against polar solvents e.g. alcohol). Low weight (in terms of handling the concentrates); storage stability and a wide operational temperature range are also important considerations. Various constituents are added to basic foam concentrates to modify their fire fighting properties. Examples of such additives are (Wilkinson 1994):

- Preservatives, to prevent the growth of bacteria and moulds and increase shelf life;
- Metal salts, in protein foams to increase fire resistance;
- Anti-freeze agents;
- Corrosion inhibitors;
- Solvents, to reduce viscosity;
- Substances to stabilise the foam bubbles;
- Dyestuffs, for brand recognition.

2.2.1 Protein based foam concentrates

Protein foams (P)

Simple protein foams were developed in the 1930's and were the first type of mechanical foam to be widely used. Since the 1960's additives were incorporated to improve stability and shelf life.

The modern protein foam concentrates are liquids that contain hydrolysed protein, solvent, sodium chloride, iron and calcium salts and preservatives in a neutral aqueous solution. The starting materials for production, which provide the protein include: soya beans, corn gluten, animal blood, horn and hoof meal, waste fish products or feather meal (HM Fire Service Inspectorate 2000).

Simple protein foams extinguish fires primarily by blanketing i.e. excluding flow of air to the liquid fuel surface and restricting the flow of vapour from the fuel surface. The finished foams are characterised by being reasonably stable, with low liquid drainage rates, they are relatively stiff, have excellent heat resistance and are relatively inexpensive. Their disadvantages are lack of fuel tolerance, slow fire knockdown performance and unsuitability for polar solvents. The stiffness of protein foams coupled with a relatively high surface tension tends to restrict their ability to flow across liquid surfaces.

Protein based foams are relatively inexpensive and are typically available in 3 or 6% concentrates. They should only be used to produce low expansion foams.

Fluoroprotein foams (FP)

The fluoroprotein foams were developed in the 1960's and 70's. They are typically composed of hydrolysed protein, fluoro-surfactants, solvent, sodium chloride, iron, magnesium and zinc salts and preservatives in a neutral aqueous solution. Fluoroprotein foams are derivatives of protein foams with the addition of fluoro-surfactants, which provide oleophobic (oil repelling) properties and improve the fuel tolerance and fire knockdown performance.

Since fluoroprotein foams still contain a large proportion of hydrolysed protein they retain the properties of stability and heat resistance associated with protein foam. Their main disadvantage is poor performance with polar fuels.

FP foams are available in 3 and 6% concentrations and are primarily intended for the production of low expansion foams, but have been effective as medium expansion foams. They should not be used for production of high expansion foams.

Film forming fluoroproteins (FFFP)

Film forming fluoroprotein foams were developed during the 1980's. They are based on FP foam concentrates with the addition of film-forming fluorinated surface active agents. In some circumstances this combination of chemicals can produce a very thin film of foam solution to flow over the surface of some liquid hydrocarbons sealing in vapour.

They possess good knockdown performance combined with fluoroprotein burnback resistance and fuel tolerance. Their main disadvantage is their high cost.

FFFP foam concentrates are available in 3 or 6% concentrates and can be used for the production of low and medium expansion foams only.

2.2.2 Synthetic based foam concentrates

Synthetic detergent foam (SYNDET)

Synthetic detergent foams were first developed during the 1930's from early synthetic detergent foams. They are composed of a mixture of anionic hydrocarbon surfactants, solvents and foam stabilisers.

SYNDET foams are versatile, as they can be used to produce low, medium and high expansion foams. They can also be used on class A and B fires. The foams have good fluidity and achieve a rapid knockdown. Their versatility makes them suitable for general-purpose fire brigade operational use. Their main disadvantages are their low stability and relatively rapid drain times (time taken for the fluid to drain form a foam blanket i.e. blanket collapse). They dissipate quickly and so provide little heat resistance. They also have poor fuel tolerance (Wilkinson, 1994).

Aqueous film forming foams (AFFF)

Aqueous film forming foams were developed during the 1960's. They were developed specifically for crash fire situations where fast knockdown is vital to maximise chances of survival.

AFFFs are a combination of fluorocarbon surfactants, synthetic foaming agents, solvents, and a low proportion of halide ions. In fires involving flammable liquids the fluorinated surfactants contained in the foam position themselves on the foam solution-air interface. This leads to the formation and spreading of a very thin foam film over the hydrocarbon liquid fuel which limits the evaporation of the fuel and decreases heat flux from the flame to the fuel, extinguishing the fire (Dlugogorski, *et al,*. 2002). AFFFs are exceptionally quick at extinguishing fire, are highly resistant to thermal, chemical, electrical and biological attack and are moderately heat resistant and fuel tolerant.

They are intended for the production of low and medium expansion foams only and with high dilution can also be used to extinguish Class A fires.

2.2.3 Alcohol Resistant Foams

Alcohol resistant concentrates have been developed to deal with fires involving polar solvents, water miscible liquids such as alcohol and petrol containing up to 20% alcohol. Conventional foam blankets disintegrate on contact with polar solvents or alcohol because they mix freely with the water content of the foam.

Two types of alcohol resistant foams have been developed, based on either synthetic detergent film forming foams or on film forming fluoroprotein foams. Both types contain a polymeric additive, which forms a membrane over the flammable liquid preventing the water miscible liquids from mixing with the foam blanket. In hydrocarbon fuel fires the polymeric membrane does not form, but an aqueous film can form on some hydrocarbon fuels.

Alcohol resistant foams are primarily designed for the production of low expansion foams although they may also be used to produce medium expansion foams.

Alcohol resistant AFFF (AR-AFFF)

Alcohol resistant AFFFs were developed during the 1980's. They are composed of a synthetic detergent-based film forming foam, which contains water-soluble polymers. The soluble polysaccharide polymers form a polymeric membrane at the fuel/solvent interface, which prevents the foam blanket breaking down by water being drawn out of foam into the fuel or solvent. As with AFFFs, the finished foams are relatively fluid and provide fast fire extinction and good post-fire security.

Alcohol resistant FFFP (AR-FFFP)

Alcohol resistant FFFP foams were also developed during the 1980's. They are film forming fluoroprotein foams that contain water-soluble polymers. The polymer is present within the foam bubble and as with synthetic detergent based film forming foams, the initial water extraction by the solvent causes a polymeric membrane to form on the liquid surface, which prevents further destruction of the foam blanket. They have similar performances to standard FFFP foams.

2.2.4 Hazmat foam concentrates

Hazmat foams were developed in the 1970's for the suppression of hazardous vapour from fires, as many industrial and chemical processes use toxic substances that could be released as vapours during fires. Such chemicals may also react with conventional foam blankets destroying them. Consequently Hazmat foams were designed to be effective on these chemically reactive products. They have also been developed to be resistant to extremes of pH so they can be used in both acid and alkaline situations.

Hazmat foams are usually used to produce medium expansion foams with optimum expansion ratios of approximately 60:1 (HM Fire Service Inspectorate, 2000).

2.2.5 Class A foam concentrates

Class A foams have been used in the USA for the last 20 years for use in fighting forest and wild-land fires. More recently they have also been used in structural fire fighting.

Class A foams are often synthetic SYNDET foam concentrates that have been formulated for use on class A fires. Class A foams reduce the surface tension of water and allow greater penetration into class A fuels.

Generally they are formulated at concentrations of up to 1% and are intended to be used without aspiration equipment.

2.3 Foam products available in the UK

Table 2.1 lists the trade names of the fire fighting foams formulated in the UK, including a selected number of overseas foams. The foams have been grouped by type using the classifications given in the Fire Service Technical Manual on fire fighting foams (HM Fire Service Inspectorate, 2000)

Table 2.1 Fire fighting foam products available in the UK

Product Type	Product Name	Formulator
Protein foams	Profoam 803	Croda Kerr
	Profoam 806	Croda Kerr
	Profoam 303	Croda Kerr
	Profoam 606	Croda Kerr
	Regular Protein Foam 3%	Chubb Fire
	Nicerol	Angus Fire
	Nicerol HC	Angus Fire
Fluoroprotein foams	Fluorofoam 803	Croda Kerr
	Fluorofoam 806	Croda Kerr
	Fluorofoam 903	Croda Kerr
	Fluorofoam 903 Plus	Croda Kerr
	Fluorofoam 906	Croda Kerr
	Plus F 6%	Chubb Fire
	Plus F 3%	Chubb Fire
	FP70 Plus	Angus Fire
	PF70	Angus Fire
	FP350	Angus Fire
	FP570	Angus Fire
	FP600	Angus Fire
FFFP	Centrifoam 803	Croda Kerr
	Centrifoam 806	Croda Kerr
	Centrifoam 903	Croda Kerr
	Centrifoam 906	Croda Kerr
	Centrifoam 903 UL	Croda Kerr
	Centrifoam 906 UL	Croda Kerr
	Centrifoam A936	Croda Kerr
	Chubb 3% FFFP	Chubb Fire
	Aerofilm 33	Chubb Fire
	Aer-o-film 66	Chubb Fire
	Petroseal 6	Angus Fire
	Petroseal 3	Angus Fire
FFFP AR	Polarfoam 3x3	Chubb Fire
	Polarfoam 3x6	Chubb Fire
	Niagara 1-3	Angus Fire
	Niagara 3-3	Angus Fire
	Alcoseal 3-6	Angus Fire
	Alcoseal 3-6 LT	Angus Fire
	Alcoseal 3-3	Angus Fire
AFFF	Filmfoam 216	Croda Kerr
	Filmfoam 713	Croda Kerr
	Filmfoam 716	Croda Kerr
	Filmfoam 811	Croda Kerr
	Filmfoam 813	Croda Kerr

Table 2.1 Cont.

Product Type	Product Name	Formulator
AFFF	Filmfoam 816	Croda Kerr
	Filmfoam 911	Croda Kerr
	Filmfoam 913	Croda Kerr
	Filmfoam 916	Croda Kerr
	Filmfoam A836	Croda Kerr
	Filmfoam A933	Croda Kerr
	Filmfoam A833	Croda Kerr
	Eurofoam 6% AFFF	Chubb Fire
	Eurofoam 3% AFFF	Chubb Fire
	Eurofoam 1% AFFF	Chubb Fire
	Aer-o-Water Low Freeze 6%	Chubb Fire
	Aer-o-Water Low Freeze 3%	Chubb Fire
	Aer-o-Water Low Freeze 1%	Chubb Fire
	Tridol S 1	Angus Fire
	Tridol S 3	Angus Fire
	Tridol S 3 LT	Angus Fire
	Tridol S 6	Angus Fire
	Tridol S 6 LT	Angus Fire
	Tridol C 3	Angus Fire
	Tridol C 6	Angus Fire
	Cafilm	Auxquima S.A.
	Schmitz class B foam	Schmitz
AFFF AR	Polyfoam 3/3	Auxquima S.A.
	Tridol ATF 1-3	Angus Fire
	Tridol ATF 3-3	Angus Fire
	Tridol ATF 3-3 LT	Angus Fire
	Tridol ATF 3-6	Angus Fire
	Tridol ATF 3-6 LT	Angus Fire
	Tridol M	Angus Fire
	Universal Gold Low Freeze	Chubb Fire
	Universal Plus	Chubb Fire
	Chubb 3x6 AFFF-AR Low Freeze	Chubb Fire
Hazmat foam	Vapourshield Acid	Chubb Fire
Training foam	Training Foam 1%	Chubb Fire
	Training Foam 3%	Chubb Fire
Synthetic detergent - High Expansion	Hex	Chubb Fire
	Expandol	Angus Fire
	Expandol LT	Angus Fire
	Hi-foam S	Croda Kerr
	Hi-foam 2%	Croda Kerr
Class A foam	Bio for N	Bio-Ex
	Cafoam	Auxquima S.A.
	Schmitz class A foam	Schmitz
	Forexpan S	Angus Fire

2.4 Key points – Section 2

- The main features of fire fighting foams are:
  - Expansion volume
  - Stability in use
  - Fluidity in use and over flammable liquids
  - Contamination resistance to flammable liquids
  - Sealing and resealing of foam blanket
  - Knockdown and extinction of fires
  - Burn-back resistance to thermal breakdown
- Fire fighting foams extinguish liquid fuel fires in the following ways (HM Fire Service Inspectorate 2000):
  - By decreasing water droplet size thereby increasing the cooling capacity (Class A wet water products)
  - By excluding air form the surface of the fuel;
  - By separating the flames and the fuel;
  - By reducing the release of flammable vapour form the fuel;
  - By forming a radiant heat barrier, which reduces the feedback of heat from the flames to the fuel and therefore reducing the production of flammable vapour;
  - By cooling the fuel surface as the foam solution drains out of the foam blanket. This also produces steam, which dilutes the oxygen around the fire.
- There are approximately seven different types of fire fighting foams, These seven types fit into two basic generic families:

  <u>hydrolysed protein based foams</u>
  - Protein (P)
  - Fluoroprotein (FP)
  - Film-forming fluoroprotein (FFFP)
  - Alcohol resistant FFFP (AR-FFFP)

  <u>synthetic based foams</u>
  - synthetic detergents (SYNDET)
  - Aqueous film forming foam (AFFF)
  - Alcohol resistant AFFF (AR-AFFF)
- There are also a small number of specialised foam concentrates. Those that are of relevance to this review are: Hazmat foam concentrates – which suppress toxic and odorous vapours and/or flammable liquids; Class A foam concentrates – which are for use on class A fires, such as forest fires and training foams.

3. ENVIRONMENTAL FATE AND EFFECTS OF FOAM PRODUCTS AND THEIR CONSTITUENTS

3.1 Introduction

3.1.1 Assessment criteria

When fire-fighting foams are released into the environment, whether it is through emergency use, training exercises or accidental spills, they may have an adverse effect on local environmental conditions and resident organisms. In order to assess the type and extent of that effect a number of parameters associated with the foam have to be quantified. For the purposes of this report the environmental impact of foams and their constituents have been assessed in terms of their toxicity, fate and persistence/biodegradation.

The environmental toxicity of a chemical is measured using ecotoxicity tests in which organisms are exposed to the chemical for a specified time and the response of the organisms (e.g. number that die) is measured. The toxicity of different chemicals are compared by measuring the concentration of a chemical required to cause a specified response (e.g. 50% death) in a group of test organisms. The more toxic a chemical is the lower the concentration needed to cause the specified response.

Toxicity tests can be acute or chronic. Acute toxic effects occur over short periods of time (<96 hours) and indicate that a chemical is toxic enough to induce a response rapidly. Chronic toxicity occurs over long periods of time (weeks to years depending on the life cycle of the species) and indicate that the effects would arise from prolonged exposure.

The fate of a chemical is very important when trying to establish where in the environment (air, water, soil or sediment) it is going to end up and therefore, which types of organisms might be affected. The fate of a chemical is governed by its physical and chemical properties. For example, chemicals that remain in the water column (hydrophilic – water loving) will exert their effects on swimming organisms such as fish. Chemicals that partition to sediments and biological matter (hydrophobic – water hating) will exert their effects mainly on organisms in the sediment.

The physical and chemical properties also govern how persistent and biodegradable a chemical is likely to be. Chemicals may be broken down in the environment by a number of processes. Some will degrade by physical and chemical processes (photodegradation, hydrolysis, etc.), others may be subject to biological breakdown (biodegradation by bacteria), or they may be subject to a combination of both. The longer it takes for a chemical to break down in the environment the more persistent it is. Chemicals that are both persistent and toxic pose a greater threat to the environment than chemicals that degrade rapidly and have low toxicity.

3.1.2 Data collection

It was not possible to locate data on the toxicity, fate and persistence of fire fighting foam products and their constituents from the open literature. Consequently foam manufacturers were approached for data relating to their products and constituents. Unfortunately, none were willing to supply any information on their foam products due to the confidentiality of the formulations. As a result the only product or constituent data that could be located were taken from publicly available Material Safety Data Sheets (MSDSs) downloaded from company web sites.

3.1.3 Data evaluation

Using the data available in the MSDSs an attempt was made to establish which fire fighting foams posed a risk to the environment. However, the variations in the form and content of the MSDSs from different manufacturers were considerable and made direct comparisons of foam products very difficult. Where possible, the products as a whole have been assessed for their toxicity and persistence (biodegradation). It was not possible to investigate the environmental fate of foam products due to a lack of physical and chemical data.

Due to the variations in the content of the MSDSs an assessment of the environmental effects of individual chemical constituents (ingredients) of the foams has also been carried out. It was hoped that information on the toxicity, persistence and bioaccumulation of the individual components of the foams would help provide an indication of the environmental effects of the foam products. As such the chemical constituents have been prioritised in terms of their toxicity, persistence and bioaccumulative properties. Analysis of the environmental fate of the individual constituents has also been carried out.

The following chapter is divided into two sections. The first (3.2) deals with the toxicity and persistence of fire fighting foam products. The second section (3.3) deals with the environmental fate and effects of the individual fire fighting foam constituents. The constituents section deals firstly with the toxicity of foam ingredients, and then attempts to prioritise the foam constituents in terms of their persistence, toxicity and bioaccumulation. Finally the environmental fate of the individual constituents is investigated. An overall discussion is presented at the end of the chapter (3.4) tying in the results from each of the previous sub-sections.

3.2 Ecotoxicity and environmental fate of fire fighting foam products

3.2.1 Ecotoxicity of foam products

Data on the toxicity of fire fighting foam products are presented in Appendix A. As stated previously, product toxicity data were only available from Material Safety Data Sheets (MSDSs). However, MSDSs did not always contain ecotoxicity data, or they did not contain full toxicity data sets i.e. they did not present data for all of algae, invertebrates and fish. Consequently it was not possible to assess the toxicity of all UK fire fighting foams.

Another issue with the MSDSs toxicity data was that only acute data were presented in the sheets. As such it was not possible to evaluate the chronic effects of fire fighting foam products or to ascertain if they would pose a long-term hazard.

The toxicity data contained in the MSDSs and subsequently presented here relate to the toxicity of the foam concentrate, as sold, and not to the finished foam as applied in fire fighting or training situations.

Due to the paucity of toxicity data the foam products have been grouped by foam type in order to obtain a generalised picture of the toxicity of the foam groups.

Protein foams

The limited information available for protein based foam concentrates indicate that these products are of low toxicity to aquatic organisms, with all effect concentrations greater than 1000 mg/l. In tests exposing rainbow trout (*Oncorhynchus mykiss*) to Nicerol, LC50s (concentration required to kill 50% of test organisms in a specified time) of 4800, 4200 and 2400 mg/l for 24, 48 and 96 hour exposure periods, respectively were reported. The foam was also of low toxicity to water flea (*Daphnia magna*) with EC50s (the concentration having a specified effect on 50% of test organism) of 4262 and 1443 mg/l after a 24 and 48 hour exposure periods, respectively. Similar results were reported for Profoam 803 and Profoam 806 foams with 96 hour LC50s for fish and *D. magna* of >2000 mg/l for.

Fluoroprotein foam

The fluoroprotein foam concentrates also appear to be of low aquatic toxicity. 96 hour LC50 values for rainbow trout (*Oncorhynchus mykiss*) exposed to Fluorofoam 903, Fluorofoam 906, FP70 Plus, FP570 and FP70 were all greater than 1000 mg/l. FP 70 and FP570 appeared to be the less toxic with a 48 hour LC50 of >10000 mg/l. *D. magna* appear to be less sensitive to some fluoroprotein foams than fish, with 24 and 48 hour EC50s of 8906 and 4977 mg/l, respectively for PF70.

FFFP foams

The available data indicate that FFFP foam concentrates are of low aquatic toxicity. *D. magna* 48 hour EC50s are all greater than 1000 mg/l for the whole of the Centrifoam range. Rainbow trout exhibit a similar tolerance to these products with LC50s of >1000 mg/l. The Petroseal range are of an equivalent toxicity to the Centrifoam products with respect to rainbow trout with 48 hour LC50s >3000 mg/l. Interestingly, trout appear to be more sensitive to Petroseal 6 than *D. magna* with a 48 hour LC50 of 3400 mg/l for trout and a respective EC50 of 37857 mg/l for *D. magna*.

FFFP-AR foams

The only data available for FFFP-AR foams were from Angus MSDSs. All of the Angus FFFP-AR foams appear to be of low acute toxicity. 96 hour LC50s for rainbow trout were

greater than 2800 mg/l for all of the products tested. *D. magna* also appear to be of low sensitivity to these foams with EC50s all greater than 2000 mg/l.

AFFF foams

The bulk of ecotoxicity data for foam product concentrates was available for the AFFF group. These foams appear to be of low acute toxicity. However, some may be more toxic than others. Filmfoam 911 and Filmfoam A933 are reported to have 48 hour EC50s for *D. magna* of >249 and >166 mg/l, respectively, indicating higher sensitivity *of D. magna* to these foam concentrates. However, it is not clear from the MSDSs if these concentrations were the highest tested, if so the 'true' EC50s may be higher (less toxic) than reported in the MSDSs. Tridol S3 appears to have the highest toxicity of the AFFF foams tested. When *D. magna* were exposed to this foam for 48 hours the EC50 was reported as 147 mg/l. Rainbow trout were also sensitive to this foam with a 96 hour LC50 of 390 mg/l. However, this foam would still be regarded as having low acute toxicity.

AFFF-AR foams

Only a small data set was available for these foam concentrates. Tridol ATF 1-3 and 3-3 were of low toxicity to *D. magna* with 48 hour EC50s of 10700 mg/l for both foams. Tridol M was slightly more toxic with an LC50 of 719 mg/l for the killifish (*Fundulus heteroclitus*), but is still of low toxicity.

Hazmat foams

No data were available on the toxicity of these foam products.

Training foams

No data were available on the toxicity of these foam products

SYNDET foams

The available data suggest that synthetic detergent foam concentrates have the highest toxicity of the foam concentrates tested. LC50s for rainbow trout have been reported as 89, 60 and 45 mg/l for 24, 48 and 96 hours, respectively. EC50s for *D. magna* of 10 and 50 mg/l for Expandol and Expandol LT, respectively have also been reported These data indicate that SYNDET foams are of moderate acute toxicity to aquatic organisms.

Class A foams

Only one data point was available on the aquatic toxicity of Class A concentrates. A 96 hour LC50 of 10.4 mg/l was reported for Rainbow trout exposed to Forexspan, indicating moderate toxicity of this foam to fish. However, due to the lack of data it is not possible to establish if all Class A foams are of similar toxicity.

3.2.2 Biodegradation of foam products

Biodegradation tests

The only data available with which to evaluate the fate of fire fighting foam products were biodegradation data presented in the MSDSs. The degradation data were expressed as BOD (Biochemical Oxygen Demand - the amount of oxygen needed by micro-organisms to degrade the organic components of the foam) COD (Chemical Oxygen Demand – the amount of oxygen required to oxidise the total organic and inorganic components of the foam) ratios expressed as percentages.

The BOD/COD ratios of a chemical can be used to assess its biodegradability. Chemicals with a BOD/COD ratio of ≥50% after 5 days are usually regarded as readily biodegradable and of low persistence in the environment (HSE, 1994). Chemicals that do not achieve this ratio within five days cannot be regarded as readily biodegradable. However, this does not mean that such chemicals will be non-biodegradable or highly persistent. With time the bacteria used in the biodegradation tests may become acclimatised to the chemicals and degrade the substance, indicating that the chemical is biodegradable, but not necessarily readily biodegradable.

Ready biodegradability can be seen as an advantage as degradable chemicals will not be present in the environment for long enough to have a negative impact. However, fire fighting foam concentrates can have very high BODs (up to 400,000 mg/l as compared with an average river BOD of 5 mg/l) and although the BODs will reduce when the concentrate is diluted in the finished foam they may still be very high (e.g. if a 6% concentrate has a BOD of 300,000 mg/l, then the finished foam would have a BOD of 18,000 mg/l, six hundredths of the concentrate). The consequence of this is that chemicals with high BODs may strip water of its oxygen. Therefore, if a foam degrades rapidly (ready biodegradable) it can cause water bodies to become anoxic and asphyxiate resident aquatic organisms. This can be a particular problem in water bodies with low dilution and/or slow flow rates. Therefore, in some circumstances (e.g. where foams are of low toxicity and/or are released to small static water bodies) slower biodegradation of foams may be more desirable.

It should be noted that in the case of fire fighting foams, which are complex mixtures of organic and inorganic chemicals, biodegradation tests might not give a true representation of the biodegradation of all the components of the foams. Bacteria are capable of degrading organic chemicals, but they will not be able to degrade all of the components of the foams such as the metals and the fluorine-carbon bonds of the fluorosurfactants. Therefore, a biodegradation test will give an indication of the degradation of the major components of a foam, but will not highlight the more persistent minor components.

The biodegradation data presented in the MSDSs were assessed using the CHIP classification for ready biodegradability for the labelling of substances for supply (Figure 3.1) (HSE, 1994).

Figure 3.1 Approved Guide to the Classification and Labelling of Substances and Preparations Dangerous for Supply

Substances are considered readily degradable if the following criteria hold true:

(a) If in 28-day biodegradation studies the following levels of degradation are achieved;

- in tests based upon dissolved organic carbon: 70%
- in tests based upon oxygen depletion or carbon dioxide generation: 60% of the theoretical maxima

These levels of biodegradation must be achieved within 10 days of the start of degradation, which point is taken as the time when 10 % of the substance has been degraded.
or

(b) if in those cases where only COD or BOD_5 data are available when the ratio of BOD_5/COD is greater than or equal to 0.5;

or

(c) if other convincing scientific evidence is available to demonstrate that the substance can be degraded (biotically and/or abiotically) in the aquatic environment to a level of > 70% within a 28-day period.

Biodegradation data for UK fire fighting foams

Summaries of the relevant biodegradation data are contained in Table 3.1 and Appendix B. It should be noted that the biodegradation data presented in the MSDSs related to the foam concentrate, as sold, and not to the finished foam as applied in fire fighting or training situations. Biodegradation data could only be located for Croda Kerr, Chubb and Angus foams and even then not for all the available products.

Protein Based Foams

According to the CHIP classification none of the basic protein-based foam concentrates would be regarded as readily biodegradable, as none achieve a BOD/COD ratio of >50% after 5 days. However, a BOD/COD ratio of >60% was achieved within 28 days, indicating that these foams are biodegradable over periods greater than 5 days. Therefore they would not be expected to persist in the environment for extended periods of time. The advantage of this delayed degradation is that it is gradual, with only 21% and 52% degradation within 5 and 20 days, respectively for Profoam 803 and 806, so these foams would not be expected to rapidly strip oxygen from water bodies and as such their environmental effects are likely to be minimal.

The majority of fluoroprotein foam concentrates would also not be regarded as readily biodegradable (they do not achieve a BOD/COD ratio of >50% over five days), but they do achieve a BOD/COD ratio of >60% after 28 days indicating reasonable biodegradation and

limited persistence. They also degrade gradually so they would not be expected to have a negative impact in terms of rapid oxygen depletion of receiving waters. However, FP70, has a BOD_5/COD ratio of 96% after only 5 days. Therefore, this foam can be regarded as readily biodegradable, but it could also pose an acute hazard to aquatic organisms due to asphyxiation by rapid oxygen depletion of a water body.

FFFP and FFFP-AR foam concentrates follow a similar trend to the other protein based foams with the majority only achieving >50% biodegradation within 28 days, indicating biodegradation, but not ready biodegradation. However, three foams Petroseal 3, and Niagara 1-3 and 3-3 had a BOD_5/COD ratio of >60% after 5 days. These foams would be regarded as readily biodegradable, but they may also pose an acute hazard due to rapid oxygen depletion.

Synthetic Foams

On the basis on the biodegradation data available, the majority of synthetic foam concentrates appear to be degraded more rapidly than the protein foams.

A third of the AFFF and AFFF-AR concentrates achieved a BOD/COD ratio of >50% after 5 days, indicating ready biodegradability (Table 3.1). The Aer-o-water and Universal ranges had BOD_5/COD ratios of >70%, which may have implications for the aquatic environment in terms of rapid oxygen depletion. The data for the remaining AFFF and AFFF-AR concentrates indicate that most are not readily biodegradable. Only two (Tridol S3 LT and Tridol M) have data for durations greater than 5 days and these foams achieved a BOD/COD ratios of >60% after 28 days, indicating reasonable and gradual biodegradation. Consequently these foams would not be expected to be highly persistent in the aquatic environment.

The only data for Hazmat foams was for Vapoursheild Acid. This foam was not readily biodegradable within 5 days and no further data was reported for longer test periods.

For the two training foams only BOD_5 data were available (Table 3.1). The 1% concentrate did not achieve a 50% BOD/COD ratio within 5 days, but the weaker 3% concentrate did. Therefore, the 3% training foam is more likely to have a negative effect on oxygen levels in receiving water, than the 1% concentrate.

The only other synthetic foam type for which data were available was for SYNDET foams. Biodegradation data for Expandol did not indicate ready biodegradability (BOD/COD of 14% after 5 days). However, Expandol LT had a BOD/COD ratio of 70% within 5 days and as such may pose an acute hazard in terms of oxygen depletion of receiving waters.

3.2.3 Effect on sewage treatment works

Information on the effects of fire fighting foams to sewage treatment works is limited, but it is possible that discharges of foams directly to sewers could have adverse effects on sewage treatment processes. Possible impacts include toxicity to micro-organisms, inhibition of microbial oxygen uptake, foam formation and sludge settling problems in clarifiers.

AFFF concentrates have been shown to cause foaming problems in aeration basins of wastewater treatment plants. It has been reported that if AFFF concentrations exceed 100 mg l^{-1} (for 6% concentrate) or 50 mg l^{-1} (for 3% concentrate) foaming is likely to occur (Andrews, 1992). Foaming can be prevented by adjusting the discharge rate so that the

concentration reaching activated sludge aeration basins is less than 50 mg l^{-1} (1 gallon of product concentrate in >20,000 gallons of sewage). Anti-foaming agents have also been found to be effective in controlling foaming (3M, 1990, cited in Wilkinson, 1994).

Studies carried out by the 3M company (1990), who were manufacturing foams at the time, indicated that concentrations of up to 1000 mg l^{-1} of a number of AFFF-AR foams was satisfactorily treated in 10-day laboratory scale activated sludge studies (reported in Wilkinson, 1994). No apparent toxic effect on the microorganisms was observed (3M, 1990, cited in Wilkinson 1994). However, Chan and Chian (1986) reported that 200 mg/l (v/v) of an AFFF foam significantly reduced the performance of an activated sludge process.

It would be fair to assume that a number of the constituents of foams would be toxic to micro-organisms, particularly the bactericides such as ammonium chloride. However, toxicity to sewage treatment facilities could be minimised by introducing the foams to the sludge at suggested rates, thereby diluting the toxic components of the foams. Uncontrolled discharges could lead to treatment problems, particularly from excessive foaming.

Table 3.1 Foam concentrate biodegradation data

Foam concentrate	BOD_5/COD ratio (%)	BOD_{20}/COD ratio (%)	BOD_{21}/COD ratio (%)	BOD_{28}/COD ratio (%)
Protein				
Profoam 803	21	52	ND	100
Profoam 806	21	52	ND	100
Regular protein foam 3%	13.6	ND	ND	ND
Nicerol	ND	ND	ND	67
Fluoroprotein				
Fluorofoam 903	17	43	ND	75
Fluorofoam 906	17	43	ND	75
Plus F 6%	12.7	ND	ND	ND
Plus F 3%	13	ND	ND	ND
FP70	96	ND	ND	ND
FP570	ND	ND	59	65
FFFP				
Centrifoam 903 UL	23	46	ND	83
Centrifoam 906 UL	19	66	ND	97
Aer-o-film 33	16.8	ND	ND	ND
Aer-o-film 66	16.3	ND	ND	ND
Petroseal 6	34	ND	100	ND
Petroseal 3	63	ND	ND	ND
FFFP-AR				
Polar foam 3x3	14	ND	ND	ND
Polar foam 3x6	14	ND	ND	ND
Niagara 1-3	63	ND	ND	ND
Niagara 3-3	63	ND	ND	ND
Alcoseal 3-6	26	ND	ND	92
Alcoseal 3-6 LT	36	ND	ND	70
AFFF				
Aer-o-water low freeze 6%	78	ND	ND	ND
Aer-o-water low freeze 3%	75	ND	ND	ND
Aer-o-water low freeze 1%	72	ND	ND	ND
Tridol S 1	44	ND	ND	ND
Tridol S 3	34	ND	ND	ND
Tridol S 3 LT	34	ND	86-94	87-93
Tridol C3	9	ND	ND	ND
Tridol C6	11	ND	ND	ND
AFFF-AR				
Tridol ATF 3-6	8	ND	ND	ND
Tridol M	ND	67	ND	ND
Universal gold low freeze	74	ND	ND	ND
Universal plus	70	ND	ND	ND
Hazmat				
Vapoursheild Acid	38	ND	ND	ND

Table 3.1 Cont.

Foam concentrate	BOD_5/COD ratio (%)	BOD_{20}/COD ratio (%)	BOD_{21}/COD ratio (%)	BOD_{28}/COD ratio (%)
Training foam				
Training foam 1%	34	ND	ND	ND
Training foam 3%	64	ND	ND	ND
SYNDET foam				
Expandol	14	ND	ND	53
Expandol LT	70	ND	ND	ND
Class A foams				
ND	ND	ND	ND	ND

Note ND – No Data

3.3 Ecotoxicity and environmental fate of fire fighting foam constituents

The only chemical constituent information that could be located was taken from product datasheets downloaded from company web sites. The variations in form and content of these sheets were considerable. Where details of the exact chemical constituents were given, toxicity, persistence and fate data were collected from the open literature. However, for a number of constituents only details of the chemical group was supplied i.e. 'metal salts', 'fluorosurfactants'. Consequently, it was not possible to collect toxicity and fate data for these constituents.

Tables 3.2 –3.11 list (in alphabetical order) the individual chemicals and chemical groups present in each foam class, with an annotation of the number of products from which the constituent lists were taken. It should be noted that the chemical lists represent all constituents from each foam category. Therefore, each foam product will not necessarily contain all the constituents presented in each table.

Table 3.2 Basic Protein constituents (7 products)

Chemical constituents	Chemical function	CAS No
2,4-dichloro-3,5-dimethylphenol	Biocide/Preservative	133-53-9
Bactericide	Biocide/Preservative	
Hexylene glycol	Solvent	107-41-5
Hydrolysed protein (animal)	Foaming agent	100085-61-8
Hydrolysed protein	Foaming agent	
Iron (II) sulphate heptahydrate	Heat resistor	7782-63-0
Magnesium chloride	Heat resistor	7786-30-3
Other metal salts	Heat resistor	
Sodium chloride	Heat resistor	7647-14-5
Water remaining	Fire suppression	
Zinc Oxide	Heat resistor	1314-13-2

Table 3.3 FP constituents (12 Products)

Chemical Constituents	Chemical function	Cas No
2,4-dichloro-3,5-dimethylphenol	Biocide/Preservative	133-53-9
Bactericide	Biocide/Preservative	
Fluorosurfactant	Knockdown/foam fluidity	
Hexylene glycol	Solvent	107-41-5
Hydrocarbon surfactants	Knockdown/foam fluidity	
Hydrolysed protein (animal)	Foaming agent	100085-61-8
Hydrolysed protein	Foaming agent	
Iron (II) sulphate heptahydrate	Heat resistor	7782-63-0
Magnesium chloride	Heat resistor	7786-30-3
Other metal salts	Heat resistors	
Sodium chloride	Heat resistor	7647-14-5
Water	Fire suppression	
Zinc Oxide	Heat resistor	1314-13-2

Table 3.4 FFFP constituents (12 Products)

Chemical Constituent	Chemical function	CAS No
2,4-dichloro-3,5-dimethylphenol	Biocide/Preservative	133-53-9
Bactericide	Biocide/Preservative	
Fluorosurfactant	Knockdown/foam fluidity	
Hexylene glycol	Solvent	107-41-5
Hydrocarbon surfactants	Knockdown/foam fluidity	
Hydrolysed protein (animal)	Foaming agent	100085-61-8
Hydrolysed protein	Foaming agent	
Other metal salts	Heat resistors	
Sodium chloride	Heat resistor	7647-14-5
Water	Fire suppression	
Water soluble polymer	Stabiliser	
Zinc Oxide	Heat resistor	1314-13-2

Table 3.5 FFFP-AR constituents (7 Products)

Chemical Constituent	Chemical function	CAS No
Bactericide	Biocide/Preservative	
Ethylene glycol	Solvent	107-21-1
Fluorosurfactants	Knockdown/foam fluidity	
Hexylene glycol	Solvent	107-41-5
Hydrocarbon surfactants	Knockdown/foam fluidity	
Hydrolysed protein	Foaming agent	
Polymer	Stabiliser	
Sodium chloride	Heat resistors	7647-14-5
Water	Fire suppression	

Table 3.6 AFFF constituents (27 Products)

Chemical Constituent	Chemical function	CAS No
Alfa Olefins	Knockdown/foam fluidity	
Ammonium chloride	Biocide/Preservative	12125-02-9
Buffer	Buffer	
Butyl diglycol	Solvent	112-34-5
Chelating agent	Chelating agent	
Decyl sodium sulphate	Knockdown/foam fluidity	142-87-0
Dipropylene glycol methyl ether	Solvent	34590-94-8
Ethylene glycol	Solvent	107-21-1
Fluorosurfactants	Knockdown/foam fluidity	
Hydrocarbon surfactants	Knockdown/foam fluidity	
Magnesium sulphate	Heat resistor	7487-88-9
Polyethylene glycol	Solvent	25322-68-3
Propylene glycol	Solvent	57-55-6
Tetrasodium salt	Chelating agent	64-02-8
Urea	Deicer	57-13-6
Water	Fire suppressant	
Water soluble polymer	Stabiliser	

Table 3.7 AFFF-AR constituents (10 Products)

Chemical Constituent	Chemical function	CAS No
5-Chloro-2-Methyl-4-Isothiazolin-	Biocide/Preservative	26172-55-4
Alkyl polyglycoside surfactant	Knockdown/foam fluidity	132778-08-6
Butyl diglycol	Solvent	112-34-5
Corrosion inhibitor	Corrosion inhibitor	
Decyl sodium sulphate	Knockdown/foam fluidity	142-87-0
Ethylene glycol	Solvent	107-21-1
Fluorosurfactants	Knockdown/foam fluidity	
Heteropolysaccharide	Stabiliser	
Hexylene glycol	Solvent	107-41-5
Hydrocarbon surfactant	Knockdown/foam fluidity	
Magnesium sulphate	Heat resistor	7487-88-9
Octyl sodium sulphate	Knockdown/foam fluidity	142-31-4
Other salts		
Polymer	Stabiliser	
Polysaccharide	Stabiliser	
Tetrasodium salt	Chelating agent	64-02-8
Water	Fire suppressant	
Xanthan Gum	Stabiliser	11138-66-2

Table 3.8 Class A foam Constituents (4 Products)

Chemical Constituent	Chemical function	**CAS No**
Butyl diglycol	Solvent	112-34-5
Corrosion inhibitor	Corrosion inhibitor	
Dipropylene glycol methyl ether	Solvent	34590-94-8 5
Ethylene glycol	Solvent	107-21-1
fluorosurfactant	Knockdown/foam fluidity	
Hydrocarbon surfactant	Knockdown/foam fluidity	
Preservatives	Preservative	
Primary alcohol blend	Solvent	
Primary alcohol ether sulphate Salts	Knockdown/foam fluidity	68585-34-2
Sulphosuccinate	Knockdown/foam fluidity	
Surfactants	Knockdown/foam fluidity	
Water	Fire suppressant	

Table 3.9 Hazmat foam constituents (1 Product)

Chemical Constituent	Chemical function	CAS No
2-Butoxy ethanol	Solvent	111-76-2
Amine Oxide		
Primary alcohol blend	Solvent	
Glycerine	Solvent	
Glacial acetic acid	Solvent	64-19-7

Table 3.10 SYNDET (High expansion) constituents (5 Products)

Chemical Constituent	Chemical function	CAS No
2-Butoxy ethanol	Solvent	111-76-2
Alpha olefin sulphonate	Knockdown/foam fluidity	
Borax	Biocide	1330-43-4
Butyl glycol	Solvent	112-34-5
Ethylene glycol	Solvent	107-21-1
Fatty alcohol sulphate (Alkyl-(C10-C16) alcohol sulphuric acid ammonium salt)	Knockdown/foam fluidity	68081-96-9
Lauryl ether sulphate	Knockdown/foam fluidity	78330-29-7
Monopotassium phosphate	Heat resistor	7778-77-0
Primary alcohol blend	Solvent	
Primary alcohol ether sulphates	Knockdown/foam fluidity	
Sulphosuccinate	Knockdown/foam fluidity	
Water	Fire Suppressant	

Table 3.11 Training foam constituents (2 Products)

Chemical Constituent	Chemical function	CAS No
Butyl glycol	Solvent	112-34-5
Hydrocarbon surfactants	Knockdown/foam fluidity	
Water	Fire suppressant	

3.3.1 Ecotoxicity of foam constituents

Ecotoxicity data located for individual chemicals listed in the MSDSs as ingredients in fire fighting foams are presented in Appendix D. As mentioned previously a number of the constituents were only reported as chemical groups and as a result it was not possible to collect data for these constituents. Chemical constituents have been categorised according to the function they serve in the final product, as follows:

- Fluorosurfactants
- Surfactants
- Solvents
- Preservatives (biocides)
- Other 'performance additives' such as foam boosters, and freeze protectors e.g. metal salts, viscosifiers, buffers

In the following sections, the ecotoxicity of chemicals within each of these categories are summarised. In some cases, no data could be located and these are highlighted. For others, large datasets are available and, for some, Environmental Quality Standards (EQSs) have been derived. These are useful because they provide an environmental benchmark reflecting the highest concentration in a water body that is not expected to result in adverse effects to aquatic life.

Most of the available data describe the acute (i.e. short-term ≤96 hour) effects of individual chemicals on survival or growth of fish, invertebrates (notably the water fleas, *Daphnia magna, Daphnia hyalina* and *Ceriodaphnia dubia*) and unicellular algae. In a few examples, data are available for other taxa such as molluscs, polychaete worms and amphibians. In a very few cases, chronic (i.e. long-term) toxicity data, describing effects on reproduction of *Daphnia* or survival of crayfish, are also available. Whilst the majority of data are for freshwater species, some examples of toxicity studies using saltwater species are also reported.

For detailed information about the environmental fate and behaviour of fluorosurfactants the reader is referred to Section 4.

Surfactants

Surfactants are added to foam to increase its knock down performance. Not only do they add to the foaming process by reducing the surface tension of water, but their properties as oil repellents make the foams more fluid. Where surfactants are included in fire-fighting foams, anionic surfactants tend to predominate. We have identified only one example of a non-ionic surfactant (alkyl polyglycoside) for which no ecotoxicity data are available, and no cationic surfactants. The anionic types are represented by various alcohol- or alkylether sulphates or sulphonates. Aquatic toxicity data have been reported for the ammonium salt of alkyl (C10-C16) alcohol sulphuric acid and decyl sodium sulphate. These both exhibit moderately high toxicities to aquatic organisms with acute LC/EC50 values lying between 3 and 190 mg/l (Appendix D). The higher values are associated with particularly short exposure durations (6 and 12h) but longer exposure periods give rise to higher toxicities (i.e. lower LC/EC50 values).

Fluorosurfactants

Fluorosurfactants have the same properties as other surfactants. However, fluorosurfactants reduce the surface tension of foams more effectively than other surfactants and remain active under greater extremes of temperature. Significantly, no aquatic toxicity data have been located for any fluorosurfactants. In part this is because data have not been made available whilst in other cases it is because the chemical identity of the fluorosurfactants present in products has not been specified. Therefore, it has not been possible to locate ecotoxicity data for the group as a whole, because this is normally expressed in terms of a specific chemical.

Solvents

Solvents are present in fire fighting foams to reduce viscosity and add foam enhancing properties. They may also act as antifreeze components in finished foams. Synthetic foams tend to contain higher proportions of solvents than protein-based foams. Amongst these, glycol-based ingredients such as butyl diglycol, dipropylene glycol methyl ether, ethylene glycol, hexylene glycol, polyethylene glycol and propylene glycol predominate. These are likely to impart other beneficial characteristics to the foams but have previously been classified as ‘solvents’ (Wilkinson, 1994). The only other solvents for which ecotoxicity data have been located are glycerine and 2-butoxy ethanol.

Substantial datasets are available for the glycols listed above (Appendix D) but are largely confined to acute toxicity to freshwater species. They are all characterised by low acute toxicities, with LC and EC50[1] values being reported in the g/l range, 2–3 orders of magnitude less toxic than the surfactants described above, for example. Higher toxicities (LC50s of 98->62000 mg/l) were evident in a series of studies with propylene glycol and fathead minnows (*Pimephales promelas*) (Pillard, 1995). However, these show a high degree of variability even in apparently identical test scenarios; consequently the reliability of these particular studies is regarded with some doubt.

[1] For butyl diglycol, much of the dataset comprises LC/EC0 and LC/EC100 data

Glycerine is also of low toxicity to freshwater organisms. Reported LC50 and EC50 values exceed the highest test concentration, indicating that no toxicity was evident even at concentrations of 10 g/l. 2-Butoxy ethanol is more toxic by comparison, but with LC/EC50 values lying in the range 550-1815 mg/l, this too may be regarded as having only low toxicity. This was the only example where a substantial dataset for saltwater species has been reported (Price et al, 1974; Blackman, 1974 and Dawson *et al*, 1977).

Biocides

Biocides increase the shelf life of foams by inhibiting the action of bacteria, fungi and moulds. Protein-based foams, and also foams containing high proportions of glycols, are prone to biodegradation. Therefore, biocides may be added to offset this degradation. As they are designed to be biologically active, it is reasonable to expect that biocides might be more toxic to aquatic organisms than most other foam constituents. Aquatic toxicity data have been located for the isothiazolinone, 5-chloro-2-methyl-4-isothiazolin-3-one, borax and ammonium chloride (Appendix D).

Of these biocides, the isothiazolinone is the most hazardous to aquatic life with acute EC50 and NOEC values lying between 0.3 and 4.7 mg/l. In chronic studies with *Daphnia magna*, EC50 and NOECs were estimated at broadly similar concentrations (0.17-5 mg/l), suggesting a rather narrow acute:chronic ratio. Ammonium chloride and borax both undergo rapid transformations in water. Studies with ammonium chloride give rise to acute LC50 values between 0.2 and 295 mg/l, whilst acute toxicity values (LC50 and LOEC) for borax lie between 0.6 and 1298 mg/l, depending on the test species and endpoint. In both cases, a very wide range of toxicities is apparent, although it is clear that both compounds are less acutely toxic than 5-chloro-2-methyl-4-isothiazolin-3-one, for which all acute effects are reported to range from 0.3 -5 mg/l.

Other 'performance additives'

Fire-fighting foams contain between 1 and 5% of metal salts. These are added to fire fighting foams to increase the heat resistance of the foam. Of most significance are salts of iron, magnesium and zinc although in some products the identity of the metal salts present is not specified. Metal salts are of environmental significance because of their high persistence and, under certain environmental conditions, high toxicity to aquatic life. The importance of the prevailing environmental conditions is critical because these affect the concentrations of bioavailable (and therefore toxic) forms of the metal. Factors favouring bioavailability are usually low pH, low hardness and low complexing capacity. This is reflected in EQSs for several metals where the hardness and/or pH band to which the EQS applies is specified. EQSs are available for iron and zinc for protection of both freshwater and saltwater life (Table 3.13). In addition, toxicity data for zinc oxide are presented in Appendix D. It is unclear from these data whether zinc will be bioavailable and it is quite possible that these data underestimate the toxicity of zinc salts under conditions that favour formation of the toxic Zn^{2+} ion. Compared to iron and zinc, magnesium salts are much less toxic with acute LC/EC50 values lying between 27 and 7070 mg/l, depending on test species and endpoint (Appendix D).

Table 3.12 EQSs for iron, zinc and EDTA

Substance	EQS
Iron (dissolved)	1 mg/l as an Annual Average (freshwater)
Zinc	Freshwater: 8-50 ug/l, depending on water hardness (expressed as an Annual Average) Saltwater: 10 ug/l (expressed as an Annual Average)
EDTA	4 mg/l (Maximum Allowable Concentration) 0.4 mg/l (Annual Average)*

*Standards apply to both freshwater and saltwater

Ethylenediamine tetra-acetic acid (EDTA), urea and xanthan gum are included in some fire fighting foam formulations as chelating agents, stabilisers and antifreeze agents. They are of low acute toxicity to aquatic organisms (Appendix D) with LC/EC50 values typically in the g/l range. However, isolated examples of apparently higher toxicity are evident (e.g. a LOEC for the green alga *Scenedesmus quadricauda* of 11 mg/l tetrasodium salt of EDTA (Bringmann and Kuhn, 1978), and a 96h LC50 of 5 mg/l to giant gourami exposed to urea (Pandey and Shukla, 1983). An EQS for EDTA is available (Table 3.13). Slightly higher toxicity is evident when aquatic organisms are exposed to another additive, monopotassium phosphate (Appendix D). Marine polychaete worms appear to be particularly sensitive to chronic exposure (28d) to this substance, for which LC50 values of 0.9-2.1 mg/l have been reported (Reish, 1970), but a freshwater polychaete (*Capitella capitata*) and zebra mussels (*Dreissena polymorpha*) were much less sensitive (Reish, 1970).

The only other additive for which ecotoxicity data have been located is acetic acid (Appendix D). It is moderately toxic to aquatic life, with reported acute LC/EC50 values in the range 49-6000 mg/l. A single study with African clawed toad (*Xenopus laevis*) stands out because it yielded a much lower toxicity (6123-6403 mg/l) (Dawson *et al*, 1996).

3.3.2 Environmental risk of foam constituents

Evaluation of environmental risk

The previous section has indicated that some constituents of fire fighting foams could pose a toxic threat in the environment if they occur at sufficiently high concentrations for sufficiently long periods of time. However, to ascertain the true environmental risk of the foam constituents other properties of the chemicals have to be evaluated along with its toxicity. A chemical is likely to be more of a hazard if it is toxic and also persistent, because it will be present in the environment for long periods of time.. If the same chemical is also bioaccumulative (accumulates in the bodies of organisms) then organisms are likely to be exposed to higher internal concentrations with further negative effects. Therefore, chemicals that are toxic, persistent and bioaccumulative pose a greater hazard to the environment than those that are not. In an attempt to establish which of the fire fighting foam constituents pose the greatest environmental risk, constituents were assessed using the Stakeholder Forum Criteria for Persistence, Bioaccumulation and Toxicity (PBT) (DEFRA 2001) (Figure 3.2). It was hoped that by ranking the constituents in terms of their environmental harm, the foam

products could also be prioritised by the presence and proportions of their persistent, bioaccumulative and toxic (PBT) constituents.

UK foam formulators were approached for relevant data on the exact chemical constituents and their proportions in their foam products. However, due to the confidentiality of their formulations none were willing to supply this information. As a result, the only information sources available for chemical constituent lists were manufacturers Material Safety Data Sheets (MSDSs). As stated previously these varied in their format and quality. Where possible, relevant ecotoxicological, persistence and bioaccumulation data were collected from the open literature for the 50 constituents typically contained in fire fighting foams (Table 3.13). However, complete PBT data sets were only available for four substances: 5-chloro-2-methyl-4-isothiazolin-3-one, ethylene glycol, glacial acetic acid and urea. For a further six substances toxicity and bioaccumulation data were available. For the remaining forty substances, either no PBT data could be located in the literature, or the MSDSs only provided information on the generic chemical group, for which specific PBT data cannot be obtained.

Results and discussion

Of the ten substances for which some data were available none possessed PBT properties that would indicate high priority for environmental concern as described in Figure 4.1. However, it should be noted that due to the lack of PBT data in the literature and particularly the lack of specific chemical information in the MSDSs, a number of the other constituents of fire fighting foams may have the potential to be hazardous to the environment. This is highlighted by the fact that with the current information even fluorosurfactants, of which individual perfluorinated compounds are known to be persistence and bioaccumulative, cannot be singled out as a priority. For specific information of the environmental risk associated with fluorosurfactants see Section 4.

The lack of PBT data for the majority of the constituents of fire fighting foams does not mean that these chemicals are benign. The lack of information and subsequent uncertainty about their potential environmental risk highlights these chemicals for further research and evaluation. In order to prioritise the constituents of fire fighting foams further data need to be collected or possibly generated for their toxicity, persistence and bioaccumulation. In the meantime an alternative may be to take a precautionary approach and assume that all chemicals with data gaps have high P,B or T i.e. assume they are guilty until proven innocent.

Figure 3.2 Stakeholder Forum recommendations on criteria for Persistence, Bioaccumulation and Toxicity (PBT) (as agreed on 30 November 2000)

Stakeholder Forum recommendations on criteria for Persistence, Bioaccumulation and Toxicity (PBT) (as agreed on 30 November 2000)

Persistence

t ½ water > 2 months **or**
t ½ soil or sediment > 6 months

The Forum recognised that such half life data may frequently not be available and that screening data such as the results of ready biodegradation testing may need to be used in the first instance.

Bioaccumulation

Log Kow $\geq$ 5 for the substances of highest priority, unless the experimental BCF <5000

Log Kow $\geq$4 for other priority substances for the Forum, unless the experimental BCF <500

Where experimentally derived bioconcentration factors (BCFs) are available these would be given precedence over Log Kow.

Toxicity

Toxicity or ecotoxicity data that indicate potential for damage, in the immediate or longer term, and through direct or indirect effects. Such data may include acute and/or chronic aquatic toxicity data, with thresholds of $L(E)C_{50} \leq 1$ mg/l and long-term no observable effect concentration (NOEC) $\leq$ 0.1 mg/l respectively; and category 1 and 2 carcinogenic, mutagenic or reproductive toxins (CMR) and category 3 mutagens or chronic toxicity data, with reference to the thresholds and provisions set out in EC Directive 67/548/EEC.

If no toxicity information is available from animal tests, QSAR or expert judgement, it would be assumed that the toxicity criterion was met.

Persistence and bioaccumulation without toxicity

If persistence and bioaccumulation criterion were met but the toxicity criterion was not, the Forum would not assume that the chemical was safe but it would not be as high a priority as chemicals which met the toxicity criterion.

Safety net procedure

A safety net procedure would apply where chemicals did not meet the PBT criteria but there were reasons to believe that the chemicals raised equivalent concerns. It was anticipated that chemicals giving rise to concerns related to endocrine disrupting effects could be considered under this procedure. The Forum would receive expert advice in such cases.

Table 3.13 PBT data for foam constituents

Constituent	CAS no.	Lowest reliable toxicity value				Bioaccumulation			Persistence	
		Species	Endpoint and duration	Conc. mg/l	Ref.	BCF Range	Log kow	Ref.	Half life water (days)	Ref.
2,4-dichloro-3,5-dimethylphenol	133-53-9	ND	ND	ND	-	ND	ND	-	ND	-
2-Butoxy ethanol	**111-76-2**	**Carp**	**LC50 (48 hour)**	**1395**	**1**	**~2.5**	**0.83**	**2**	ND	-
5-Chloro-2-Methyl-4-Isothiazolin-3-	**26172-55-4**	***Daphnia magna***	**NOEC (21 day)**	**0.172**	**3**	**67-114**	**0.5**	**4**	**17.3 (hours)**	4
Alfa Olefins		ND	ND	ND	-	ND	ND	-	ND	-
Alkyl polyglycoside surfactant	132778-08-6	ND	ND	ND	-	ND	ND	-	ND	-
Alpha olefin sulphonate		ND	ND	ND	-	ND	ND	-	ND	-
Amine Oxide		ND	ND	ND	-	ND	ND	-	ND	-
Ammonium chloride	**12125-02-9**	**Rainbow trout**	**LC50 (72 day)**	**0.056**	**5**	ND	ND	-	ND	-
Bactericide		ND	ND	ND	-	ND	ND	-	ND	-
Borax	**1330-43-4**	**Sunfish**	**LC50 (24 hour)**	**15**	**6**	ND	ND	-	ND	-
Buffer		ND	ND	ND	-	ND	ND	-	ND	-
Butyl diglycol	**112-34-5**	**Sun fish**	**LC50 (96 hour)**	**1300**	**7**	**~2.8**	**~0.91**	**2**	ND	-
Chelating agent		ND	ND	ND	-	ND	ND	-	ND	-
Corrosion inhibitor		ND	ND	ND	-	ND	ND	-	ND	-
Decyl sodium sulphate	**142-87-0**	**Common carp**	**LC50 (48 hour)**	**13**	**8**	**3**	**1.44**	**9**	ND	-
Dipropylene glycol methyl ether	**34590-94-8**	***Notropis atherinoides***	**LC50 (72 hour)**	**150**	**10**	**~100**	**~0.35**	**9**	ND	-
Ethylene glycol	**107-21-1**	**Duckweed**	**EC50 (ND)**	**10920**	**11**	**10-190**	**-1.36**	**2**	**1.5**	**12**
Fatty alcohol sulphate (Alkyl-(C10-C16) alcohol sulphuric acid ammonium salt)	**68081-96-9**	**Golden orfe**	**LC50 (48 hour)**	**~3**	**13**	ND	ND	-	ND	-
Fluorosurfactant		ND	ND	ND	-	ND	ND	-	ND	-
Glacial acetic acid	**64-19-7**	***Daphnia magna***	**EC50 (48 hour)**	**65**	**14**	**<1**	**-0.17**	**12**	**6**	**2**
Glycerine	**56-81-5**	**Green algae**	**EC10 (24 hour)**	**>1000**	**15**	**0.2-3**	**-1.76**	**12**	ND	-
Heteropolysaccharide		ND	ND	ND	-	ND	ND	-	ND	-

Table 3.13 Cont.

Constituent	CAS no.	Lowest toxicity value				Bioaccumulation			Persistence	
		Species	Endpoint and duration	Conc. mg/l	Ref.	BCF Range	Log kow	Ref.	Half life water (days)	Ref.
Hexylene glycol	**107-41-5**	**Fathead minnow**	**LC50 (96 hour)**	**1050**	**16**	ND	ND	-	ND	-
Hydrocarbon surfactant		ND	ND	ND	-	ND	ND	-	ND	-
Hydrolysed protein (animal)	100085-61-8	ND	ND	ND	-	ND	ND	-	ND	-
Hydrolysed protein		ND	ND	ND	-	ND	ND	-	ND	-
Iron (II) sulphate heptahydrate	7782-63-0	ND	ND	ND	-	ND	ND	-	ND	-
Lauryl ether sulphate	78330-29-7	ND	ND	ND	-	ND	ND	-	ND	-
Magnesium chloride	**7786-30-3**	***Daphnia magna***	**LC50 (48 hour)**	**27.4-37.4**	**17**	ND	ND	-	ND	-
Magnesium sulphate	**7487-88-9**	***Daphnia magna***	**LC50 (96 hour)**	**158**	**18**	ND	ND	-	ND	-
Monopotassium phosphate	**7778-77-0**	**Zebra mussel**	**LC50 (24 hour)**	**80-105**	**19**	ND	ND	-	ND	-
Octyl sodium sulphate	**142-31-4**	ND	ND	ND	-	ND	**-0.27**	**9-**	ND	-
Other metal salts		ND	ND	ND	-	ND	ND	-	ND	-
Other salts		ND	ND	ND	-	ND	ND	-	ND	-
Polyethylene glycol	**25322-68-3**	**Atlantic salmon**	**LC50 (96 hour)**	**>1000**	**20**	ND	ND	-	ND	-
Polymer		ND	ND	ND	-	ND	ND	-	ND	-
Polysaccharide		ND	ND	ND	-	ND	ND	-	ND	-
Primary alcohol blend		ND	ND	ND	-	ND	ND	-	ND	-
Primary alcohol ether sulphate	68585-34-2	ND	ND	ND	-	ND	ND	-	ND	-
Primary alcohol ether sulphates		ND	ND	ND	-	ND	ND	-	ND	-
Propylene glycol	**57-55-6**	**Fathead minnow**	**NOEC (7 day)**	**98**	**21**	**<1**	**-0.92**	**2**	ND	-
Sodium chloride	7647-14-5	ND	ND	ND	-	ND	ND	-	ND	-
Sulphoscuccinate		ND	ND	ND	-	ND	ND	-	ND	-
Surfactant blend		ND	ND	ND	-	ND	ND	-	ND	-
Tetrasodium salt	**64-02-8**	**Sun fish**	**NOEC (96**	**115**	**22**	ND	ND	-	ND	-
Urea	**57-13-6**	**Gourami fish**	**LC50 (96 hour)**	**5**	**23**	**Low**	**-2.97**	**24**	**4**	**24**
Water		NA	NA	NA	-	NA	NA	-	NA	-
Water soluble polymer		ND	ND	ND	-	ND	ND	-	ND	-
Xanthan Gum	**11138-66-2**	**Rainbow trout**	**LC50 (96 hour)**	**320-560**	**25**	ND	ND	-	ND	-
Zinc Oxide	**1314-13-2**	***Daphnia magna***	**LC50 (48 hour)**	**0.098**	**26**	ND	ND	-	ND	-

Notes ND = No Data, NA = Not Applicable

3.3.3 Environmental fate of foam constituents

Due to a lack of relevant physical and chemical property data available from the manufacturers Material Safety Data Sheets it was not possible to establish the fate of the fire fighting foam products. Consequently, an attempt was made to investigate the fate of the foam constituents to try and establish which compartments (air, water, soil, sediment, sewage) are likely to be at greatest risk from exposure to fire fighting foam chemicals.

Using physical and chemical data (Log Kow, half-lives in water and soil, volatility constants, Henrys law constants etc.) located in the open literature and/or predicted using chemical profiling software (SRC 2000), the probable partitioning and environmental pathways for the constituent chemicals of the different fire-fighting foam types were investigated (Figures 3.3-3.12). In addition, the chemicals have been further classified (colour coded using the Chemical Stakeholder Forum criteria DEFRA, 2001) with respect to their environmental persistence to establish the extent of the exposure to each compartment:

- Red indicates that the chemical is persistent with a half-life of greater than 2 months in water or 6 months in sediment, or has a high bioaccumulation potential in biota.

- Orange indicates that a chemical is inherently biodegradable (there is unequivocal evidence of biodegradation in any test of biodegradability) or has a medium potential to bioaccumulate.

- Green chemicals are readily biodegradable and/or degrade by greater than 70% in 28 days.

- Purple coded chemicals are those containing metals and therefore are technically persistent. However, a release of these chemicals is unlikely to cause an environmental impact as the concentrations of these metals are not expected to be higher than background levels.

The fate of some chemicals could not be evaluated because they were reported as chemical groups (e.g. metals, surfactants) in the MSDSs. These constituents have been included in a separate area within the diagrams, indicating that they are present within the foam type, but could not be classified in terms of their fate.

Assumptions

Due to lack of specific chemical information and/or lack of relevant fate data a number of assumptions have been made regarding some of the chemicals. The exact fluorosurfactant components present in many of the foams are unspecified. Therefore, it is not possible to assign specific fate and persistence data to this group of chemical. In such cases the worst case scenario has been assumed i.e. that all the fluorosurfactants have a high degree of fluorination and are highly persistent. Information on the exact sulphosuccinates (anionic surfactants) present in the foams was also not provided in the MSDSs. The only available data on this group was for dialkyl sulphosuccinates and so this information has been used as a surrogate for assessing the environmental fate for all of these compounds.

Depending on the temperature of a fire, some components of foams may combust or volatilise and would consequently enter the air compartment. However, due to the unpredictable

conditions of a fire the extent of volatilisation would be difficult to predict and quantify. Therefore, chemicals have only been included in the air compartment if they are likely to volatilise from water or soil surfaces under normal conditions.

Fate and persistence of foam constituents

The environmental pathways of fire fighting foam constituents are presented in Figures 3.3 – 3.12.

Of the constituents of the fire fighting foams, fluorosurfactants appear to be the main environmental concern by virtue of their high persistence and consequently it is the only this chemical group that has been labelled a red substance (highly persistent in each compartment) in the following diagrams. Fluorosurfactants are found in Training foams, AFFFs, FPs, FFFPs, Class A, FFFP-ARs and AFFF-AR foams. Although some degradation of these compounds will occur, the C-F bond is extremely strong and will persist in water and ground water. Fluorosurfactants are likely to pass through sewage treatment works (STWs) into effluent and will also bioaccumulate in biota. Section 4 of this report provides further details on the problems associated with fluorosurfactants.

Four substances present in the fire-fighting foams were assigned an ‘orange’ classification (moderately persistent in each compartment). The first are the sulphosuccinates (anionic surfactants), which are inherently biodegradable and are likely to partition to soil, sediment and may pass into the sludge of STWs. The second is dipropylene glycol methyl ether. This chemical is likely to be partition to and be stable in ground water and surface water. It will not be entirely degraded within a STW and so will also be found in STW effluent. Tetrasodium salt is also inherently biodegradable. It is very soluble and so will be present in any water compartments including STWs and effluent. 2,4-dichloro-3,5-dimethylphenol is the last ‘orange’ chemical highlighted. However, it should be noted that if released to air it is likely to be readily biodegradable and so has been labelled green in the air compartment. Otherwise it is likely to be found in soil and sediment. It is unlikely to be completely degraded in a STW and so is likely to be found in effluent. Some bioaccumulation is also possible with a predicted log Kow of 3.9 (HSDB, 2002).

Of the remaining chemicals those highlighted in green are all readily biodegradable and so will not persist in the environment. However, as they are readily biodegradable they generally have a high biochemical oxygen demand (BOD). A high BOD causes rapid depletion of oxygen from a water body as the chemicals degrade. The removal of oxygen can lead to the death of fish and other aquatic life and as such it may be necessary to rapidly oxygenate water if a large volume of fire-fighting foam (solution or concentrate) is known to have entered a water body.

Figure 3.3 Environmental pathways of Protein foam constituents

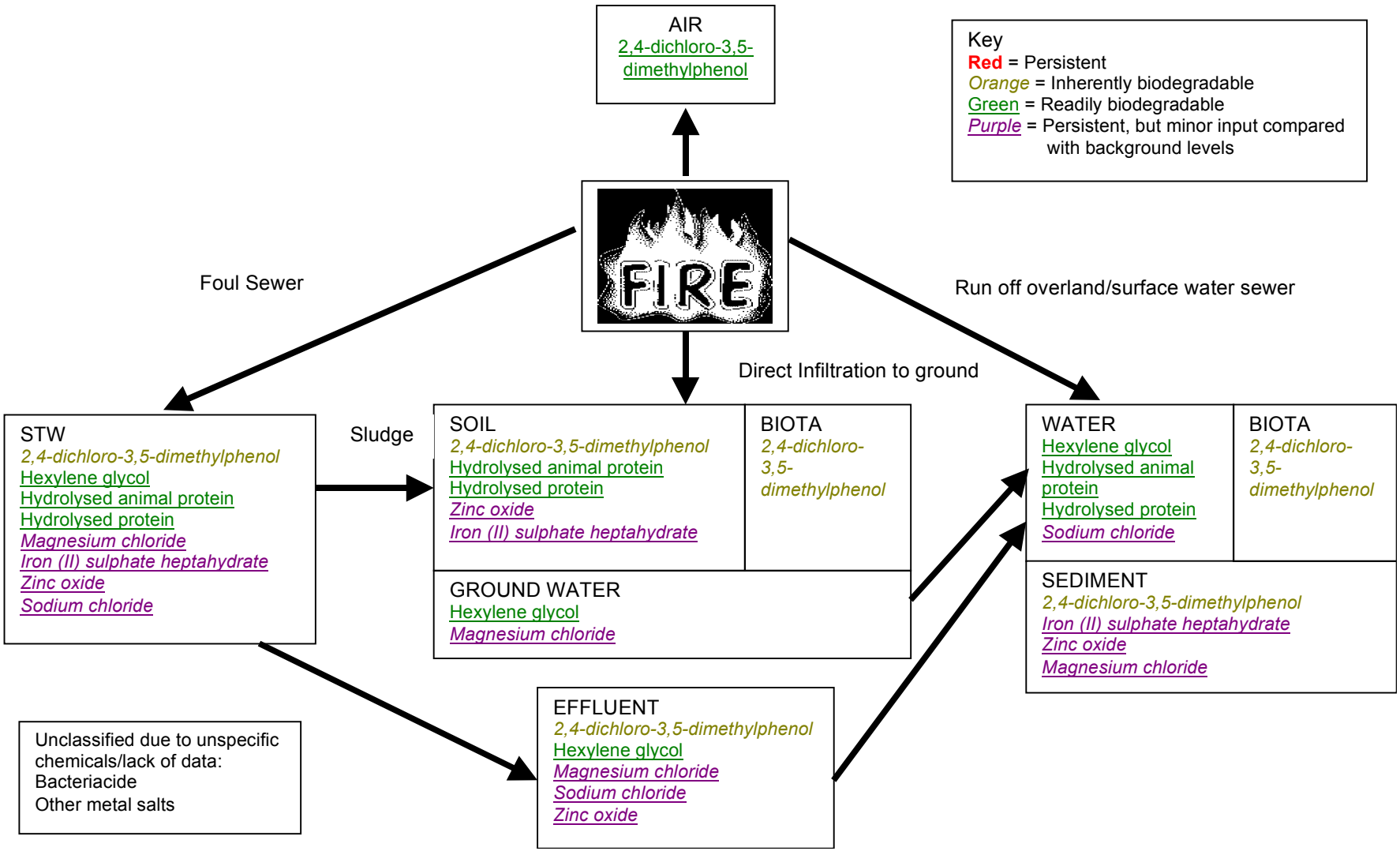


Figure 3.4 Environmental pathways of FP foam constituents

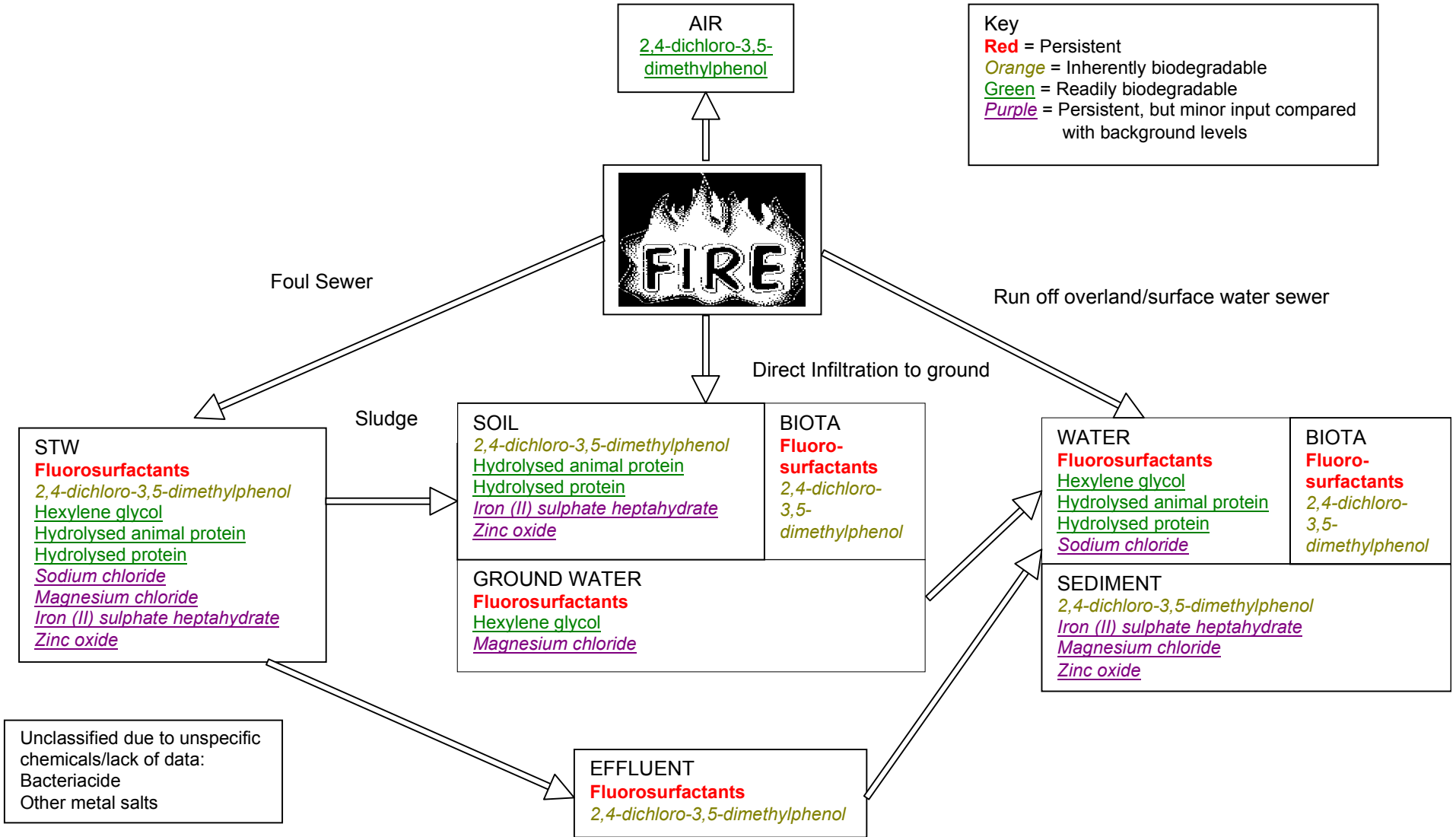


Figure 3.5 Environmental pathways of FFFP foam constituents

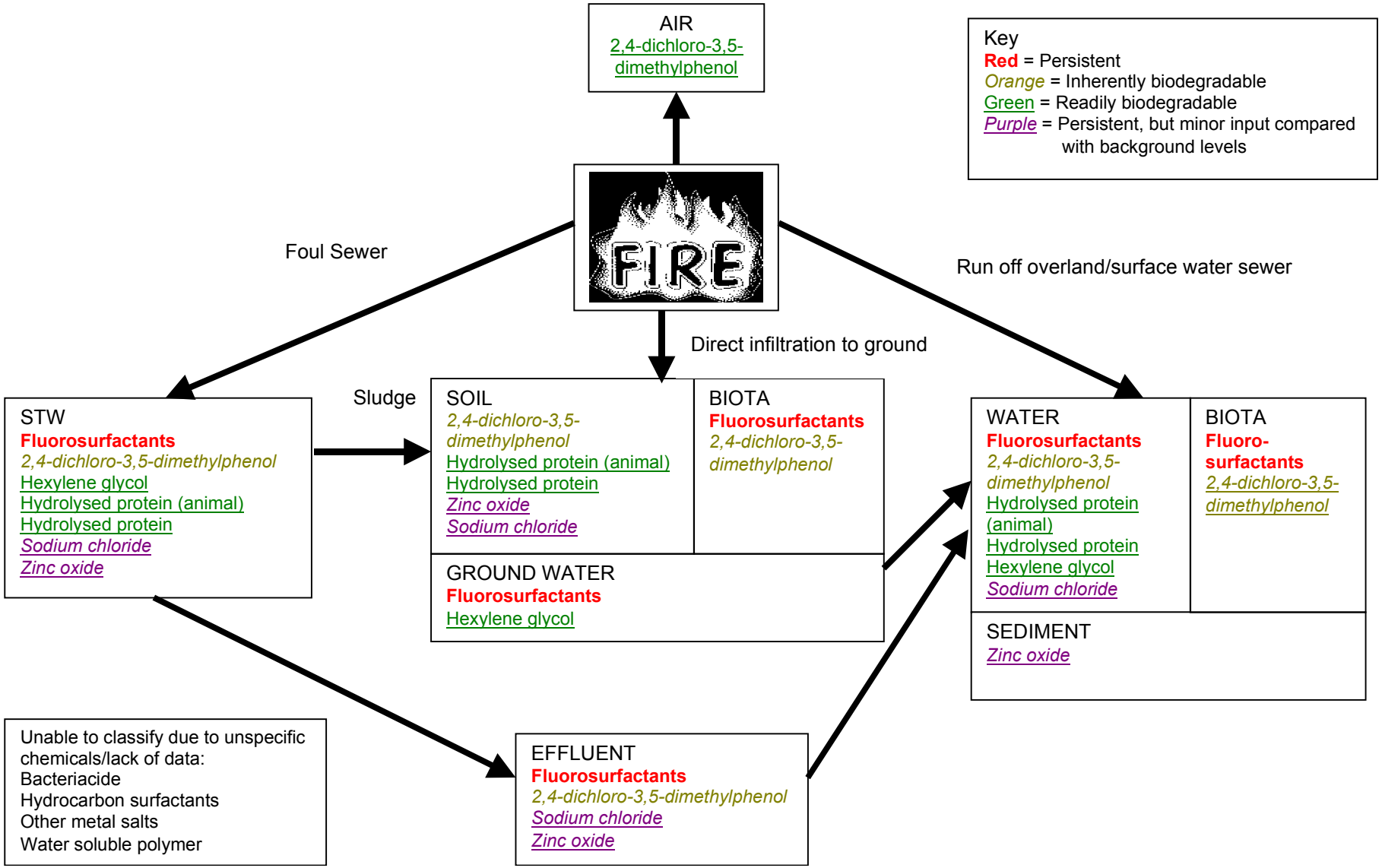


Figure 3.6 Environmental pathways of FFFP-AR foam constituents

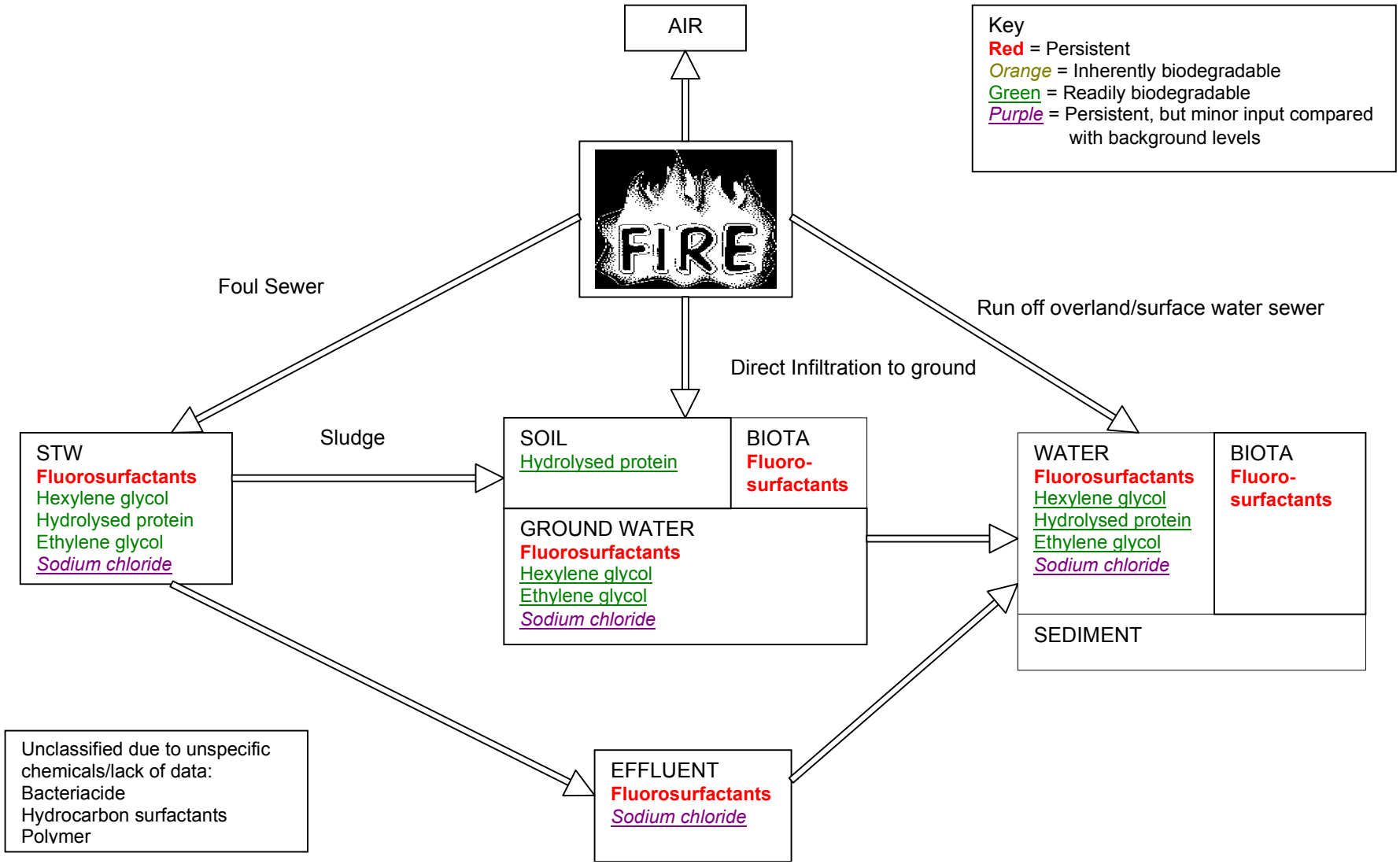


Figure 3.7 Environmental pathways of AFFF foam constituents

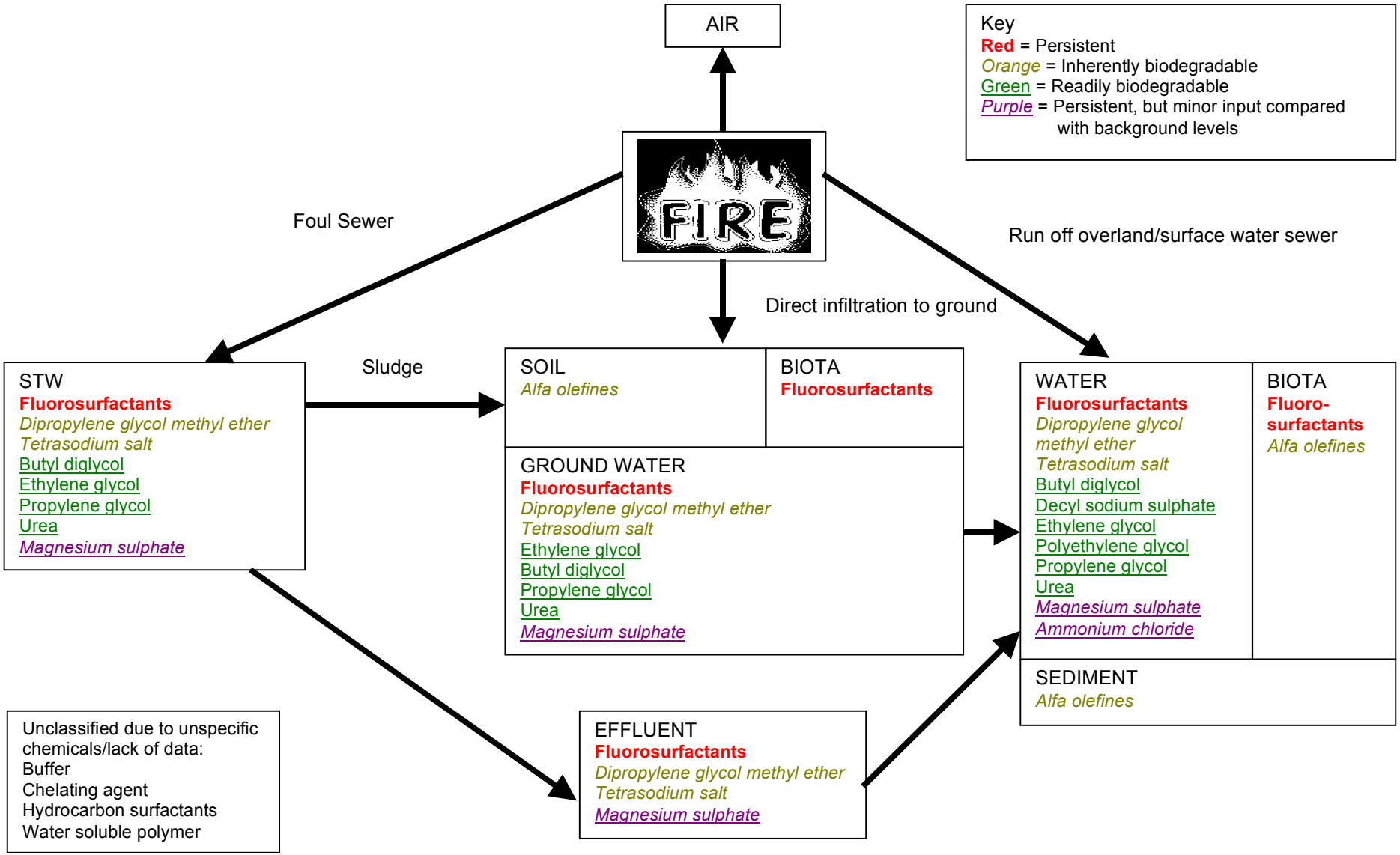


Figure 3.8 Environmental pathways of AFFF-AR foam constituents

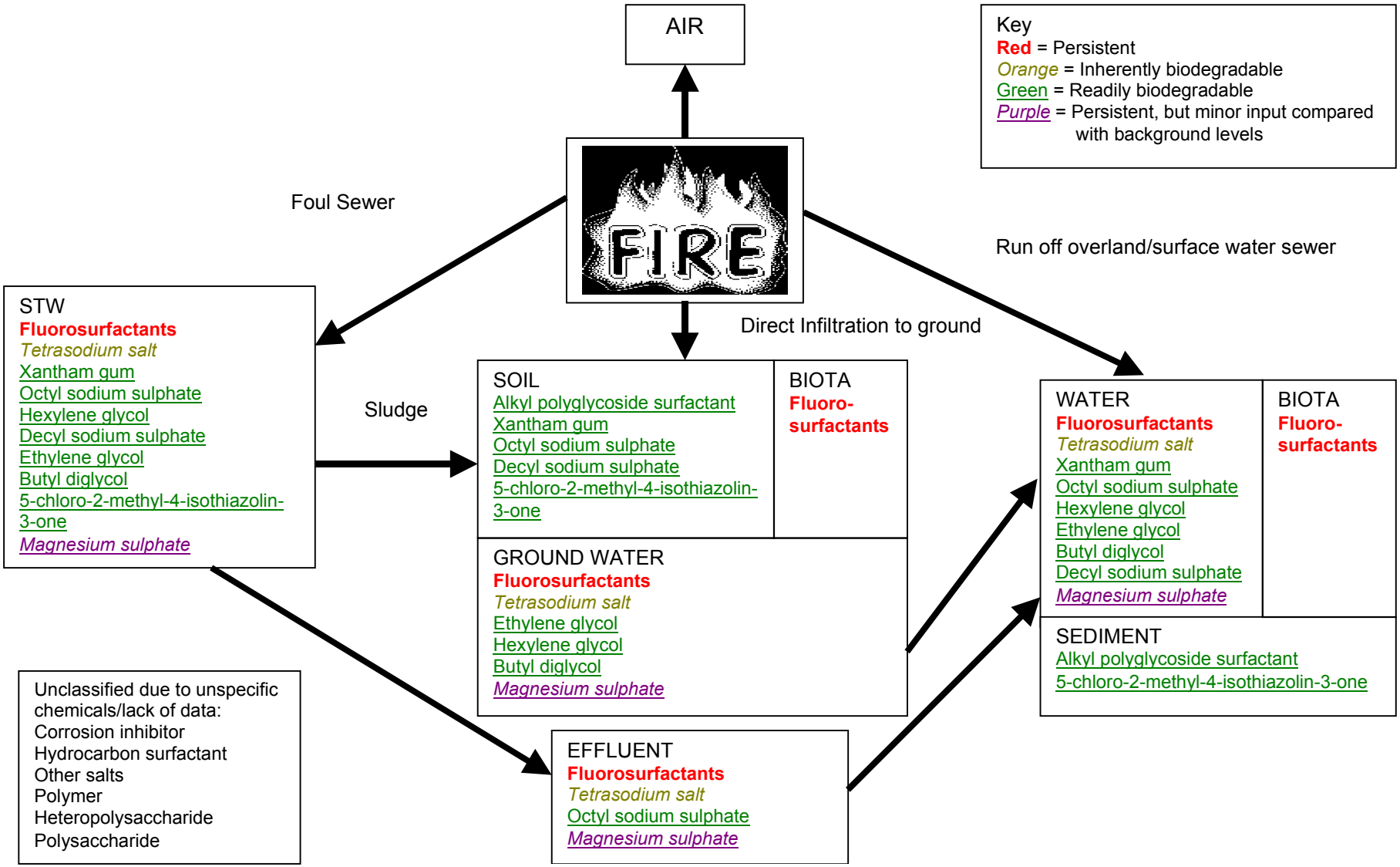


Figure 3.9 Environmental pathways of Hazmat foam constituents

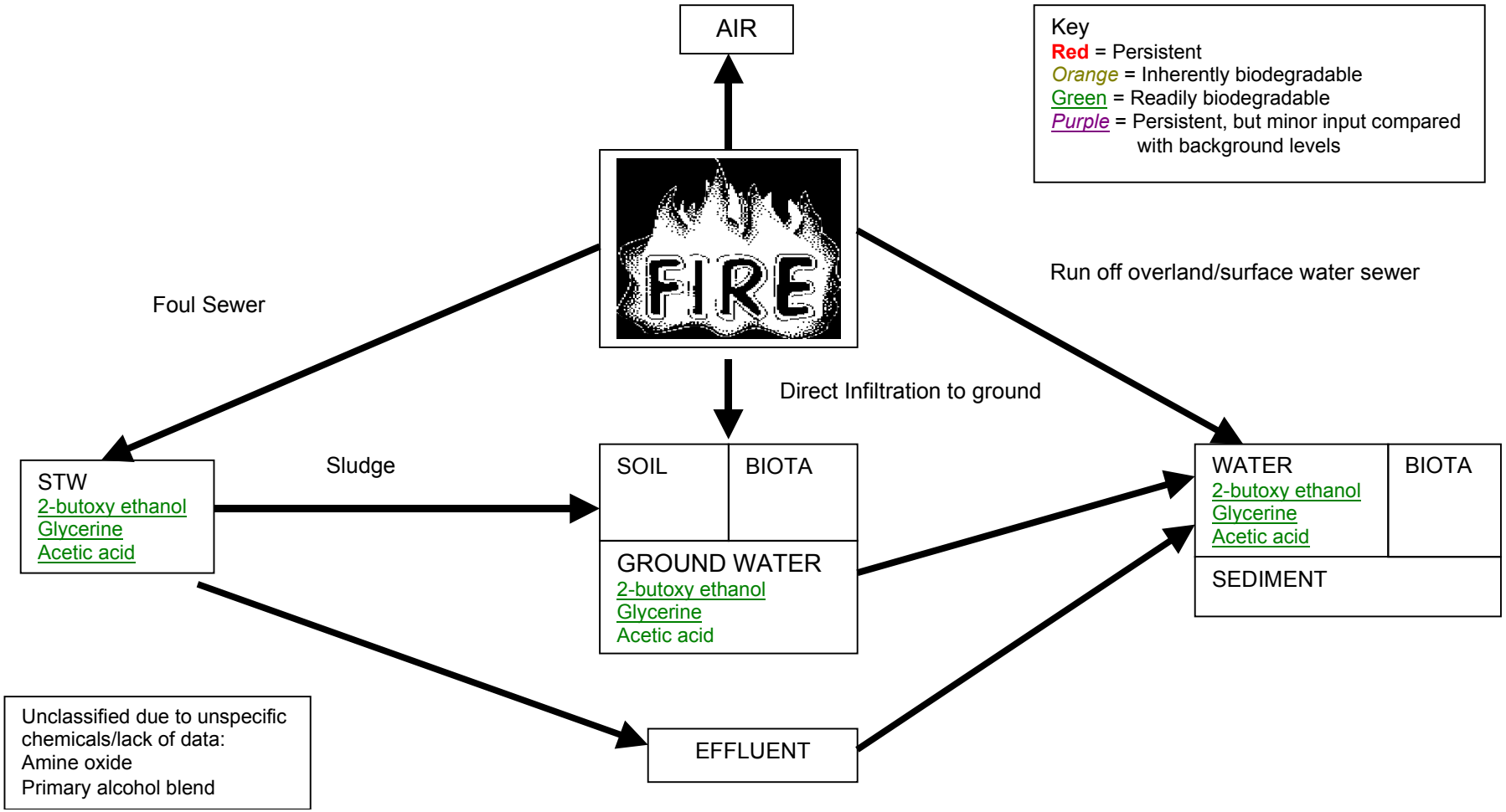


Figure 3.10 Environmental pathways of training foam constituents

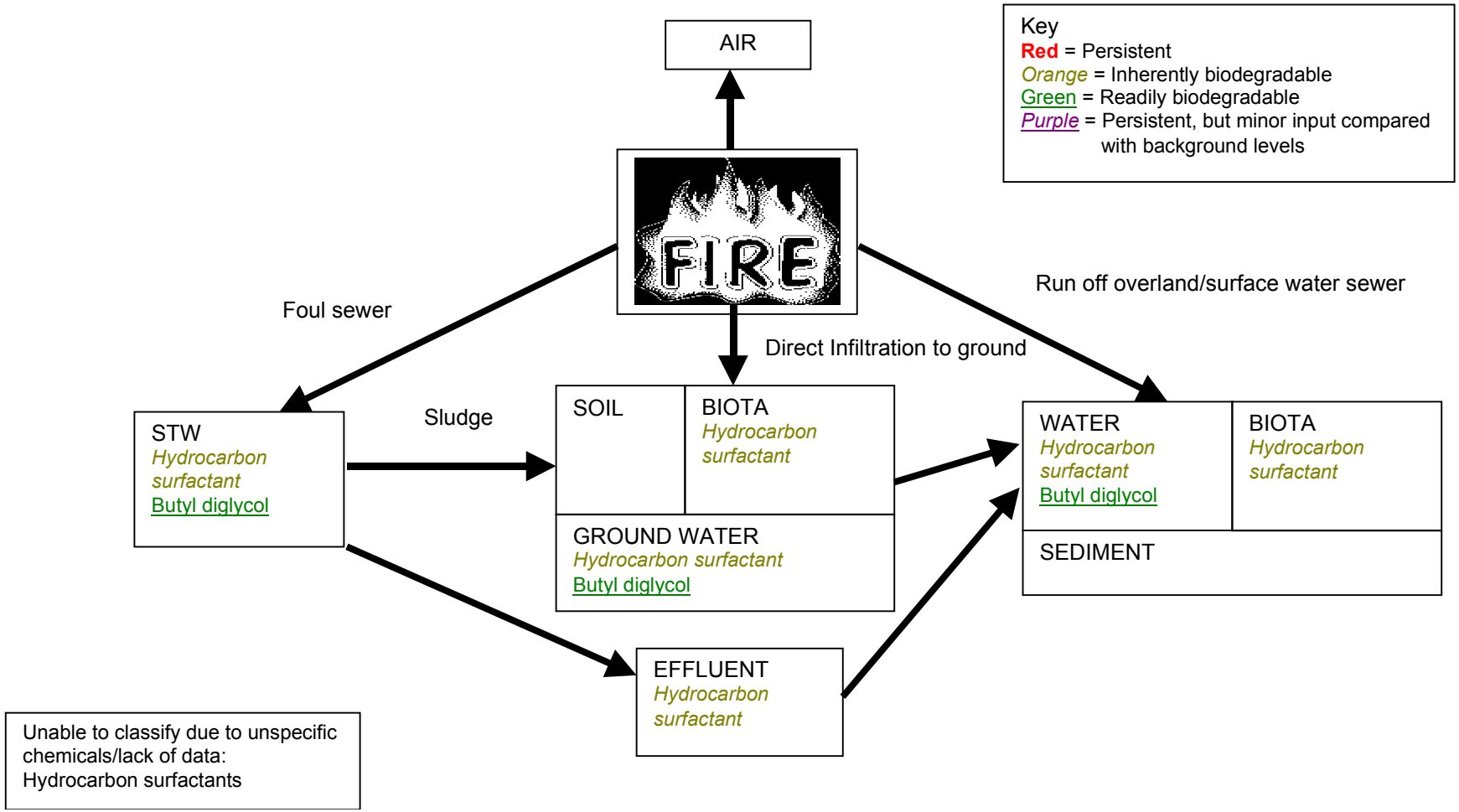


Figure 3.11 Environmental pathways of SYNDET (high expansion) foam constituents

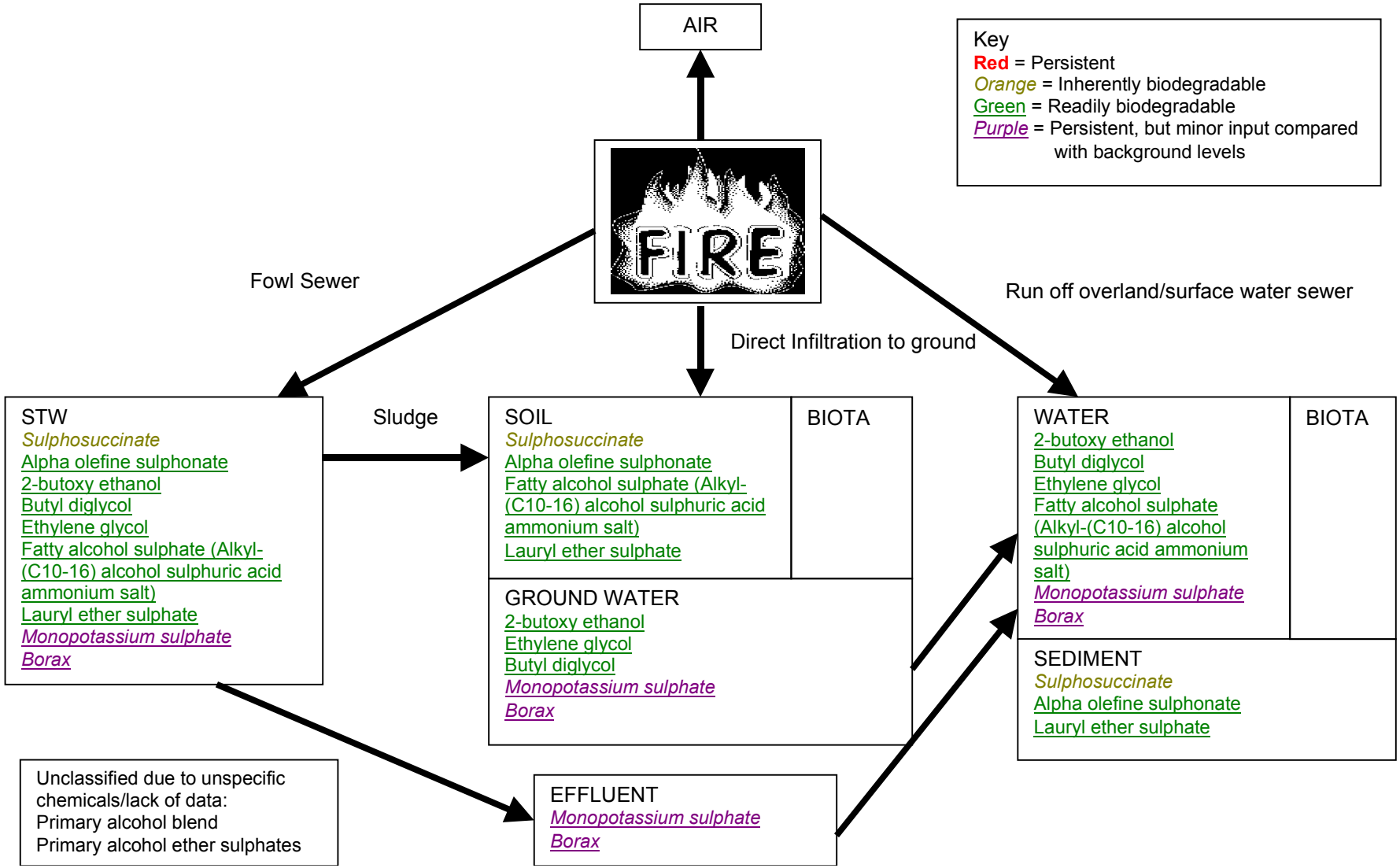
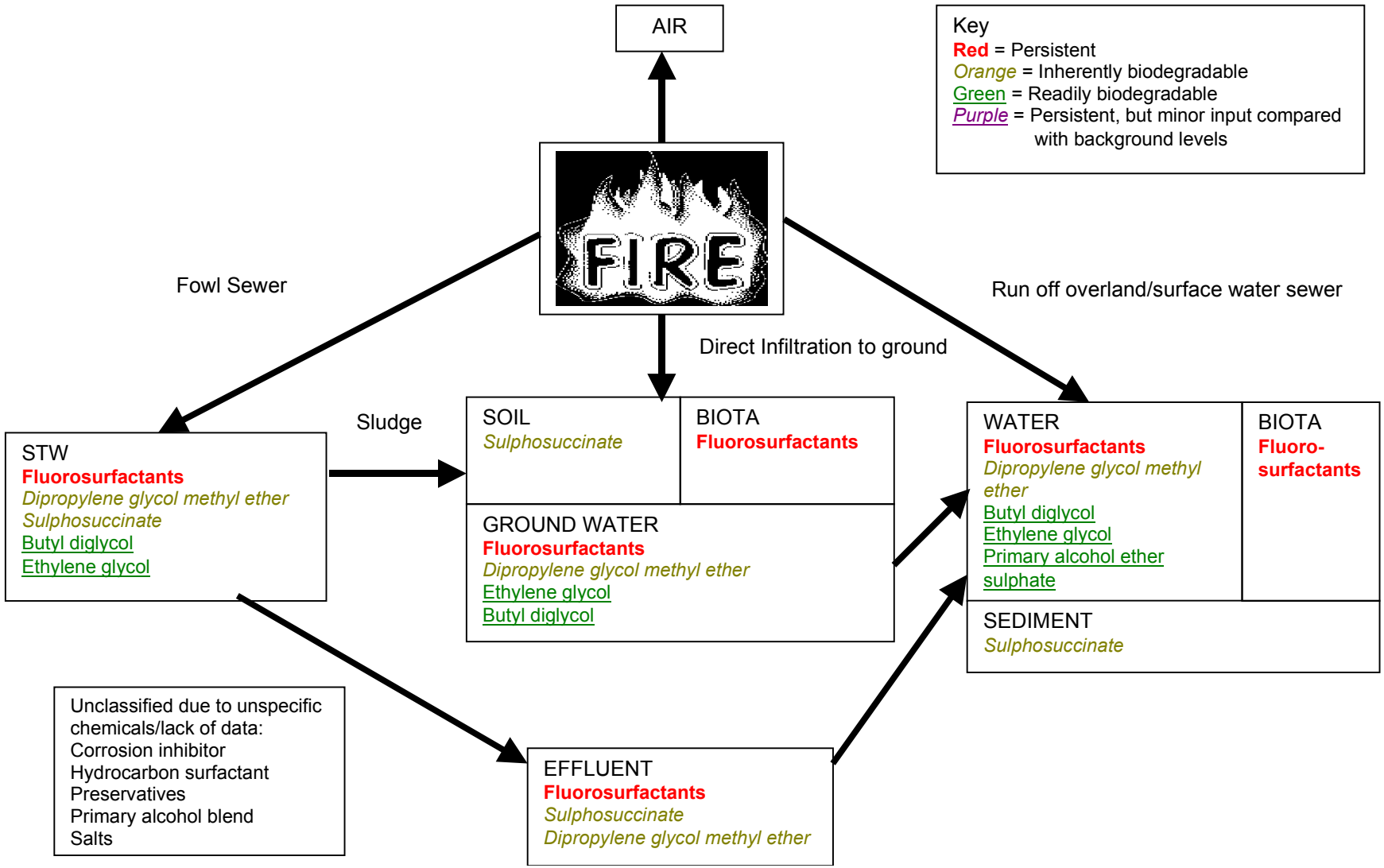


Figure 3.12 Environmental pathways of class A foam constituents



3.4 Summary and Discussion

3.4.1 Foam Products

The aim of this chapter was to assess the environmental impacts of fire fighting foams in terms of their toxicity, persistence, bioaccumulation, biodegradation and fate and where possible prioritise the foams based on this data. However, a comprehensive assessment and prioritisation of the foams has not been possible due to a lack of relevant environmental data. In fact the only data that could be located for fire fighting foams and their constituents came from publicly available MSDSs downloaded from manufacturers web sites. However, the quality and comprehensiveness of these data sources varied considerably.

According to the foam concentrate toxicity data in the MSDSs these products appear to be of low acute aquatic toxicity. Only Synthetic Detergent foams had moderate toxicity to aquatic species. However, the environmental relevance of these data are questionable as they relate to the foam concentrate, as sold, and not to the finished foam as applied in fire fighting or training situations. Therefore, they only give an indication of the toxicity of a spill of the foam concentrate and not the finished foam. Fire fighting foams are far more likely to enter the environment in fire fighting and training situations, where the products are released as finished foams and the concentrate is much diluted. Consequently, it is expected that the toxicity of the finished foams will be reduced due to these high dilution rates. However, without specific toxicity data for the finished foams it is not possible to establish the toxic risk posed by finished foams as used in operational situations.

No chronic toxicity data were available in the MSDSs for the foam concentrates. Consequently, it was not possible to evaluate the long-term effects of fire fighting foam concentrates.

Very little relevant physical and chemical data were presented in the MSDSs with which to evaluate the fate of foam concentrates. The only fate information available related to the biodegradation of foam concentrates. The data indicated that most fire fighting foam concentrates would not be regarded as readily biodegradable according to the CHIP classification (HSE, 1994), as they do not achieve a BOD/COD ratio of >50% within 5 days. However, most of them do undergo appreciable biodegradation (60-100%) over 28 days indicating reasonable and gradual biodegradation. Consequently these foams would not be expected to be highly persistent in the aquatic environment. However, 11 of the foams were reported as readily biodegradable with BOD/COD ratios of >50% after 5 days. These foams may pose a threat to the environment because they degrade so rapidly that they could strip water of its oxygen and possibly asphyxiate the resident aquatic organisms.

It is important to note that all the available biodegradation data relate to foam concentrates and not the finished foam as would be used in operational activities. Finished foams contain far less of the concentrate and its constituents and as such the environmental impact of the concentrate will be greatly reduced. However, effects of rapid oxygen depletion, due to biodegradation of these chemicals, may still occur, particularly under conditions of low dilution and flow rate in receiving waters.

Also biodegradation tests are designed to measure the biodegradation of the major components of foam and they do not take into account minor components, particularly non-biodegradable components such as fluorosurfactants. Therefore, although a foam product may be reported as biodegradable in tests a proportion of the foam will not degrade and will persist in the environment e.g. metals and fluorosurfactants.

3.4.2 Foam Constituents

The MSDSs do not contain data that are specific or comprehensive enough to properly evaluate the environmental impact of fire fighting foam products. Consequently, an attempt was made to investigate the fate and effects of the constituents of the foams in the hope that these data could provide insight into the environmental impacts of the foam products in which they are contained. Chemical constituent lists were taken from manufacturers MSDSs, but like the product concentrate data the information supplied on specific chemical constituents and proportions were sometimes incomplete. As such it was not always possible to collect all the environmental data needed for the constituents because the details of the exact chemical component used in the foams were often too vague.

Environmental data collected for specific chemicals highlighted by the MSDSs indicate that unlike the parent foam products a number of the constituents of the foams are toxic, persistent and possibly bioaccumulative. The toxicity data for the specific chemical constituents of foams indicate that a number of fire fighting foam ingredients are of moderate to high aquatic toxicity. The anionic surfactants, biocides and the metal salts are of concern due to their high toxicities compared to other foam ingredients. Analysis of the available information on the fate and persistence of fire fighting foams constituents has highlighted that foam ingredients are likely to partition to all the major environmental compartments. Five chemicals/chemical groups are expected to be highly persistent and if they are present in sufficient concentrations may pose a prolonged threat to biota (fluorosurfactants, sulphosuccinates, dipropylene glycol ethyl ether, tetrasodium salt and 2,4-dichloro-3,5-dimethylphenol).

Therefore, there appears to be a discrepancy between the general low toxicity and biodegradability (disregarding the possible acute effects of oxygen depletion due to high BODs) of fire fighting foam products and the high toxicity and persistence of a number of the foam constituents (e.g. fluorosurfactants, metals, anionic surfactants, biocides). The apparent discrepancy between the properties of the constituents and those of the products is most likely to be due to the fact that many of the hazardous (toxic, persistent and bioaccumulative) components of fire fighting foams are present in low concentrations. For example zinc salts are reported to make up <1% of fire fighting foam concentrates, once the concentrate has been diluted to its operational concentration, which may be by up to 99 times for a 1% concentrate, the zinc salts will only be present at <0.01%. Depending on the volume of water to which the finished foam is released in the environment the final proportion of zinc is likely to be very low and may possibly be below toxic concentrations.

However, if these minor constituents persist and/or bioaccumulate (accumulates in the bodies of organisms), like metals and fluorosurfactants, they may have a long-term effect on the environment even after the cessation of fire fighting operations. In such circumstances the constituents of foams may pose a chronic threat to aquatic organisms.

3.4.3 Prioritisation of foams and constituents

Using the toxicity and fate data collected for the foam constituents an attempt was made to prioritise the constituents in terms of their environmental risk. It was hoped that by ranking the constituents in terms of their environmental risk, the foam products could also be prioritised by the presence and proportions of their persistent, bioaccumulative and toxic (PBT) constituents.

Of the 50 or so constituents typically contained in fire fighting foams there were only ten substances for which some PBT data were available. Only four substances actually had complete PBT data sets (5-chloro-2-methyl-4-isothiazolin-3-one, ethylene glycol, glacial acetic acid and urea). However, none of these constituents possessed PBT properties that would indicate high priority for environmental concern.

Consequently, it was not possible to prioritise either the foam constituents or their parent products based on the available data. However, it should be noted that due to the lack of PBT data in the literature and particularly the lack of specific chemical information in the MSDSs. a number of the constituents of fire fighting foams may have the potential to be hazardous to the environment. This is highlighted by the fact that with the current available information even fluorosurfactants, of which individual perfluorinated compounds are known to be persistence and bioaccumulative, cannot be singled out as a priority. Therefore, until specific data on these chemicals is available it is reasonable to apply the precautionary principle and assume that those chemicals without data are potentially hazardous.

3.4.4 Data gaps

In this chapter we have tried to evaluate the environmental impacts of fire fighting foams and their constituents. The data have indicated that some foam products may have a negative impact on the aquatic environment due to oxygen depletion through rapid biodegradation and that a number of the constituents of foams could pose a hazard as they are toxic, persistent and/or bioaccumulative. However, it has not been possible to adequately evaluate the risk posed by all of these compounds due to a lack of specific, high quality and particularly comprehensive data.

The lack of PBT data for the majority of the constituents of fire fighting foams, which include corrosion inhibitors, alcohol blends, preservatives, surfactants and metal salts to name a few, does not mean that these chemicals are benign. The lack of information and subsequent uncertainty about the risk that they pose highlights these chemicals for further research and evaluation. In order to evaluate the potential environmental impacts of the constituents of fire fighting foams and subsequently the parent foam products further data needs to be collected or possibly generated for their toxicity, persistence and bioaccumulation and fate. In the meantime an alternative may be to apply a precautionary approach and assume that all constituents with data gaps have high P, B or T and base a prioritisation on this data.

3.5 Recommendations

- There is a need for chronic toxicity data for fire fighting foam concentrates, so that the long-term effects of these chemicals can be assessed.
- There is a need for acute and chronic toxicity data for finished foams, as opposed to foam concentrates, so that the toxic effects of the foams, as they would be used operationally in fire fighting and training situations, can be assessed.
- It would be useful to have biodegradation and BOD data for finished foams, in order to assess their potential for oxygen depletion in the aquatic environment.
- A ranking of foam constituents and subsequently foam products needs to be carried out so that fire fighting foams can be prioritised in terms of their potential environmental risk.
- In order to do this, there needs to be more detailed constituent information on the exact chemical ingredients of foams, their fate and effects and if possible the proportions present in the product. Until this information becomes it is reasonable to apply the precautionary principle and assume that all chemicals with data gaps have high P, B or T and prioritise foams on this basis.
- There is also a need for data to be collected or possibly generated for constituent toxicity, persistence and bioaccumulation and fate.

3.6 Key points – Section 3

- In general fire fighting foam concentrates appear to be of low aquatic toxicity. However, Synthetic Detergent foams are of moderate toxicity with effects occurring at concentrations below 100 mg/l.

- The toxicity data in the MSDSs relate to the concentrate as sold and not as the finished foam. Consequently, it is expected that the toxicity of the finished foams will be reduced due to dilution of the concentrate in the finished foams. However, without specific toxicity data for the final foam solutions it is not possible to establish the toxic risk posed by finished foams as used in operational situations.

- Most fire fighting foam concentrates would not be regarded as readily biodegradable according to the CHIP classification. However, the majority of foams do biodegrade within 28 days. The slow and gradual biodegradation of these foams is an advantage as they are less likely to have a negative impact on the aquatic environment in term of rapid oxygen depletion.

- Eleven of the foams were reported as readily biodegradable with BOD/COD ratios of >50% after 5 days. However, these foams may pose a threat to the environment because they degrade so rapidly that they could strip water of its oxygen and possibly asphyxiate resident aquatic organisms

- Environmental data collected for specific chemicals highlighted by the MSDSs indicate that unlike the parent foam products a number of the constituents of the foams are toxic, persistent and possibly bioaccumulative.

- The anionic surfactants, biocides and the metal salts are of particular concern due to their high toxicities when compared to other constituents. However, they are present at such low levels in the foam concentrates their toxicity is likely to be reduced when released as part of the finished foam products.

- Of the constituents of the fire fighting foams, fluorosurfactants are the main environmental concern in terms of fate and persistence. Sulphosuccinates, dipropylene glycol methyl ether., 2,4-dichloro-3,5-dimethylphenol were also highlighted as being moderately persistent in the environment.

- The apparent discrepancy between the properties of the constituents and those of the products is most likely to be due to the fact that many of the hazardous (toxic, persistent and bioaccumulative) components of fire fighting foams are present in low concentrations. However, if these minor constituents are persistent and/or bioaccumulative, like metals and fluorosurfactants, they may have a long-term effect on the environment even after the cessation of fire fighting operations.

- A prioritisation of the foam constituents could not be achieved due to a lack of specific information on chemical constituents and their properties.

4. ENVIRONMENTAL RISK OF FLUOROSURFACTANTS

4.1 Introduction

This chapter concentrates solely on one group of ingredients used in fire fighting foams, fluorosurfactants. Fluorosurfactants, and in particular their degradation products, have recently been identified as substances of concern by international bodies such as OSPAR and the USEPA, owing to their persistence, bioaccumulation potential and toxicity.

Fluoro-organic chemicals are chemicals with one or more carbon–fluorine (C-F) bond. This bond provides the molecule with excellent chemical and thermal stability as it is very short, and very strong. Surfactants are molecules that contain a lipophilic (fat loving) group at one end and hydrophilic (water loving) group at the other providing the compound with its surface-active properties. Fluorosurfactants are hydrocarbon surfactants in which hydrogen atoms are replaced by fluorine. As a result of this they tend to reduce surface tension better than other purely hydrocarbon-based surfactants. There are thousands of existing chemicals that fall under the definition of fluorosurfactant. Within the fluorosurfactant group there are a number of sub-groups: amphoteric, non-ionic, cationic and anionic groups.

In perfluorinated chemicals, all of the C-H bonds are replaced by C-F bonds (Dams, 1992; Kissa, 1994). Perfluorosurfactants possess the unique properties of being able to repel water and oil (hence their stain repellent properties, utilised in products such as 'Scotchguard').

Perfluoroctyl sulphonates ($C_8F_{17}SO_3^-$) contain a reactive sulphonyl group, which provides a link to other functional groups such as free acids, metal salts, sulphonyl halides and sulphonamides. These functional groups provide the hydrophilic (water loving) properties of the surfactant. Perfluoroctyl sulphonate surfactants degrade in the environment, with the water loving, hydrophilic group being removed from the lipophilic, fat loving stem. This leaves the residual, very persistent perfluoroctyl sulphonate ($C_8F_{17}SO_3^-$) other wise known as PFOS, available to bioaccumulate and exert toxicity in the environment. .

Two main groups of perfluorinated degradation products exist in the environment (Figure 6.1), PFOS from surfactants generated using the electrochemical fluorination process, and perfluorinated octanoic acids (PFOA) generated from an alternative production process known as telomerisation (see section 4.2).

Figure 4.1 Structure of perfluorooctanyl sulphonate (PFOS), which is one of the main degradation product of fluorosurfactants generated by the 3M, electrochemical fluorination process

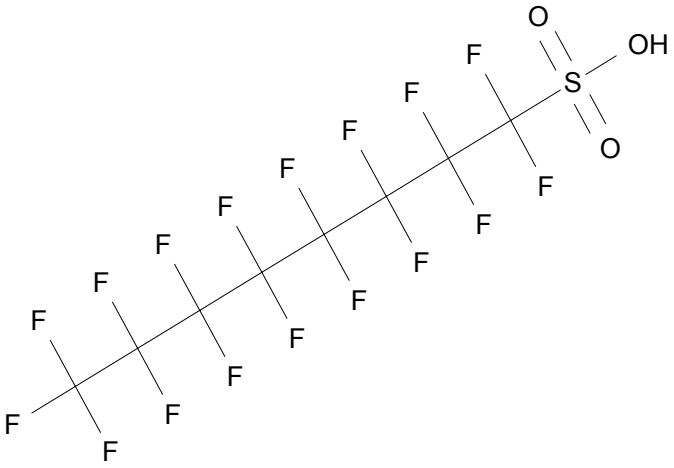
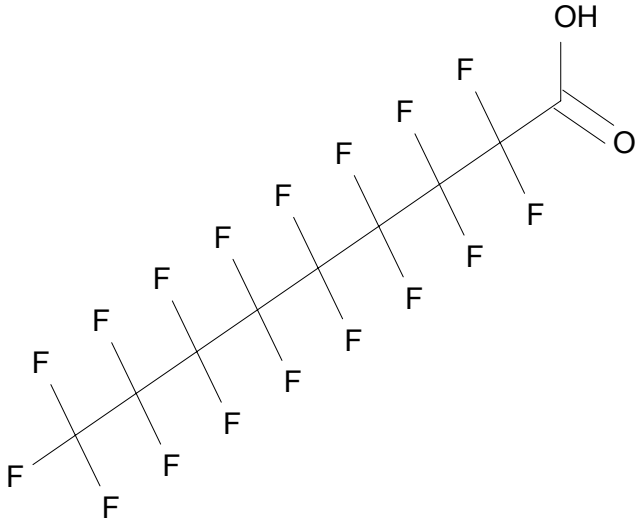


Figure 4.2 Structure of perfluorooctanoic acid (PFOA), which is one of the main degradation products of fluorosurfactants generated by the telomeration process



For most applications (e.g. fire-fighting foams, fabric treatment) perfluorinated surfactants are the preferred chemicals as they possess the most enhanced surface-active and physico-chemical properties (e.g. thermal and chemical stability). However, partially fluorinated surfactants can be used in certain circumstances and also exist as impurities in perfluorinated compounds. Historically, PFOS-based surfactants have been the main fluorosurfactants used in commercial applications. However, with 3M ceasing production of these surfactants perfluorinated surfactants with other functional groups are likely to predominate in the future.

As scientists have discovered that certain organic compounds persist in the environment (particularly halogenated ones) increasing interest has been focused on perfluorinated chemicals. This lead to the reporting of widespread contamination of human tissue by fluoro-compounds derived from commercial products in 1976 (Guy and Taves, 1976). Concerns about accumulation and chronic toxicity have lead 3M; the principal manufacturer of perfluorosulphonated compounds via electrochemical fluorination; to announce in May 2000 that it would phase out production (see below). Other producers using different production methods (e.g. telomerisation – see section 4.2) also generate perfluorinated surfactants (e.g. with alcohol hydrophilic end-groups) which lack the potentially bioaccumulating sulphonyl moiety. These fluorosurfactants are often interchangeable with PFOS-type surfactants in applications and are now replacing them in products such as fire-fighting foams. However, perfluoroalkylated surfactants are also likely to degrade to potentially persistent perfluorinated alkyl compounds (e.g. PFOA) in the environment and so regulators need to assess the risk.

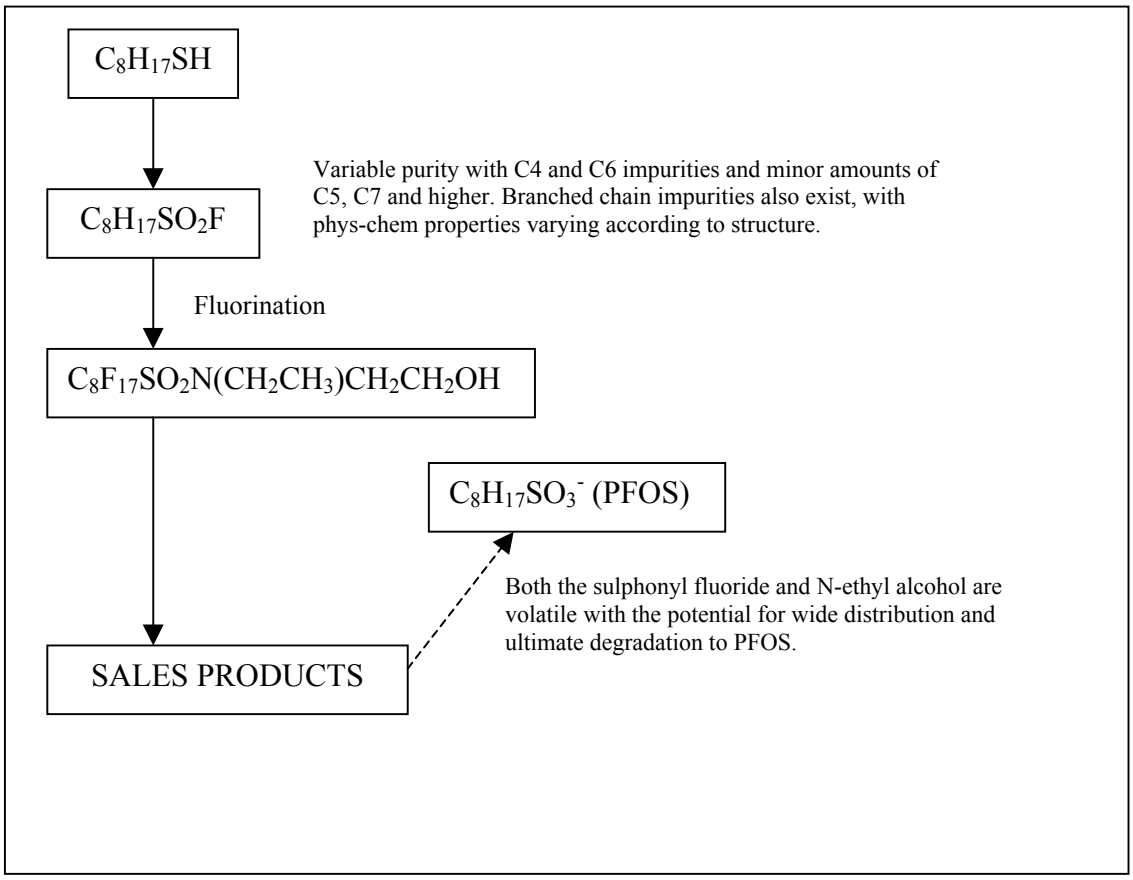
The concerns regarding PFOS has lead to a number of toxicity studies being carried out and a certain amount of environmental monitoring. Currently there is little known data on the sources, concentrations and toxicity of other (non-sulphonyl containing) perfluoroalkylated surfactants and their breakdown products. However, the heightened concern about perfluorinated chemicals in general is likely to also lead to their replacement in products in future years (including fire fighting foams).

The persistence, bioaccumulation properties and toxicity of perfluorinated sulphonate surfactants, in particular, are currently of concern to regulators. This review will therefore concentrate on perfluoro sulphonyl-based surfactants, their likely replacements and their breakdown products. The principal sources of data used have been recent scientific papers, books (e.g. Kissa, 1994, 2001) and reports (e.g. Fisk, 2001; Hekster *et al*., 2002; USEPA, 2002 & OECD, 2002). It is highly recommended that the reader draw on these documents for background information.

4.2 Production

Two main production methods have been used to generate fluorinated compounds. Electrochemical fluorination (Figure 4.3), as used by 3M, which produces PFOS breakdown products from the fluorosurfactants formed; and telomerisation which produces predominantly perfluorinated alkyl substances when degraded.

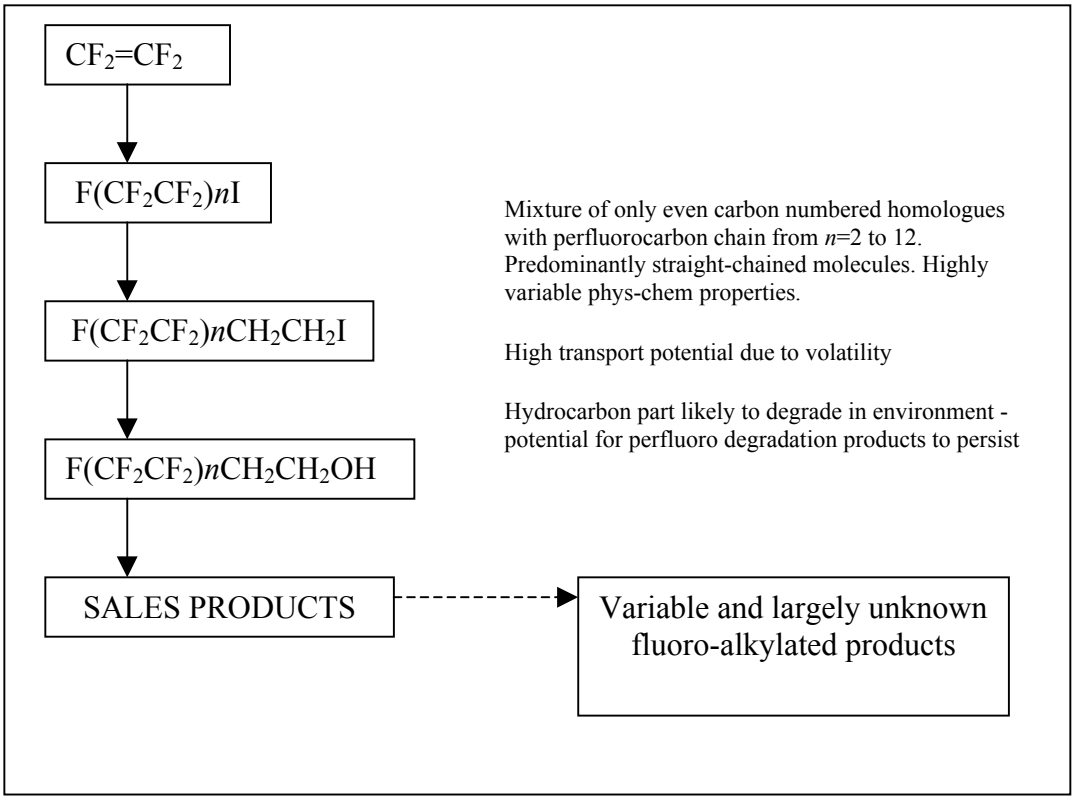
Figure 4.3 Electrochemical Fluorination



EDF:

- Process developed by 3M Gives rise to PFOS when degraded in the environment

Figure 4.4 Telomerisation



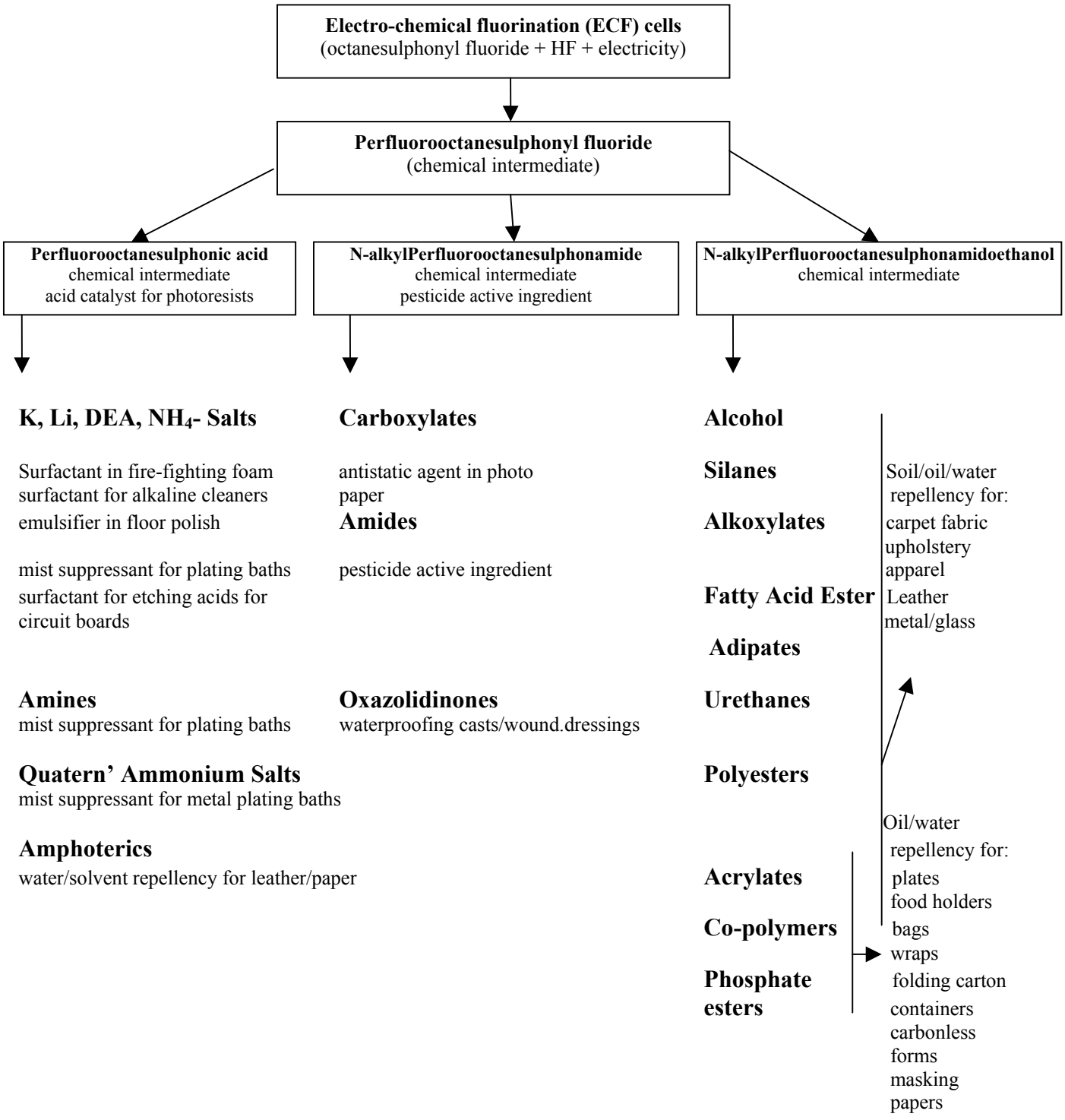
Telomerisation process:

- Used by manufacturers other than 3M, including DuPont
- Breakdown products include perfluorooctanoic acid (PFOA), not PFOS

Telomer alcohol technology is also used but as a minor process, with the main products containing one $–CH_2$ group between the perfluoroalkyl group and hydroxyl group and carry a terminal hydrogen atom..

Historically, the major product categories for perfluorooctyl sulphonates is presented in Figure 4.5.

Figure 4.5 Perfluorooctyl sulphonates - major product categories (PFOS risk assessment, 2001)



With perfluorosulphonyl compounds being phased out of production, it likely that perfluorinated surfactants generated via the telomer process will substitute the ones in the above figure.

4.3 Physico-chemical properties

The perfluorooctane sulphonate anion does not have a specific CAS number, the salts however, have the following CAS numbers (Table 4.1).

Table 4.1 Perfluorooctane sulphonate acids and salts

Perfluorooctane sulphonate acid or salt	CAS Number
Acid	1763-23-1
Ammonium salt	29081-56-9
Diethanolamine (DEA) salt	70225-14-8
Potassium salt	2795-39-3
Lithium salt	29457-72-5

Other perfluorinated chemicals that are on the OSPAR list of chemicals of possible concern and/or are in the EU database of existing substances (IUCLID) as a medium production volume (annual production/import tonnage of 10-100 tonnes) are presented in Table 4.2.

Table 4.2 Perfluorinated chemicals in the OSPAR list of chemicals of possible concern and/or the EU database of existing substances (IUCLID)

Perfluoroalkylated surfactants	**CAS No.**
Octanoic acid, pentadecafluoro-, ammonium salt	3825-26-1
1-Octanesulphonamide, N-[3-(dimethylamino)propyl]-heptadecafluoro-	13417-01-1
2-Propenoic acid,2-[[(heptadecafluorooctyl)sulphonyl]methylamino]ethyl ester	25268-77-3
1-Octanesulphonamide,N-ethyl-heptadecafluoro-N-[2-(phosphonooxy)ethyl]-diammonium salt	67969-69-1
Octanoic acid, pentadecafluoro-	335-67-1
1-Butanesulphonyl fluoride, -nonafluoro-	375-72-4
1-Hexanesulphonyl fluoride, -tridecafluoro-	423-50-7
1-Octanesulphonic acid,-heptadecafluoro-, potassium salt	2795-39-3
Glycine, N-ethyl-N-[(heptadecafluorooctyl)sulphonyl]-, potassium salt	2991-51-7
1-Octanesulphonamide, N-ethyl-heptadecafluoro-N-(2-hydroxyethyl-)	1691-99-2
Other Perfluoroalkylated substances	
Octane, octadecafluoro-	307-34-6
Furan, 2,2,3,3,4,4,5-heptafluorotetrahydro-5-(nonafluorobutyl)-	335-36-4
Heptane, hexadecafluoro-	335-36-4
Hexane, tetradecafluoro-	335-42-0
Hexane, tridecafluoro-6-iodo	355-43-1
Octane, -heptadecafluoro-8-iodo-	507-63-1
Pentane, dodecafluoro-8-iodo	678-26-2

The MSDSs supplied with fire fighting foams do not specify which fluorosurfactant are used as constituents.

When fluorine is a constituent in organic compounds, unique chemical properties are observed due to the electronegativity of fluorine and the overlap between the 2s and 2p orbitals of fluorine and carbon (Kissa, 1994; Hudlicky and Pavlath, 1995). The presence of fluorine atoms contributes to the rigidity of perfluorocarbon chains (Key *et al*., 1997) relative to hydrocarbon chains. The highly polarised C-F bond is the strongest known covalent bond (Kissa, 1994). All the above give the molecules their chemical and thermal properties which make them such popular speciality chemicals.

Due to the surface-active properties of most of these perfluorinated alkylated surfactants (including PFOS) an octanol:water partition coefficient (log Kow) cannot be determined. Consequently, the various physico-chemical properties (e.g. organic carbon:water partition coefficient – log Koc, bioconcentration factor) which are often calculated using the log Kow value, cannot be estimated.

Data available for PFOS, reviewed by the OECD is presented in Table 4.3.

Table 4.3 Physico-chemical data summary for PFOS (K-salt) taken from Fisk, 2001

	System	Protocol	Results
Melting point		OECD 102	>400^{o}C
Boiling point			N/A
Density			No test
Vapour pressure	Spinning rotor gauge		3.3 x 10^{-4} Pa (whole substance).
Kow	Shake-flask	OECD 104	No reliable data.
Solubility	Shake-flask	Preliminary test only	519 mg/l
pH/pKa		OECD 105	The sulphonic acid is a strong acid, and ionisation is complete at all relevant pH values.
Oxidation/reduction potential	No test		The sulphonate group is fully oxidised, stable in respect of reduction.
Photo-degradation	Aqueous solution, solar simulation	No standard available	Non-reactive
Stability in water			Non-reactive, on the basis of no observed degradation in many aqueous studies.
Transport and distribution		N/A	Reported Koc of 66 is of low reliability. Fugacity modelling, suggests typically 80% in water, 20% in soil/sediment.
Biodegradation	Various, non-standard study designs	Non-standard	Non-biodegradable
Bioaccumulation	Non-standard (field measurements for fish from contaminated lake	Non-standard	6300-125000 for PFOS (Moody *et al*., 2002)

4.4 Use

Fluorocarbon surfactants cost significantly more to produce than their hydrocarbon equivalents, and so are used as speciality chemicals at low concentrations. Perfluorinated compounds have been used since the 1950s in soil- and stain resistant coatings for fabrics, carpets, and leather, as well as in grease- and oil resistant coatings for paper products. These uses accounted for approximately 2500 tons (World-wide) of all perfluorinated chemicals used in 2000 (Mabury, 2001). Specialised uses (accounting for *ca*. 700 tones in 2000) include fire-fighting foams; mining and oil well surfactants; acid mist suppressants for metal plating and electronic etching baths; alkaline cleaners; floor polishes; photographic film; denture cleaners; shampoos; and insecticides (Mabury, 2001). The proportion of the 700 tonnes used in fire fighting foams was not stated. Applications are performed at textile mills, leather tanneries, finishers, and carpet manufacturing facilities. The Scotchguard market also allows such treatments in the home. Between 1988 and 1997, the average global consumption of fluorinated polymers rose by almost 220% (Mabury, 2001).

In the UK it has been estimated that around 400 tonnes of perfluorinated compounds were imported in 2000 (Fisk, 2001) for uses including carpet and textile treatment (49%), speciality surfactants (17.5%), paper and board treatment (15%), and fire-fighting chemicals (16%).

Overall there is little specific data available for the actual distribution of perfluorinated substances used in the UK by specific industries (Fisk, 2001), which makes estimations of the amount of these substances and their breakdown products generated from different sources almost impossible.

4.5 Standards & Legislation

4.5.1 Standards

For guidance purposes, a lifetime drinking water health advisory for PFOS, modelled on the USEPA Drinking Water Health Advisory Panel (DWHA), has been developed by the USEPA. It represents the concentration of PFOS in drinking water that is not expected to cause any adverse effects (non-cancerous) over a lifetime of exposure (2l consumption per day – assuming drinking water represents 20% of the total daily exposure to PFOS), with a substantial margin for safety. The draft DWHA is based on a reference dose that was derived using a conservative composite uncertainty factor of 1000 based on the no-observed adverse effect level in a 6 month primate study and supported by a database of human and animal health effects. The derived value of 1 μg/l of PFOS does not represent an absolute value above which health risk is imminent, rather it is a *diminimus* risk level for lifetime exposure for non-cancer effects incorporating a safety margin (USEPA, 2001).

4.5.2 Legislation

The EPA is seeking to bring fully fluorinated alkyl sulphonate-containing compounds having 4-10 carbons under regulatory control (USEPA, 2000), which covers all of the compounds that 3M is phasing out. These compounds have been identified because they:

- Are present in human and animal blood
- Are pesticide active ingredients
- Cause tumours and developmental toxicity in animal studies
- Are metabolites of 38 perfluorinated chemicals satisfying DEBITS criteria

The OECD, with the US as lead co-ordinators, are carrying out a hazard assessment of PFOS and its salts, which will be followed by a risk assessment once the information is available. This will lead to decisions regarding the need for international risk management, although individual countries may act independently.

The Canadian Government required industry to notify it where greater than 100kg were imported or exported between 1997 and 2000. This lead to 182 substances being identified in 22 classes of perfluorinated substances (Fisk, 2001). The Canadian Government requires concentrations, fate, behaviour and toxicity data to be compiled and submitted for all 182 chemicals.

The OSPAR Convention for the Protection of the Marine Environment of the Northeast Atlantic identifies 17 perfluorinated chemicals of priority concern.

4.6 Pathways to the environment

Manufacturing is generally the main source of contaminants to the environment, via aqueous, solid and atmospheric discharges. The phasing out of PFOS-type surfactants by 3M is therefore likely to result in reduction in environmental discharges. However, replacement of PFOS substances in products with other perfluoro-chemicals may still result in other potentially persistent perfluorinated compounds entering, and accumulating in the environment. Given the products that these compounds are used in, sources other than their manufacture includes landfill leachates, atmospheric inputs via combustion and wash-off from the use of fire-fighting foams.

One of the main routes of entry to the environment has been the runoff of fire-fighting foams. At installations such as military bases and commercial airports, fire training exercises are part of emergency preparation plans and, therefore, are conducted frequently and usually in the same place. Weekly use of up to 3200 l of aqueous AFFF (3% - 6%) solutions can be used (Moody and Field, 1999). Wastewater from these exercises may be impounded and treated on-site prior to discharge to sewer (e.g. precipitation, coagulation, adsorption onto activated carbon, Howell and Tucker 1996), or the chemicals may have been historically left to simply soak away into the soil (this practice is now discouraged). Hyperfiltration (filtration by molecular weight) has also been evaluated to remove tetraethylammonium perfluorooctanesulphonate from rinse solutions in the electrochemical plating industry (Staude *et al.*, 1984).

Discharge to sewers can be problematic due to the resistance of the fluorosurfactants to biodegradation. Foaming may also occur at a STW and in its discharge to receiving waters. Additionally, the high percentage of organic solvents and protein substrate used in the foams

can lead to a high biochemical oxygen demand (BOD) in the loads to sewers, which may affect treatment efficiency.

Fluorinated surfactants have unique properties, which makes their presence in products vital. Their potential effect on the environment can be reduced by (a) using synergism with hydrocarbon-type surfactants to minimise the concentration of fluorinated surfactant where feasible and (b), removing fluorinated surfactants from wastewater at industrial sites by adsorption or converting the surfactant by partial biodegradation to less toxic substances.

The fact that:

(1) the perfluorocarbon back bone (with or without a functional group attached) of perfluorinated surfactants is resistant to chemical or biological degradation and;

(2) PFOS, and potentially other perflourinated compounds, are soluble,

means that once discharged to the environment they will find their way into rivers (if not discharged directly) and finally the oceans. Their solubility and stability will also mean that they are likely to pass through sewage treatment works largely undegraded and be discharged in the effluent to receiving waters.

Consequently, perfluorinated chemicals are likely to be abstracted in water used for human consumption. No data is available on the efficiency of water treatment processes to remove perfluorinated surfactants and degradation products. Given that they are chemically inert and also resist photo-oxidation, it is possible that a significant proportion will pass through into the mains supply water. Although there is no supporting evidence, this route being a significant source of perfluorinated chemical exposure in humans, cannot be ruled out.

Direct atmospheric release of perfluorinated surfactants such as PFOS-type (and PFOA-type) ones during production is unlikely as they are not sufficiently volatile (Mabury, 2001). Other sources of perfluorinated chemicals to the environment, and humans, are therefore thought to be from volatile precursors.

4.7 Environmental Concentrations

The greatest attention to date has been focussed on PFOS, as they have been the most popular fluorocarbon surfactants marketed. However, there is still little environmental monitoring data available even for these compounds, with almost none for PFAS. Analytical difficulties have been partially to blame as they are non-volatile and generally do not contain chromophores, which limits their detection using commonly available detectors. Furthermore, the extraction and pre-concentration of perfluorinated surfactants from water is complicated by their high water solubility.

Of the limited data available for environmental concentrations of perfluorinated surfactants, groundwater monitoring near air fields and chemical installations have shown that high levels of PFOS and perfluorinated alkyated substances (PFAS) may occur.

The limited data available for environmental concentrations of PFOS compounds show a wide variation (Table 4.4). Concentrations in surface waters and sediments are generally in the ng/l

and ng/kg range respectively. However, levels may be 4 orders of magnitude higher if waters or sediments are directly downstream of a manufacturing facility or where fire-fighting foam contamination exists. Other than in extremely contaminated areas surface water values for PFOS do not exceed the USEPA advisory limit for drinking water of 1 μg/l (USEPA, 2001). There also seems to be geographic variations in the concentrations of PFOS in biota with, for example, levels in the livers and blood of birds being slightly greater in the USA than other countries (Giesy and Kamman, 2001b). The detection of PFOS substances in the fatty tissue of biota (albeit very low – typically μg/kg), suggests that it may be bioaccumulated, with higher levels generally detected in marine mammals and fish-eating birds, providing some evidence for biomagnification up the food chain (Moody *et al*, 2002).

The only data available for other perfluorinated surfactants are for perfluorocarboxylate surfactants in groundwater concentrations at disused air force bases in the US. The data shows that these compounds were persistent and present at significant levels, many years after their use had ceased (Moody & Field, 1999).

In order to better understand levels of perfluoro substances in the environment the Environment Agency has recently developed analytical methodologies for a number of perfluorinated molecules. The analysis meets UKAS accreditation to the ISO 17025 standard, and is designed to measure levels in groundwater, but may be suitable for use in other environmental waters.

Table 4.4 Environmental concentrations of perfluorinated surfactants

Type of sample	Chemical	Sample site and details	Date	Lowest reported concentration ($\mu g\ l^{-1}$)	Highest reported concentration ($\mu g\ l^{-1}$)	Mean concentration ($\mu g\ l^{-1}$)	Ref
Wastewater treatment effluent	PFOS	4 USA cities effluents	2000	0.041	5.29		1
Sewage sludge	PFOS	4 USA cities effluents	2000	<0.2 μg/kg	3120 μg/kg (dw)		1
Drinking water	PFOS	4 USA cities effluents	2000	< lod	0.063		1
Landfill leachate	PFOS	4 USA cities effluents	2000	< lod	53.1		1
Surface water	PFOS	4 USA cities effluents	2000	< lod	0.138		1
Surface water	PFOS	Upstream of 3M facility	2000	0.009	0.053		6
		Downstream of 3M facility		82	150		
Surface water	PFOS	Samples from lake contaminated by fire-fighting foam from an airport in Toronto, Canada	2000	0.28	995		10
		Upstream sample		< lod	< lod		
		Downstream sample		< lod	2210		
Surface water	Perfluorohexane sulphonate anion (PFHxS)	Samples from lake contaminated by fire-fighting foam from an airport in Toronto, Canada	2000	< lod	134		10
		Upstream sample		< lod	< lod		
		Downstream sample		< lod	49.6		

Table 4.4 Cont.

Type of sample	Chemical	Sample site and details	Date	Lowest reported concentration ($\mu g\ l^{-1}$)	Highest reported concentration ($\mu g\ l^{-1}$)	Mean concentration ($\mu g\ l^{-1}$)	Ref
Surface water	Perfluorooctanoic acid anion (PFOA)	Samples from lake contaminated by fire-fighting foam from an airport in Toronto, Canada	2000	< lod	9.82		10
		Upstream sample		< lod	0.033		
		Downstream sample		< lod	11.3		
Surface water	PFOS	Upstream of industrial perfluorochemical discharge	2000	0.021	0.053	30.7 (n=19)	12
		Downstream of industrial perfluorochemical discharge		0.030	0.14	102 (n=21)	
Surface water	PFOA	Upstream of industrial perfluorochemical discharge	2000	<0.025	<0.025	<0.025 (n=19)	12
		Downstream of industrial perfluorochemical discharge		<0.025	0.60	0.34 (n=21)	
Groundwater	Perfluorocarboxylate surfactants	Wurtsmith Air Force Base, USA	2000	3	110		8
Groundwater	Perfluorohexanoic acid	NAS Fallon, Air Force Base, USA	1998	< lod	372		7
		Tyndall AFB, USA		< lod	144		
Groundwater	Perfluoroheptanoic acid	NAS Fallon, Air Force Base, USA	1998	< lod	149		7
		Tyndall AFB, USA		< lod	38		
Groundwater	Perfluorooctanoic acid	NAS Fallon, Air Force Base, USA	1998	< lod	6570		7
		Tyndall AFB, USA		<lod	116		

Table 4.4 Cont.

Type of sample	Chemical	Sample site and details	Date	Lowest reported concentration ($\mu g\ l^{-1}$)	Highest reported concentration ($\mu g\ l^{-1}$)	Mean concentration ($\mu g\ l^{-1}$)	Ref
Sediment	PFOS	Upstream of 3M facility	2000	0.18 µg/kg (ww)	0.98 µg/kg (ww)		6
		Downstream of 3M facility		1299µg/kg (ww)	5930µg/kg (ww)		
Sediment	PFOS	4 USA cities effluents	2000	< lod	1.13 µg/kg (dw)		1
Humans	PFOS	Non-specific human serums	2000	6.7	81.5	28.4 (n=65)	13
Humans	PFOA	Non-specific human serums	2000	1.0	18.4	6.4 (n=65)	13
Humans	Perfluorohexane sulphonic acid	Non-specific human serums	2000	<1	2.2		13
Biota	PFOS	Fish upstream of 3M facility	2000			59.1 µg/kg (ww)	6
		Fish downstream of 3M facility				1332 µg/kg (ww)	
Biota	PFOS	Clam upstream of 3M facility	2000			15.6 µg/kg (ww)	6
		Clam downstream of 3M facility				14.1 µg/kg (ww)	
Biota	PFOS	Liver of bottlenose dolphin in Florida	1979-1999			1520 µg/kg (ww)	2,9
Biota	PFOS	Blood of ringed seal in N. Baltic Sea	1979-1999			475	2,9
Biota	PFOS	Plasma in fish eating birds	1979-1999	< 1	1047		2
Biota	PFOS	Liver of fish eating birds	1979-1999	< 1	2055		2
Biota	PFOS	Muscle of fish from Belgium estuary	1979-1999		923 µg/kg (ww)		2

Table 4.4 Cont.

Type of sample	Chemical	Sample site and details	Date	Lowest reported concentration ($\mu g\ l^{-1}$)	Highest reported concentration ($\mu g\ l^{-1}$)	Mean concentration ($\mu g\ l^{-1}$)	Ref
Biota	PFOS	Muscle of carp from US Great Lakes	1979-1999		297 μg/kg (ww)		2
Biota	PFOS	Muscle of fish from inland Michigan lakes, USA; N Pacific & Antarctic	1979-1999		< lod		2
Biota	PFOS	Plasma in bald eagles of mid west USA	1979-1999	< lod	2220	330	3,11
Biota	PFOS	Highest measured concentration in liver of US birds (Brandts cormorant)	1979-1999		1780 μg/kg (ww)		3, 11
Biota	PFOS	Sera of N. Pacific albatross	1979-1999	3	34		3
Biota	PFOS	Livers of mink & river otters of US	1995-2000		4800 μg/kg (ww)		4
Biota	PFOS	Livers of river otters in Washington and Oregon	1997-1998	34 μg/kg (ww)	994 μg/kg (ww)		4
Biota	PFOS	Oysters from Chesapeake Bay and G Mexico (51-77 sample locations)	2000	<42 μg/kg (dw)	1225 μg/kg (dw)		5
Biota	PFOS	Fish liver tissue from lake contaminated by fire-fighting foam from an airport in Toronto, Canada	2000	2 mg/kg	72 mg/kg	26.5 mg/kg, mean of 6 samples	10
		Upstream sample				9.2 mg/kg	
		Downstream sample*				39.9 mg/kg	

Table 4.4 Cont.

Type of sample	Chemical	Sample site and details	Date	Lowest reported concentration ($\mu g\ l^{-1}$)	Highest reported concentration ($\mu g\ l^{-1}$)	Mean concentration ($\mu g\ l^{-1}$)	Ref
Biota	Perfluorobutane sulphonate anion (PFBS)	Fish liver tissue from lake contaminated by fire-fighting foam from an airport in Toronto, Canada	2000	< lod	9 μg/kg	n=6	10
		Upstream sample				< lod	
		Downstream sample*				< lod	
Biota	Perfluorohexane sulphonate anion (PFHxS)	Fish liver tissue from lake contaminated by fire-fighting foam from an airport in Toronto, Canada	2000	< lod	62 μg/kg	n=6	10
		Upstream sample				46 μg/kg	
		Downstream sample*				290 μg/kg	
Biota	Perfluoropentanoic acid anion (PFPeA)	Fish liver tissue from lake contaminated by fire-fighting foam from an airport in Toronto, Canada	2000	< lod	13 μg/kg	5.2 μg/kg (n=6)	10
		Upstream sample				< lod	
		Downstream sample*				< lod	
Biota	Perfluorohexanoic acid anion (PFHxA)	Fish liver tissue from lake contaminated by fire-fighting foam from an airport in Toronto, Canada	2000	< lod	40 μg/kg	16.7 μg/kg (n=6)	10
		Upstream sample				< lod	
		Downstream sample*				< lod	

Table 4.4 Cont.

Type of sample	Chemical	Sample site and details	Date	Lowest reported concentration (μg l^{-1})	Highest reported concentration (μg l^{-1})	Mean concentration (μg l^{-1})	Ref
Biota	Perfluoroheptanoic acid anion (PFHpA)	Fish liver tissue from lake contaminated by fire-fighting foam from an airport in Toronto, Canada	2000	4.6 μg/kg	48 μg/kg	20.8 μg/kg (n=6)	10
		Upstream sample				100 μg/kg	
		Downstream sample*				110 μg/kg	
Biota	Perfluorooctanoic acid anion (PFOA)	Fish liver tissue from lake contaminated by fire-fighting foam from an airport in Toronto, Canada	2000	6 μg/kg	40 μg/kg	35 μg/kg (n=6)	10
		Upstream sample				88 μg/kg	
		Downstream sample*				91 μg/kg	
Biota	Perfluorodecanoic acid anion (PFDA)	Fish liver tissue from lake contaminated by fire-fighting foam from an airport in Toronto, Canada	2000	32 μg/kg	140 μg/kg	77 μg/kg (n=6)	10
		Upstream sample				190 μg/kg	
		Downstream sample*				390 μg/kg	
Biota	Perfluoroundecanoic acid anion (PFUnA)	Fish liver tissue from lake contaminated by fire-fighting foam from an airport in Toronto, Canada	2000	13 μg/kg	93 μg/kg	52 μg/kg (n=6)	10
		Upstream sample				180 μg/kg	
		Downstream sample*				240 μg/kg	

Table 4.4 Cont.

Type of sample	Chemical	Sample site and details	Date	Lowest reported concentration ($\mu g\ l^{-1}$)	Highest reported concentration ($\mu g\ l^{-1}$)	Mean concentration ($\mu g\ l^{-1}$)	Ref
Biota	Perfluorotetradecanoic acid anion (PFTDA)	Fish liver tissue from lake contaminated by fire fighting foam from an airport in Toronto, Canada	2000	8.8 μg/kg	34 μg/kg	18 μg/kg (n=6)	10
		Upstream sample				250 μg/kg	
		Downstream sample*				190 μg/kg	

Notes * downstream samples represent 2 pooled liver tissue samples. LOD = limit of detection

1. 3M (2001a),
2. Giesy & Kannan (2001a)
3. Giesy & Kannan (2001b)
4. Giesy & Kannan (2001c)
5. Giesy & Kannan (2001d)
6. Giesy & Kannan (2001e)
7. Moody & Field (1999)
8. Moody C.A. et al., (2002)
9. Kannan et al., (2001)
10. Moody et al., (2002)
11. Kannan et al., (2001)
12 Hansen et al., (2002)
13. Hansen et al., (2001)

A compilation of data for PFOS occurrence in animal tissue has been provided by Giesy *et al*, 2001 (Table 4.5).

Table 4.5 Frequency and maximum concentrations of PFOS in animal tissue (from Giesy *et al*., 2001)

Animal Class	n	Detection frequency (%)	Maximum concentration (μg/kg, wet weight)
Marine mammals	400	77	1520 (liver)
Inland aquatic mammals (mink)	200	100	4900 (liver)
Birds including penguins	460	60	2220 (plasma)
Fishes and shellfish	470	38	920 (muscle)
Terrestrial wild mammals	50	50	200 (liver)
Frogs & turtles	40	14	700 (liver)

4.8 Environmental Fate and Behaviour

As with sources and levels of perfluorinated surfactants entering and present in the environment, there is little information available on the environmental fate and behaviour of these compounds. From their physico-chemical properties assumptions can be made and some field data is available in the literature to support them. It has already been established that perfluorinated surfactants are highly soluble and are resistant to biodegradation. These properties mean that release of perfluorosurfactants into soil will result in them behaving conservatively, with concentrations simply reflecting dilution with ground and pore water. This has been demonstrated with PFOS in field experiments (Moody and Field, 2000). Perfluorinated carboxylate surfactants are weaker acids, and so their transport may be affected by pH and ionic strength, although there is no current data to prove this (Moody and Field, 2000).

Biodegradation in the natural environment has not been demonstrated, the detection of perfluorocarboxylates in the groundwaters of air fields not used for between 7 and 11 years supports this assumption (Moody and Field, 1999). Of the tests that have been carried out (Rosen, 1989; Darwin *et al*., 1995; Remde and Debus, 1996; Key, 1996; Key *et al*., 1997), PFOS was shown to not degrade under aerobic or anaerobic conditions (Remde and Debus, 1996). Partially fluorinated surfactants do degrade under aerobic and sulphur-limiting conditions (Key *et al*., 1997), but is limited to the non-fluorinated portion of the molecule, e.g. 1H,1H,2H,2H-perfuorodecanol being converted to perfluorooctanoate (Hagen *et al*., 1981).

In mammals (rats) perfluorodecanol has been shown to be metabolised to perfluorooctanoate (Hagen *et al*., 1981). Four fluorine-containing metabolites were detected with one being

perfluorooctanoate, which suggested that the biotransformation of the decanol involved defluorination of the CF_2 group adjacent to the CH_2 group in the parent compound:

$C_7F_{15}CF_2CH_2CH_2OH \quad \Rightarrow \quad C_7F_{15}CO_2^- + 2HF$

4.9 Environmental Toxicity

Most persistent organic pollutants (POPs) accumulate in fats due to their high lipophilicity. But, as a surfactant with lipophobic and hydrophobic properties, PFOS (and PFOA) does not accumulate in lipids. So, octanol-water partitioning, the standard method for predicting bioaccumulation is meaningless for PFOS or PFOA. However, the sulphonate group of the PFOS molecule binds to blood proteins and accumulates in the liver and gall bladder. Non-PFOS perfluorinated surfactants such as PFOA, which lack a protein-binding sulphonate group, are considered not to bioaccumulate to a significant extent (USEPA, 2002). As a consequence they have not been added to OSPAR's list of substances of possible concern, although this conclusion may be revised at a later date when further testing has been undertaken (OSPAR, 2002).

A summary of available toxicity data for PFOS was presented in Fisk (2001), and is reproduced below (Table 4.6).

Table 4.6 Ecotoxicological data summary for PFOS K-salt (Fisk, 2001)

Organism	Duration (hr)	Endpoint	Toxicity (mg/l) unless otherwise stated)
Fish			
Pimephales promelas (fathead minnow)	96hr (acute)	LC_{50}	9.5
	96hr (acute)	NOEC	3.3
	42 day (chronic)	$NOEC_{(survival)}$	0.3
Lepomis macrochirus (bluegill sunfish)	96hr (acute)	LC_{50}	7.8
		NOEC	4.5
Invertebrates – freshwater			
Daphnia magna (water flea)	48hr (acute)	EC_{50}	27
	28 day	$NOEC_{(reproduction)}$	7
Unio complamatus (freshwater mussel)	96hr (acute)	LC_{50}	59
	96hr (acute)	NOEC	20
Invertebrates – saltwater			
Mysidopsis bahia (mysid shrimp)	96hr (acute)	LC_{50}	3.6
	96hr (acute)	NOEC	1.1
	35 day	$NOEC_{(reproduction)}$	0.25
Crassostrea virginica (Eastern oyster)	96hr (acute)	EC_{50}	>3.0
	96hr (acute)	NOEC	1.9
Algae			
Selanastrum capricornutum	96hr	$E_bC_{50(biomass)}$	71
	96hr	$E_rC_{50(growth)}$	126
	96hr	$NOEC_{(biomass/growth)}$	44
Microorganisms			
Activated sludge	3hr	IC_{50}	>905
Birds			
Anas platyrhynchos		LC_{50}	628 mg/l (in diet)
		$NOEC_{(mortality)}$	146 mg/l (in diet)
		$NOEC_{(body\ weight)}$	37 mg/l (in diet)
Colinus virginianus (Northern bobwhite quail)		LC_{50}	220 mg/l (in diet)
		$NOEC_{(mortality)}$	73 mg/l (in diet)
		$NOEC_{(body\ weight)}$	73 mg/l (in diet)

The reported data is generally only for the K-PFOS salt, with only limited data for the lithium, ammonium, didecyldimethylammonium and DEA (diethanolamine) salts. However, because all of the salts dissociate at environmental pHs to the PFOS anion, toxicity would be expected to be similar given that it is the PFOS anion that is likely to be the toxic portion of the molecule. The exception is the didecyldimethyl ammonium salt as the quarternary ammonium moiety exhibits toxicity in its own right.

Ecotoxicological data for other perfluorosurfactants is not currently available. Ecotoxicity values in the order of mg/l do not immediately classify PFOS in the highest categories for environmental concern, however it is their mammalian toxicology that has been identified by regulators to be of particular concern (Table 4.7).

Table 4.7 Mammalian acute oral toxicity data for perfluorosurfactants

Compound	**Organism/ endpoint**	**Toxicity (g/kg) unless otherwise stated)**	**Reference**
Ammonium perfluorooctanoate ($C_7F_{15}COONH_4$)	Rat/ LD_{50}	0.47	Kissa 2001
Ammonium perfluorooctanoate ($C_7F_{15}COONH_4$)	Rat/ LD_{50}	0.54	Griffiths & Long (1980)
Tetraethylammonium perfluorooctanesulphonate ($C_8F_{17}SO_3(C_2H_5)_4$	Rat/ LD_{50}	0.19	Meussdoeffer and Niderprum (1980)

In general the acute oral toxicity of perfluorosurfactants is greater than their hydrocarbon analogues (Kissa, 2001), although they are normally present in products at between 10 and 100 times lower amounts.

No toxicity data for any perfluorinated surfactants or breakdown products have been determined with sediment or soil dwelling invertebrates or terrestrial plants. In the absence of test data it is theoretically possible that concentrations of perfluorosurfactants in interstitial waters of soil and sediments and Predicted No Effect Concentrations (PNEC) could be determined by applying equilibrium partitioning models to the data for water column organisms. However, confidence in any estimates would be low due to:

- There are few reliable physico-chemical parameters available for perfluorosurfactants and degradation products (e.g. Kow, Koc, BCF).
- The nature of the adsorption process cannot be assumed to be linearly dependent upon concentration.
- The adsorption is likely to be dependent on soil and sediment characteristics.
- The kinetics of partitioning are unknown.

In human blood samples, PFOS has been detected in the serum of occupational and general populations in the μg/l (general population) to mg/l (occupational exposure) range. In the USA, recent serum levels in manufacturing employees have been as high as 12.8 mg/l (OECD, 2002). Mean levels of typically 1.32 mg/l have been measured in Belgium. In the general population concentrations are typically 100-1000 times lower , with serums collected from blood banks indicating a mean PFOS concentration of 2-44 μg/l (OECD, 2002). There is some anecdotal evidence of an increased risk of bowel cancer in employees with over 20 years service in a 3M plant manufacturing fluoro-chemicals (3 male mortalities compared with expected 0.12, OECD, 2002). A detailed study into the health of plant workers showed that increased risks did not occur or were not statistically significant in most cases. Although, increased risk of episodes were reported for neoplasms of the male reproductive system and the overall category of cancers and benign growths of the gastrointestinal tract. These ratios were highest in employees with the highest and longest exposures to fluoro-chemicals.

Animal studies show that PFOS is absorbed orally and distributes mainly in the serum and the liver, where no further metabolism is expected. Elimination from the body is slow and occurs in urine and faeces (estimated half-life of ~ 4 years). Signs of toxicity occur in monkeys at oral doses of 2 mg/kg/day. At a dose of 10 mg/kg/day no monkey survived beyond 3 weeks (OECD, 2002). No effect levels have been reported in the range 0.03 to 0.15 mg/kg/day.

Perfluorinted chemicals such as PFOS and perfluorooctanoic acid are known to promote liver cancer, even though they are chemically inert and so do not damage DNA (Upham *et al.*, 1998). However, it is thought that because compounds like PFOS bind to proteins they block or replace natural compounds that should bind to proteins and that perform important duties in the body (e.g. the generation of bile acids from cholesterol). Perfluorinated chemicals also tend to accumulate in physiologically important organs such as are recognised by the body as a bile acid and recycled between the gall bladder and the liver (where they can interfere with the their functioning). These fluorinated surfactants can also weaken cell membranes making it easier for environmental contaminants to enter the body's cells (Hu *et al.*, 2000). This effect has been observed for PFOS but not other fluorinated organics with similar structures but different C-F chain lengths.

There is little data available on the accumulation and toxicity of other perfluorinated surfactants, although it has been stated by DuPont that no elevation of fluoro-chemicals generated by the telomer process has been measured in factory workers (Mabury, 2001).

4.10 Conclusions

The data currently available for perfluorinated substances in the environment serve to illustrate that we do not know enough about the concentrations, fate, behaviour and toxicity of perfluorinated surfactants in the environment to make a sound scientific judgement on their risk. Obviously sufficient data has been gathered on the toxicity and persistence of PFOS to result in 3M ceasing production. The unique properties of perfluorinated chemicals, however, means that they are not easily substituted in commercial products such as fire-fighting foams and chemical fabric treatments.

It is likely that in the short term, perfluorinated sulphonyl surfactants will be replaced in products by other perfluorinated chemicals derived by the telomer process producing fluorocarbon surfactants with other types of function groups (e.g. alcohol). These surfactants

will, however, degrade to highly persistent fluorocarbons with or without a functional group attached to one end. Currently, the environmental fate and effects of these types of compounds can only be postulated.

4.11 Recommendations

- Investigate from manufacturers, if possible, which perfluorosurfactants are or will be, replacing sulphonyl based ones in commercial products such as fire fighting foams. This will allow the derivation of accurate risk assessments and targeted monitoring.

- Targeted environmental monitoring is required to identify the sources and the significance of fluorinated surfactants and their degradation products in the environment and humans.

- Greater knowledge of the toxicity and mode of action of perfluorinated chemicals is required, particularly for chemicals other than the sulphonyl ones.

- Once sufficient data is obtained, a full environmental risk assessment should be performed for perfluorinated surfactants.

4.12 Key points – Section 4

- There is little environmental monitoring data available for perfluorinated surfactants. What is available, is almost exclusively for PFOS, the stable breakdown product of surfactants generated via the electrochemical fluorination (3M) method.

- All perfluorinated surfactants will degrade to very persistent fluorocarbons with or without a functional group attached (depending on the parent compound), that will remain in the environment for years.

- Perfluorinated sulphonyl compounds (such as PFOS) accumulate in the liver of mammals up to mg/kg levels. Perfluorinated substances not containing the sulphonate group (e.g. PFOA) do not appear to bioaccumulate to a significant degree.

- PFOS is toxic to mammals when dosed at the low mg/kg/day rate, with toxicity being observed at liver concentrations of only 10 times that observed in wild animals.

- The toxic action of perfluorosulphonate chemicals is believed to be via disruption to liver functioning, which has been observed for PFOS.

- The toxicity of other perfluorinated compounds with functional groups other than sulphonyl have not been investigated.

- The routes leading to human exposure are not known, although drinking water and most surface water concentrations are below USEPA guideline value of 1 μg/l, unless near areas of contamination (e.g. near fire-fighting foam use or fluoro-chemical manufacture).

5. TREATMENT OF SPENT FIRE FIGHTING FOAMS

5.1 Introduction

In emergency fire fighting situations the primary objective of fire fighters is to save lives and property. The environmental impacts of the incident are obviously a secondary concern. However, when fire fighting foams are used for training purposes their environmental impact needs to be a higher priority. As the previous sections have highlighted (chapters 3 and 4), fire fighting foams and their constituents have the potential to cause negative effects in the surrounding environment. Consequently, it necessary to put in place procedures to minimise the environmental impacts of fire fighting foam training exercises.

At the simplest level there are three main components within the run-off of fire fighting foam discharges that require addressing, namely:

- the hydrocarbon content where kerosene is used as a fuel for practise fires;
- the BOD or oxygen depleting potential of the foam solution, and;
- the persistent constituents of foams namely the fluorosurfactant content.

To deal with these components there may be a number of procedures for treatment and reduction of their environmental effects. This chapter highlights the current practice used by fire fighting training grounds in dealing with firewater run-off and then gives guidance on the 'ideal' procedures for minimising the environmental impacts of fire fighting foams used in training situations.

5.2 Current treatment procedures for firewater run-off from training ground

The design of most European and International live fire training facilities is such that when fire fighting foam is applied to a controlled burning flammable liquid surface e.g. kerosene, it is drained-off or run-off to the facility water treatment plant, if one exists. This water treatment plant will usually consists of an oil/water separator or interceptor which levels off the hydrocarbons and a pump which transfers the waste water away for re-use or disposal to private or public drainage systems. The hydrocarbons are pumped off when the level reaches a specified design height.

Several live fire training facilities use retention basins to hold discharged firewater and foam solutions. However, this is not necessarily to reduce the environmental impact, but is more for firewater recycling reasons. Whilst such water can be reused for training purposes, the continual addition of foam solution will eventually render the fluids useless for producing foam. When the wastewater becomes unsuitable for training purposes the storage basin is again drained or pumped out to private or public drainage systems without foam separation. At the current time there is no evidence to suggest fire training facilities have the capability to treat the recovered fluids from live fire fighting exercises by removal or treatment of the foam concentrate/produced foam and the surfactants (Ramsden, 2002).

Separate from training facilities, at one UK petrochemical site there has been some research carried out to allow firewater from cooling water streams, applied on to Liquefied Petroleum Gas (LPG) spheres, to run freely to the facility Effluent Treatment Plant (Ramsden, 2002). However, if foam application is used, say for a LPG spill, the firewater and foam solution/produced foam fluids are diverted to a large retention basin. Thereafter, with the fluids held in the retention basin, the company has time to investigate the best method of disposing of the fluids. However, the research has not concluded how to achieve this disposal, efficiently or effectively (Ramsden, 2002).

In conclusion, there are only limited procedures in place at fire training facilities to treat the negative effects of fire fighting foam run off. The impact of these chemicals are being reduced by storage and release to waste water drain and sewer, but this just tends to move the problem somewhere else i.e. sewage treatment works. On a positive note the hydrocarbon element of training fires is dealt with by separation and storage. However, the other environmental issues of fire fighting foams such as, oxygen depletion due to high BODs and persistent constituents such as fluorosurfactants, are unlikely to be dealt with at the majority of training establishments.

5.3 Procedures for the reduction of environmental impacts of firewater run-off from training grounds

This section puts forward some suggestions for the treatment of fire fighting foam run-off from training grounds. It is by no means a definitive guide to the treatment of fire fighting foam run-off, but provides some guidance on procedures that will help reduce their environmental impacts. These procedures sometimes represent ‘ideal’ circumstances, although these may be difficult to achieve in the ‘real world’ due to high cost or other impracticalities. Where this is the case the limitations of the procedures have been highlighted.

Even before considering any form of treatment of fire fighting foam run-off, it is necessary to have an impervious surface to the training area so as to contain and collect the run-off. Existing facilities which do not have effective means of containing run-off from their foam exercises need to provide some practical measures to prevent run-off outside of the training area. Measures may include:

- A raised hump around the perimeter of the live fire scene area. This hump needs be no more than 75/100 mm at the centre and in the form of a gently rising and broad hump that allows trainees to walk over safely. Drainage to a retention basin is needed otherwise fire ground flooding would occur.

- A perimeter drainage system with open top grids to prevent flows beyond. The hazard of unburned hydrocarbons flashing into ignition in such drains needs to be carefully prevented with the strategic placement of flame traps and short length compartmentation.

- Sloping of all areas where foam is to be applied toward the centre of the live fire simulation structure, to ensure that the applied foam will enter the hydrocarbon or water drain.

The collection of fire water run-off leaves the training ground personnel with the question of what to actually do with it once it is stored. Perhaps the simplest way of dealing with training ground run-off is not to treat it, but to direct it to a blind (no outlet) tank which is subsequently emptied by a registered waste carrier taking it to a suitably licensed disposal facility. However, affording the ongoing charges for the service will be an issue and there still may be issues with releases to ground or surface waters of hydrocarbon or foam residues left in the rig after the tank valve is returned to the 'rainwater' setting.

On the other hand the local sewerage undertaker may permit the run-off to go into the public foul sewer for treatment at the local municipal waste water treatment works provided the proportions are not too great. Adverse effects on activated sludge type of sewage treatment have been reported as well as on subsequent treatment of sludge in anaerobic digesters (Section 3). Again, quality conditions may be applied by the issue of a formal consent (under the Water Industry Act 1991 in England and Wales, Section 6), but the conditions are likely to be much less challenging to meet. The discharge might be liable for treatment charges and this would have to be taken into consideration in any options appraisal for training ground run-off disposal.

Neither of the above options actually treat the run-off on site. Instead they move the problem elsewhere. However, there are some measures that it may be possible to put in place to deal with the negative impacts of fire water run-off, namely the hydrocarbon fuel, high BODs and the persistent constituents of the foams such as fluorosurfactants.

Most fire training grounds already have an interceptor or separator designed to retain free-floating fuel and prevent its discharge. Therefore, the hydrocarbon fuel issue of fire water run-off is usually adequately dealt with on site. However, it must be remembered that a separator will do nothing for the foam content of the incoming flow, as foam is entirely miscible with water and will not separate out even with long term standing. Therefore, other measures will be needed to try and deal with negative impacts of the foams (high BOD and persistent constituents).

Possibly the simplest (as in least technology involved) method of treating the BOD is the use of reed beds which can cope quite well with the fluctuating loads from training establishments. However, there are obvious cost and space implications with trying to set up a reed bed system at a training ground.

Removal of the fluorosurfactant content is likely to be more challenging. Absorption by activated carbon appears to be a practical way forward. This does not destroy the fluorosurfactant but removes it from the effluent stream, producing a concentrated, reduced volume waste requiring specialist disposal. Highly technical (and therefore costly) ways of removing or directly destroying these constituents are not likely to find much favour with airports where the whole RFFS expenditure is seen as an unavoidable overhead in the first place.

It may also be possible to reduce the impacts of the persistent components of the foams by using training foams that do not contain fluorosurfactants. However, the fire sizes would probably have to be scaled down to be manageable in comparison to actual fire fighting foams since training foams will not be as efficient in extinguishment. Also training foams will still contain chemical constituents, which are undesirable in the environment e.g. hydrocarbon surfactants and would still need collection, separation and clean up.

Another possibility to reduce the environmental impacts of fire fighting foam run-off may be to not use fire fighting foams in training situation at all. Some training facilities use LPG as a fuel in training exercises, which produces minimum smoke and does not require foam application to extinguish. This means limiting fire exercises to the use of water streams for cooling from a distance and for fire team protection close-up at the fire area. However, this has clear disadvantages in that the tactical use of foam cannot be demonstrated or practised. Video tapes of foam use in a series of live fire events could be used to explain, graphically and pictorially, the correct ways to apply foam on to fires and unignited flammable spills. The use of such video tapes would mean only one significant use of foam applications that could then be viewed as and when required. However, watching videos is no real substitute for live fire training.

5.4 Key Points - Section 5

- At the simplest level there are three main components within the run-off of fire fighting foam discharges that require addressing, namely:
  - the hydrocarbon content where kerosene is used as a fuel for practise fires;
  - the BOD or oxygen depleting potential of the foam solution, and;
  - the persistent constituents of foams namely the fluorosurfactant content.
- There are currently only limited procedures in place at fire training facilities to treat the negative effects of fire fighting run off containing foam. The impact of foams are being reduced by storage and release to waste water drain and public sewer.
- The hydrocarbon element of training fires is dealt with at the facilities, by separation and storage. However, the other environmental issues of fire fighting foams, oxygen depletion and fluorosurfactants, are unlikely to be dealt with at the majority of training establishments.
- Possibly the simplest (as in least technology involved) method of treating the BOD is the use of reed beds which can cope quite well with the fluctuating loads which result from not training or doing appliance tests every day.
- Removal of the fluorosurfactant content is likely to be more challenging. Absorption by activated carbon appears to be a practical way forward.
- Another possibility to reduce the environmental impacts of fire fighting foam run-off may be to not use fire fighting foams in training situation at all. Training with fires that do not require foams for exstinguishment may be used e.g. LPG or Video tapes of foam use in a series of live fire events could be presented. However, these methods are no substitute for live fire training with foams.
- There is a clear need for further investigation into how foam solution can be separated effectively from firewater and for the identification of companies which are qualified to carry out such work and the plant and equipment that may be used to achieve this

6. REGULATORY FRAMEWORK POLICY AND GUIDANCE RELATING TO FIRE FIGHTING FOAMS

6.1 Introduction

The control of fire-fighting foams in the UK is not covered by any specific regulation. However, there are a number of legal sources that apply to the general release of substances to the environment that are relevant to the release of fire-fighting foams to controlled waters. In many cases the source of this legislation is the European Union.

This chapter highlights the UK and European legislation that is most likely to apply to the use and disposal of fire-fighting foams and its run-off. It's intended use should be as a general guide to the available legislation and regulation that should be considered when disposing of fire fighting foam and its run-off. However, without detailed knowledge of the substances used in the production of fire-fighting foam concentrates it is not possible to give a definitive guide to the legislation that needs to be complied with in any given situation. The reviewed information is based on the legislation applicable to the known constituents and the general provisions for the release of substances to water (surface and groundwater) and sewer (foul and surface).

6.2 Environmental Legislation

6.2.1 Water Resources Act (WRA) (1991)

The most important legislation relevant to the control of discharges to 'controlled waters' (surface waters and groundwaters) from non-prescribed IPC (Integrated Pollution Control) processes in England and Wales is the Water Resources Act 1991 (HMSO 1991a). The Water Resources Act 1991 (WRA) came into effect in 1991 and replaced the corresponding sections of the Water Act 1989. The Environment Agency is the regulatory authority responsible for protecting controlled waters under this legislation.

The Water Resources Act makes it an offence to discharge sewage or trade effluent to controlled waters unless a consent from the Environment Agency has been issued. "Controlled waters" are defined in the WRA as:

a) relevant territorial waters (waters that extend seaward for 3 miles)

b) coastal waters

c) inland freshwaters

d) groundwaters[2].

[2] The Groundwater Regulations 1998 supplement the WRA by specifying when authorisations for discharges to groundwaters may be issued and the substances that may or may not be contained in such discharges.

Section 85 of the WRA is the primary water pollution offence provision and states that 'no person shall cause or knowingly permit any poisonous, noxious or toxic material or solid waste to enter a controlled water'. 'Causing' means not only deliberately releasing any polluting matter but also causing the pollution accidentally, by being the operator of a plant or process. However, the discharger, who in the case of fire fighting foams is likely to be the Emergency Authorities, may be exempt from prosecution provided all the requirements of Section89 (1) of the act are met. Therefore, the use of fire fighting foams and the possible subsequent entry of spent foams into controlled waters in emergency situations (i.e. fire fighting incidents) should be exempt from prosecution.

Section89(1)

A person shall not be guilty of an offence under section 85 above in respect of the entry of any matter into any waters or any discharge if—

> *(a) the entry is caused or permitted, or the discharge is made, in an emergency in order to avoid danger to life or health;*
>
> *(b) that person takes all such steps as are reasonably practicable in the circumstances for minimising the extent of the entry or discharge and of its polluting effects; and*
>
> *(c) particulars of the entry or discharge are furnished to the Authority as soon as reasonably practicable after the entry occurs.*

However, if fire fighting foams are used for training or for demonstration purposes then the run-off from these exercises is not exempt from the Water Resources Act. In such circumstances the individuals involved the training exercise would not be allowed to release the run-off from the exercise to controlled waters without a discharge consent from the Environment Agency.

Consents

The procedures for obtaining a consent from the Environment Agency are contained in Schedule 10 of the Water Resources Act 1991 and the Control of Pollution (Applications, Appeals, and Registers) Regulations 1996. Consent conditions are usually based on Environmental Quality Standards (EQSs).

Environmental Quality Standards are numerical benchmarks based on scientific data that propose a concentration of a chemical in the receiving water which is regarded as ‘safe’ for a specified receptor i.e. aquatic life. EQSs are set for those chemicals contained in Lists I and II of the Dangerous Substances Directive (76/464/EEC) (Appendix E).

In 1976 the EU Council of Ministers adopted the Dangerous Substances Directive (76/464/EEC) (CEC 1976a) to control pollution caused by certain dangerous substances discharged to the aquatic environment. The Directive established two lists of compounds:

- List I (also known as the Black List) dealing with substances regarded as being particularly dangerous because of their toxicity, persistence and bioaccumulation. Pollution by List I substances must be eliminated; and

- List II (also known as the Grey List) containing substances which are less dangerous but which nevertheless have a deleterious effect on the aquatic environment. Pollution by List II substances must be reduced.

For List I substances, the Directive stipulates two approaches for control: uniform emission standards (UESs) (also known as limit values) and environmental quality standards (EQSs). Both types of standard are set on a Community level but Member States are given the discretion to select which approach to adopt. Most EU Member States have favoured the UES approach, whereas the UK has adopted the EQS approach. For List II substances, Member States are required to set environmental quality standards (EQSs) developed on a national level. Any LIST I substance is considered a LIST II substance until a daughter directive is established by the EC and then adopted by member states.

The setting of standards for List II substances is the responsibility of the individual Member States. The UK have set statutory EQSs for List II substances, although several others use them for guidance purposes. In the UK standards for List II substances were originally implemented by 'Circular Letter' (HMSO 1989d) defining the standards for the different water uses, the action to be taken and the timescale for compliance. More recently List II EQSs have been put on a statutory footing by the introduction of the Surface Waters (Dangerous Substances)(Classification) Regulations 1997 and 1998 (HMSO 1997c; HMSO 1998c).

Consent conditions are usually set to ensure that Environmental Quality Standards (EQSs) are not exceeded. In terms of fire fighting foams a number of constituents of foam products have EQS values derived for them under List II of the Dangerous Substances Directive (Section 3). Therefore, in terms of a discharge of fire fighting foam or run-off from a training ground a consent may be set based on the EQS values for those constituents and providing the discharge does not lead to an exeedance of these benchmarks the discharge consent may be granted.

It should also be noted that for discharges to groundwater containing chemicals covered by List I and II of the Groundwater Directive (these lists are not identical to Lists I and II of the Dangerous Substances Directive) the Water Resources Act is superseded and the discharge must be consented under the Groundwater Directive (See Groundwater Directive Section 6.2.7).

6.2.2 The Water Industry Act (1991)

The Water Industry Act came into force in 1991 and consolidated various enactments relating to the appointment of water and sewerage undertakers, conditions of appointment, supply of water and the provision of sewerage services. The Sections of the Act that are of particular importance to industry are concerned with the criteria for discharging effluent into the sewerage system.

Sections 118-134 of the Water Industry Act lay down the framework for control of any discharges of trade effluent to sewers. Trade effluent is any liquid waste of any composition, in any quantity, that is produced from an organisation's operations. No effluent can be discharged into the sewer that may damage the sewer, injure the people working in it or interfere with the working of the sewage treatment works.

The Trade Effluents (Prescribed Processes and Substances) Regulations 1989 (amended 1990, 1992) apply to companies which have, or are seeking, a consent to discharge specified trade effluents containing List I substances (under the Dangerous Substances Directive) under the Water Industry Act. These Regulations relate principally to the procedures adopted by the sewerage undertaker and the Environment Agency. The sewerage undertaker must refer all applications covering special category waste to the Environment Agency, who decide if the discharge should be prohibited or permitted, subject to conditions.

Effluent from fire stations could be classified as special category effluent if they contain List I substances. In such circumstances non-emergency discharges of foams or foam containing run-off would have to be consented by the sewerage undertaker. The available information indicates that fire fighting foams do not contain any List I substances so are unlikely to require a consent under the Water Industry Act. However, as the chemical constituent list in the MSDSs are sometimes vague and only provide information on chemical groups, it is not possible to say categorically that is the case.

6.2.3 Waste Water Authority Act, 1991

As some sites may have on-site treatment works that treat fire-water run-off, the Waste Water Authority Act, (1991) may also be relevant for the regulating of fire-fighting foams, in both a training environment and in use in an emergency situation.

A consent system is in place under the Waste Water Authority Act, (1991) which regulates both the design, planning and operation of any sewer system or treatment works used to treat effluent.

As well as regulating the operation, the design of wastewater works is covered by this act, as well as the, testing and maintenance which should be carried out in accordance with the British Standard Code of Practice in current use.

Of particular relevance is the reference to substances which may impair the operation of any effluent treatment process either singly or by interaction with other wastes. As it is possible for fire-fighting run-off to interfere with the processes at a treatment plant (Section 3) run-off from training sites may subject to control under this act.

6.2.4 Environmental Protection Act 1990

The main area of relevance to the control of pollution of the aquatic environment contained in the Environmental Protection Act (HMSO 1990) is the provision for Integrated Pollution Control (IPC). This is dealt with below.

The act requires that the release of all controlled substances is administered through a consent system. Limits regarding concentration levels as well as quantities are set.

Prescribed industrial processes are also covered by the act and the prevention of releases of substances is to be minimised by the best available techniques not entailing excessive cost. Although this act does not cover the use of fire fighting foams it does relate to the formulation of foam concentrates.

6.2.5 Integrated Pollution Control (IPC)

Sites covered by IPC will generally by definition be handling prescribed substances, as described in the Environmental Protection (Prescribed Processes and Substances) Regulations 1991. The prescribed substances for releases into controlled waters are derived from the 'Black List' (List I of the Dangerous Substances Directive). These substances (plus carbon tetrachloride) are also known in the UK as the 'Red List', substances controlled under the Trade Effluent (Prescribed Processes) Regulations 1989 (amended 1990), concerning discharges to sewer. The release of prescribed substances to controlled waters or sewers should be prevented or minimised as far as reasonably practicable (using Best Available Techniques Not Entailing Excessive Cost, BATNEEC).

The available information indicates that fire fighting foams do not contain any Black or Red List substances and as such would not be covered by IPC. However, as the chemical constituent list in the MSDSs are sometimes vague and only provide information on chemical groups, it is not possible to say categorically that they do not contain controlled substances under IPC.

6.2.6 Integrated Pollution Prevention and Control (IPPC)

Integrated Pollution Prevention and Control (IPPC) has replaced IPC and is being introduced into the UK under the European Council Directive 96/61/EC on Integrated Pollution Prevention and Control. The IPPC Directive 96/61/EC lays down a framework requiring Member States to issue operating permits for certain installations carrying on industrial activities. Permits must contain conditions based on best available techniques (BAT), to achieve a high level of protection of the environment as a whole.

IPPC regulation will cover installations previously regulated under IPC but will extend integrated control to many more industrial companies, and will regulate the installation rather than the process. This expansion of the scope of legislation to cover an installation rather than a process may well have implications for the release of fire-fighting foams on installations covered by IPPC.

6.2.7 The Groundwater Regulations

The Groundwater Regulations 1998 have implemented the Groundwater Directive (86/68/EEC) in the UK. The Directive will be repealed by the Water Framework Directive (2000/60/EC). Member States are required by the groundwater directive to prevent the introduction into groundwaters of List I substances and to limit the introduction of List II substances so as to prevent pollution. The Lists I and II referred to in the Groundwater Directive are not identical to those contained in the Dangerous Substances Directive, also, unlike the Dangerous Substances Directive, List I status is definitive and does not need confirmation in a daughter directive.

These regulations are likely to be of relevance on sites undertaking on site storage or containment measures as recommended in the Agency guidelines (PG18). The regulations would be applicable in particular to the recommendations of constructing containment lagoons or sacrificial areas for the storage of run-off. However, discharge to ground of spent

foam from training exercises of fire fighting foams containing List I or List II substances will require an authorisation under the Groundwater Directive.

The presence of List I/II substances does not normally affect the *use* of foams in normal operation (i.e. in emergency response or training activities), although the Secretary of State has powers to serve a Statutory Code of Practice and the Agency has powers to issue a Notice to control or prohibit an activity to prevent groundwater pollution. During or following emergency use, the disposal of fire fighting foams containing listed substances will require an authorisation from the Agency. In reaching a decision on whether to authorise the disposal of waste foam onto land, the Agency adopts a risk assessment approach that considers the fate and transport of the substance in the soil and unsaturated zone to determine whether there is likely to be a discernible discharge to groundwater.

Some of the constituents of foams such as the fluorosurfactants, which are organohalogens fall within list I of the Groundwater Directive and as such fire fighting foam run-off containing fluorosurfactants are likely require a consent from the Environment Agency. However, the Directive allows individual substances on List I to be treated as List II on the basis of low risk of toxicity, persistence and bioaccumulation. (These determinations are undertaken by the UK Environment Agencies).

In 1992 the National Rivers Authority (NRA), published its policy on groundwater that was revised by the Environment Agency in 1998. This policy does not have any statutory force, but is a source of official guidance for the protection of groundwater supplies and may be used in this context by planning and waste regulatory authorities. Two of the central principles of the policy are:

- Classification of groundwaters according to their vulnerability; and
- Definition of three-tier Source Protection Zones.

These two principles form the basis for controls on activities posing a potential threat to groundwater resources.

6.2.8 CONTROL OF MAJOR ACCIDENT HAZARDS REGULATIONS 1999 (COMAH)

The COMAH regulations[3] apply to the release of fire-fighting foams by inference only as there is no direct reference made to them in the regulations. Nevertheless this indirect reference does imply certain responsibilities for sites covered by the regulations. One of the key responsibilities is the production of a Major Accident Prevention Policy, or MAPP.

Their main aim is to prevent and mitigate the effects of those major accidents involving dangerous substances that can cause serious damage to people and/or the environment. As such these regulations apply to the release of fire-fighting foams in an emergency situation rather than in a training activity, (or accidental release in transport).

[3] The COMAH Regulations implement the Seveso II Directive. They replaced the Control of Industrial Major Accident Hazards regulations 1984 (CIMAH) and came into force on 1st April 1999.

Both the prevention and mitigation measures required under COMAH are relevant to the release of fire-fighting run-off. For example, the prevention of releases in a fire situation may refer to general measures aimed at the reduction of the risk of fire, thereby reducing the chances that fire-fighting foams would need to be used at all. Another example of the requirements to mitigate the impact of accidents may be the construction of containment systems for run-off (PPG 18 Section 6.3.1).

6.3 Environment Agency Guidance

The Environment Agency, as well as issuing guidance on measures to limit the damage caused by run-off has also agreed a Protocol in conjunction with the Local Government association. The aim of the Protocol is to ensure co-ordination and co-operation between the fire services and the Agency in limiting the potential for pollution in incidents involving the possible pollution of controlled waters or disposal of wastes. The Protocol also forms the basis of the relationship between the Agency and the Fire Service in regard to the disposal of foams during training. Following the issue of the Protocol each brigade was advised by Her Majesty's Fire Service Inspectorate to contact the Agency to make arrangements for the safe disposal of foam following training. This practise is a consultative exercise with the Agency advising on the most suitable option given local conditions and in some cases can involve minor changes being made by the training facility to ensure that the disposal method (changes to sewers for example) is suitable.

6.3.1 Managing Fire Water and Major Spillages (PPG 18)[4]

This guidance document gives examples of good practice for the protection of the environment in the management of run-off generated in the event of fire (or fire water) and major spillages.

The focus of the guidance is on containment measures encompassing physical structures that can be used to contain firewater and spillages (Section 5). Other approaches to protect the environment, such as operational and management controls are also recommended. Further recommendations are made to support all, physical, operational and managerial measures with contingency or pollution incident response plans.

6.3.2 Environmental sensitivity of site location

The location of sensitive sites will have a bearing on the type of measures that may be required on a site (See NRA's 'Pollution Prevention Measures for the Control of Spillages and Fire Fighting Run-off' guidance note, Appendix B, for definitions of sensitive sites).

Types of site for consideration could be as follows:

[4] The information in the guidance note is based on CIRIA (Construction Industry Research and Information Association) Report 164 (Reference 3), which contains detailed information on hazard identification, risk assessment and secondary containment systems.

- Sites under Integrated Pollution Control.
- Sites storing significant quantities of hazardous materials.
- Sites storing/using/producing low/non-hazardous products that have the potential for polluting water.

There are threshold quantities of materials above which pollution could be possible if this amount were to be spilt and released into the aquatic environment. Also there are certain types of occasion on which the EA should generally be notified. However, this should be a matter for discussion on a local basis between the fire brigade and the EA.

6.4 European sources of National Legislation

6.4.1 The Groundwater Directive (80/68/EEC)

The Directive on the protection of groundwater against pollution caused by certain dangerous substances (80/68/EEC) requires Member States to prevent the introduction into groundwaters of List I substances and to limit the introduction of List II substances so as to prevent pollution. These Lists are similar but not identical to those used in the Dangerous Substances Directive (76/464/EEC). The UK Agencies determine whether individual substances fall into List I/II and that they can be contacted if a determination is required. In this way, the Groundwater Directive differs from the Dangerous Substances Directive under which the EC formally designate substances as List I.

6.4.2 Dangerous Substances Directive (67/548/EEC)

The Dangerous Substances Directive (76/464/EEC) and its 'daughter' Directives control discharges to surface waters that are liable to contain Dangerous Substances. The aim is to prevent adverse impacts on the environment. There are two lists of Dangerous Substances. List I covers those which are particularly toxic, persistent, and which may tend to accumulate in the Environment. List II covers substances whose effects are less serious. It should be noted that, unlike the Groundwater Directive, responsibility for identifying List I substances under the Dangerous Substances Directive lies with the European Commission. Member States must identify those pollutants in List II that are relevant for their country and introduce appropriate controls

The process of assigning environmental quality standards (EQS) has proved a slow one and relatively few have been assigned at present. A list of those assigned is given in Appendix E.

6.4.3 Dangerous Preparations Directive (88/379/EEC)

Directive (88/379/EEC) was recently replaced by a new Dangerous Preparations Directive. However, until the new Directive is transposed into national law (expected in 2003) its predecessor remains the basis for the legal requirements with regard to preparations under CHIP).

6.4.4 Safety Data Sheet Directive (91/155/EEC) as amended by 93/112/EEC

The Commission Directive on Safety Data Sheets (91/155/EEC) defines the EC system for provision of specific information relating to dangerous preparations (and substances). Material Safety Data Sheets generated and provided by product formulators should comply with this directive.

6.5 Key Points - Section 6

- The control of fire-fighting foams in the UK is not covered by any specific regulation.
- There are a number of legal sources that apply to the general release of substances to the environment that are relevant to the release of fire-fighting foams to controlled waters.
- Without detailed knowledge of the substances used in the production of fire-fighting foam concentrates it is not possible to give a definitive guide to the legislation that needs to be complied with in any given situation.
- In emergency situations discharges of fire fighting foam run-off may not subject to regulation. However, discharges of foam run-off from training exercises will be and as such may require a consent to discharge from the Environment Agency.
- The two most relevant pieces of legislation in relation to discharges of fire fighting foam run-off from training exercises are the Water Resources Act and The Groundwater Directive.

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7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

- A review of the ecotoxicity of foam products indicates that in general foam concentrates are of low acute aquatic toxicity. Exceptions were the synthetic detergent foams, which were found to be of moderate acute aquatic toxicity. It is important to note that this conclusion relates to the available toxicity data obtained from MSDSs, that only provide information on the foam concentrates as sold and not on finished products as used operationally. Consequently, the toxicity of the foam products is likely to be reduced due to the dilution of the concentrate in the finished foams.

- Although the majority of fire fighting foams are of low aquatic toxicity, a quarter of the foam concentrates reviewed may pose a threat to the environment due to their rapid biodegradation. The BODs of the these foam concentrates can be so high that the finished diluted product may still have a negative impact on the oxygen levels in the receiving water body.

- Although the review of whole products indicated that foam concentrates may be of low toxicity, a review of the fate and effects of the individual constituents listed in the product MSDSs has indicated that a number of these constituents are toxic, persistent and possibly bioaccumulative.

- The anionic surfactants, biocides and metal salts are of particular concern due to their high toxicities when compared to other constituents. Although they are present at low levels in the finished foams and may not pose an acute hazard, the persistent nature of some of these constituents may lead to their accumulation to toxic levels in the environment.

- The fluorosurfactant content of foams are of concern due to their persistence and bioaccumulative properties. All perfluorinated surfactants will degrade to very persistent fluorocarbons with or without a functional group attached (depending on the parent compound), that will remain in the environment for years.

- There is little environmental monitoring data available for perfluorinated surfactants. What is available, is almost exclusively for PFOS, the stable breakdown product of surfactants generated via the electrochemical fluorination (3M) method. Perfluorinated sulphonyl compounds (such as PFOS) accumulate in the liver of mammals up to mg/kg levels. However, perfluorinated substances that do not contain the sulphonate group (e.g. PFOA) do not appear to bioaccumulate to the same degree. PFOS has been reported to be toxic to mammals when dosed at the low mg/kg/day rate. The toxic action of perfluorosulphonate chemicals is believed to be via disruption to liver functioning, which has been observed for PFOS. However, the toxicity of other perfluorinated compounds with functional groups other than sulphonyl has not been investigated.

- In terms of dealing with fire fighting foam run-off at training grounds there are three main components within the run-off that require addressing, namely:
  - the hydrocarbon content where kerosene is used as a fuel for practise fires;
  - the BOD or oxygen depleting potential of the foam solution, and;
  - the persistent components of foams, e.g. fluorosurfactants and metals
- There are currently only limited procedures in place at fire training facilities to treat the negative effects of fire fighting foam run off. The impact of foams are being reduced by storage and release to waste water drain and public sewer. However, there are methods which could be put into place that may reduce the impacts of foam run-off such as, reed beds to treat BOD, activated carbon to remove the persistent constituents of foams such as the fluorosurfactants and separation of the hydrocarbon elements.

- The control of fire-fighting foams in the UK is not covered by any specific regulation. However, there are a number of legal sources that apply to the general release of substances to the environment that are relevant to the release of fire-fighting foams, particularly in training exercises. The two most relevant pieces of legislation in relation to discharges of fire fighting foam run-off from training exercises are the Water Resources Act and the Groundwater Directive. However, without detailed knowledge of the substances used in the production of fire-fighting foam concentrates it is not possible to give a definitive guide to the legislation that needs to be complied with in any given situation.

- Due to the lack of detailed information on the foam constituents available on product MSDSs and the unwillingness of foam formulators to disclose this information, a prioritisation of the foam constituents and subsequently the foam products could not be achieved.

7.2 Recommendations

- More detailed and specific data are required on the fate and effects of fire fighting foam concentrates and finished foam solutions. Ideally this data should include:
  - chronic toxicity data for fire fighting foam concentrates, so that their long-term effects can be assessed
  - acute and chronic toxicity data and biodegradation and BOD data for finished foams so that the environmental effects of foams, as they would be used operationally in fire fighting and training situations, can be assessed.
- A ranking of foams constituents and subsequently foam products needs to be carried out so that fire fighting foams can be prioritised in terms of their environmental effects. In order to do this, there needs to be more detailed constituent information on the exact chemical ingredients of foams, their fate and effects and if possible the proportions present in the product. Until this information becomes it is reasonable to apply the precautionary principle and assume that all chemicals with data gaps have high P, B or T and prioritise foams on this basis.
- There is a clear need for further investigation into how foam solutions can be separated effectively from firewater and treated to reduce their potential environmental impact, particularly from training exercises. Companies that are qualified to carry out such work and the plant and equipment that may be used to achieve this need to be identified.
- Investigate from manufacturers, if possible, which perfluorosurfactants are or will be, replacing sulphonyl based ones in commercial products such as fire fighting foams. This will allow the derivation of accurate risk assessments and targeted monitoring.
- Targeted environmental monitoring is required to identify the sources and the significance of fluorinated surfactants and their degradation products in the environment and humans.
- Greater knowledge of the toxicity and mode of action of perfluorinated chemicals is required, particularly for chemicals other than the sulphonyl ones.
- Once sufficient data is obtained, a full environmental risk assessment should be performed for perfluorinated surfactants.

GLOSSARY

Acute Having a sudden onset, lasting a short time. Of a stimulus, severe enough to induce a response rapidly. Can be used to define either the exposure or the response to exposure (effect). For clarity, the length of exposure (short, medium, or long) and the nature of the effect end point (lethal or non-lethal) should be specified. The duration of an acute aquatic toxicity test is generally 4 d or less and mortality is the response measured.

Additive toxicity The toxicity of a mixture of chemicals that is approximately equivalent to that expected from a simple summation of the known toxicities of the individual chemicals present in the mixture (i.e., algebraic summation of effects)

Alcohol resistant foam concentrates These may be suitable for use on hydrocarbon fuels, and additionally are resistant to breakdown when applied to the surface of water-miscible liquid fuels. Some alcohol resistant foam concentrates may precipitate a polymeric membrane on the surface of water-miscible liquid fuels.

Application rate The rate at which a foam solution is applied to fire. Usually expressed as litres of foam solution per square metre of the fire surface are per minute (1pm/m²)

AFFF concentrate Aqueous film-forming foam. AFFFs are generally based on mixtures of hydrocarbon and fluorinated surface active agents and have the ability to form an aqueous film on the surface of *some* hydrocarbon fuels.

Aspiration The addition or entrainment of air into foam solution.

Aspirated foam Foam that is made when foam solution is passed through purpose designed foam-making equipment, such as a foam-making branch. These mix in air (aspirate) and then agitate the mixture sufficiently to produce finished foam. (see also primary aspirated foam and secondary aspirated foam).

Bioaccumulation General term describing a process by which chemicals are taken up by aquatic organisms directly from water as well as through exposure through other routes, such as composition of food and sediment containing the chemicals.

Bioaccumulation factor (BAF) A value that is the ratio of tissue chemical residue to chemical concentration in an external environmental phase (i.e., sediment or food). BAF is measured at steady state in situations where organisms are exposed from multiple sources (i.e., water, sediment, food), unless noted otherwise.

Biochemical (or biological) oxygen demand (BOD) A measure of the rate at which molecular oxygen is consumed by microorganisms during oxidation of organic matter. The standard test is the 5-day BOD test, in which the amount of dissolved oxygen required for oxidation over a 5-day period is measured. The results are measured in mg of oxygen/L (mg/L).

Bioconcentration A process by which there is a net accumulation of a chemical directly from water into aquatic organisms resulting from simultaneous uptake (e.g., by gill or epithelial tissue) and elimination.

Bioconcentration factor (BCF) A term describing the degree to which a chemical can be concentrated in the tissues of an organism in the aquatic environment as a result of exposure to a water-borne chemical. At steady state during the uptake phase of a bioconcentration test, the BCF is a value which is equal to the concentration of a chemical in one or more tissues of the exposed aquatic organisms divided by the average exposure water concentration of the chemical in the test.

Biodegradation The transformation of a material resulting from the complex enzymatic action of microorganisms (e.g., bacteria, fungi). It usually leads to disappearance of the parent structure and to the formation of smaller chemical species, some of which are used for cell anabolism. Although typically used with reference to microbial activity, it may also refer to general metabolic breakdown of a substance by any living organism.

Biomagnification Result of the processes of bioconcentration and bioaccumulation by which tissue concentrations of bioaccumulated chemicals increase as the chemical passes up through two or more trophic levels. The term implies an efficient transfer of chemical from food to consumer, so that residue concentrations increase systematically from one trophic level to the next.

Burnback resistance The ability of a foam blanket to resist direct flame and heat impingement.

Chemical foam A finished foam produced by mixing two or more chemicals. The bubbles are typically caused by carbon dioxide released by the reaction.

Chemical oxygen demand (COD) When organic materials are not easily degraded by micro-organisms, strong oxidising agents (e.g., potassium permanganate) are used to enhance oxidation. COD is thus measured instead of BOD (see BOD). COD values will be larger than BOD values.

Chronic Involving a stimulus that is lingering or continues for a long time; often signifies periods from several weeks to years, depending on the reproductive life cycle of the aquatic species. Can be used to define either the exposure or the response to an exposure (effect). For clarity the length of the exposure and the nature of the effect end point should be specified. Chronic exposure typically induces a biological response of relatively slow progress and long continuance. The chronic aquatic toxicity test is used to study the effects of continuous, long-term exposure to a chemical or other potentially toxic material on aquatic organisms.

Concentration The quantifiable amount of chemical in a specific volume or mass of water, food, tissue or sediment. The choice of units for concentration depends on the minimum that is being measured or described. In water, a common expression of concentration is mass of chemical (μg or mg) per unit volume (L) of water or μg/L or mg/L. In sediment, a common expression is mass of chemical per unit mass (mg/kg) of sediment.

Dose The quantifiable amount of material introduced into the animal by injection or ingestion is considered to be the exposure dose. The amount of a material at receptor or target sites in the animal that elicits a response is the target dose.

End point In toxicity testing and evaluation it is the adverse biological response in question that is measured. End points vary with the level of biological organisation being examined but include changes in biochemical markers or enzyme activities, mortality or survival, growth, reproduction, primary production, and changes in structure (and abundance) and function in a community. End points are used in toxicity tests as criteria for effects.

Environmental availability The portion of the total chemical material present in all or part of the environment that is actually involved in a particular process or processes and is subject to all physical, chemical, and biological modifying influences. It defines the total amount of material potentially available to organisms.

Environmental bioavailabilty The ratio of the uptake clearance divided by the rate at which an organism encounters a given contaminant in a medium (e.g., water, food) being processed by the organism. This is a measure of an organism's extraction efficiency, via respiratory, dietary, and surface absorption processes, from the environmentally available portion of a material.

Expansion ratio The ratio of the total volume of finished foam to the volume of foam solution used to produce it:

$$\text{Expansion ratio} = \frac{\text{volume of finished foam}}{\text{Volume of foam solution used to produce it.}}$$

Exposure The contact reaction between a chemical or physical agent and a biological system.

Fate Disposition of a material in various environmental compartments (e.g., soil or sediment, water, air, biota) as a result of transport, transformation, and degradation.

Film-forming A finished foam, foam solution or foam concentrate that forms a spreading, thin, aqueous film on the surface of some hydrocarbon liquids.

FFFP foam concentrates Film-forming fluoroprotein. These are fluoroprotein foam concentrates, which have the ability to form an aqueous film on the surface of the hydrocarbon fuels.

Finished foam The foam as applied to the fire. It will consist of a mixture of foam solution that has been mixed with air. The foam may be primary aspirated or secondary aspirated.

Flashback The re-ignition of a flammable liquid caused by the exposure of its vapour to a source of ignition such as a hot metal surface or a spark.

Flow-through system An exposure system for aquatic toxicity tests in which the test material solutions and control water flow into and out of test chambers on a once-through basis either intermittently or continuously.

Fluoroprotein (FP) foam concentrate A hydrolysed protein based foam concentrate with added fluorinated surface active agents.

Foam The result of mixing foam concentrates, water and air to produce bubbles.

Foam concentrate The foam as supplied by the manufacturer in liquid form; this is sometimes referred to as 'foam compound', 'foam liquid' or by trade or brand names

Foam, dry Foam with a long drainage time, i.e. the liquid content of the foam takes a long period of time to drain out of the foam; the foam is very stable.

Foam solution A well mixed solution of foam concentrate in water at the approximate concentration.

Foam, wet Foam with a short drainage time, i.e. the liquid content of the foam takes a short period of time to drain out of the foam; the foam breaks down quickly.

Half-life Time required to reduce by one-half the concentration of a material in a medium (e.g., soil or water) or organism (e.g., fish tissue) by transport, degradation, transformation, or depuration.

Hazmat A proprietary trade name used to describe special types of foam, which can be used to suppress the vapour production of certain hazardous materials (toxic, odorous and/or flammable)

Heat resistance The ability of a foam blanket to withstand the effects of exposure to heat.

High expansion foam (HX) Finished foam of expansion ratio greater than 200:1.

Indirect toxicity Adverse effects or toxicity that results from the agent(s) acting on and producing changes in the chemical, physical and/or biological environment external to the organisms under study (e.g., decrease in food for predatory species due to direct toxicity from a chemical to prey may produce adverse effects in the predator species due to starvation rather than inducing any direct chemical toxicity in predator organisms).

Knockdown The ability of a foam to quickly control flames. Knockdown does not necessarily mean extinguishment.

Lethal Causing death by direct action. Death of aquatic organisms is the cessation of all visible signs of biological activity.

Life cycle study A chronic (or full chronic) study in which all the significant life stages of an organism are exposed to a test material. Generally, a life cycle test involves an entire reproductive cycle of the organism.

Low expansion foam (LX) Finished foam of expansion ratio of less than or equal to 20:1.

Lowest observed effect concentration (LOEC) The lowest concentration of a material used in a toxicity test that has a statistically significant adverse effect on the exposed population of test organisms compared with the controls. When derived from a life cycle or partial life cycle test, it is numerically the same as the upper limit of the MATC. Also called lowest observed adverse effect level (LOAEL).

Median effective concentration (EC50) The concentration of material in water to which test organisms are exposed that is estimated to be effective in producing some sublethal response in 50% of the test organisms. The EC50 is usually expressed as a time-dependant value (e.g.,

24-h or 96-h EC50). The sublethal response elicited from the test organisms as a result of exposure to the test material must be clearly defined. For example, test organisms may be immobilised, lose equilibrium, or undergo physiological or behavioural changes.

Median lethal concentration (LC50) The concentration of material in water to which test organisms are exposed that is estimated to be lethal to 50% of the test organisms. The LC50 is often expressed as a time-dependant value (e.g., 24-h or 96-h LC50; the concentration estimated to be lethal to 50% of the test organisms after 24 or 96 h of exposure). The LC50 may be derived by *observation* (i.e., 50% of the test organisms may be observed to be dead in one test material concentration), by *interpolation* (i.e., mortality of more than 50% of the test organisms occurred at one test concentration and mortality of fewer than 50% of the test organisms died at a lower test concentration, and the LC50 is estimated by interpolation between these two data points), or by *calculation* (i.e., the LC50 is statistically derived by analysis of mortality data from all test concentration).

Medium expansion foam (MX) Finished foam of expansion ratio greater than 20:1, but less than or equal to 200:1.

No observed effect concentration (NOEC) The highest concentration of a material in a toxicity test that has no statistically significant adverse effect on the exposed population of test organisms compared with the controls. When derived from a life cycle or partial life cycle test, it is numerically the same as the lower limit of the MATC. Also called no observed adverse effect level (NOAEL) or no observed effect level (NOEL).

pH (Acidity/Alkalinity) Measurement of the acidity to alkalinity of a liquid on a scale of 1 to 14. A pH of 7 is neutral (like that of pure water), a pH of 1 is very acidic, a pH of 14 is very alkaline.

Polar solvent This term is generally used to describe any liquid which destroys standard foams, although it actually refers to liquids whose molecules possess a permanent dielectric discharge e.g. Alcohol, ketones. Most polar solvents are water-miscible.

Protein (P) foam concentrate Protein foam concentrate contains organic concentrates derived from natural vegetable or animal sources. Hydrolysed products of protein provide exceptionally stable and heat resistant properties to foams although they lack fuel tolerance and have slow knockdown performance.

Risk A statistical concept defined as the expected frequency or probability of undesirable effects resulting from a specified exposure to known or potential environmental concentrations of a material. A material is considered safe if the risks associated with its exposure are judged to be acceptable. Estimates of risk may be expressed in absolute or relative terms. Absolute risk is the excess risk due to exposure. Relative risk is the ratio of the risk in the exposed population to the risk in an unexposed population.

Static system An exposure system for aquatic toxicity tests in which the test chambers contain still solutions of the test material or control water.

Synthetic detergent (SYNDET) foam concentrate These are based upon mixtures of hydrocarbon surface active agents and may contain fluorinated surface active agents with additional stabilisers. They are multipurpose foams in that they can be used at low, medium and high expansion.

Toxicity The inherent potential or capacity of an agent or material to cause adverse effects in a living organism when the organism is exposed to it. See Direct toxicity and indirect toxicity.

Toxicity test The means by which the toxicity of a chemical or other test material is determined. A toxicity test is used to measure the degree of response produced by exposure to a specific level of stimulus (or concentration of chemical).

Water-immiscible liquid A liquid that is not soluble in water.

Water-miscible liquid A liquid that is soluble in water. Polar solvents and hydrocarbon liquids that are water-miscible can dissolve normal fire fighting foams (see also alcohol resistant foam concentrates).

Water quality criterion An estimate, based on scientific judgements, of the concentration of a chemical or other constituent in water which, if not exceeded, will protect an organism, an organism community, or a prescribed water use or quality with an adequate degree of safety. In some jurisdictions terminology may be different and the term guideline or objective may be substituted for criterion. Criteria may also refer to the scientific principals and data that are used to formulate recommended guidelines or limits.

Water quality guideline or limit A scientifically based numerical concentration limit or narrative statement recommended to support and maintain a designated water use.

Water quality objective A scientifically based numerical concentration limit or narrative statement (e.g., receiving water should sustain a healthy population of salmonids) that has been established support and protect designated uses of water, often at a specified site or sites. Objectives reflect desired conditions in receiving waters, usually do not carry the force of law (i.e., are not water quality standards), and often consider various receiving waters separately.

Water quality standards are established for regulatory purposes and have a legal meaning that may vary between jurisdictions. A standard, numerical criterion or narrative that is based on the limiting concentration of a chemical (or degree of intensity of some adverse condition, e.g., pH) which is permitted in an effluent or waterway. It is usually formulated with reference to specific enabling legalisation and is the product of both legal and scientific judgements. A water quality standard is typically dependant on the use (e.g., potable, agricultural) of the water to be protected.

Wetting agent A chemical compound which, when added to water in correct proportions, materially reduces its surface tension, increases its penetrating and spreading abilities and may also provide foaming characteristics.

Xenobiotic A foreign chemical or material usually not produced in nature and not normally considered a constitutive component of a specified biological system. This term is usually applied to manufactured chemicals.

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APPENDIX A PRODUCT CONCENTRATE TOXICITY

Table A1.1 Product toxicity data for protein based product concentrates

Product name	Species	Duration	Effect	Concentration	Ref
Nicerol	Rainbow Trout (*Oncorhynchus mykiss*)	3h	LC50	>10000 mg/l	Angus Fire MSDS Nicerol (1999)
	Rainbow Trout (*Oncorhynchus mykiss*)	6h	LC50	7500 mg/l	Angus Fire MSDS Nicerol (1999)
	Rainbow Trout (*Oncorhynchus mykiss*)	24h	LC50	4800 mg/l	Angus Fire MSDS Nicerol (1999)
	Rainbow Trout (*Oncorhynchus mykiss*)	48h	LC50	4200 mg/l	Angus Fire MSDS Nicerol (1999)
	Rainbow Trout (*Oncorhynchus mykiss*)	72h	LC50	2400 mg/l	Angus Fire MSDS Nicerol (1999)
	Rainbow Trout (*Oncorhynchus mykiss*)	96h	LC50	2400 mg/l	Angus Fire MSDS Nicerol (1999)
	Water flea (*Daphnia magna*)	24h	EC50	4262 mg/l	Angus Fire MSDS Nicerol (1999)
	Water flea (*Daphnia magna*)	48h	EC50	1443 mg/l	Angus Fire MSDS Nicerol (1999)
Nicerol HC	ND				Angus Fire MSDS Nicerol (1999)
Profoam 803	Rainbow Trout (*Oncorhynchus mykiss*)	96 h	LC50	>2000mg/l	Croda MSDS Profoam (803/806) MSDS/F1/Revision3/Dec00.
	Water flea (*Daphnia magna*)	24 h	EC50	>2000mg/l	Croda MSDS Profoam (803/806) MSDS/F1/Revision3/Dec00.
	Water flea (*Daphnia magna*)	48h	EC50	>2000mg/l	Croda MSDS Profoam (803/806)

Table A1.1 Product toxicity data for protein based product concentrates – Cont.

Product name	Species	Duration	Effect	Concentration	Ref
Profoam 806	Rainbow Trout (Oncorhynchus mykiss)	96 h	LC50	>2000mg/l	Croda MSDS Profoam (803/806) MSDS/F1/Revision3/Dec00.
	Water flea (*Daphnia magna*)	24 h	EC50	>2000mg/l	Croda MSDS Profoam (803/806) MSDS/F1/Revision3/Dec00.
	Water flea (*Daphnia magna*)	48h	EC50	>2000mg/l	Croda MSDS Profoam MSDS/F1/Revision3/Dec00.
Profoam 303	ND				Croda MSDS Profoam MSDS/F1/Revision3/Dec00.
Profoam 606	ND				Croda MSDS Profoam MSDS/F1/Revision3/Dec00.
Regular Protein Foam 3%	ND				Chubb Fire MSDS

ND = No Data

Table A.1.2 Toxicity of Fluoroprotein based product concentrates

Product name	Species	Duration	Effect	Concentration	Ref
Fluorofoam 803	ND				Croda MSDS Fluorofoam MSDS/F2/Revision3/Dec00.
Fluorofoam 806	ND				Croda MSDS Fluorofoam MSDS/F2/Revision3/Dec00.
Fluorofoam 903	Rainbow Trout (Oncorhynchus mykiss)	96 h	LC50	>1000mg/l	Croda MSDS Fluorofoam (903/906) MSDS/F2/Revision3/Dec00.
	Water flea (*Daphnia magna*)	24 h	EC50	>1000mg/l	Croda MSDS Fluorofoam (903/906) MSDS/F2/Revision3/Dec00.
	Water flea (*Daphnia magna*)	48h	EC50	>1000mg/l	Croda MSDS Fluorofoam (903/906) MSDS/F2/Revision3/Dec00.
Fluorofoam 903 Plus	ND				Croda MSDS Fluorofoam (903/906) MSDS/F2/Revision3/Dec00.
Fluorofoam 906	Rainbow Trout (Oncorhynchus mykiss)	96 h	LC50	>1000mg/l	Croda MSDS Fluorofoam (903/906) MSDS/F2/Revision3/Dec00.
	Water flea (*Daphnia magna*)	24 h	EC50	>1000mg/l	Croda MSDS Fluorofoam (903/906) MSDS/F2/Revision3/Dec00.
	Water flea (*Daphnia magna*)	48h	EC50	>1000mg/l	Croda MSDS Fluorofoam MSDS/F2/Revision3/Dec00.
Plus F 6%	ND	ND	ND	ND	Chubb Fire MSDS

Table A.1.2 Toxicity of Fluoroprotein based product concentrates - Cont.

Product name	Species	Duration	Effect	Concentration	Ref
Plus F 3%	ND				Chubb Fire MSDS
FP70 Plus	Rainbow Trout (*Oncorhynchus mykiss*)	3h	LC50	>10000 mg/l	Angus Fire MSDS FP70 Plus (1998)
	Rainbow Trout (*Oncorhynchus mykiss*)	6h	LC50	>10000 mg/l	Angus Fire MSDS FP70 Plus (1998)
	Rainbow Trout (*Oncorhynchus mykiss*	24h	LC50	>10000 mg/l	Angus Fire MSDS FP70 Plus (1998)
	Rainbow Trout (*Oncorhynchus mykiss*)	48h	LC50	>10000 mg/l	Angus Fire MSDS FP70 Plus (1998)
	Rainbow Trout (*Oncorhynchus mykiss*)	72h	LC50	5400 mg/l	Angus Fire MSDS FP70 Plus (1998)
	Rainbow Trout (*Oncorhynchus mykiss*)	96h	LC50	4200 mg/l	Angus Fire MSDS FP70 Plus (1998)
PF70	Rainbow Trout (*Oncorhynchus mykiss*)	24h	LC50	3860 mg/l	Angus Fire MSDS FP70 (1998)
	Rainbow Trout (*Oncorhynchus mykiss*)	48h	LC50	3400 mg/l	Angus Fire MSDS FP70 (1998)
	Rainbow Trout (*Oncorhynchus mykiss*)	72h	LC50	3220 mg/l	Angus Fire MSDS FP70 (1998)
	Rainbow Trout (*Oncorhynchus mykiss*)	96h	LC50	2540 mg/l	Angus Fire MSDS FP70 (1998)
	Water flea (*Daphnia magna*)	24h	EC50	8906 mg/l	Angus Fire MSDS FP70 (1998)
	Water flea (*Daphnia magna*)	48h	EC50	4977 mg/l	Angus Fire MSDS FP70 (1998)
FP350	ND	ND	ND	ND	-

Table A.1.2 Toxicity of Fluoroprotein based product concentrates - Cont

Product name	Species	Duration	Effect	Concentration	Ref
FP570	Rainbow Trout (*Oncorhynchus mykiss*)	3h	LC50	>10000 mg/l	Angus Fire MSDS FP570 (1999)
	Rainbow Trout (*Oncorhynchus mykiss*)	6h	LC50	>10000 mg/l	Angus Fire MSDS FP570 (1999)
	Rainbow Trout (*Oncorhynchus mykiss*)	24h	LC50	>10000 mg/l	Angus Fire MSDS FP570 (1999)
	Rainbow Trout (*Oncorhynchus mykiss*)	48h	LC50	>10000 mg/l	Angus Fire MSDS FP570 (1999)
	Rainbow Trout (*Oncorhynchus mykiss*)	72h	LC50	>10000 mg/l	Angus Fire MSDS FP570 (1999)
	Rainbow Trout (*Oncorhynchus mykiss*)	96h	LC50	7200 mg/l	Angus Fire MSDS FP570 (1999)
FP600	ND				Angus Fire MSDS

ND = No Data

Table A.1.3 Toxicity of FFFP based product concentrates

Product name	Species	Duration	Effect	Concentration	Ref
Centrifoam 803	Rainbow Trout (Oncorhynchus mykiss)	96 h	LC50	>1000mg/l	Croda MSDS Centrifoam (803/806) MSDS/F20/Revision3/Dec00.
	Water flea (*Daphnia magna*)	24 h	EC50	>1000mg/l	Croda MSDS Centrifoam (803/806) MSDS/F20/Revision3/Dec00.
	Water flea (*Daphnia magna*)	48h	EC50	>1000mg/l	Croda MSDS Centrifoam (803/806) MSDS/F20/Revision3/Dec00.
Centrifoam 806	Rainbow Trout (Oncorhynchus mykiss)	96 h	LC50	>2000mg/l	Croda MSDS Centrifoam 806 MSDS/F5/Revision3/Dec00.
	Water flea (*Daphnia magna*)	24 h	EC50	>2000mg/l	Croda MSDS Centrifoam 806 MSDS/F5/Revision3/Dec00.
	Water flea (*Daphnia magna*)	48h	EC50	>2000mg/l	Croda MSDS Centrifoam 806 MSDS/F5/Revision3/Dec00.
Centrifoam 903	ND				Croda MSDS Centrifoam (903/906 UL) MSDS/F3/Revision3/Dec00.
Centrifoam 906	ND				Croda MSDS Centrifoam (903/906 UL) MSDS/F3/Revision3/Dec00.
Centrifoam 903 UL	Rainbow Trout (Oncorhynchus mykiss)	96 h	LC50	>1000mg/l	Croda MSDS Centrifoam (903/906 UL) MSDS/F3/Revision3/Dec00.

Table A.1.3 Toxicity of FFFP based product concentrates – Cont.

Product name	Species	Duration	Effect	Concentration	Ref
	Water flea (*Daphnia magna*)	24 h	EC50	>1000mg/l	Croda MSDS Centrifoam (903/906 UL) MSDS/F3/Revision3/Dec00.
	Water flea (*Daphnia magna*)	48h	EC50	>1000mg/l	Croda MSDS Centrifoam (903/906 UL) MSDS/F3/Revision3/Dec00.
Centrifoam 906 UL	Rainbow Trout (Oncorhynchus mykiss)	96 h	LC50	>2000mg/l	Croda MSDS Centrifoam (903/906 UL) MSDS/F3/Revision3/Dec00.
	Water flea (*Daphnia magna*)	24 h	EC50	>2000mg/l	Croda MSDS Centrifoam (903/906 UL) MSDS/F3/Revision3/Dec00.
	Water flea (*Daphnia magna*)	48h	EC50	>2000mg/l	Croda MSDS Centrifoam (903/906 UL) MSDS/F3/Revision3/Dec00.
Centrifoam A936	Rainbow Trout (Oncorhynchus mykiss)	96 h	LC50	>750mg/l	Croda MSDS Centrifoam A936 MSDS/F4/Revision3/Dec00.
	Water flea (*Daphnia magna*)	24 h	EC50	>1000mg/l	Croda MSDS Centrifoam A936 MSDS/F4/Revision3/Dec00.

ND = No Data

Table A.1.3 Toxicity of FFFP based product concentrates – Cont.

Product name	Species	Duration	Effect	Concentration	Ref
	Water flea (*Daphnia magna*)	48h	EC50	>1000mg/l	Croda MSDS Centrifoam A936 MSDS/F4/Revision3/Dec00.
Chubb 3% FFFP	ND				Chubb MSDS
Aer-o-film 33	ND				Chubb MSDS
Aer-o-film 66	ND				Chubb MSDS
Petroseal 6	Rainbow Trout (*Oncorhynchus mykiss*)	3h	LC50	>10000 mg/l	Angus Fire MSDS Petroseal 6 (1997)
	Rainbow Trout (*Oncorhynchus mykiss*)	6h	LC50	>10000 mg/l	Angus Fire MSDS Petroseal 6 (1997)
	Rainbow Trout (*Oncorhynchus mykiss*)	24h	LC50	>10000 mg/l	Angus Fire MSDS Petroseal 6 (1997)
	Rainbow Trout (*Oncorhynchus mykiss*)	48h	LC50	3400 mg/l	Angus Fire MSDS Petroseal 6 (1997)
	Rainbow Trout (*Oncorhynchus mykiss*)	72h	LC50	1300 mg/l	Angus Fire MSDS Petroseal 6 (1997)
	Rainbow Trout (*Oncorhynchus mykiss*)	96h	LC50	1300 mg/l	Angus Fire MSDS Petroseal 6 (1997)
	Water flea (*Daphnia magna*)	24h	EC50	167878 mg/l	Angus Fire MSDS Petroseal 6 (1997)
	Water flea (*Daphnia magna*)	48h	EC50	37857 mg/l	Angus Fire MSDS Petroseal 6 (1997)
Petroseal 3	Rainbow Trout (*Oncorhynchus mykiss*)	3h	LC50	>10000 mg/l	Angus Fire MSDS Petroseal 3 (1998)
	Rainbow Trout (*Oncorhynchus mykiss)*	6h	LC50	>10000 mg/l	Angus Fire MSDS Petroseal 3 (1998)
	Rainbow Trout (*Oncorhynchus mykiss*)	24h	LC50	6100 mg/l	Angus Fire MSDS Petroseal 3 (1998)

Table A.1.3 Toxicity of FFFP based product concentrates – Cont.

Product name	Species	Duration	Effect	Concentration	Ref
	Rainbow Trout (*Oncorhynchus mykiss*)	48h	LC50	4500 mg/l	Angus Fire MSDS Petroseal 3 (1998)
	Rainbow Trout (*Oncorhynchus mykiss*)	72h	LC50	4200 mg/l	Angus Fire MSDS Petroseal 3 (1998)
	Rainbow Trout (*Oncorhynchus mykiss)*	96h	LC50	4200 mg/l	Angus Fire MSDS Petroseal 3 (1998)
	Water flea (*Daphnia magna*)	24h	EC50	22200 mg/l	Angus Fire MSDS Petroseal 3 (1998)
	Water flea (*Daphnia magna*)	48h	EC50	12300 mg/l	Angus Fire MSDS Petroseal 3 (1998)

Table A.1.4 Toxicity of FFFP-AR based product concentrates

Product name	Species	Duration	Effect	Concentration	Ref
Polarfoam 3x3	ND				Chubb Fire MSDS
Polarfoam 3x6	ND				Chubb Fire MSDS
Niagara 1-3	Rainbow Trout (*Oncorhynchus mykiss*)	24h	LC50	6230 mg/l	Angus Fire MSDS Niagara 1-3 (2000)
	Rainbow Trout (*Oncorhynchus mykiss)*	48h	LC50	4410 mg/l	Angus Fire MSDS Niagara 1-3 (2000)
	Rainbow Trout (*Oncorhynchus mykiss*)	72h	LC50	2830 mg/l	Angus Fire MSDS Niagara 1-3 (2000)
	Rainbow Trout (*Oncorhynchus mykiss*)	96h	LC50	2830 mg/l	Angus Fire MSDS Niagara 1-3 (2000)
	Water flea (*Daphnia magna*)	48h	EC50	34860 mg/l	Angus Fire MSDS Niagara 1-3 (2000)
Niagara 3-3	Rainbow Trout (*Oncorhynchus mykiss*)	24h	LC50	6230 mg/l	Angus Fire MSDS Niagara 3-3 (2000)
	Rainbow Trout (*Oncorhynchus mykiss)*	48h	LC50	4410 mg/l	Angus Fire MSDS Niagara 3-3 (2000)
	Rainbow Trout (*Oncorhynchus mykiss*)	72h	LC50	2830 mg/l	Angus Fire MSDS Niagara 3-3 (2000)
	Rainbow Trout (*Oncorhynchus mykiss*)	96h	LC50	2830 mg/l	Angus Fire MSDS Niagara 3-3 (2000)
	Water flea (*Daphnia magna*)	48h	EC50	34860 mg/l	Angus Fire MSDS Niagara 3-3 (2000)
Alcoseal 3-6	Rainbow Trout (*Oncorhynchus mykiss*)	3h	LC50	8500 mg/l	Angus Fire MSDS Alcoseal 3-6 (2000)

Table A.1.4 Toxicity of FFFP-AR based product concentrates – Cont.

Product name	Species	Duration	Effect	Concentration	Ref
	Rainbow Trout (*Oncorhynchus mykiss)*	6h	LC50	6400 mg/l	Angus Fire MSDS Alcoseal 3-6 (2000)
	Rainbow Trout (*Oncorhynchus mykiss*)	24h	LC50	3700 mg/l	Angus Fire MSDS Alcoseal 3-6 (2000)
	Rainbow Trout (*Oncorhynchus mykiss)*	48h	LC50	3300 mg/l	Angus Fire MSDS Alcoseal 3-6 (2000)
	Rainbow Trout (*Oncorhynchus mykiss*)	72h	LC50	3300 mg/l	Angus Fire MSDS Alcoseal 3-6 (2000)
	Rainbow Trout (*Oncorhynchus mykiss*)	96h	LC50	3300 mg/l	Angus Fire MSDS Alcoseal 3-6 (2000)
	Water flea (*Daphnia magna*)	2h	EC50	38300 mg/l	Angus Fire MSDS Alcoseal 3-6 (2000)
	Water flea (*Daphnia magna*)	24h	EC50	10700 mg/l	Angus Fire MSDS Alcoseal 3-6 (2000)
	Water flea (*Daphnia magna*)	48h	EC50	9800 mg/l	Angus Fire MSDS Alcoseal 3-6 (2000)
Alcoseal 3-6 LT	Rainbow Trout (*Oncorhynchus mykiss*)	3h	LC50	9100 mg/l	Angus Fire MSDS Alcoseal 3-6 LT (1997)
	Rainbow Trout (*Oncorhynchus mykiss)*	6h	LC50	7500 mg/l	Angus Fire MSDS Alcoseal 3-6 LT (1997)
	Rainbow Trout (*Oncorhynchus mykiss*)	24h	LC50	4200 mg/l	Angus Fire MSDS Alcoseal 3-6 LT (1997)
	Rainbow Trout (*Oncorhynchus mykiss)*	48h	LC50	4200 mg/l	Angus Fire MSDS Alcoseal 3-6 LT (1997)
	Rainbow Trout (*Oncorhynchus mykiss*)	72h	LC50	4200 mg/l	Angus Fire MSDS Alcoseal 3-6 LT (1997)
	Rainbow Trout (*Oncorhynchus mykiss*)	96h	LC50	4200 mg/l	Angus Fire MSDS Alcoseal 3-6 LT (1997)
	Water flea (*Daphnia magna*)	2h	EC50	48200 mg/l	Angus Fire MSDS Alcoseal 3-6 LT (1997)

Table A.1.4 Toxicity of FFFP-AR based product concentrates – Cont.

Product name	Species	Duration	Effect	Concentration	Ref
	Water flea (*Daphnia magna*)	24h	EC50	14300 mg/l	Angus Fire MSDS Alcoseal 3-6 LT (1997)
	Water flea (*Daphnia magna*)	48h	EC50	13400 mg/l	Angus Fire MSDS Alcoseal 3-6 LT (1997)
Alcoseal 3-3	Rainbow Trout (*Oncorhynchus mykiss*)	3h	LC50	17000 mg/l	Angus Fire MSDS Alcoseal 3-3 (2000)
	Rainbow Trout (*Oncorhynchus mykiss)*	6h	LC50	8500 mg/l	Angus Fire MSDS Alcoseal 3-3 (2000)
	Rainbow Trout (*Oncorhynchus mykiss*)	24h	LC50	4300 mg/l	Angus Fire MSDS Alcoseal 3-3 (2000)
	Rainbow Trout (*Oncorhynchus mykiss)*	48h	LC50	2400 mg/l	Angus Fire MSDS Alcoseal 3-3 (2000)
	Rainbow Trout (*Oncorhynchus mykiss*)	72h	LC50	2400 mg/l	Angus Fire MSDS Alcoseal 3-3 (2000)
	Rainbow Trout (*Oncorhynchus mykiss*)	96h	LC50	2400 mg/l	Angus Fire MSDS Alcoseal 3-3 (2000)
	Water flea (*Daphnia magna*)	2h	EC50	35000 mg/l	Angus Fire MSDS Alcoseal 3-3 (2000)
	Water flea (*Daphnia magna*)	24h	EC50	12000 mg/l	Angus Fire MSDS Alcoseal 3-3 (2000)
	Water flea (*Daphnia magna*)	48h	EC50	10000 mg/l	Angus Fire MSDS Alcoseal 3-3 (2000)

ND = No Data

Table A.1.5 Toxicity of AFFF foam Product concentrates

Product name	Species	Duration	Effect	Concentration	Ref
Filmfoam 216	ND				Croda MSDS Filmfoam
Filmfoam 713	ND				Croda MSDS Filmfoam
Filmfoam 716	ND				Croda MSDS Filmfoam
Filmfoam 811	ND				Croda MSDS Filmfoam
Filmfoam 813	ND				Croda MSDS Filmfoam
Filmfoam 816	ND				Croda MSDS Filmfoam
Filmfoam 911	Rainbow Trout (*Oncorhynchus mykiss*)	96 h	LC50	>750mg/l	Croda MSDS Filmfoam (911) MSDS/F24/Revision3/Dec00.
	Water flea (*Daphnia magna*)	24 h	EC50	>389mg/l	Croda MSDS Filmfoam (911) MSDS/F24/Revision3/Dec00.
	Water flea (*Daphnia magna*)	48h	EC50	>249mg/l	Croda MSDS Filmfoam (911) MSDS/F24/Revision3/Dec00.
Filmfoam 913	Rainbow Trout (*Oncorhynchus mykiss*)	96 h	LC50	>4000mg/l	Croda MSDS Filmfoam (913/916) MSDS/F6/Revision5/Dec00
	Water flea (*Daphnia magna*)	24 h	EC50	>2000mg/l	Croda MSDS Filmfoam (913/916) MSDS/F6/Revision5/Dec01

Table A.1.5 Toxicity of AFFF foam Product concentrates – Cont.

Product name	Species	Duration	Effect	Concentration	Ref
	Water flea (*Daphnia magna*)	48h	EC50	>1000mg/l	Croda MSDS Filmfoam (913/916) MSDS/F6/Revision5/Dec02
Filmfoam 916	Rainbow Trout (*Oncorhynchus mykiss*)	96 h	LC50	>4000mg/l	Croda MSDS Filmfoam (913/916) MSDS/F6/Revision5/Dec03
	Water flea (*Daphnia magna*)	24 h	EC50	>2000mg/l	Croda MSDS Filmfoam (913/916) MSDS/F6/Revision5/Dec04
	Water flea (*Daphnia magna*)	48h	EC50	>1000mg/l	Croda MSDS Filmfoam (913/916) MSDS/F6/Revision5/Dec05
Filmfoam A836	ND				Croda MSDS Filmfoam
Filmfoam A933	Rainbow Trout (*Oncorhynchus mykiss*)	96 h	LC50	>663mg/l	Croda MSDS Filmfoam Centrium A933 MSDS/F17/Revision4/Dec00.
	Water flea (*Daphnia magna*)	24 h	EC50	>203mg/l	Croda MSDS Filmfoam Centrium A933 MSDS/F17/Revision4/Dec00.
	Water flea (*Daphnia magna*)	48h	EC50	>166mg/l	Croda MSDS Filmfoam Centrium A933 MSDS/F17/Revision4/Dec00.
Filmfoam A833	ND				Croda MSDS
Eurofoam 6% AFFF	ND				Chubb Fire MSDS
Eurofoam 3% AFFF	ND				Chubb Fire MSDS
Eurofoam 1% AFFF	ND				Chubb Fire MSDS

Table A.1.5 Toxicity of AFFF foam Product concentrates – Cont.

Product name	Species	Duration	Effect	Concentration	Ref
Aer-o-Water Low Freeze 6%	ND				Chubb Fire MSDS
Aer-o-Water Low Freeze 3%	ND				Chubb Fire MSDS
Aer-o-Water Low Freeze 1%	ND				Chubb Fire MSDS
Tridol S 1	ND				Angus Fire MSDS Tridol
Tridol S 3	Rainbow Trout (*Oncorhynchus mykiss*)	3h	LC50	>560 mg/l	Angus Fire MSDS Tridol S 3 (1997)
	Rainbow Trout (*Oncorhynchus mykiss)*	6h	LC50	>560 mg/l	Angus Fire MSDS Tridol S 3 (1997)
	Rainbow Trout (*Oncorhynchus mykiss*)	24h	LC50	390 mg/l	Angus Fire MSDS Tridol S 3 (1997)
	Rainbow Trout (*Oncorhynchus mykiss)*	48h	LC50	390 mg/l	Angus Fire MSDS Tridol S 3 (1997)
	Rainbow Trout (*Oncorhynchus mykiss*)	72h	LC50	390 mg/l	Angus Fire MSDS Tridol S 3 (1997)
	Rainbow Trout (*Oncorhynchus mykiss*)	96h	LC50	390 mg/l	Angus Fire MSDS Tridol S 3 (1997)
	Water flea (*Daphnia magna*)	24h	EC50	681 mg/l	Angus Fire MSDS Tridol S 3 (1997)
	Water flea (*Daphnia magna*)	48h	EC50	147 mg/l	Angus Fire MSDS Tridol S 3 (1997)
Tridol S 3 LT	ND				Angus Fire MSDS Tridol
Tridol S 6	Rainbow Trout (*Oncorhynchus mykiss*)	3h	LC50	>1800 mg/l	Angus Fire MSDS Tridol S 6 (1999)

Table A.1.5 Toxicity of AFFF foam Product concentrates – Cont.

Product name	Species	Duration	Effect	Concentration	Ref
	Rainbow Trout (*Oncorhynchus mykiss)*	6h	LC50.	>1600 mg/l	Angus Fire MSDS Tridol S 6 (1999)
	Rainbow Trout (*Oncorhynchus mykiss*)	24h	LC50.	1300 mg/l	Angus Fire MSDS Tridol S 6 (1999)
	Rainbow Trout (*Oncorhynchus mykiss)*	48h	LC50.	1300 mg/l	Angus Fire MSDS Tridol S 6 (1999)
	Rainbow Trout (*Oncorhynchus mykiss*)	72h	LC50.	1300 mg/l	Angus Fire MSDS Tridol S 6 (1999)
	Rainbow Trout (*Oncorhynchus mykiss*)	96h	LC50.	1300 mg/l	Angus Fire MSDS Tridol S 6 (1999)
Tridol S 6 LT	ND				Angus Fire MSDS Tridol S 6 (1999)
Tridol C 3	Water flea (*Daphnia magna*)	24h	EC50	8200 mg/l	Angus Fire MSDS Tridol C 3 (1997)
Tridol C 6	Water flea (*Daphnia magna*)	24h	EC50	13700 mg/l	Angus Fire MSDS Tridol C 6 (1997)
Schmitz class B	ND				Schmitz MSDS
Cafilm	ND				Auxquima MSDS

ND = No Data

Table A.1.6 Toxicity of AFFF-AR based foam product concentrates

Product name	Species	Duration	Effect	Concentration	Ref
Tridol ATF 1-3	Water flea (*Daphnia magna*)	24h	EC50	14500 mg/l	Angus Fire MSDS Tridol ATF 1-3 (2000)
	Water flea (*Daphnia magna*)	48h	EC50	10700 mg/l	Angus Fire MSDS Tridol ATF 1-3 (2000)
Tridol ATF 3-3	Water flea (*Daphnia magna*)	24h	EC50	14500 mg/l	Angus Fire MSDS Tridol ATF 3-3 (2000)
	Water flea (*Daphnia magna*)	48h	EC50	10700 mg/l	Angus Fire MSDS Tridol ATF 3-3 (2000)
Tridol ATF 3-3 LT	ND				Angus Fire MSDS Tridol
Tridol ATF 3-6	Water flea (*Daphnia magna*)	24h	EC50	3000 mg/l	Angus Fire MSDS Tridol ATF 3-6 (1997)
Tridol ATF 3-6 LT	ND				Angus Fire MSDS Tridol
Tridol M	Killifish (*Fundulus herteroclitus*)		LC50	719 mg/l	Angus Fire MSDS Tridol M (2000)
Universal Gold Low Freeze	ND				Chubb fire MSDS
Universal Plus	ND				Chubb fire MSDS
Chubb 3x6 AFFF-AR Low Freeze	ND				Chubb fire MSDS
Polyfoam	ND				Chubb fire MSDS

ND = No Data

Table A.1.7 Toxicity of Hazmat and training foam product concentrates

Product name	Species	Duration	Effect	Concentration	Ref
Vapourshield Acid	ND				Chubb fire MSDS
Training foam 1%	ND				Chubb fire MSDS
Training foam 3%	ND				Chubb fire MSDS

ND = No Data

Table A.1.8 Toxicity of SYNDET based foam product concentrates

Product name	Species	Duration	Effect	Concentration	Ref
Hi-foam S	ND				Croda Kerr MSDS
Hi-foam 2%	ND				Croda Kerr MSDS
Expandol	Rainbow Trout (*Oncorhynchus mykiss*)	3h	LC50	>180 mg/l	Angus Fire MSDS Expandol (2000)
	Rainbow Trout (*Oncorhynchus mykiss)*	6h	LC50	>180 mg/l	Angus Fire MSDS Expandol (2000)
	Rainbow Trout (*Oncorhynchus mykiss*)	24h	LC50	89 mg/l	Angus Fire MSDS Expandol (2000)
	Rainbow Trout (*Oncorhynchus mykiss)*	48h	LC50	60 mg/l	Angus Fire MSDS Expandol (2000)
	Rainbow Trout (*Oncorhynchus mykiss*)	72h	LC50	45 mg/l	Angus Fire MSDS Expandol (2000)
	Rainbow Trout (*Oncorhynchus mykiss*)	96h	LC50	45 mg/l	Angus Fire MSDS Expandol (2000)
	Water flea (*Daphnia magna*	24h	EC50	37 mg/l	Angus Fire MSDS Expandol (2000)
	Water flea (*Daphnia magna*	48h	EC50	10 mg/l	Angus Fire MSDS Expandol (2000)
Expandol LT	Goldfish (*Carassius auratus*)	48h	LC50	1000 mg/l	Angus Fire MSDS Expandol LT (2000)
	Water flea (*Daphnia magna*	48h	EC50	50 mg/l	Angus Fire MSDS Expandol LT (2000)
Hex	ND				Chubb fire MSDS

ND = No Data

Table A.1.9 Toxicity of Class A foam product constituents

Product name	Species	Duration	Effect	Concentration	Ref
Bio for N	ND				Bio-Ex MSDS
Cafoam	ND				Auxquima S.A. MSDS
Schmitz Class A foam	ND				Schmitz MSDS
Forexpan S	Rainbow Trout (*Oncorhynchus mykiss*)	96h	LC50	10.4 mg/l	Angus Fire MSDS Forexpan S (1997)

ND = No Data

APPENDIX B BIODEGRADATION OF FOAM PRODUCT CONCENTRATES

Results in mg/l unless otherwise stated.

Table.B.1 Product concentrate biodegradation data

Product name	COD	BOD 5 day	BOD 7 day	BOD 14 day	BOD 15 day	Biodeg within 17 days	BOD 20 day	BOD 21 day	BOD 28 day	Source
Profoam 803	16785	3600 (21% biodeg)	-	-	-		8700 (52%)	-	18300 (100%)	Croda MSDS Profoam (803/806) MSDS/F1/Revision3/Dec00.
Profoam 806	16785	3600 (21% biodeg)	-	-	-		8700 (52%)	-	18300 (100%)	Croda MSDS Profoam (803/806) MSDS/F1/Revision3/Dec00.
Profoam 303	-	-	-	-	-		-	-	-	Croda MSDS Profoam (803/806) MSDS/F1/Revision3/Dec00.
Profoam 606	-	-	-	-	-		-	-	-	Croda MSDS Profoam (803/806) MSDS/F1/Revision3/Dec00.
Fluorofoam 803	-	0.23	-	-	-		0.46	-	0.83	Croda MSDS Centrifoam (803/806) MSDS/F20/Revision/Dec00.
Fluorofoam 806	-	0.19	-	-	-		0.66	-	0.97	Croda MSDS Centrifoam (803/806) MSDS/F20/Revision/Dec00.
Fluorofoam 903	353000	60000 (17%)	-	-	-		150000 (43%)	-	264000 (75%)	Croda MSDS Fluorofoam (903/906) MSDS/F2/Revision3/Dec00.
Fluorofoam 903 Plus	-		-	-	-		-	-	-	Croda MSDS Fluorofoam (903/906) MSDS/F2/Revision3/Dec00.
Fluorofoam 906	353000	60000 (17%)	-	-	-		150000 (43%)	-	264000 (75%)	Croda MSDS Fluorofoam (903/906) MSDS/F2/Revision3/Dec00.

Table.B.1 Product concentrate biodegradation data-Cont.

Product name	COD	BOD 5 day	BOD 7 day	BOD 14 day	BOD 15 day	Biodeg within 17 days	BOD 20 day	BOD 21 day	BOD 28 day	Source
Centrifoam 803	-	0.23	-	-	-		0.46	-	0.83	Croda MSDS Centrifoam (803/806) MSDS/F20/Revision3/Dec00.
Centrifoam 806	-	0.19	-	-	-		0.66	-	0.97	Croda MSDS Centrifoam (803/806) MSDS/F20/Revision3/Dec00.
Filmfoam 216	-	-	-	-	-		-	-	-	Croda MSDS Filmfoam MSDS
Filmfoam 713	-	-	-	-	-		-	-	-	Croda MSDS Filmfoam MSDS
Filmfoam 716	-	-	-	-	-		-	-	-	Croda MSDS Filmfoam MSDS
Filmfoam 811	-	-	-	-	-		-	-	-	Croda MSDS Filmfoam MSDS
Filmfoam 813	-	-	-	-	-		-	-	-	Croda MSDS Filmfoam MSDS
Filmfoam 816	-	-	-	-	-		-	-	-	Croda MSDS Filmfoam MSDS
Filmfoam 911	-	0.14	-	-	-		0.69	-	0.85	Croda MSDS Filmfoam (911) MSDS/F24/Revision3/Dec00.
Filmfoam 913	-	0.21	-	-	-		0.73	-	0.81	Croda MSDS Filmfoam (913/916) MSDS/F6/Revision5/Dec00
Filmfoam 916	-	0.21	-	-	-		0.73	-	0.81	Croda MSDS Filmfoam (913/916) MSDS/F6/Revision5/Dec01
Filmfoam A836	-	-	-	-	-		-	-	-	Croda MSDS Filmfoam MSDS
Filmfoam A933	-	0.36	-	-	-		0.59	-	-	Croda MSDS Filmfoam Centrium A933 MSDS/F17/Revision4/Dec00.

Table.B.1 Product concentrate biodegradation data-Cont.

Product name	COD	BOD 5 day	BOD 7 day	BOD 14 day	BOD 15 day	Biodeg within 17 days	BOD 20 day	BOD 21 day	BOD 28 day	Source
Filmfoam A833	-	-	-	-	-		-	-	-	
Centrifoam 803	-	0.23	-	-	-		0.46	-	0.83	Croda MSDS Centrifoam (803/806) MSDS/F20/Revision3/Dec00.
Centrifoam 806	17391	0.19	-	-	-		0.66	-	0.97	Croda MSDS Centrifoam 806 MSDS/F5/Revision3/Dec00.
Centrifoam 903	-	-	-	-	-		-	-	-	
Centrifoam 906	-	-	-	-	-		-	-	-	
Centrifoam 903 UL	38200	87000 (23%)	-	-	-		174000 (46%)	-	318000 (83%)	Croda MSDS Centrifoam (903/906 UL) MSDS/F3/Revision3/Dec00.
Centrifoam 906 UL	17391	3300 (19%)	-	-	-		11400 (66%)	-	16800 (97%)	Croda MSDS Centrifoam (903/906 UL) MSDS/F3/Revision3/Dec00.
Centrifoam A936	-	-	-	-	-		-	-	-	Croda MSDS Centrifoam
Hi-foam S	-	-	-	-	-		-	-	-	Croda MSDS
Hi-foam 2%	-	-	-	-	-		-	-	-	Croda MSDS
Powerex	-	-	-	-	-		-	-	-	
Fluorofilm 6%	420 mg g	210 mg g (50%)	-	-	-		-	-	-	Chubb MSDS Fluorofilm 6% (1999)
Fluorofilm 6% inhibited	420 mg g	210 mg g (50%)	-	-	-		-	-	-	Chubb MSDS Fluorofilm 6% inhibited (1999)

Table.B.1 Product concentrate biodegradation data-Cont.

Product name	COD	BOD 5 day	BOD 7 day	BOD 14 day	BOD 15 day	Biodeg within 17 days	BOD 20 day	BOD 21 day	BOD 28 day	Source
Vapourshield Acid	505 mg g	192 mg g (38%)	-	-	-		-	-	-	Chubb MSDS Vapourshield Acid (1999)
Training Foam 1%	692 mg g	241 mg g	-	-	-		-	-	-	Chubb MSDS Training Foam 1% (1999)
Training Foam 3%	235 mg g	151 mg g (64.3%)	-	-	-		-	-	-	Chubb MSDS Training Foam 3% (1999)
Universal Gold Low Freeze	566 mg g	420 mg g (74.6%)	-	-	-		-	-	-	Chubb MSDS Universal Gold Low Freeze (1999)
Universal Plus	240 mg g	170 mg g (70.8%)	-	-	-		-	-	-	Chubb MSDS Universal Plus (1999)
Chubb 3x6 AFFF-AR Low Freeze	-	-	-	-	-		-	-	-	Chubb MSDS
Eurofoam 6% AFFF	-	-	-	-	-		-	-	-	Chubb MSDS
Eurofoam 3% AFFF	-	-	-	-	-		-	-	-	Chubb MSDS
Eurofoam 1% AFFF	-	-	-	-	-		-	-	-	Chubb MSDS
Aer-o-Water Low Freeze 6%	447 mg g	349 mg g (76%)	-	-	-		-	-	-	Chubb MSDS Aer-o-Water Low Freeze 6% (1999)
Aer-o-Water Low Freeze 3%	636 mg g	481 mg g (76%)	-	-	-		-	-	-	Chubb MSDS Aer-o-Water Low Freeze 3% (1999)
Aer-o-Water Low Freeze 1%	845 mg g	614 mg g (74.4%)	-	-	-		-	-	-	Chubb MSDS Aer-o-Water Low Freeze 1% (1999)

Table.B.1 Product concentrate biodegradation data-Cont

Product name	COD	BOD 5 day	BOD 7 day	BOD 14 day	BOD 15 day	Biodeg within 17 days	BOD 20 day	BOD 21 day	BOD 28 day	Source
Regular Protein Foam 3%	521 mg g	71 mg g (13.6%)	-	-	-		-	-	-	Chubb MSDS Regular Protein Foam 3% (1999)
Plus F 6%	354 mg g	45 mg g (12.7%)	-	-	-		-	-	-	Chubb MSDS Plus F 6% (1999)
Plus F 3%	493 mg g	65 mg g (13.2%)	-	-	-		-	-	-	Chubb MSDS Plus F 3% (1999)
Hex	-	-	-	-	-		-	-	-	Chubb MSDS
Chubb 3% FFFP	-	-	-	-	-		-	-	-	Chubb MSDS
Aerofilm 33	451 mg g	76 mg g (16.8%)	-	-	-		-	-	-	Chubb MSDS Aerofilm 33 (2000)
Aer-o-film 66	338 mg g	55 mg g (16.3%)	-	-	-		-	-	-	Chubb MSDS Aer-o-film 66 (1999)
Polarfoam 3x3	425 mg g	60 mg g (16.8%)	-	-	-		-	-	-	Chubb MSDS Polarfoam 3x3 (1999)
Polarfoam 3x6	425 mg g	60 mg g (16.8%)	-	-	-		-	-	-	Chubb MSDS Polarfoam 3x6 (1999)
Niagara 1-3	0.65 g g	0.41 g g (63%)	-	-	-		-	-	-	Angus Fire MSDS Niagara 1-3 (2000)
Niagara 3-3	0.65 g g	0.41 g g (63%)	-	-	-		-	-	-	Angus Fire MSDS Niagara 3-3 (2000)

Table.B.1 Product concentrate biodegradation data-Cont

Product name	COD	BOD 5 day	BOD 7 day	BOD 14 day	BOD 15 day	Biodeg within 17 days	BOD 20 day	BOD 21 day	BOD 28 day	Source
Alcoseal 3-6	0.29 g g	0.078 g g (27%)	-	-	0.23 g g (79%)		-	-	0.27 g g (92%)	Angus Fire MSDS Alcoseal 3-6 (2000)
Alcoseal 3-6 LT	0.52 g g	0.19 g g (36%)	-	-	0.23 g g (45%)		-	-	0.36 g g (70%)	Angus Fire MSDS Alcoseal 3-6 LT (1997)
Alcoseal 3-3	-	-	-	-	-		-	-	-	
Petroseal 6	0.34 g g	0.12 g g (34%)	-	-	-		-	0.34 g g (100%)	-	Angus Fire MSDS Petroseal 6 (1997)
Petroseal 3	0.65 g g	0.41 g g (63%)	-	-	-		-	-	-	Angus Fire MSDS Petroseal 3 (1998)
FP70 Plus	0.65 g g	-	-	-	-		-	-	-	Angus Fire MSDS FP70 Plus (1998)
PF70	0.46 g g	0.44 g g (96%)	-	-	-		-	-	-	Angus Fire MSDS FP70 (1998)
FP350	-	-	-	-	-		-	-	-	Angus Fire MSDS
FP570	0.40 g g	-	-	-	-		-	0.236 g g (59%)	0.26 g g (65%)	Angus Fire MSDS FP570 (1999)
FP600	-	-	-	-	-		-	-	-	Angus Fire MSDS
Tridol S 1	0.945 g g	0.419 g g (44%)	-	-	-		-	-	-	Angus Fire MSDS Tridol S 1 (2000)
Tridol S 3	0.65 g g	0.22 g g (34%)	-	-	-		-	-	-	Angus Fire MSDS Tridol S 3 (1997)

Table.B.1 Product concentrate biodegradation data-Cont

Product name	COD	BOD 5 day	BOD 7 day	BOD 14 day	BOD 15 day	Biodeg within 17 days	BOD 20 day	BOD 21 day	BOD 28 day	Source
Tridol S 3 LT	0.39 g g	-	0.27 g g (34%)	-	-		-	0.34-0.37 g g (86-94%)	0.34-0.36 g g (87-93%)	Angus Fire MSDS Tridol S 6 (1999)
Tridol S 6	-	-	-	-	-		-	-	-	Angus Fire MSDS Tridol
Tridol S 6 LT	-	-	-	-	-		-	-	-	Angus Fire MSDS Tridol
Tridol C 3	0.49 g g	0.043 g g (9%)	-	-	-		-	-	-	Angus Fire MSDS Tridol C 3 (1997)
Tridol C 6	0.26 g g	0.028 g g (11%)	-	-	-		-	-	-	Angus Fire MSDS Tridol C 6 (1997)
Tridol ATF 1-3	-	-	-	-	-		-	-	-	Angus Fire MSDS Tridol
Tridol ATF 3-3	-	-	-	-	-		-	-	-	Angus Fire MSDS Tridol
Tridol ATF 3-3 LT	-	-	-	-	-		-	-	-	Angus Fire MSDS Tridol
Tridol ATF 3-6	0.28 g g	0.023 g g (8%)	-	-	-		-	-	-	Angus Fire MSDS Tridol ATF 3-6 (1997)
Tridol ATF 3-6 LT	-	-	-	-	-		-	-	-	Angus Fire MSDS Tridol
Tridol M	528904 mg/l	-	-	-	-		BOD20/ COD = 0.67	-	-	Angus Fire MSDS Tridol M (2000)
Nicerol	0.40 g g	-	0.13 g g (32%)	0.16 g g (40%)	-		-	-	0.27 g g (67%)	Angus Fire MSDS Nicerol (1999)

Table.B.1 Product concentrate biodegradation data-Cont

Product name	COD	BOD 5 day	BOD 7 day	BOD 14 day	BOD 15 day	Biodeg within 17 days	BOD 20 day	BOD 21 day	BOD 28 day	Source
Nicerol HC	-	-	-	-	-		-	-	-	
Expandol	0.62 g g	0.087 g g (14%)	-	-	0.30 g g (49%)		-	-	0.33 g g (53%)	Angus Fire MSDS Expandol (2000)
Expandol LT	0.41 g g	0.29 g g (70%)	-	-	-		-	-	-	Angus Fire MSDS Expandol LT (2000)
Forexpan S	-	-	-	-	-		-	-	>50%	Angus Fire MSDS Forexpan S (1997)
Schmitz class A	-	-	-	-	0.998	-	-	-	-	Schmitz Produktinofrmation OS-10.1, Dec 2001
Schmitz class B	-	-	-	-	-	0.998	-	-	-	Schmitz Produktinofrmation OS-11.1, Dec 2001

- = Not Data

APPENDIX C PRODUCT CONSTITUENT LIST

Table C1 Constituent list of Croda Kerr fire fighting foams

Foam type	Product name	Constituent chemicals name and CAS number	% Make up
Basic protein	Profoam 803	Hydrolysed protein (animal) 100085-61-8	70-80%
		Hexylene glycol 107-41-5	2-6%
		Sodium chloride 7647-14-5	8-15%
		Magnesium chloride 7786-30-3	8-15%
		Iron (II) sulphate heptahydrate 7782-63-0	0-2%
		2,4-dichloro-3,5-dimethylphenol 133-53-9	0.5%
Basic protein	Profoam 806	Hydrolysed protein (animal) 100085-61-8	70-80%
		Hexylene glycol 107-41-5	2-6%
		Sodium chloride 7647-14-5	8-15%
		Magnesium chloride 7786-30-3	8-15%
		Iron (II) sulphate heptahydrate 7782-63-0	0-2%
		2,4-dichloro-3,5-dimethylphenol 133-53-9	0.5%
Basic protein	Profoam 303	Hydrolysed protein (animal) 100085-61-8	70-80%
		Hexylene glycol 107-41-5	2-5%
		Sodium chloride 7647-14-5	6-12%
		Magnesium chloride 7786-30-3	6-12%
		Iron (II) sulphate heptahydrate 7782-63-0	0-2%
		2,4-dichloro-3,5-dimethylphenol 133-53-9	0.5%
Basic protein	Profoam 606	Hydrolysed protein (animal) 100085-61-8	70-80%
		Hexylene glycol 107-41-5	2-5%
		Sodium chloride 7647-14-5	6-12%
		Magnesium chloride 7786-30-3	6-12%
		Iron (II) sulphate heptahydrate 7782-63-0	0-2%
		2,4-dichloro-3,5-dimethylphenol 133-53-9	0.5%

Table C1 Constituent list of Croda Kerr fire fighting foams – Cont.

Foam type	Product name	Constituent chemicals name and CAS number	% Make up
Fluoroprotein	Fluorofoam 803	Hydrolysed protein (animal) 100085-61-8	75-85%
		Hexylene glycol 107-41-5	5-10%
		Sodium chloride 7647-14-5	10-15%
		Fluorosurfactant	5-12%
		2,4-dichloro-3,5-dimethylphenol 133-53-9	0.05%
Fluoroprotein	Fluorofoam 806	Hydrolysed protein (animal) 100085-61-8	75-85%
		Hexylene glycol 107-41-5	5-10%
		Sodium chloride 7647-14-5	10-15%
		Fluorosurfactant	5-12%
		2,4-dichloro-3,5-dimethylphenol 133-53-9	0.05%
Fluoroprotein	Fluorofoam 903	Hydrolysed protein (animal) 100085-61-8	80-90%
		Hexylene glycol 107-41-5	2-6%
		Sodium chloride 7647-14-5	8-15%
		Magnesium chloride 7786-30-3	8-15%
		Iron (II) sulphate heptahydrate 7782-63-0	0-2%
		Fluorosurfactant	0.1-0.5%
		2,4-dichloro-3,5-dimethylphenol 133-53-9	0.05%
Fluoroprotein	Fluorofoam 903 Plus	Hydrolysed protein (animal) 100085-61-8	80-90%
		Hexylene glycol 107-41-	5 2-6%
		Sodium chloride 7647-14-5	8-15%
		Magnesium chloride 7786-30-3	8-15%
		Iron (II) sulphate heptahydrate 7782-63-0	0-2%
		Fluorosurfactant	0.7-1.1%
		2,4-dichloro-3,5-dimethylphenol 133-53-9	0.05%

Table C1 Constituent list of Croda Kerr fire fighting foams – Cont.

Foam type	Product name	Constituent chemicals name and CAS number	% Make up
Fluorofoam	Fluorofoam 906	Hydrolysed protein (animal) 100085-61-8	80-90%
		Hexylene glycol 107-41-5	2-6%
		Sodium chloride 7647-14-5	8-15%
		Magnesium chloride 7786-30-3	8-15%
		Iron (II) sulphate heptahydrate 7782-63-0	0-2%
		Fluorosurfactant 0	.1-0.5%
		2,4-dichloro-3,5-dimethylphenol 133-53-9	0.05%
FFFP	Centrifoam 803	Hydrolysed protein (animal) 100085-61-8	75-85%
		Hexylene glycol 107-41-5	5-10%
		Sodium chloride 7647-14-5	10-15%
		Fluorosurfactant	5-12%
		2,4-dichloro-3,5-dimethylphenol 133-53-9	0.05%
FFFP	Centrifoam 806	Hydrolysed protein (animal) 100085-61-8	75-85%
		Hexylene glycol 107-41-5	5-10%
		Sodium chloride 7647-14-5	10-15%
		Fluorosurfactant	5-12%
		2,4-dichloro-3,5-dimethylphenol 133-53-9	0.05%
AFFF	Filmfoam 216	Water	63-87%
		Butyl diglycol 112-34-5	10-20%
		Fluoro-alkyl surfactants	1-6%
		Alfa Olefines	2-6%
		Polyethylene glycol 25322-68-3	0-5%
AFFF	Filmfoam 713	Water	25-90%
		Butyl diglycol 112-34-5	5-35%
		Fluoro-alkyl surfactants	1-10%
		Alfa Olefines	3-30%
		Polyethylene glycol 25322-68-3	1-13%

Table C1 Constituent list of Croda Kerr fire fighting foams – Cont.

Foam type	Product name	Constituent chemicals name and CAS number	% Make up	
AFFF	Filmfoam 716	Water	25-90%	
		Butyl diglycol 112-34-5	5-35%	
		Fluoro-alkyl surfactants	1-10%	
		Alfa Olefines	3-30%	
		Polyethylene glycol 25322-68-3	1-13%	
AFFF	Filmfoam 811	Water	25-90%	
		Butyl diglycol 112-34-5	5-35%	
		Fluoro-alkyl surfactants	1-10%	
		Alfa Olefines	3-30%	
		Polyethylene glycol 25322-68-3	1-13%	
AFFF	Filmfoam 813	freeze protected	-20°C & - -10°C 25°C	
		Water	45-60%	50-75%
		Butyl diglycol 112-34-5	5-10%	5-10%
		Fluoro-alkyl surfactants	2-4%	2-4%
		Alfa Olefines	3-10%	3-10%
		Polyethylene glycol 25322-68-3	2-12%	2-12%
		Monoethylene glycol 107-21-1	25-30%	10-15%
AFFF	Filmfoam 816	freeze protected	-20C & - -10°C 25C	
		Water	45-60%	50-75%
		Butyl diglycol 112-34-5	5-10%	5-10%
		Fluoro-alkyl surfactants	2-4%	2-4%
		Alfa Olefines	3-10%	3-10%
		Polyethylene glycol 25322-68-3	2-12%	2-12%
		Monoethylene glycol 107-21-1	25-30%	10-15%

Table C1 Constituent list of Croda Kerr fire fighting foams – Cont.

Foam type	Product name	Constituent chemicals name and CAS number	% Make up
AFFF	Filmfoam 911	Water	25-90%
		Butyl diglycol 112-34-5	5-30%
		Fluoro-alkyl surfactants	2-11%
		Alfa Olefines	3-18%
		Polyethylene glycol 25322-68-3	2-12%
AFFF	Filmfoam 913	Water	25-90%
		Butyl diglycol 112-34-5	5-30%
		Fluoro-alkyl surfactants	2-11%
		Alfa Olefines	3-18%
		Polyethylene glycol 25322-68-3	2-12%
AFFF	Filmfoam 916	Water	25-90%
		Butyl diglycol 112-34-5	5-30%
		Fluoro-alkyl surfactants	2-11%
		Alfa Olefines	3-18%
		Polyethylene glycol 25322-68-3	2-12%
AFFF	Filmfoam A836	Water	55-60%
		Butyl diglycol 112-34-5	5-15%
		Fluoro-alkyl surfactants	3-6%
		Polyethylene glycol 25322-68-3	1-3%
		Water soluble polymer	5-1%
		Urea 57-13-6 %	11-15
		Ammonium chloride 12125-02-9	0.5-1%
AFFF	Filmfoam A933	Water	-
		Butyl diglycol 112-34-5	-
		Fluoro-alkyl surfactants	-
		Polyethylene glycol 25322-68-3	-
		Water soluble polymer	-

Table C1 Constituent list of Croda Kerr fire fighting foams – Cont.

Foam type	Product name	Constituent chemicals name and CAS number	% Make up
		Urea 57-13-6	-
		Ammonium chloride 12125-02-9	-
AFFF	Filmfoam A833	Water	-
		Butyl diglycol 112-34-5	-
		Fluoro-alkyl surfactants	-
		Polyethylene glycol 25322-68-3	-
		Water soluble polymer	-
		Urea 57-13-6	-
		Ammonium chloride 12125-02-9	-
FFFP	Centrifoam 803	Hydrolysed protein (animal) 100085-61-8	75-85%
		Hexylene glycol 107-41-5	5-10%
		Sodium chloride 7647-14-5	10-15%
		Fluorosurfactants	5-12%
		2,4-dichloro-3,5-dimethylphenol 133-53-9	0.05%
FFFP	Centrifoam 806	Hydrolysed protein (animal) 100085-61-8	75-85%
		Hexylene glycol 107-41-5	5-8%
		Sodium chloride 7647-14-5	10-15%
		Surfactant ble-	5-8%
		2,4-dichloro-3,5-dimethylphenol 133-53-9	0.05%
FFFP	Centrifoam 903	-	-
FFFP	Centrifoam 906-	-	-
FFFP	Centrifoam 903 UL	Hydrolysed protein (animal) 100085-61-8	75-85%
		Hexylene glycol 107-41-5	5-10%
		Sodium chloride 7647-14-5	10-15%
		Fluorosurfactants	5-12%
		2,4-dichloro-3,5-dimethylphenol 133-53-9	0.05%

Table C1 Constituent list of Croda Kerr fire fighting foams – Cont.

Foam type	Product name	Constituent chemicals name and CAS number	% Make up
FFFP	Centrifoam 906 UL	Hydrolysed protein (animal) 100085-61-8	75-85%
		Hexylene glycol 107-41-5	5-10%
		Sodium chloride 7647-14-5	10-15%
		Fluorosurfactants	5-12%
		2,4-dichloro-3,5-dimethylphenol 133-53-9	0.05%
FFFP	Centrifoam A936	Hydrolysed protein (animal) 100085-61-8	85-90%
		Hexylene glycol 107-41-5	5-8%
		Water soluble polymer	<2%
		Fluorosurfactants	5-7%
		2,4-dichloro-3,5-dimethylphenol 133-53-9	0-0.5%
SYNDET - high expansion	Hi-foam S	Water	60-80%
		Butyl diglycol 112-34-5	5-10%
		Alpha olefine sulphonate	10-20%
SYNDET - high expansion	Hi-foam 2%	Water	1-52%
		Borax 1330-43-4	0.1-0.5%
		Monopotassium phosphate 7778-77-0	0.1-0.5%
		Lauryl ether sulphate 78330-29-7	12-26%
		Fatty alcohol sulphate (Alkyl-(C10-C16) alcohol sulfuric acid ammonium salt) 68081-96-9	22-50%
		Butyl glycol 112-34-5	10-25%
		Monoethylene glycol 107-21-1	18-22%

Table C.2 Constituents of Chubb fire fighting foams

Foam type	Product name	Constituent chemicals name and CAS number	% Make up
Hazmat	Vapourshield Acid	2-Butoxy ethanol 111-76-2	<35%
		Amine Oxide	<20%
		Amine oxide	<5%
		Primary alcohol blend	<5%
		Glycerine	<5%
		Glacial acetic acid 64-19-7	<5%
Training foam	Training Foam 1%	Butyl diglycol 112-34-5	<17%
		Hydrocarbon surfactants	<20%
		Water remaining	-
	Training Foam 3%	Butyl diglycol 112-34-5	<8%
		Hydrocarbon surfactants	<5%
		Hydrocarbon surfactants	<5%
		Water remaining	-
AFFF AR	Universal Gold Low Freeze	Butyl diglycol 112-34-5	<5%
		Ethylene glycol 107-21-1 %	<15
		Octyl sodium sulfate 142-31-4	<5%
		Alkyl polyglycoside surfactant 132778-08-6	<5%
		Fluorosurfactants	<2%
		Heteropolysaccharide	<5%
AFFF AR	Universal Plus	Butyl diglycol 112-34-5	<5%
		Hydrocarbon surfactant	<5%
		Fluorosurfactants	<5%
		Heteropolysaccharide	<5%
		Water remaining	-

Table C.2 Constituents of Chubb fire fighting foams – Cont.

Foam type	Product name	Constituent chemicals name and CAS number	% Make up
AFFF AR	Chubb 3x6 AFFF-AR Low Freeze	Ethylene glycol 107-21-1	<21%
		Butyl diglycol 112-34-5	<6%
		Decyl sodium sulfate 142-87-0	<8%
		Alkyl polyglycoside surfactant 132778-08-6	<4%
		Fluorosurfactants	<2%
		Heteropolysaccharide	<2%
		Tetrasodium salt 64-02-8	<0.5%
		5-Chloro-2-Methyl-4-Isothiazolin-3-One 26172-55-4	<0.5%
		Other salts	<1%
		Water remaining	-
AFFF	Eurofoam 6% AFFF	Dipropylene glycol methyl ether 34590-94-8	<2%
		Decyl sodium sulfate 142-87-0	<2%
		Hydrocarbon surfactants	<1%
		Fluorosurfactants	<1%
		Propylene glycol 57-55-6	<1%
		Chelating agent	<1%
		Water remaining	-
AFFF	Eurofoam 3% AFFF	Dipropylene glycol methyl ether 34590-94-8	<4%
		Decyl sodium sulfate 142-87-0	<3%
		Hydrocarbon surfactants	<2%
		Fluorosurfactants	<2%
		Propylene glycol 57-55-6	<2%
		Chelating agent	<1%

Table C.2 Constituents of Chubb fire fighting foams – Cont.

Foam type	Product name	Constituent chemicals name and CAS number	% Make up
		Buffer	<0.5%
		Water remaining	-
AFFF	Eurofoam 1% AFFF	Dipropylene glycol methyl ether 34590-94-8	<12%
		Decyl sodium sulfate 142-87-0	<10%
		Hydrocarbon surfactants	<5%
		Fluorosurfactants	<4%
		Chelating agent	<1%
		Buffer	<0.5%
		Water remaining	-
AFFF	Aer-o-Water Low Freeze 6%	Butyl diglycol 112-34-5	<5-10%
		Ethylene glycol 107-21-1	<25%
		Hydrocarbon surfactants	1-5%
		Tetrasodium salt 64-02-8	<1%
		Fluorosurfactants	1-5%
		Water remaining	-
AFFF	Aer-o-Water Low Freeze 3%	Butyl diglycol 112-34-5	<5-10%
		Ethylene glycol 107-21-1	<25%
		Hydrocarbon surfactants	5-9%
		Tetrasodium salt 64-02-8	<1%
		Fluorosurfactants	1-5%
		Water remaining	-
AFFF	Aer-o-Water Low Freeze 1%	Butyl diglycol 112-34-5	<5-10%
		Ethylene glycol 107-21-1	10-24%
		Hydrocarbon surfactants	5-20%
		Tetrasodium salt 64-02-8	<1%
		Fluorosurfactants	1-5%

Table C.2 Constituents of Chubb fire fighting foams – Cont.

Foam type	Product name	Constituent chemicals name and CAS number	% Make up
		Water remaining	-
Protein type foams	Regular Protein Foam 3%	Hexylene glycol 107-41-5	<10%
		Sodium chloride 7647-14-5	5-10%
		Hydrolysed protein	20-50%
		Bacteriacide	<2%
		Water remaining	-
FP	Plus F 6%	Hexylene glycol 107-41-5	<10%
		Sodium chloride 7647-14-5	5-10%
		Other metal salts	1-5%
		Zinc Oxide 1314-13-2	<1%
		Hydrolysed protein	20-50%
		Fluorosurfactants	<1%
		Hydrocarbon surfactants	<1%
		Bacteriacide	<2%
		Water remaining	-
FP	Plus F 3%	Hexylene glycol 107-41-5	<10%
		Sodium chloride 7647-14-5	5-10%
		Other metal salts	1-5%
		Zinc Oxide 1314-13-2	<1%
		Hydrolysed protein	20-50%
		Fluorosurfactants	<5%
		Hydrocarbon surfactants	<1%
		Bacteriacide	<2%
		Water remaining	-

Table C.2 Constituents of Chubb fire fighting foams – Cont.

Foam type	Product name	Constituent chemicals name and CAS number	% Make up
SYNDET – high expansion	Hex	2-Butoxy ethanol 111-76-2	20-30%
		Ethylene glycol 107-21-1	<10%
		Primary alcohol ether sulphate	5-15%
		Sulphoscuccinate	5-15%
		Primary alcohol ble-	<5%
		Water remaining	-
FFFP	Chubb 3% FFFP	Hexylene glycol 107-41-5	<10%
		Sodium chloride 7647-14-5	5-10%
		Hydrolysed protein	20-50%
		Fluorosurfactants	<1%
		Hydrocarbon surfactants	<1%
		Bacteriacide	<2%
		Water remaining	-
FFFP	Aer-o-film 33	Hexylene glycol 107-41-5	<10%
		Sodium chloride 7647-14-5	5-10%
		Hydrolysed protein	20-50%
		Fluorosurfactants	<5%
		Hydrocarbon surfactants	<1%
		Bacteriacide	<2%
		Water remaining	-
FFFP	Aer-o-film 66	Hexylene glycol 107-41-	5 <10%
		Sodium chloride 7647-14-5	5-10%
		Hydrolysed protein	10-30%
		Fluorosurfactants	<5%
		Hydrocarbon surfactants	<1%
		Bacteriacide	<2%

Table C.2 Constituents of Chubb fire fighting foams – Cont.

Foam type	Product name	Constituent chemicals name and CAS number	% Make up
		Water remaining	-
FFFP -AR	Polarfoam 3x3	Hexylene glycol 107-41-	5 <10%
		Sodium chloride 7647-14-5	5-10%
		Hydrolysed protein	20-50%
		Fluorosurfactants	<7%
		Hydrocarbon surfactants	<1%
		Bacteriacide	<2%
		Water remaining	-
FFFP -AR	Polarfoam 3x6	Hexylene glycol 107-41-5	<10%
		Sodium chloride 7647-14-5	5-10%
		Hydrolysed protein	20-50%
		Fluorosurfactants	<6%
		Hydrocarbon surfactants	<1%
		Bacteriacide	<2%
		Water remaining	-

Table C.3 Constituents of Angus fire fighting foams

Foam type	Product name	Constituent chemicals name and CAS number	% Make up
FFFP - AR	Niagara 1-3	Hexylene glycol 107-41-5	<10%
		Ethylene glycol 107-21-1	<5%
		Sodium chloride 7647-14-5	5-10%
		Hydrolysed protein	20-50%
		Fluorosurfactants	<5%
		Bacteriacide	<2%
		Water remaining	-
FFFP - AR	Niagara 3-3	Hexylene glycol 107-41-5	<10%
		Ethylene glycol 107-21-1	<5%
		Sodium chloride 7647-14-5	5-10%
		Hydrolysed protein	20-50%
		Fluorosurfactants	<5%
		Bacteriacide	<2%
		Water remaining	-
FFFP - AR	Alcoseal 3-6	Hexylene glycol 107-41-5	<10%
		Hydrolysed protein	<30%
		Polymer	<5%
		Fluorosurfactants	<5%
		Bacteriacide	<1%
		Water remaining	-
FFFP - AR	Alcoseal 3-6 LT	Hexylene glycol 107-41-5 5-	10%
		Ethylene glycol 107-21-1	10-20%
		Hydrolysed protein	<30%
		Polymer	<5%

Table C.3 Constituents of Angus fire fighting foams - Cont

Foam type	Product name	Constituent chemicals name and CAS number	% Make up
		Fluorosurfactants	<5%
		Bacteriacide	<1%
		Water remaining	-
FFFP - AR	Alcoseal 3-3	Hexylene glycol 107-41-5	5-10%
		Hydrolysed protein	<30%
		Polymer	<5%
		Fluorosurfactants	<5%
		Bacteriacide	<2%
		Water remaining	-
FFFP	Petroseal 6	Hexylene glycol 107-41-5	1-10%
		Sodium chloride 7647-14-5	5-10%
		Hydrolysed protein	10-30%
		Fluorosurfactants	<5%
		Bacteriacide	<2%
		Water remaining	-
FFFP	Petroseal 3	Hexylene glycol 107-41-5	1-10%
		Sodium chloride 7647-14-5	5-10%
		Other metal salts	1-5%
		Zinc Oxide 1314-13-2	<0.5%
		Hydrolysed protein	20-50%
		Fluorosurfactants	<5%
		Bacteriacide	<2%
		Water remaining	-
FP	FP70 Plus	Hexylene glycol 107-41-5	1-10%
		Sodium chloride 7647-14-5	5-10%
		Other metal salts	1-5%

Table C.3 Constituents of Angus fire fighting foams – Cont

Foam type	Product name	Constituent chemicals name and CAS number	% Make up
		Zinc Oxide 1314-13-2	<1%
		Hydrolysed protein	<50%
		Fluorosurfactants	<5%
		Bacteriacide	<2%
		Water remaining	-
FP	PF70	Hexylene glycol 107-41-5	1-10%
		Sodium chloride 7647-14-	5 5-10%
		Other metal salts	1-5%
		Zinc Oxide 1314-13-2	<1%
		Hydrolysed protein	35%
		Fluorosurfactants	<5%
		Bacteriacide	<2%
		Water remaining	-
FP	FP350	Hexylene glycol 107-41-5	<10%
		Sodium chloride 7647-14-5	5-10%
		Other metal salts	1-5%
		Zinc Oxide 1314-13-2	<1%
		Hydrolysed protein	~35%
		Fluorosurfactants	<5%
		Bacteriacide	<2%
		Water remaining	-
FP	FP570	Hexylene glycol 107-41-5	<10%
		Sodium chloride 7647-14-5	5-10%
		Other metal salts	1-5%
		Zinc Oxide 1314-13-2	<1%
		Hydrolysed protein	~30%
		Fluorosurfactants	<5%

Table C.3 Constituents of Angus fire fighting foams - Cont

Foam type	Product name	Constituent chemicals name and CAS number	% Make up
		Bacteriacide	<2%
		Water remaining	-
FP	FP600	Hexylene glycol 107-41-5	<10%
		Sodium chloride 7647-14-5	5-10%
		Other metal salts	1-5%
		Zinc Oxide 1314-13-2	<1%
		Hydrolysed protein	~25%
		Fluorosurfactants	<5%
		Bacteriacide	<2%
		Water remaining	-
AFFF	Tridol S 1	Butyl diglycol 112-34-5	15-40%
		Ethylene glycol 107-21-1	10-20%
		Hydrocarbon surfactants	<1-10%
		Fluorosurfactants	1-5%
		Water remaining	-
AFFF	Tridol S 3	Butyl diglycol 112-34-5	15-30%
		Hydrocarbon surfactants	1-5%
		Fluorosurfactants	1-5%
		Magnesium sulphate 7487-88-9	<5%
		Water remaining	-
AFFF	Tridol S 3 LT	Butyl diglycol 112-34-5	15-30%
		Ethylene glycol 107-21-1	10-20%
		Hydrocarbon surfactants	1-5%
		Fluorosurfactants	1-5%
		Magnesium sulphate 7487-88-9	<5%
		Water remaining	-

Table C.3 Constituents of Angus fire fighting foams – Cont

Foam type	Product name	Constituent chemicals name and CAS number	% Make up
AFFF	Tridol S 6	Butyl diglycol 112-34-5	10-19%
		Hydrocarbon surfactants	<5%
		Fluorosurfactants	<5%
		Magnesium sulphate 7487-88-9	<5%
		Water remaining	-
AFFF	Tridol S 6 LT	Butyl diglycol 112-34-5	5-15%
		Ethylene glycol 107-21-1	10-20%
		Hydrocarbon surfactants	1-5%
		Fluorosurfactants	1-5%
		Magnesium sulphate 7487-88-9	<5%
		Water remaining	-
AFFF	Tridol C 3	Butyl diglycol 112-34-5	10-20%
		Hydrocarbon surfactants	1-5%
		Fluorosurfactants	1-5%
		Magnesium sulphate 7487-88-9	<5%
		Water remaining	-
AFFF	Tridol C 6	Butyl diglycol 112-34-5	5-15%
		Hydrocarbon surfactants	<5%
		Fluorosurfactants	<5%
		Magnesium sulphate 7487-88-9	<5%
		Water remaining	-
AFFF –AR	Tridol ATF 1-3	Hexylene glycol 107-41-5	5-15%
		Hydrocarbon surfactants	1-5%
		Fluorosurfactants	1-5%
		Xanthan Gum 11138-66-2	<5%
		Water remaining	
AFFF –AR	Tridol ATF 3-3	Hexylene glycol 107-41-5 %	5-15

Table C.3 Constituents of Angus fire fighting foams - Cont

Foam type	Product name	Constituent chemicals name and CAS number	% Make up
		Hydrocarbon surfactants	<10%
		Fluorosurfactants	1-5%
		Xanthan Gum 11138-66-2	<5%
		Water remaining	-
AFFF -AR	Tridol ATF 3-3 LT	-	-
AFFF -AR	Tridol ATF 3-6	Butyl diglycol 112-34-5	5-15%
		Hydrocarbon surfactants	1-5%
		Fluorosurfactants	1-5%
		Magnesium sulphate 7487-88-9	<5%
		Polysaccharide	<5%
		Water remaining	-
AFFF -AR	Tridol ATF 3-6 LT	Butyl diglycol 112-34-5	5-15%
		Ethylene glycol 107-21-1	30-40%
		Hydrocarbon surfactants	1-5%
		Fluorosurfactants	1-5%
		Polymer	<5%
		Water remaining	-
AFFF -AR	Tridol M	Butyl diglycol 112-34-5 10-	25%
		Hydrocarbon surfactants	<5%
		Fluorosurfactants	1-8%
		Magnesium sulphate 7487-88-9	<5%
		Corrosion inhibitor	<0.5%
		Water remaining	-
Protein	Nicerol	Hexylene glycol 107-41-5	<10%
		Sodium chloride 7647-14-5	5-10%
		Other metal salts	1-5%
		Zinc Oxide 1314-13-2	<1%

Table C.3 Constituents of Angus fire fighting foams – Cont

Foam type	Product name	Constituent chemicals name and CAS number	% Make up
		Hydrolysed protein	<20%
		Bacteriacide	<2%
		Water remaining	
Protein	Nicerol HC	Hexylene glycol 107-41-5	<10%
		Sodium chloride 7647-14-5	5-10%
		Other metal salts	1-5%
		Zinc Oxide 1314-13-2	<1%
		Hydrolysed protein	35-40%
		Bacteriacide	<2%
		Water remaining	-
SYNDET – high expansion	Expandol	2-Butoxy ethanol 111-76-2	20-30%
		Primary alcohol ether sulphates	5-15%
		Sulphosuccinate	<10%
		Primary alcohol ble- (gives CAS for magnesium sulphate)	<5%
		Water remaining	-
SYNDET – high expansion	Expandol LT	2-Butoxy ethanol 111-76-2	20-30%
		Ethylene glycol 107-21-1	10-20%
		Primary alcohol ether sulphates	5-15%
		Sulphosuccinate	<10%
		Primary alcohol ble-	<5%
		Water remaining	-

Table C.3 Constituents of Angus fire fighting foams - Cont

Foam type	Product name	Constituent chemicals name and CAS number	% Make up
Class A foam	Forexpan S	Butyl diglycol 112-34-5	15-40%
		Primary alcohol ether sulphate 68585-34-2	10-25%
		Sulphosuccinate	<5%
		Dipropylene glycol methyl ether 34590-94-8	5-15%
		Primary alcohol ble-	<5%
		Corrosion inhibitor	<1%

Table .C.4 Constituents of Schmitz fire fighting foams

Foam type	Product name	Constituent chemicals name and CAS number	% Make up
Class A foam	Class A foam	fluorinated surfactant	-
		hydrogenated surfactant	-
		Water	-
AFFF	Class B Foam	fluorinated surfactant	-
		hydrogenated surfactant	-
		Water	-

Table .C.5 Constituents of Bio Ex fire fighting foams

Foam type	Product name	Constituent chemicals name and CAS number	% Make up
Class A foam	Bio for N	Surfactants	10-20%
		Butyl diglycol 112-34-5	<15%
		Salts	<2%
		Preservatives	<1%
		Water remaining	-

Table C.6 Constituents of Auxquimia S.A. fire fighting foams

Foam type	Product name	Constituent chemicals name and CAS number	% Make up
Class A foam	Cafoam	Ethylene glycol 107-21-1	<20%
		Butyl diglycol 112-34-5	<15%
		Hydrocarbon surfactants	-
		Water remaining	-
AFFF	Cafilm	Butyl diglycol 112-34-5	<15%
		Hydrocarbon surfactants	-
		Fluorosurfactants	-
		Water remaining	-
AFFF-AR	Polyfoam 3/3	Ethylene glycol 107-21-1	<20%
		Butyl diglycol 112-34-5	<15%
		Hydrocarbon surfactants	-
		Fluorosurfactants	-
		Polysaccharides	-
		Water remaining	-

APPENDIX D CONSTITUENT TOXICITY

2-Butoxy ethanol (111-76-2)

Species	Duration	Effect	Conc mg/l	Ref
Green algae (*Chlorococcales*)	24h	EC10 -	>1000	Krebs, 1991.
Blue-green algae (*Microcystis aeruginosa*)	-	LOEC	35	Bringmann a- Kuhn, 1978.
Green algae (*Scenedesmus quadricauda*)	-	LOEC	900	Bringmann a- Kuhn, 1978.
Water flea (*Daphnia magna*)	24h	EC50 - BEH	1815	Bringmann a- Kuhn, 1982.
Water flea (*Daphnia magna*)	24h	LC50	1720 l	Bringmann a- Kuhn, 1977.
Carp (*Leuciscus idus melanotus*)	48h	LC50	1395	Juhnke a- Luedemann, 1978.
Goldfish (*Carassius auratus*)	24h	LC50	1700	Bridie et al, 1979.
Brine shrimp (*Artemia salina*)	24h	LC50	1000	Price et al, 1974.
Common sa- shrimp (*Crangon crangon*)	48h	LC50	600-1000	Blackman, 1974.
Common sa- shrimp (*Crangon crangon*)	96h	LC50	550-950	Blackman, 1974.
Bluegill sunfish (*Lepomis macrochirus*)	96h	LC50	1490	Dawson et al, 1977.
Inla- silverside (*Menidia beryllina*)	96h	LC50	1250	Dawson et al, 1977.

5-Chloro-2-Methyl-4-Isothiazolin-3-One (26172-55-4)

Species	Duration	Effect	Conc mg/l	Ref
Algae (*Anabaena flos-aquae*)	120 h	NOEC - growth rate	0.25	THOR CHEMIE Speyer (IUCLID)
Algae (*Anabaena flos-aquae*)	120 h	EC50	0.31	THOR CHEMIE Speyer (IUCLID)
Water flea (*Daphnia magna*)	48h	EC50	4.71	THOR CHEMIE Speyer (IUCLID)
Water flea (*Daphnia magna*)	21d	NOEC - reproduction	0.172	THOR CHEMIE Speyer (IUCLID)
Water flea (*Daphnia magna*)	21d	LOEC - reproduction	0.572	THOR CHEMIE Speyer (IUCLID)
Water flea (*Daphnia magna*)	21d	EC50 - reproduction	5.06	THOR CHEMIE Speyer (IUCLID)
*Rainbow trout (*Oncorhynchus mykiss*)*	96h	NOEC	1.1	THOR CHEMIE Speyer (IUCLID)
*Rainbow trout (*Oncorhynchus mykiss*)*	96h	LC50	1.6	THOR CHEMIE Speyer (IUCLID)

Ammonium chloride (12125-02-9)

Species	Duration	Effect	Conc mg/l	Ref
Water flea (Daphnia pulicaria)	48h	LC50	0.96	DeGraeve, G.M. et al, 1980 (IUCLID)
Sow bug *(Asellus racovitzai)*	96h	LC50	4.95	Arthur, J.W. et al, 1987 (IUCLID)
*Pericard (*Crangonyx pseudogracilis)	96h	LC50	1.63	Arthur, J.W. et al, 1987 (IUCLID)
Shrimp *(Macrobrachium rosenbergii)*	6d	LC50	0.21	Armstrong, D.A. et al., 1978 (IUCLID)
Shrimp (*Macrobrachium rosenbergii)*	24h	LC50	0.54	Armstrong, D.A. et al., 1978 (IUCLID)
*Rainbow trout (*Oncorhynchus mykiss*)*	96h	LC50	0.16 - 0.468	Calamari D. et al, 1981 (IUCLID)
*Rainbow trout (*Oncorhynchus mykiss*)*	72d	LC50	0.056	Calamari D. et al, 1977 (IUCLID)
Mummichog (*Fu-ulus heteroclitus*)	48 h	LC50	1.6	Burton, D.T., Fisher, D.J., 1990 (IUCLID)
Carp (*Cyprinus carpio*)	48h	LC50	103-109	Dabrowska H. a- Sikora H., 1986 (IUCLID)
Carp (*Cyprinus carpio)*	24h	LC50	275	Rao T.S. et al, 1975 (IUCLID)
Carp (*Cyprinus carpio)*	96h	LC50	209 l	Rao T.S. et al, 1975 (IUCLID)
Channel catfish (*Ictalurus punctatus*)	24h	LC50	2.83 - 7.3	Sheenan R.J. a- Lewis W.M., 1986 (IUCLID)
Barb (*Barbus ambassis*)	24h	LC50	315	D'Silva C. a- Verlencar X.N., 1976 (IUCLID)
Barb (*Barbus ambassis*)	48h	LC50	295	D'Silva C. a- Verlencar X.N., 1976 (IUCLID)

Borax (1330-43-4)

Species	Duration	Effect	Conc mg/l	Ref
Water flea (*Daphnia magna*)	48h	LC50	123-159	Maier a- Knight, 1991.
Bluegill sunfish (*Lepomis macrochirus*)	24h	LC50	15	Turnbull et al, 1954.
Western mosquitofish (*Gambusia affinis*)	24h	LC50	346	Wallen et al, 1957.
Western mosquitofish (*Gambusia affinis)*	48h	LC50	236	Wallen et al, 1957.
Western mosquitofish (*Gambusia affinis*)	6d	LC50	54.7	Wallen et al, 1957.
Western mosquitofish (*Gambusia affinis*)	96h	LC50	104	Wallen et al, 1957.
Midge (*Chrionomus decorus*)	48h	LC50	1298-1453	Maier a- Knight, 1991.
Blue-green algae (*Microcystis aeruginosa*)	-	LOEC	73	Bringmann a- Kuhn, 1978.
Green algae (*Scenedesmus quadricauda*)	-	LOEC	0.58	Bringmann a- Kuhn, 1978.

Butyl diglycol (112-34-5)

Species	Duration	Effect	Conc mg/l	Ref
Water flea (*Daphnia magna*)	24h	EC0 - BEH	2333	Bringmann a- Kuhn, 1982.
Water flea (*Daphnia magna*)	24h	EC50 - BEH	3200	Bringmann a- Kuhn, 1982.
Water flea (*Daphnia magna*)	24h	EC100 - BEH	5000	Bringmann a- Kuhn, 1982.
Water flea (*Daphnia magna*)	24h	LC50	2850	Bringmann a- Kuhn, 1977.
Carp (*Leuciscus idus melanotus*)	48h	LC0	1140	Juhnke a- Luedemann, 1978.
Carp (*Leuciscus idus melanotus*)	48h	LC50	1805 l	Juhnke a- Luedemann, 1978.
Carp (*Leuciscus idus melanotus*)	48h	LC100	2185	Juhnke a- Luedemann, 1978.
Bluegill sunfish (*Lepomis macrochirus*)	96h	LC50	1300	Dawson et al, 1977.
Goldfish (*Carassius auratus*)	24h	LC50	2700	Bridie et al, 1979.
Green algae (*Chlorococcales*)	24h	EC10 - PHY	>1000	Pauli et al, 1993.
Blue-green algae (*Microcystis aeruginosa*)	8d	NOEC - Growth	53	Bringmann a- Kuhn, 1978.

Decyl sodium sulphate (142-87-0)

Species	Duration	Effect	Conc mg/l	Ref
Common mirror carp (*Cyprinus carpio*)	12h	LC50	180	Kikuchi et al, 1976.
Common mirror carp (*Cyprinus carpio*)	24h	LC50	180	Kikuchi et al, 1976.
Common mirror carp (*Cyprinus carpio*)	48h	LC50	13	Kikuchi et al, 1976.
Common mirror carp (*Cyprinus carpio*)	6h	LC50	190	Kikuchi et al, 1976.

Dipropylene glycol methyl ether (34590-94-8)

Species	Duration	Effect	Conc mg/l	Ref
Water flea (*Daphnia magna*)	48h	LC50	1919	Bartlett EA, 1979 (IUCLID)
Fathead minnow (*Pimephales promelas)*	96h	LC50	10000	Bartlett EA, 1979 (IUCLID)

Ethylene glycol (107-21-1)

Species	Duration	Effect	Conc mg/l	Ref
Lemna gibbas (duckweed)	-	EC50	10,920	Barber JT et al, 1999
Water flea (Daphnia magna)	48h	LC50	46,300	Cowgill UM et al, 1985
Water flea (Ceriodaphnia dubia)	48h	LC50	25,800-10,000	Cowgill UM et al, 1985
Goldfish (Carassius auratus)	24 hr	LD50	>5000	Verschueren, 1983.
Guppies (Poecilia reticulata)	7d	LC50	49300	Jank BE et al, 1984.
Rainbow Trout (Oncorhynchus mykiss)	96h	LC50	18500	Jank BE et al, 1984.
Rainbow Trout (Oncorhynchus mykiss)	96h	LC50	41000	Johnson a- Finley, 1980.

Fatty alcohol sulphate (Alkyl-(C10-C16) alcohol sulfuric acid ammonium salt) (68081-96-9)

Species	Duration	Effect	Conc mg/l	Ref
Pseudomonas putida	30 m	EC10	100	IUCLID data set Henkel KGaA, April 26 1995
Algae (*Scenedesmus subspicatus*)	96h	EC50 - growth rate	42	IUCLID data set Henkel KGaA
Water flea (*Daphnia magna)*	24h	EC50	56	IUCLID data set 26 Apr 1995
Golden orfe (*Leuciscus idus*)	48h	LC50	19	IUCLID data set Henkel KGaA April-26-1995
Golden orfe (*Leuciscus idus*)	48h	LC50	ca. 3	IUCLID data set Henkel KGaA 26-Apr-1995

Glacial acetic acid (64-19-7)

Species	Duration	Effect	Conc mg/l	Ref
Green algae (*Chlorococcales*)	24h	EC10 -PHY	105	Krebs, 1991.
Green algae (*Chlorococcales*)	24h	EC50 - PHY	156	Krebs, 1991.
Blue-green algae (*Microcystis aeruginosa*)	-	LOEC	90	Bringmann a- Kuhn, 1978.
Green algae (*Scenedesmus quadricauda*)	-	LOEC	4000	Bringmann a- Kuhn, 1978.
Water flea (*Daphnia magna*)	24h	EC50 - beh	6000	Bringmann a- Kuhn, 1982.
Water flea (*Daphnia magna*)	48h	EC50 - ITX	65	Janssen et al, 1993.
Carp (*Leuciscus idus melanotus*)	48h	LC50	410	Juhnke a- Luedemann, 1978.
Common mirror carp (*Cyprinus carpio*)	48h	LC50	49	Funasaka et al, 1976.
Western mosquitofish (*Gambusia affinis)*	24h	LC50	251	Wallen et al, 1957.
Channel Catfish (*Ictalurus punctatus*)	24h	LC50	446	Clemens a- Sneed, 1959.
Bluegill sunfish (*Lepomis macrochirus*)	96h	LC50	75	Academy of Natural Sciences, 1960.
Rainbow Trout (*Oncorhynchus mykiss*)	48h	LC0	105	Lysak a- Marcinek, 1972.
River snail (Elimia livescens liver elimia)	48h	EC50 - ITX	460	Cairns et al, 1976.
Po- snail (Lymnaea emarginata angulata)	48h	EC50 - ITX	320	Cairns et al, 1976.
Fathead minnow (Pimphales promelas)	48h	LC50	92	Mattson et al, 1976.
Fathead minnow (Pimphales promelas)	96h	LC50	79	Mattson et al, 1976.
Clawed toad (Xenopus laevis)	96h	LC50	6132-6403	Dawson et al, 1996.

Glycerine (56-81-5)

Species	Duration	Effect	Conc mg/l	Ref
Green algae (*Chlorococcales*)	24h	EC10 - PHY	>1000	Krebs, 1991.
Blue-green algae (*Microcystis aeruginosa*)	-	LOEC	2900	Bringmann a- Kuhn, 1978.
Water flea (*Daphnia magna*)	24h	LC50	>10000	Bringmann a- Kuhn, 1977.
Water flea (*Daphnia magna*)	24h	EC50 - BEH	>10000	Bringmann a- Kuhn, 1982.
Carp (*Leuciscus idus melanotus*)	48h	LC50	>10000	Juhnke a- Luedemann, 1978.
Goldfish (*Carassius auratus*)	24h	LC50	>5000	Bridie et al, 1979.
Rainbow Trout (*Oncorhynchus mykiss*)	96h	LC50	51000-57000	Johnson a- Finley, 1980.

Hexylene glycol (107-41-5)

Species	Duration	Effect	Conc mg/l	Ref
Water flea (*Daphnia magna*)	48h	EC50 - ITX	2700-3700	Elnabarawy et al, 1986.
Water flea (*Ceriodaphnia reticulata*)	48h	EC50 - ITX	2400-3200	Elnabarawy et al, 1986.
Goldfish (*Carassius auratus*)	24h	LC50	>5000	Applegate et al, 1957.
Bluegill sunfish (*Lepomis macrochirus*)	96h	LC50	>10000	Dawson et al, 1977.
Inla- silverside (*Menidia beryllina*)	96h	LC50	10000	Dawson et al, 1977.
Fathead minnow (*Pimphales promelas*)	96h	LC50	1050-1100	Brooke et al, 1984.

Magnesium chloride (7786-30-3)

Species	Duration	Effect	Conc mg/l	Ref
Crayfish (*Austropotamobius pallipepall*)	30d	LC50	270	Boutet a- Chaisemartin, 1973.
Crayfish (*Orconectes limosus*)	30d	LC50	440	Boutet a- Chaisemartin, 1973.
Water flea (*Ceriodaphnia dubia)*	24h	LC50	880-1770	Mount et al, 1997.
Water flea (*Daphnia hyalina*)	48h	LC50	27.4-37.4	Baudouin a- Scoppa, 1974.
Water flea (*Daphnia magna*)	25h	LC50	864	Dowden a- Bennett, 1965.
Water flea (*Daphnia magna*)	48h	EC50 - ITX	140	Biesinger a- Christensen, 1972.
Water flea (*Daphnia magna)*	21d	EC50 - REP	125	Biesinger a- Christensen, 1972.
Calanoid copepod (*Eudiaptomus padanus padanus*)	48h	EC50 - ITX	95-342	Baudouin a- Scoppa, 1974.
Western mosquitofish (*Gambusia affinis)*	96h	LC50	421	Wallen et al, 1957.
Rainbow Trout (*Oncorhynchus mykiss*)	28d	LC50	119-150	Birge et al, 1980.
Fathead minnow (*Pimphales promelas*)	48h	LC50	1970-3880	Mount et al, 1997.

Magnesium sulphate (7487-88-9)

Species	Duration	Effect	Conc mg/l	Ref
Water flea (*Ceriodaphnia dubia*)	24h	LC50	1770	Mount et al, 1997.
Water flea (*Daphnia magna*)	24h	EC50 - ITX	332.9-482.1	Khangarot a- Ray, 1989.
Water flea (*Daphnia magna*)	48h	EC50 - ITX	266.4-417.3	Khangarot a- Ray, 1989.
Water flea (*Daphnia magna*)	24h	LC50	193	Dowden a- Bennett, 1965.
Water flea (*Daphnia magna*)	48h	LC50	186	Dowden a- Bennett, 1965.
Water flea (*Daphnia magna*)	96h	LC50	158	Dowden a- Bennett, 1965.
Western mosquitofish (*Gambusia affinis)*	24h	LC50	3100	Wallen et al, 1957.
Medaka high-eyes (*Oryzias latipes*)	24h	LC50	>1000	Tsuji et al, 1986.
Fathead minnow (*Pimephales promelas)*	24h	LC50	3180-7070	Mount et al, 1997.
Fathead minnow (*Pimephales promelas)*	96h	LC50	2610-3080	Mount et al, 1997.
Po- snail (*Lymnaea*)	24h	EC50 - MOR	2106	Dowden a- Bennett, 1965.
Po- snail (*Lymnaea)*	96h	EC50 - MOR	1250	Dowden a- Bennett, 1965.
Tubificid worm (*Tubifex tubifiex*)	24h	EC50 - ITX	265-350	Khangarot, 1991.
Tubificid worm (*Tubifex tubifiex*)	96h	EC50 - ITX	139-185 l	Khangarot, 1991.

Monopotassium phosphate (7778-77-0)

Species	Duration	Effect	Conc mng/l	Ref
Polychaete worm (*Capitella capitata*)	28d	LC50	24	Reish, 1970.
Zebra mussel (*Dreissena polymorpha*)	24h	LC50	80-105	Fisher et al, 1991.
Zebra mussel (*Dreissena polymorpha*)	24h	LC50	116-159	Fisher et al, 1991.
Zebra mussel (*Dreissena polymorpha*)	24h	LC50	147-194	Fisher et al, 1991.
Polychaete worm (*Neanthes grubei*)	28d	LC50	0.92	Reish, 1970.
Polychaete worm (*Nereis arenaceodentata*)	28d	LC50	1.9	Reish, 1970.
Polychaete worm (*Stauronereis rudolphi*)	28d	LC50	2.1	Reish, 1970.

Polyethylene glycol (25322-68-3)

Species	Duration	Effect	Conc mg/l	Ref
Goldfish (*Carassius auratus*)	24h	LC50	>5000	Bridie et al, 1979.
Crucian carp (*Carassius carassius*)	96h	LC50	>20000	Bridie et al, 1979.
Rainbow Trout (Oncorhynchus mykiss)	96h	LC50	>20000	Bridie et al, 1979.
Medaka, high-eyes (*Oryzias latipes*)	24h	LC50	>1000	Tsuji et al, 1986.
Medaka, high-eyes (*Oryzias latipes*)	48h	LC50	>1000	Tsuji et al, 1986.
Atlantic salmon (*Salmo salar*)	24h	LC50	>1000	Wildish, 1974.
Atlantic salmon (*Salmo salar)*	48h	LC50	>1000	Wildish, 1974.
Atlantic salmon (*Salmo salar)*	96h	LC50	>1000	Wildish, 1974.

Propylene glycol (57-55-6)

Species	Duration	Effect	Conc mg/l	Ref
Green algae (*Selenastrum capricornutum*)	14d	EC50 - growth rate	19,000	IUCLID, 1996
Algae (*Skeletonema costatum*)	14d	EC50 - growth rate	19,000	IUCLID, 1996
Water flea (*Daphnia magna*)	24h	EC50 - ITX	>10000	Bringmann a- Kuhn, 1982.
Water flea (*Daphnia magna*)	48h	EC50 - ITX	>10000	Kuhn et al, 1989.
Goldfish (*Carassius auratus*)	24h	LC50	>5000	Bridie et al, 1979.
Water flea (*Ceriodaphnia dubia*)	48h	LC50	1020	Pillard, 1995.
Water flea (*Ceriodaphnia dubia*)	48h	LC50	18340	Pillard, 1995.
Water flea (*Ceriodaphnia dubia)*	48h	NOEC	660	Pillard, 1995.
Water flea (*Ceriodaphnia dubia*)	48h	NOEC	13020	Pillard, 1995.
Rainbow Trout (*Oncorhynchus mykiss*)	96h	LC50	41000-47000 l	Mayer a- Ellersieck, 1986.
Fathead minnow (*Pimephales*	48h	LC50	790	Pillard, 1995.
Fathead minnow (*Pimephales*	96h	LC50	710	Pillard, 1995.
Fathead minnow (*Pimephales*	96h	LC50	>62000	Pillard, 1995.
Fathead minnow (*Pimephales*	7d	NOEC	98	Pillard, 1995.
Fathead minnow (*Pimephales*	7d	NOEC	<11530	Pillard, 1995.
Fathead minnow (*Pimephales*	7d	NOEC	270 l	Pillard, 1995.
Fathead minnow (*Pimephales*	96h	NOEC	600	Pillard, 1995.
Fathead minnow (*Pimephales*	96h	NOEC	52930	Pillard, 1995.

Tetrasodium salt (64-02-8)

Species	Duration	Effect	Conc mg/l	Ref
Water flea (*Daphnia magna*)	24h	EC0 - BEH	939	Bringmann a- Kuhn, 1982.
Water flea (*Daphnia magna*)	24h	EC50 - BEH	1033	Bringmann a- Kuhn, 1982.
Water flea (*Daphnia magna*)	24h	EC50 - MOR	570-640	Sorvari a- Sillanpaa, 1996.
Water flea (*Daphnia magna)*	24h	EC100 - BEH	1136	Bringmann a- Kuhn, 1982.
Bluegill sunfish (*Lepomis macrochirus*)	96h	LC50	472-500	Batchelder et al, 1980.
Bluegill sunfish (*Lepomis macrochirus*)	96h	LC50	2320-3540	Batchelder et al, 1980.
Bluegill sunfish (*Lepomis macrochirus*)	96h	NOEC	115	Batchelder et al, 1980.
Blue-green algae (*Microcystis aeruginosa*)	-	LOEC	76	Bringmann a- Kuhn, 1978.
Green algae (*Scenedesmus quadricauda*)	-	LOEC	11	Bringmann a- Kuhn, 1978.

Urea (57-13-6)

Species	Duration	Effect	Conc mg/l	Ref
Blue-green algae (*Microcystis aeruginosa*)	-	LOEC - POP	47	Bringmann a- Kuhn, 1978.
Green algae (*Scenedesmus quadricauda*)	-	LOEC	>10000	Bringmann a- Kuhn, 1978.
Water flea (*Daphnia magna*)	24h	LC50	>10000	Bringmann a- Kuhn, 1977.
Water flea (*Daphnia magna*)	48h	EC50 - ITX	3910	Janssen et al, 1993.
Water flea (*Daphnia magna*)	24h	EC50 - BEH	>10000	Bringmann a- Kuhn, 1982.
Water flea (*Ceriodaphnia dubia*)	48h	EC50 - ITX	6119-7061	Warne a- Schifko, 1999.
Rohu (*Labeo rohita*)	96h	LC50	13.8-19.6	Sarkar, 1991a.
Snake-head catfish (*Channa punctata*)	24h	LC50	25000	Pa-ey et al, 1979.
Giant gourami (*Colisa fasciata*)	96h	LC50	5	Pa-ey a- Shukla, 1983.
Guppy (*Poecilia reticulata*)	96h	LC50	16200-18300	Chouchan a- Pa-ey, 1987.
Harlequinfish, Red rasbora (*Rasbora heteromporpha)*	96h	LC50	12000	Tooby et al, 1975.
Creek chub (*Semotilus atromaculatus*)	24h	LC100	30000	Gillette et al, 1952.
Mozambique tilapia (*Tilapia mossambica*)	96h	LC50	22.5	Planichamy et al, 1985.
Mozambique tilapia (*Tilapia mossambica*)	96h	LC50	590-730	Sarkar, 1991b.

Xanthan Gum (11138-66-2)

Species	Duration	Effect	Conc mg/l	Ref
Rainbow Trout (*Oncorhynchus mykiss*)	96h	LC50	420	Sprague a- Logan, 1979.
Rainbow Trout (*Oncorhynchus mykiss*)	96h	LC50	320-560	Falk a- Lawrence, 1973.

Zinc Oxide (1314-13-2)

Species	Duration	Effect	Conc mg/l	Ref
Water flea (*Daphnia magna*)	48h	EC50 - ITX	>1000	Office of Pesticide Programs, 1995.
Water flea (*Daphnia magna*)	48h	LC50	24.6	Gale et al, 1992.
Water flea (*Daphnia magna*)	48h	LC50	0.098	Gale et al, 1992.
Bluegill sunfish (*Lepomis macrochirus*)	96h	LC50	>320	Office of Pesticide Programs, 1995.
Striped bass (*Morone saxatilis*)	48h	LC50	1.77-2.51	O'Rear, 1972.
Striped bass (*Morone saxatilis*)	48h	LC50	0.67-2.4	O'Rear, 1972.
Rainbow Trout (*Oncorhynchus mykiss*)	96h	LC50	0.59-2.5	Office of Pesticide Programs, 1995.
Fathead minnow (*Pimephales promelas*)	96h	LC50	2246	Gale et al, 1992.

APPENDIX E LIST I AND II SUBSTANCES OF THE DANGEROUS SUBSTANCES DIRECTIVE

LIST 1 substances

Any LIST I substance is considered a LIST II substance until a daughter directive is established which sets limit values for the substance. Currently daughter directives exist for the those substances in table E1 below.

Table E1

Substance	Directive	Formal compliance
Substances already granted List I status		
Cadmium	83/513/EEC (CEC 1983)	1/1/89
Mercury	82/176/EEC (CEC 1982)	1/7/86
Mercury	84/156/EEC (CEC 1984a)	1/7/89
Lindane (hexachlorocyclohexane)	84/491/EEC (CEC 1984b)	1/10/88
Pentachlorophenol	86/280/EEC (CEC 1986)	1/1/91
DDT	86/280/EEC (CEC 1986)	1/1/91
Carbon tetrachloride	86/280/EEC (CEC 1986)	1/1/91
Chloroform	88/347/EEC (CEC 1988)	1/1/90
Hexachlorobenzene	88/347/EEC (CEC 1988)	1/1/90
Hexachlorobutadiene	88/347/EEC (CEC 1988)	1/1/90
Dieldrin	88/347/EEC (CEC 1988)	1/1/89
Aldrin	88/347/EEC (CEC 1988)	1/1/89
Isodrin	88/347/EEC (CEC 1988)	1/1/89
Endrin	88/347/EEC (CEC 1988)	1/1/89
1,2-dichloroethane	90/415/EEC (CEC 1990)	1/1/93 and 1/1/95
Trichloroethylene	90/415/EEC (CEC 1990)	1/1/93 and 1/1/95
Perchloroethylene	90/415/EEC (CEC 1990)	1/1/93 and 1/1/95
Trichlorobenzene	90/415/EEC (CEC 1990)	1/1/93 and 1/1/95

Full listing of LIST I substances

Table E2

	Priority	CAS Number	Chemical name
1	***	309-00-2	Aldrin
2		95-82-2	2-Amino-4-chlorophenol
3		120-12-7	Anthracene
4	**	7440-38-2	Arsenic and its mineral compounds
5		2642-71-9	Azinphos-ethyl
6		86-50-0	Azinphos-methyl
7	**	71-43-2	Benzene
8	**	92-87-5	Benzidine
9		100-44-7	Benzyl chloride (Alpha-chlorotoluene)
10		98-87-3	Benzylidene chloride (Alpha, alpha-dichlorotoluene)

	Priority	CAS Number	Chemical name
11		92-52-4	Biphenyl
12	***	7440-43-9	Cadmium and its compounds
13	**	56-23-5	Carbon tetrachloride
14		302-17-0	Chloral hydrate
15	***	57-74-9	Chlordane
16		79-11-8	Chloroacetic acid
17		95-51-2	2-Chloroaniline
18		108-42-9	3-Chloroaniline
19		106-47-8	4-Chloroaniline
20	*	108-90-7	Chlorobenzene
21		97-00-7	1-Chloro-2,4-dinitrobenzene
22		107-07-3	2-Chloroethanol
23	**	67-66-3	Chloroform
24		59-50-7	4-Chloro-3-methylphenol
25		90-13-1	1-Chloronaphthalene
26			Chloronaphthalenes (technical mixture)
27		89-63-4	4-Chloro-2-nitroaniline
28		89-21-4	1-Chloro-2-nitrobenzene
29		88-73-3	1-Chloro-3-nitrobenzene
30		121-73-3	1-Chloro-4-nitrobenzene
31		89-59-8	4-Chloro-2-nitrotoluene
32			Chloronitrotoluenes (other than 4-Chloro-2-nitrotoluene)
33		95-57-8	2-Chlorophenol
34		108-43-0	3-Chlorophenol
35		106-48-9	4-Chlorophenol
36		126-99-8	Chloroprene (2-Chlorobuta-1,3-diene)
37		107-05-1	3-Chloropropene (Allyl chloride)
38		95-49-8	2-Chlorotoluene
39		108-41-8	3-Chlorotoluene
40		106-43-4	4-Chlorotoluene
41			2-Chloro-p-toluidine
42			Chlorotoluidines (other than 2-Chloro-p-toluidine)
43		56-72-4	Coumaphos
44		108-77-0	Cyanuric chloride (2,4,6-Trichloro-1,3,5-triazine)
45		94-75-7	2,4-D (including 2,4-D-salts and 2,4-D-esters)
46	**	50-29-3	DDT (including metabolites DDD and DDE)
47		298-03-3	Demeton (including Demeton-o, Demeton-s, Demeton-s-methyl and Demeton-s-methyl-sulphone)
48	*	106-93-4	1,2-Dibromethane
49			Dibutyltin dichloride
50			Dibutyltin oxide
51			Dibutyltin salts (other than Dibutyltin dichloride and Dibutyltin oxide)
52			Dichloroanilines
53		95-50-1	1,2-Dichlorobenzene
54		541-73-1	1,3-Dichlorobenzene

	Priority	CAS Number	Chemical name
55		106-46-7	1,4-Dichlorobenzene
56			Dichlorobenzidines
57		108-60-1	Dichlorodiisopropyl ether
58	*	75-34-3	1,1-Dichloroethane
59	*	107-06-2	1,2-Dichloroethane
60	*	75-35-4	1,1-Dichloroethylene (Vinylidene chloride)
61	*	540-59-0	1,2-Dichloroethylene
62	*	75-09-2	Dichloromethane
63			Dichloronitrobenzenes
64		120-83-2	2,4-Dichlorophenol
65	*	78-87-5	1,2-Dichloropropane
66		96-23-1	1,3-Dichloropropan-2-ol
67		542-75-6	1,3-Dichloropropene
68		78-88-6	2,3-Dichloropropene
69		120-36-5	Dichlorprop
70		62-73-7	Dichlorvos
71	***	60-57-1	Dieldrin
72		109-89-7	Diethylamine
73		60-51-5	Dimethoate
74		124-40-3	Dimethlyamine
75		298-04-4	Disulfoton
76	**	115-29-7	Endosulfan
77	***	72-20-8	Endrin
78		106-89-8	Epichlorohydrin
79		100-41-4	Ethylbenzene
80		122-14-5	Fenitrothion
81		55-38-9	Fenthion
82	***	76-44-8	Heptachlor (including Heptachlorepoxide)
83	**	118-74-1	Hexachlorobenzene
84	**	87-68-3	Hexachlorobutadiene
85	**	608-73-1	Hexachlorocyclohexane
		58-89-9	(including all isomers and Lindane)
86		67-72-1	Hexachloroethane
87		98-83-9	Isopropylbenzene
88		330-55-2	Linuron
89	*	121-75-5	Malathion
90		94-74-6	MCPA
91		93-65-2	Mecoprop
92	***	7439-97-6	Mercury and its compounds
93		10265-92-6	Methamidophos
94		7786-34-7	Mevinphos
95		1746-81-2	Monolinuron
96		91-20-3	Naphthalene
97		1113-02-6	Omethoate
98		301-12-2	Oxydemeton-methyl
99	**		PAH (with special reference to: Benzo[b]pyrene and Benzo[a]fluoranthene)
100		56-38-2	Parathion

	Priority	CAS Number	Chemical name
		298-00-0	(including Parathion-methyl)
101	**		PCB (including PCT)
102	**	87-86-5	Pentachlorophenol
103		14816-18-3	Phoxim
104		709-98-8	Propanil
105		1698-60-8	Pyrazon
106		122-34-9	Simazine
107		93-76-5	2,4,5-T (including 2,4,5-T salts and 2,4,5-T esters)
108			Tetrabutyltin
109		95-94-3	1,2,4,5-Tetrachlorobenzene
110	*	79-34-5	1,1,2,2-Tetrachloroethane
111	*	127-18-4	Tetrachlorethylene
112		108-88-3	Toluene
113		24017-47-8	Trizzophos
114		126-73-8	Tributyl phosphate
115			Tributyltin oxide
116		52-68-6	Trichlorfon
117	*		Trichlorobenzene (technical mixture)
118		120-82-1	1,2,4-Trichlorobenzene
119	*	71-55-6	1,1,1-Trichloroethane
120	*	79-00-5	1,1,2-Trichloroethane
121	*	79-01-6	Trichloroethylene
122	**	95-95-4	Trichlorophenols
		88-06-2	
123		76-13-1	1,1,2-Trichlorotrifluoroethane
124		1582-09-8	Trifluralin
125		900-95-8	Triphenyltin acetate (Fentin acetate)
126			Triphenyltin chloride (Fentin chloride)
127		76-87-9	Triphenyltin hydroxide (Fentin hydroxide)
128		75-01-4	Vinyl chloride (Chloroethylene)
129			Xylenes (technical mixture of isomers)

Notes:

*** Substances which are the subject of a proposal or a communication to the Council

** Substances which have or are being studied

* Substances to be studied next