

Environmental Management of Firefighting Foam Policy Explanatory Notes

Revision 2

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Environmental Management of Firefighting Foam Policy

Explanatory Notes

(Revision 2)

1 Introduction

These Explanatory Notes provide background and clarification to the *Environmental Management of Firefighting Foams* Policy document and should be read in conjunction with that Policy. This version of the Explanatory Notes has been updated to reflect the additional review of recent and rapidly evolving scientific literature, input of expert opinion and expansion of some sections according to issues raised in stakeholder consultation. This document is not a draft.

There has been very significant evidence emerging in recent years regarding the potential for all types of firefighting foams to have immediate and long-term detrimental effects on environmental and other values during operational incidents, training, maintenance activities and waste disposal when handled improperly resulting in releases of foam to the environment to bodies of water, soils and groundwater.

Existing environmental legislation in Australia requires that any person, corporation or organisation carrying out an activity must take all reasonable and practicable measures to prevent or minimise the potential for environmental harm or pollution, having regard to the current state of technical knowledge for the operation or activity and other relevant matters.

The state-of-knowledge regarding the potential for firefighting foams to cause adverse effects on human health and the environment has improved significantly in the last decade. This has been especially so in the area of published research on fluorinated organic chemicals over the last few years. Over the same period of time the development of technologies to assess and mitigate these effects has also progressed significantly. There now needs to be a consolidation of information and standards to guide users towards achieving best practice and ensuring that appropriate protective measures are taken and that the liabilities for human health, protection of the environment, safety of the end-user as well as the community and its infrastructure are properly assessed and managed.

1.1 Background

An extensive review has been undertaken by the Queensland Department of Environment and Heritage Protection in conjunction with the Western Australian Department of Environmental Regulation into the potential impacts of the use of firefighting foams. This has included a very extensive literature review and consultation with agencies, regulators, other stakeholder and experts in Australia, and overseas.

The Foam Management Policy sets out foam management standards that need to be met, the baseline information that is necessary, with relevant test standards, so that users, regulators and incident responders have a reasonable basis on which to make appropriate comparisons, soundly based decisions and appropriate choices when it comes to selecting a firefighting foam for any particular situation and to be able to plan for, and respond to incidents so that environmental and other values are least likely to be compromised. Much of the necessary information to support balanced decision making has been poorly guided, hard to access or lacking in relevant content and these are deficiencies that are addressed by the Explanatory Notes and the Policy.

While the review and the development of the Policy have primarily focussed on the potential for environmental harm or pollution to be caused, they also take into consideration human health impacts, workplace health and safety, firefighting performance, public amenity and economic issues.

Consultation with a wide range of stakeholders on the draft Policy has raised a variety of general and specific issues, as well as additional information having become available, all of which has been considered in redrafting of the Policy and in the coverage and content of these Explanatory Notes which provide the evidence base for the Policy and guidance on understanding and practically managing the environmental impacts of firefighting foam use.

1.2 Firefighting foam defined

Firefighting foam refers to concentrates and their aqueous solutions that are used in the production of streams or blankets of air/gas-filled bubbles to suppress flammable or toxic vapours, increase water penetration, reduce static spark generation, control or extinguish fires, and prevent re-ignition by excluding air and cooling the fuel.

Firefighting foams may be used to prevent or extinguish fires involving:

- **Class A** fires – in carbonaceous combustible materials, such as wood, paper, fabric, plastics and rubber, where the fire can be deep-seated in the burning material.
- **Class B** fires – of flammable and combustible liquids or spills such as liquid hydrocarbon fuels and polar solvents where the fire and vapours are on the surface of the liquid.

Foam for these hazards and fires can be supplied by fixed piped systems or portable foam-generating systems and be applied by methods such as portable hose streams using hand-held foam nozzles, large-capacity monitor nozzles, surface pourers or subsurface injection systems [1].

For the purposes of this review and the Policy the terms *Class A foam* and *Class B foam* are used to refer to the foams formulated for dealing with Class A and Class B fires respectively. Where the term *firefighting foam* is used it refers to both Class A and Class B foams unless specified.

1.3 General principles

The use of any firefighting foam has the potential to have a combination of environmental, health and economic impacts and it is ultimately the end-user that will bear the range of risks and liabilities associated with its albeit infrequent use.

When deciding on the most appropriate foam for a particular application, and whether or not current systems are adequate, the user has an obligation to carefully consider the full range of short-term and long-term risks and factors that influence how they can achieve and demonstrate best practice [2] in the balance of the options for protection of *Life-Property-Environment*.

Firefighting systems need to be thought of in terms of not only their day-to-day utility and firefighting performance during incidents but also in terms of the entire lifecycle cost [3] including the potential downstream acute and chronic effects of releases on the environment, human health, amenity and economic values. It is acknowledged that every situation is different and to achieve the appropriate balance the user at least needs to take into consideration:

- Firefighting performance for the particular application and circumstances.
- Adjacent environmental values (e.g. wetlands, bodies of water, soils, groundwater, etc.).
- Adjacent urban, amenity and economic values that could be impacted.
- Pathways for contaminants to affect adjacent values.
- The particular foam formulation (every foam is unique in its composition or mixture).
- Potential impacts of available firefighting system and foam options.
- Ability to capture, contain and treat wastes and firewater.

- Operational practicalities and compatibilities.
- Workplace health and safety (day-to-day and during incidents).
- Compliance with regulatory requirements and standards.
- Potential costs for clean-up and harm or pollution caused on and off site.
- Appropriate insurance to cover potential costs of harm and remediation [4].
- Costs and practicalities of waste treatment and disposal.
- Corporate reputation and liability.
- Value for money through a cost-benefit analysis.

There will never be a “one-size-fits-all” firefighting foam system that achieves all-round best-practice protection for all circumstances and considerations. In attempting to properly assess the risks inherent in their situation and to make a confident and informed choice when selecting an appropriate system and foam, users are often significantly hampered by a lack of information, incomplete knowledge and inadequate and/or inaccurate advice in one or more relevant areas.

The benchmark for overall best practice in firefighting foam formulations and their use has changed progressively in recent years. Increasing awareness of the adverse health and environmental effects associated with some compounds in formulations, which were previously regarded as acceptable or were the only available effective solution at the time, has in particular driven the need for continuous improvement and development of better practices and formulations with more acceptable health and environmental outcomes.

This now means that many users need to periodically reassess their risks and liabilities and, where necessary, improve their performance against current and emerging best practice. In some cases this can be easily achieved but for some foam users, particularly with legacy systems, this represents a significant operational, financial and cultural challenge.

In addition to the increased knowledge about the behaviour and effects of pollutants generally there is now also a greater expectation by the community that health, amenity and environmental values will be properly considered and protected with decisions based on comprehensive and balanced risk assessments that take all relevant factors into account.

1.4 The *Precautionary Principle*

An important requirement when making any decision that can have long-term impact on environmental values is the appropriate consideration of the *Precautionary Principle*. This requirement arises from its well established status in international agreements, Commonwealth, states’ and territories’ legislation.

Precautionary Principle – Key Issues:

- The *Precautionary Principle* places particular obligations on users, manufacturers and regulators in terms of the of the product content, allowable uses, management considerations and decision making that are pertinent to any potential for adverse impacts, especially in the long term.
- Recent legal judgements have made clear the considerations necessary to meet the intent and obligations under ESD and the *Precautionary Principle* as required by legislation in all Australian jurisdictions.
- A current absence of evidence for an adverse effect by a product or activity is not proof that there will be no effect unless it is demonstrated by relevant, comprehensive and definitive studies.
- The burden of proof lies with the proponent of a new technology or activity to show that it will not cause significant harm. Ultimately the end-user must take this into account.
- Where there is insufficient scientific evidence upon which to base a decision a conservative or precautionary approach must be taken, especially if there are suspicions, indications or reasonable scientific plausibility of possible adverse effects, especially in the long term.
- There is ample evidence that firefighting foams have significant potential to cause short-term and long-term adverse environmental and health effects and need to be properly managed.

The *Precautionary Principle* was firmly established in Australia in 1992 by the signing of the Intergovernmental Agreement on the Environment by the Commonwealth, States and Territories and the Australian Local Government Association [5].

The *Precautionary Principle* is one of four principles directed at achieving ecologically sustainable development (ESD) and has since been widely adopted in environmental policy and legislation (including state environmental protection acts and regulations) and is far more than a “*general guiding principle*” as has sometimes been assumed.

The other three ESD principles closely related to the *Precautionary Principle* are:

- Intergenerational equity.
- Conservation of biological diversity and ecological integrity.
- Improved valuation, pricing and incentive mechanisms (“the polluter pays” principle).

The obligation for those carrying out an activity, manufacturers of products and regulators making decisions to consider and apply the *Precautionary Principle* is now well established in Australian law by various legal decisions and judgements [6]. A judgement by Chief Justice Preston in 2006 [67 NSWLR 256] has particular relevance as His Honour addressed the application of the *Precautionary Principle* in detail holding that it applied when there was:

- A threat of serious or irreversible environmental damage; and
- Scientific uncertainty as to the nature and scope of the threat of environmental damage.

Preston CJ held that the threat (not the actuality) was sufficient and that there was “*reasonable scientific plausibility*” for that threat. Given these preconditions the consequences are the “*shifting of [the] evidentiary burden of proof*” in that:

- A decision maker must assume that the threat of serious or irreversible environmental damage *is no longer uncertain but is a reality*.
- The burden of showing that this threat does not in fact exist or is negligible effectively reverts to the proponent of the new technology or activity [6,7].

The overall effect is therefore that decision makers at all levels including regulatory agencies, manufacturers, product suppliers, purchasers and end users must have due regard to the application of the *Precautionary Principle* in their assessment and management of the potential consequences of their decisions and activities. Preston CJ emphasised the importance of “*preventative participation*” with *the rationale for requiring this shift of the burden of proof [being] to ensure preventative anticipation; to act before scientific certainty of cause and effect is established [as it] may be too late, or too difficult and costly, to change a course of action once it is proven to be harmful* [6].

In assessing the extent and scope of the seriousness and/or reversibility of a threat of environmental damage Preston CJ outlined the factors that need to be considered [8], this includes the:

- **Spatial scale** of the threat (e.g. local, regional, state-wide, national, international).
- **Magnitude** of possible impacts, on both natural and human systems.
- **Perceived value** of the threatened environment.
- **Temporal scale** of possible impacts, in terms of both the timing and the longevity (or persistence) of the impacts.
- **Manageability** of possible impacts, having regard to the availability of means and the acceptability of means.
- **Level of public concern**, and the rationality of and scientific or other evidentiary basis for the public concern.
- **Reversibility** of the possible impacts and, if reversible, the time frame for reversing the impacts, and the difficulty and expense of reversing the impacts.

In regards to assessing the level of scientific uncertainty the factors to be considered are the:

- **Sufficiency of the evidence** that there might be serious or irreversible environmental harm caused by the development plan, programme or project.

- **Level of uncertainty**, including the kind of uncertainty (such as technical, methodological or epistemological uncertainty).
- **Potential to reduce uncertainty** having regard to what is possible in principle, economic and within a reasonable time frame.

Clearly there are a range of issues in regards to the environmental and health management of all types and uses of firefighting foam that need to be addressed under the *Precautionary Principle* that relate primarily to the potential for long-term adverse effects. These are expanded on and considered in subsequent sections.

The *Precautionary Principle* imposes clear obligations at all levels for the user, manufacturer, regulator even to the extent of Ministerial decisions being fatally flawed because of a failure by regulators to consider the *Precautionary Principle*. [*Walker v Minister for Planning* (2007) 157 LGERA 124] [6].

1.5 Regulatory basis and impact considerations

The aim of these Explanatory Notes and the Policy is to clarify the requirements and expectations under existing legislative provisions for the handling, transport, storage, use, release, waste treatment, disposal and environmental protection measures relevant to the use of firefighting foam in the light of the current state of technical knowledge.

The Policy provides guidance on achieving compliance with environmental legislation, in particular the *Environmental Protection Act 1994* (EP Act) and the *Environmental Protection Regulation 2008* (EP Regulation). All Queensland legislation has been subject to regulatory impact assessment and public benefit test processes in accordance with Queensland Treasury guidelines prior to being enacted and when amendments are proposed.

Regulatory basis and impact considerations – Key Issues:

- The Environmental Management of Firefighting Foam Policy clarifies the requirements and expectations under existing legislative provisions of the *EP Act 1994* and the *EP Regulation 2008* in the light of the current state-of-knowledge and likely longer-term future directions.
- Formal regulatory impact assessments are not required for the Policy however the relevance of the regulatory impacts assessments for the underpinning legislation were reviewed to ensure relevance as well as reviews against very current and directly relevant international assessments and cost-benefit models pertaining to firefighting foam chemicals.
- Foams and their related components are, contain or produce prescribed water contaminants, regulated wastes, trackable wastes and other compounds that could be reasonably expected to cause serious or material environmental harm.

The focus for considering the environmental management of firefighting foam use is on compliance with the General Environmental Duty (*the GED*) and where relevant Environmental Authority licence conditions in regards to activities and their associated potential contaminants. The GED requires that a person (including businesses and corporations) must not carry out any activity that causes, or is likely to cause, environmental harm unless the person takes all reasonable and practicable measures to prevent or minimise the harm having regard to the current state of technical knowledge for the activity and other relevant matters [9,10].

The basis of the Environmental Management of Firefighting Foam Policy grounded as it is on existing legislative provisions means that there is no formal “regulatory proposal” which would require development of primary or subordinate legislation or change, similarly it is not quasi-regulation that needs specific instruments, such as an industry code or accreditation scheme, to be made under the provisions of environmental or other legislation.

The Policy constitutes information released to inform or educate the community and businesses for the purpose of enforcement notes and the application of legislation and as such the Policy has a particular exemption from the requirement for a Regulatory Impact Statement (RIS) [11].

Notwithstanding that an RIS is not required the potential scope and regulatory impact of the Policy has been considered against regulatory best practice principles [11,10] as summarised in Table 1.5 A and also in terms of the considerations for the original and amended legislative provisions of the *Environmental Protection Act 1994* (EP Act) and *Environmental Protection Regulation 1998* (& 2008) (EP Regulation) and their applicable RIS and public benefit test processes and results.

Principle	Policy relevance
Establishing a case for action before addressing a problem.	There is a well-established and overdue case for action world-wide due to short and long-term potential and actual environmental and health impacts and related high legacy contamination costs of foam.
Considering a range of feasible policy options including self-regulatory, co-regulatory and non-regulatory approaches.	Default non- and self-regulation by most of industry has largely failed since 2005 (or earlier) when information became clear. The Policy is essentially co-regulation, informing and guiding industry to best practice with the need for compliance action by regulators only necessary where risks are not being adequately addressed.
Assessment of the benefits and costs.	An extensive cost-benefit assessment has been done for the EU with relevance to all other countries. Australia could be said to have higher and more sensitive environmental values, especially waterways, requiring more rigorous protection than that determined for the EU model [12].
Ensuring legislation should not restrict competition.	The Policy is the application of existing legislative provisions that have been considered in terms of restriction of competition. The Policy removes some aspects of competition and provides a level playing field for all suppliers and end-users (equal competition) by setting clear standards and expectations for foam management.
Providing effective guidance in order to ensure that the policy intent and expected compliance requirements are clear.	The Policy and Explanatory Notes stated intent is to provide very clear guidance and transparent reasoning for best-practice environmental management and compliance.
The benefits of the restrictions to the community as a whole outweigh the costs.	There are very high potential and demonstrated actual legacy costs for the community that are required to be managed under ESD. The cost of actions required to come into compliance pertain to compliance with what are existing provisions and obligations.
Ensuring that regulation remains relevant and effective over time.	The Policy development has specifically taken a long-term view based on very extensive research with provision for periodic review and update to reflect new information.
Consulting effectively with affected key stakeholders at all stages of the regulatory cycle.	Several rounds of wide consultation have been undertaken targeting end-user and regulatory groups most affected with all submissions considered.
Ensuring that government action is effective and proportional to the issue being addressed.	Policy content is very soundly based on the current state-of-knowledge and international directions for management and best practice for the issues.

Firefighting foams contain a range of materials and chemicals that have the potential to cause significant environmental harm and as such are regarded as potential contaminants [10] that need to be properly managed. Considerations that underpin and are relevant to the environmental management of firefighting foam under the environmental legislation provisions include:

- **Objectives of the *Environmental Protection Act 1994*** to protect Queensland's environment while allowing for development that improves the total quality of life, now and in the future, in a way that maintains the ecological processes on which life depends [9].
- **Achieving the objects of the EP Act** by an integrated management program that is consistent with *the principles of ecologically sustainable development* (ESD) that is the agreed Government policy for achieving development both in Queensland and nationally in a manner that does not lead to irreversible environmental degradation [10].

- **Application of the *Precautionary Principle*** where the consequences of the harm are uncertain, potentially widespread, irreversible, high impact and/or long term.
- **Specific management considerations** pertaining to particular contaminants through the *Environmental Protection Regulation 1998* (& 2008).
- **Environment** includes *ecosystems and their constituent parts, including people and communities, all natural and physical resources, the qualities and characteristics of locations, places and areas, however large or small, that contribute to their biological diversity and integrity, intrinsic or attributed scientific value or interest, amenity, harmony and sense of community as well as the social, economic, aesthetic and cultural conditions that affect, or are affected by the things above* (EP Act §8) [13].
- **Environmental value** includes *a quality or physical characteristic of the environment that is conducive to ecological health or public amenity or safety or another quality of the environment identified and declared to be an environmental value under an environmental protection policy or regulation* (EP Act §9) [13].

Under the EP Act thresholds apply as to the categories of environmental harm in terms of the extent of the harm to environmental values as well as the financial costs of losses or remediation. The main categories of significant environmental harm under the EP Act are:

- **Serious environmental harm** is *harm that is irreversible, of a high impact or widespread; or caused to an area of high conservation value; or an area of special significance, such as the Great Barrier Reef World Heritage Area; or that causes actual or potential loss or damage to property of an amount of, or amounts totalling, more than the threshold amount (\$50,000); or that results in costs of more than the threshold amount being incurred in taking appropriate action to prevent or minimise the harm; and rehabilitate or restore the environment to its condition before the harm* (EP Act §17) [13].
- **Material environmental harm** is *harm that is that is not trivial or negligible in nature, extent or context; or that causes actual or potential loss or damage to property of an amount of, or amounts totalling, more than the threshold amount (\$5,000) but less than the maximum amount (\$50,000); or that results in costs of more than \$5,000 but less than \$50,000 being incurred in taking appropriate action to prevent or minimise the harm and rehabilitate or restore the environment to its condition before the harm.*

The *Environmental Protection Regulation 1998* and *EP Regulation 2008* (amended) address a range of issues relevant to the use and management of firefighting foam. Both were subject to specific RIS and Public Benefit Test processes [14,15,16,13] in regards to their content which included consideration of:

- **The primary intent of the Regulation** being to provide for management of point-source pollution through effective regulation.
- **Consideration of Ecologically Sustainable Development** principles and contemporary standards in regulatory decisions.
- **Emissions of interest** specifically including halogens, organo-halogens and persistent organic pollutants.
- **Prescribed water contaminants** including any chemical that causes biochemical or chemical oxygen demand, surfactants, fire sprinkler test water, and any chemical for which guidelines are prescribed by the Australia and New Zealand Guidelines for Fresh and Marine Water Quality (PFOS [17])
- **Offences and penalties** relating to unlawful deposition of a *prescribed water contaminant* in waters or deposition where it would subsequently be carried to waters, e.g. a drain.
- **Contaminants** that are regarded as Regulated Wastes and trackable specifically including organo-halogens and surfactants under *Schedule 7 of the EP Regulation 1998 (and 2008)*.
- **Offences and penalties** relating to allowing a contaminant to be placed in a position where it could be reasonably expected to cause serious or material environmental harm.

- **Provision of a level playing field** within industry sectors to *ensure that non-compliant firms will not be able to undertake activities that jeopardise the reputation of an entire industry* [14].
- **Assist with driving internal environmental change** for environmental managers that *often experience operational inertia with colleagues in trying to develop and implement positive production changes* [14].
- **Protection of downstream values** so that downstream resources and business opportunities are not limited by a polluted environment.
- **Reducing health risks associated with pollution** and maintaining a healthy resource base for those sectors that are heavily dependent on a clean environment for their economic wellbeing.
- **The Polluter Pays principle** emphasised in terms of the operator having an awareness of the relevant matters and being required to properly manage the risks and costs of pollution.

Overall the benefits to the community of the relevant legislation as a whole including these provisions was assessed to strongly outweigh the costs of the final provisions that took also into account extensive community consultation [16,10,14].

Further to the above considerations the Policy has been considered in detail against the current state-of-knowledge, assessment models and current national and international directions by other jurisdictions and authorities with the intent of providing a long-term solution. In particular this has included assessments and costs-benefits analysis pertaining to persistent, toxic and bioaccumulative fluorinated organic long and short-chain compounds commonly occurring in firefighting foams [18,12,19,20].

Extensive work associated with submissions and independent review for a restriction proposal submitted to the European Chemicals Agency (ECHA) comprehensively demonstrated that restrictions on the use and release of PFOA and related substances were the only viable risk management measure and were proportionate to the risks [12,20,19]. The application of this assessment and review to the situation in Australia is relevant in terms of the same products and usage but would need to also factor in that for many locations in Australia the environmental values that could be impacted are higher and more pristine.

2 Impacts of firefighting foams

All firefighting foams pose a range of hazards to the environment when released during activities such as training, maintenance, testing, incident response, fires and waste disposal. The combination of chemicals used in firefighting foams can have direct and indirect acute and chronic impacts on biota, soils and waterways through their persistence, bioaccumulation, toxicity and their biochemical oxygen demand (BOD) when they are released and degrade. The impacts of the release of firefighting foams can also extend to public health and public and economic use of resources such as recreational activities, public amenity, water supply, aquaculture and fisheries.

Impacts of Firefighting Foams – Key Issues:

- The end-user is responsible for the proper management and responsible use of any product they use and they carry the liability for any adverse effects or costs resulting from its release. This includes responsibility for effects resulting from actions by the emergency services incident controller during an emergency.
- The potential adverse impacts of firefighting foam need to be considered in terms of any potential long-term (chronic) effects related to persistent toxic components as well as the short-term effects.
- Aquatic environments are particularly sensitive to impact by most pollutants including releases of firefighting foam and related firewater and wastewater which may contain a variety of toxic contaminants.
- Very high BOD (biochemical oxygen demand) is the main cause of short-term (acute) adverse impacts on waterways through depletion of oxygen and far outweighs any direct acute toxicity.
- There is ample evidence that some components of some firefighting foams have or may be linked to long-term adverse environmental and health effects and need to be properly managed.

All firefighting foams are of concern if they are released to the environment; there is no such thing as a completely “*environmentally friendly*” foam as espoused in some marketing brochures. Firefighting foams depend on a variety of compounds and formulations for their characteristics and effectiveness. Some of the compounds and formulations can have adverse short and long-term impacts on the environment, human health and other values if released.

The primary areas of concern from the release of foam or related wastes are:

- **Biochemical oxygen demand** – The majority of foams have high BOD potential. Dissolved oxygen levels in water bodies can be quickly and severely depleted when the organic components of released foam are degraded by the action of naturally occurring aerobic micro-organisms. BOD effects of foam far outweigh acute toxicity effects.
- **Acute (short-term) toxicity** – Toxicity from detergents, solvents and other components in foams can result in immediate adverse effects on organisms in the area of the release. The immediate effects of acute toxicity and BOD are difficult to separate and need to be considered in tandem.
- **Persistence** – Foams may contain compounds (or lead to production of compounds) of known, suspected and currently unknown toxicity that do not readily degrade in the environment and/or are not readily metabolised in biota and can potentially exert toxic effects over a long period of time. Persistence also means that there is an increased risk of long-term exposure, bioaccumulation of toxic compounds and dispersal with impact on wider areas, some at great distances from the source of the discharge – also known as Long-Range Transport (LRT).
- **Bioaccumulation** – The uptake of toxic compounds by organisms and the accumulation of them at higher concentrations than in the environment with the potential for the compounds to be passed up, and further bioconcentrated through the food chain (trophic magnification).
- **Chronic (long-term) toxicity** – The often overlooked potential for compounds to cause long-term impacts on humans and organisms, especially if they are persistent and/or bio-accumulative, even though their short-term toxicity may be relatively low.

2.1 Composition of firefighting foams

While the composition of firefighting foams includes general classes of compounds, such as surfactants, solvents, stabilisers and thickeners, each foam formulation is unique and even foams with the same name differ over time in the combination of specific ingredients. In operational systems there is also the potential for different foam type to have been mixed or for there to be contamination from residues of the previous foams that have not been properly cleaned out. The potential for adverse health and environmental effects depends on the physical and toxic effects of particular ingredients as well as the additive or synergistic effects of them in combination in the formulation.

Firefighting Foam Composition – Key Issues:

- For environmental management purposes the composition of firefighting foam need only be considered in relatively simple terms based on the acute effects of its biodegradable components and whether it has persistent compounds (whether or not these are known to be acutely toxic) in its formulation such as organo-halogens, siloxanes or similar compounds that may have chronic but largely unknown long-term adverse effects.
- The presence of persistent compounds (whether or not these are known to be toxic) in any products including foams requires their proper management, containment from release to the environment and proper disposal as regulated waste.
- Incomplete clean-out of old foam from storage and delivery systems can result in significant contamination of new products.

For example, a biocide or preservative in the foam formulation that is not critical to firefighting performance may have particular toxic effects in the environment that may be enhanced or

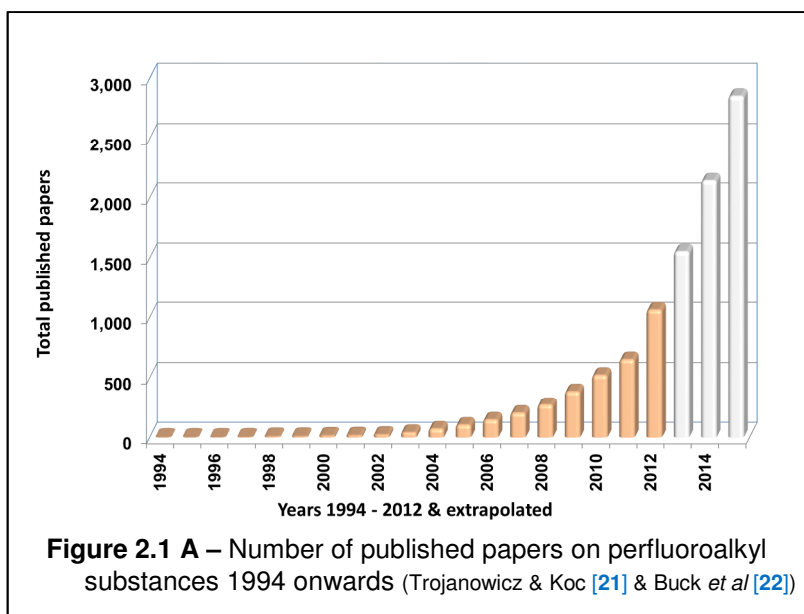
suppressed when in combination with other unrelated compounds such as surfactants that may promote entry into plant and animal cells.

Fluorinated organic compounds have been a common ingredient in firefighting foams for many decades, being the key to the properties and effectiveness of some foams. There has been a growing awareness in recent times of the potential for very significant, long-term and widespread adverse human health and environmental effects of these compounds, with the result that this has brought them under particular scrutiny and has driven a reassessment of their use, fate, effects and the need for non-persistent alternatives.

The growth in knowledge about the behaviour and effects of fluorinated organic compounds is illustrated by the number of papers published from 1994 to 2012 on the various environmental and health aspects of these compounds with this trend increasing to more than 400 per year [21,22] (Figure 2.1 A).

This shows the recent rapid increase in interest and information about fluorinated organic compounds over the last decade but also illustrates the almost complete lack of knowledge in the public domain about the environmental (and probably health) effects between the time of their first use in the 1960s to the early 2000s.

PFOS (perfluoro-octane sulfonate) and PFOA (perfluoro-octanoic acid) are the most often mentioned fluorinated organic compounds and are well recognised as being of serious concern for human health and the environment [23,24,25,26] [27,28].



From the emphasis in most popular and some scientific literature the casual reader could be forgiven for thinking that PFOS and PFOA are the only two compounds of concern [22,29]. It is very important, however, to realise that there are hundreds to thousands of possible fluorinated organic compounds [30,21], and of those in use in some firefighting foams only about 170 have been publicly identified so far [31,32,33] [34,35] with indications of a similar or greater number of others probably remaining unidentified [36,37].

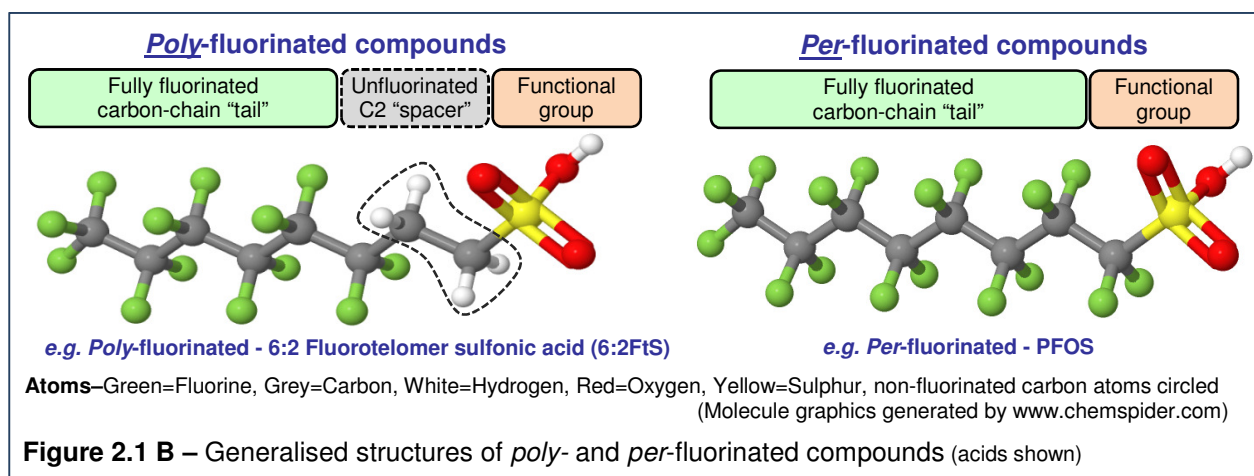
In a 2013 study of 12 samples of foam used in Canada [38,36] (and elsewhere) comparison of the concentrations of known fluorosurfactants with the total organofluorine content found less than 10% of the fluorosurfactants were identified in half of the samples and generally less than 50% of fluorinated organic compounds were identifiable overall (in some samples none were identified). PFOS was also a significant component in 6 of the 12 samples.

In another recent study (2014) a further 103 novel fluorinated surfactants were identified with fluorinated chain lengths from C3 to C15 in ten fluorinated foams and two surfactants (Table 2.1C) highlighting the enormous variety of fluorinated organic compounds that have or are being produced with impurities “*common in the form of synthetic intermediates, side products, and/or degradation products*” [39].

The lack of identification of the compounds in use, their combinations, transformation products and their behaviour is a significant impediment to risk assessment of the possible environmental and health effects.

There are two main groups of fluorinated organic compounds. These materials are commonly termed *per*-fluoroalkyl and *poly*-fluoroalkyl substances (collectively the PFASs) [22] and it is important to appreciate the difference between *poly*-fluorinated and *per*-fluorinated compounds (Figure 2.1 B), their occurrence in foams and how they subsequently behave in the environment:

- *Per*-fluorinated compounds – such as PFOS and PFOA, where all the carbon atoms in the main chain are fluorinated making that structure highly persistent and resistant to hydrolysis, photolysis and biodegradation under environmental conditions.
- *Poly*-fluorinated compounds – such as 8:2 fluorotelomers that have some carbon atoms in the chain that are not fully fluorinated but on release to the environment will transform or *partially* degrade resulting in a *per*-fluorinated end-point compound.



There have been some general suggestions that *poly*-fluorinated fluorotelomer compounds are “safer”, however for fluorotelomers and also for complex branched fluoropolymers, the eventual transformation end-point compounds are highly persistent *per*-fluorinated compounds such as the perfluorocarboxylic acid (PFCA) PFOA and a range of its higher and lower homologous PFCAs.

Where the compound is described as an *X:Y* fluorotelomer the “X” denotes the number of fully or *per*-fluorinated carbon atoms and the “Y” denotes the number of non-fluorinated carbon atoms [22,40]. The general structure of *poly*-fluorinated compounds consists of three groups [41]:

- an oleophobic/hydrophobic fully-fluorinated carbon-chain tail, (CF₃-CF₂-CF₂-...)
- a non-fluorinated organic “spacer” (dimethylene group, -CH₂-CH₂-)
- a hydrophilic functional group (sulfonate, betaine, carboxylate, etc.).

Per-fluorinated compounds are fully fluorinated and do not have the intervening, unfluorinated spacer group.

Fluorotelomers compounds are commonly composed of a straight-chain, usually but not always with an even number of fluorinated carbons (C6, C8, C10, etc.) with the unfluorinated C2 dimethylene group (-CH₂-CH₂-) between the fluoroalkyl chain and the end group that determines the compound’s functionality [40,42]. For example, 6:2 fluorotelomer sulfonate (Figure 2.1 B) or 8:2 fluorotelomer betaine.

Tables 2.1 A, B, C & D illustrate the diversity and complexity of some of the fluorinated organic compounds thus far identified as occurring in fluorinated foams or resulting from transformation. This is further complicated by some compounds also being able to exist in different structural arrangements as branched and unbranched isomers. PFOA (C₈HF₁₅O₂), for example, has 39 possible structural isomers, that is, 39 different arrangements of branching for the same molecular composition [43]. Table 2.1 also illustrates the inadequacy of current standard laboratory analyses suites for fluorinated organic compounds which can only identify about 20 to 28 individual compounds out of about 200 known and predicted compounds.

Additionally, those fluorotelomers with eight carbons (C8) in the perfluorinated chain (e.g. 8:2Ft...), including some found in foams advertised to be “PFOS and PFOA free”, are PFOA

precursors and will transform via partial degradation in the environment relatively quickly to PFOA as the major end-point *perfluorinated* degradation product [44,45,46].

A similar process occurs for the longer-chain, more toxic higher homologue compounds such as 10:2 fluorotelomers which degrade to perfluorodecanoic acid etc. (C10–PFDA) (Figure 2.5.1 A). Such compounds that transform to a perfluorinated end-point compound are termed *precursor* compounds e.g. *PFOA precursors*, *PFOS precursors*, *PFDA precursors*, etc. Similarly perfluoroalkyl sulfonamides are precursors to sulfonates, e.g. perfluorooctyl sulfonamido amine is a C8 PFOS precursor [47].

Table 2.1 A – Fluorinated organic compounds (FOCs) in samples of firefighting foams, groundwater & surfactants	
Backe, Day & Field (2013)–FOCs in AFFF and groundwater [32]	
4:2 fluorotelomer thioamido sulfonate (PFBA precursor)	Perfluoroheptyl carboxylate (C7 PFHeA) (End point)
6:2 fluorotelomer thioamido sulfonate (PFHxA precursor)	Perfluorooctyl carboxylate (C8 PFOA) (“ “)
8:2 fluorotelomer thioamido sulfonate (C8 PFOA precursor)	Perfluorononyl carboxylate (C9 PFNA) (“ “)
4:2 fluorotelomer sulfonate (4:2FtS) (PFBA precursor)	Perfluorodecyl carboxylate (C10 PFDA) (“ “)
6:2 fluorotelomer sulfonate (6:2FtS) (PFHxA precursor)	Perfluoroundecyl carboxylate (C11 PFUnDA) (“ “)
8:2 fluorotelomer sulfonate (8:2FtS) (C8 PFOA precursor)	Perfluorododecyl carboxylate (C12 PFDoDA) (“ “)
Perfluoroheptyl sulfonamido amine (C7 PFHeS precursor)	Perfluorotridecyl carboxylate (C13 PFTriDA) (“ “)
Perfluorooctyl sulfonamido amine (C8 PFOS precursor [47])	Perfluorotetradecyl carboxylate (C14 PFTeDA) (“ “)
Perfluoroheptyl sulfonamide amino carboxylate (C7)	(Fluorinated organic compounds common to both studies)
Perfluorooctyl sulfonamide amino carboxylate (PFOS prec.)	(6:2 fluorotelomer thio hydroxy ammonium)
Perfluorobutyl sulfonamido amine (C4 PFBS precursor)	(6:2 fluorotelomer sulfonamido betaine)
Perfluoropentyl sulfonamido amine (C5 PFPeS precursor)	(8:2 fluorotelomer sulfonamido betaine)
Perfluorohexyl sulfonamido amine (C6 PFHxS precursor)	(10:2 fluorotelomer sulfonamido betaine)
Perfluorobutyl sulfonamide amino carboxylate (C4)	(12:2 fluorotelomer sulfonamido betaine)
Perfluoropentyl sulfonamide amino carboxylate (C5)	(5:1:2 fluorotelomer betaine) (PFPeA precursor)
Perfluorohexyl sulfonamide amino carboxylate (C6)	(7:1:2 fluorotelomer betaine) (PFSePA precursor)
Perfluorobutyl sulfonate (C4 PFBS) (End point compound)	(9:1:2 fluorotelomer betaine) (PFNA precursor)
Perfluoropentyl sulfonate (C5 PFPeS) (“ “)	(5:3 fluorotelomer betaine) (PFPeA precursor)
Perfluorononyl sulfonate (C9 PFNS) (“ “)	(7:3 fluorotelomer betaine) (PFSePA precursor)
Perfluorodecyl sulfonate (C10 PFDS) (“ “)	(9:3 fluorotelomer betaine) (PFNA precursor)
Perfluorobutyl carboxylate (C4 PFBA) (“ “)	(Perfluorohexyl sulfonate (C6 PFHxS))
Perfluoropentyl carboxylate (C5 PFPeA) (“ “)	(Perfluoroheptyl sulfonate (C7 PFHepS))
Perfluorohexyl carboxylate (C6 PFHxA) (“ “)	(Perfluorooctyl sulfonate (C8 PFOS))

Table 2.1 B – Fluorinated organic compounds (FOCs) in samples of firefighting foams, groundwater & surfactants	
Place & Field (2012)–FOCs in MilSpec AFFF [31]	
Perfluorobutane sulfonamide amine* (C4)	6:2 fluorotelomer thioether amido sulfonic acid
Perfluoropentane sulfonamide amine* (C5)	4:2 fluorotelomer sulfonamide betaine
Perfluorohexane sulfonamide amine* (C6)	5:1:2 fluorotelomer betaine
Perfluorobutane sulfonamide amino carboxylic acid* (C4)	5:3 fluorotelomer betaine
Perfluoropentane sulfonamide amino carboxylic acid* (C5)	7:1:2 fluorotelomer betaine
Perfluorohexane sulfonamide amino carboxylic acid* (C6)	7:3 fluorotelomer betaine
Perfluorohexane sulfonamide ammonio dicarboxylic acid*	8:2 fluorotelomer sulfonamide amine
Perfluoropentane sulfonamide ammonio dicarboxylic acid*	8:2 fluorotelomer sulfonamide betaine
(* Perfluorosulfonamides are precursors for sulfonate compounds)	8:2 fluorotelomer thio hydroxy ammonium
Perfluorohexane sulfonic acid (C6 PFHxS)	8:2 fluorotelomer thioether amido sulfonic acid
Perfluoroheptane sulfonic acid (C7 PFHpS)	8:2 fluorotelomer thioether amino carboxylic acid
Perfluorooctane sulfonic acid (C8 PFOS)	9:1:2 fluorotelomer betaine
6:2 fluorotelomer sulfonamide amine	9:3 fluorotelomer betaine
6:2 fluorotelomer sulfonamide betaine	10:2 fluorotelomer sulfonamide betaine
6:2 fluorotelomer thio hydroxy ammonium	10:2 fluorotelomer thioether amino carboxylic acid
6:2 fluorotelomer thioether amido amino carboxylic acid	

Table 2.1 C – Fluorinated organic compounds (FOCs) in samples of firefighting foams, groundwater & surfactants.			
D'Agostino and Mabury (2014)–Novel FOCs in 10 AFFF concentrates and 2 commercial fluorinated surfactants. [34]			
Groups and classes of PFASs	Dominant form	Number of compounds	Total
Perfluoroalkylamido betaine (PFAAB)-related (A, B, C)			
n=3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14	n=8, C ₁₄ H ₁₄ ON ₂ F ₁₇ ⁺¹	(11 compounds)	
n=6, 7, 8, 9, 10, 11, 12, 14	n=8, C ₁₆ H ₁₆ O ₃ N ₂ F ₁₇ ⁺¹	(8 compounds)	
n=8, 10, 12	n=8, C ₁₉ H ₂₂ O ₃ N ₂ F ₁₇ ⁺¹	(3 compounds)	(22 compounds)
Fluorotelomerthioalkylamido betaine (FTSAB)-related (D, E, F, G, H)			
n=4, 6, 8, 10	n=6, C ₁₀ H ₆ O ₂ SF ₁₃ ⁻¹	(4 compounds)	
n=4, 6, 8, 10, 12	n=6, C ₁₅ H ₂₀ ON ₂ SF ₁₃ ⁺¹	(5 compounds)	
n=4, 6, 8, 10, 12, 14	n=6, C ₁₇ H ₂₂ O ₃ N ₂ SF ₁₃ ⁺¹	(6 compounds)	
n=6, 8, 10	n=6, C ₁₆ H ₂₂ ON ₂ SF ₁₃ ⁺¹	(3 compounds)	
n=6	n=6, C ₁₆ H ₂₂ O ₂ N ₂ SF ₁₃ ⁺¹	(6 compounds)	(19 compounds)
Fluorotelomermercaptoalkylamido sulfonate (FTSAS)-related (I, J, K)			
n=4, 6, 8, 10, 12, 14	n=6, C ₁₅ H ₁₇ O ₄ NS ₂ F ₁₃ ⁻¹	(6 compounds)	
n=4, 6, 8, 10	n=6, C ₁₅ H ₁₇ O ₅ NS ₂ F ₁₃ ⁻¹	(4 compounds)	
n=4, 6, 8	n=6, C ₁₁ H ₈ O ₂ SF ₁₃ ⁻¹	(3 compounds)	(13 compounds)
Fluorotelomersulfonamide alkylbetaine (FTAB)-related (L, M)			
n=6, 8, 10, 12, 14	n=6, C ₁₅ H ₂₀ O ₄ N ₂ SF ₁₃ ⁺¹ [48]	(5 compounds)	
n=6, 8, 10	n=6, C ₁₃ H ₁₈ O ₂ N ₂ SF ₁₃ ⁺¹	(3 compounds)	(8 compounds)
Fluorotelomer betaine (FTB) (N, O)			
n=5, 7, 9, 11, 13	n=5, C ₁₂ H ₁₅ O ₂ NF ₁₁ ⁺¹	(5 compounds)	
n=5, 7, 9, 11, 13, 15	n=5, C ₁₂ H ₁₄ O ₂ NF ₁₂ ⁺¹	(6 compounds)	(11 compounds)
Fluorotelomerthiohydroxyl ammonium (FTSHA) (P, Q)			
n=6, 8, 10	n=6, C ₁₄ H ₁₉ ONSF ₁₃ ⁺¹	(3 compounds)	
n=6, 8	n=6, C ₁₄ H ₁₉ O ₂ NSF ₁₃ ⁺¹	(2 compounds)	(6 compounds)
Perfluoroalkylsulfonamido-based surfactants (PFASA-) (R/S, T, U, V) (Likely C3-C9 sulfonate precursors)			
n=3, 4, 5, 6, 7, 8 (branched)	n=6, C ₁₄ H ₁₈ O ₄ N ₂ SF ₁₃ ⁺¹	(6 compounds)	
n=3, 4, 5, 6	n=6, C ₁₄ H ₁₈ O ₄ N ₂ SF ₁₃ ⁺¹	(4 compounds)	
n=3, 4, 5, 6, 7, 8	n=6, C ₁₁ H ₁₄ O ₂ N ₂ SF ₁₃ ⁺¹	(6 compounds)	
n=3, 4, 5, 6 (branched)	n=6, C ₁₇ H ₂₂ O ₆ N ₂ SF ₁₃ ⁺¹	(4 compounds)	
n=6, 7, 8, 9	n=8, C ₁₇ H ₂₂ O ₆ N ₂ SF ₁₃ ⁺¹	(4 compounds)	(24 compounds)
n = perfluorinated carbon chain lengths of C3 to C15. (For A to V refer to original paper).			Total 103 compounds
Table 2.1 D			
Herzke, Olsson and Posner (2012)–PFASs in consumer products in Norway (results for 2 current AFFF) [35].			
Perfluorobutanoate	PFBA (C4)	Perfluorooctane sulfonamide	PFOSA (PFOS precursor)
Perfluoropentanoate	PFPA (C5)	6:2 fluorotelomer sulfonate	6:2 FtS
Perfluorohexanoate	PFHxA (C6)	6:2 fluorotelomer alcohol	6:2 FtOH
Perfluorooctanoate	PFOA (C8)	8:2 fluorotelomer alcohol	8:2 FtOH (PFOA precursor)
Perfluorodecanoate	PFDA (C10)	10:2 fluorotelomer alcohol	10:2 FtOH (PFDA precursor)
Perfluorododecanoate	PFDoA (C12)		

In general the focus of concerns and discussions for fluorinated organic compounds used in firefighting foams has been on perfluorinated compounds such as PFOS and PFOA, however the range of perfluorinated higher homologues and X:Y fluorotelomer compounds also needs to be considered, each having different effects in their own right, as well as some being precursors for numerous other intermediate transformation and end-point compounds due to partial degradation.

In addition to the commonly discussed compounds other variants of fluorinated organic compounds are of similar concern, regarded as having the same potential effects and producing similar breakdown and transformation products as the fluorotelomers and perfluorinated compounds [32,31,49,22,50] including:

- X:Y:Z *fluorotelomers* indicating X fully-fluorinated, Y singly-fluorinated carbons, and Z non-fluorinated carbon atoms prior to the first functional group (e.g. 9:1:2 *fluorotelomer betaine*).

- *Fluoro-polymers* e.g. long-lived branched and side-chained compounds substituted in foam for fluorotelomers and perfluorinated compounds [51].
- *Substituted halogenated polyfluorocarbons* and perfluoropolyethers [52,53] (e.g. chlorinated polyfluorinated ether sulfonate, $C_8ClF_{16}O_4S^-$, which has similar characteristics, toxicity and behaviour to PFOS).

In regards to the use of fluoropolymers and their being considered in the same way as perfluorinated compounds and X:Y fluorotelomers, this is in line with the removal of the fluoropolymer exemption to the *Polymer Exemption Rule to Exclude Certain Perfluorinated Polymers* by U.S. EPA 2010 [54].

This exclusion refers to fluoropolymers containing, as an integral part of their composition, perfluoroalkyl moieties consisting of a CF_3 - or longer chain length including perfluoroalkyl sulfonates (PFAS), perfluoroalkyl carboxylates (PFAC), fluorotelomers, or perfluoroalkyl moieties that are covalently bound to either a carbon, oxygen or sulfur atom where the carbon, oxygen or sulfur atom is an integral part of the polymer molecule. These fluoropolymers are now regarded as posing an unreasonable risk to human health or the environment.

While the simple fluorinated homopolymers such as PTFE (Teflon®) are largely inert and not of concern, the more complex branched copolymers have the potential to be biologically active and to have similar effects to *poly*-fluoroalkyl and *per*-fluoroalkyl compounds or partially degrade to compounds of concern.

2.2 Biochemical oxygen demand (BOD)

Biochemical oxygen demand is a measure of the amount of oxygen consumed, primarily by aerobic bacteria, in breaking down organic matter in a water body (with some contribution from algal respiration, sediment and chemical uptake). The terms *biochemical* oxygen demand and *biological* oxygen demand are interchangeable for the purposes of the Policy. Assessment of BOD is by the relevant OECD 301 laboratory method.

Biochemical Oxygen Demand – Key Issues:

- BOD represents the amount of oxygen required by bacteria to break down biodegradable organic material in water bodies.
- High BOD will deplete the limited amount (~6-10 ppm) of natural dissolved oxygen in the water potentially asphyxiating aquatic organisms.
- 5-day BOD is used as an indicator of immediate, short-term impact.
- 28-day BOD is an approximation of overall BOD resulting from its complete or near complete decay. Note some products may need longer to achieve complete degradation e.g. ~30-50 days.

Notwithstanding that compounds used in the formulation of firefighting foams may have separate acute and chronic toxic effects, the primary concern regarding the high BOD potential of firefighting foam is the elevated oxygen consumption associated with degradation of organic components, such as degradable solvents and surfactants. High BOD will result in rapid depletion of dissolved oxygen in a water body causing harm to aquatic life, mainly through acute oxygen stress and asphyxiation. The majority of firefighting foams have very high potential BOD values (expressed as BOD for the concentrate) averaging about 330,000 mg/L (non-persistent foams) to 440,000 mg/L (fluorinated foams).

As illustrated in the BOD curve of [Figure 2.2 A](#) the decomposition of the degradable organics introduced to a body of water can in many (but not all) cases be assumed to have proceeded to about 70% of the final value after 5 days (the BOD₅ value) [55] and usually nears completion after 20 to 28 days with much less BOD progress after that [56,49].

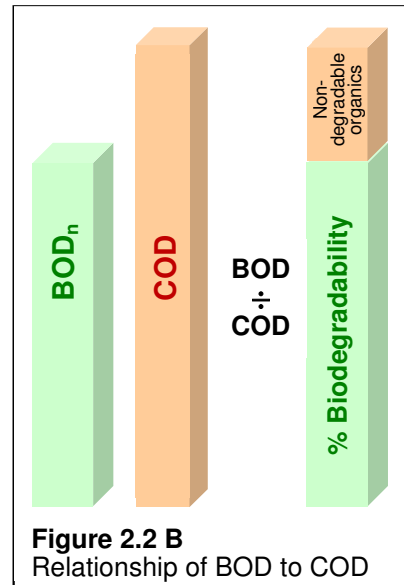
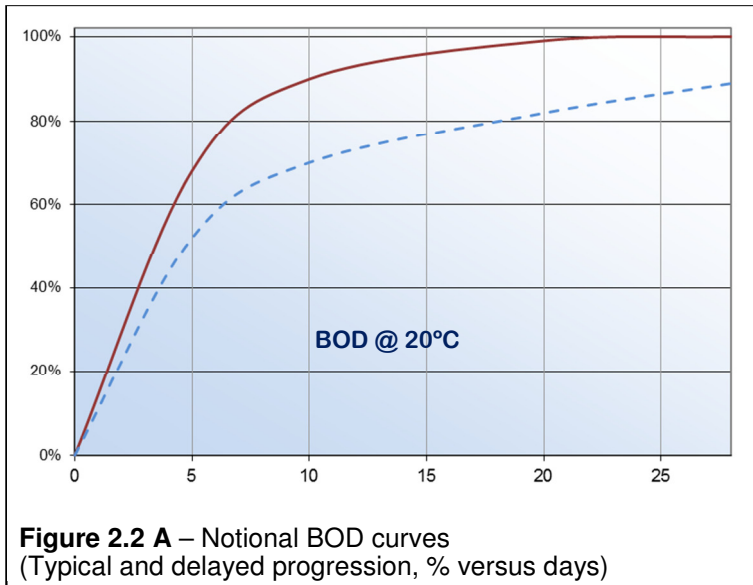
When assessing the potential for BOD to affect dissolved oxygen levels in a body of water, say from SDS information, note that the standard BOD test is carried out at 20°C, therefore biodegradation can be expected to proceed more rapidly at higher water temperatures and will be

slower at temperatures below 20°C. Accordingly the application of standard test values to field conditions needs to consider this influence, as well as other possible environmental complications.

While the BOD process in a body of water may be effectively complete by about 28 days for readily biodegradable materials after the release or during holding in a pond for treatment, there may be a further lag while dissolved oxygen levels in the water return to normal. For example, there may be an additional BOD effect associated with dying and dead aquatic vegetation and/or a delay in return to a normal equilibrium for other parameters, such as pH, as well as a delay in the reestablishment of biota in the waterway.

Analysis for the BOD of samples of firewater during an incident or the recovery phase is not useful as an aid to immediate decision making as the laboratory test takes some time. It is more useful for assessment and making decisions in the field to monitor the progression of BOD effects by measuring the levels of dissolved oxygen levels (mg/L) in the water as they decline and then recover to normal concentrations (generally between 6 mg/L to 10 mg/L (~ppm)). For incidents involving contaminants in the firewater from spills and combustion the additional contribution from those components and initial conditions needs to be considered.

It should be noted that measurement of dissolved oxygen as *percent saturation* is not recommended as *percent saturation* is highly temperature dependent and under hot conditions an apparently high *percent saturation* may not be reliable as an indicator of adequate water quality and environmental suitability as actual dissolved oxygen may be borderline. For example, 80% oxygen saturation at a water temperature of 30°C is only about 6 mg/L of dissolved oxygen.



Chemical oxygen demand (COD) is not the same as BOD. BOD is a subset of COD (Figure 2.2 B). Both COD and BOD values must be cited for foam concentrate to assess BOD progression characteristics and overall biodegradability. COD is a measure of the theoretical maximum amount of oxygen required to oxidise all of the oxidisable organics in a sample (clearly excluding persistent organic compounds not oxidisable by the method or oxidisable in the environment). The COD test is carried out using aqueous acid dichromate which has relatively strong oxidising conditions compared to environmental conditions. COD therefore does not necessarily represent the degree of oxidation that will occur in the natural environment except for fully biodegradable products. The ratio of BOD to COD represents the proportion of the organic components in a material that can be considered readily biodegradable in the environment (see below).

2.2.1 BOD of firefighting foam

The biochemical oxygen demand of all firefighting foams is high to very high although the significance of this has probably not been generally recognised or has been largely ignored in the assessment of the potential for adverse environmental effects.

Despite the BOD process being well understood and clearly being a very significant component of the immediate adverse “toxic” effects there have been very few studies into the extent and effects of BOD as relevant to firefighting foam. The availability of information on BOD in SDS for firefighting foam is highly variable. For many products it is completely absent.

BOD of Firefighting Foam–Key Issues:

- All firefighting foams have high to very high BOD regardless of type.
- BOD results primarily from the biodegradation of the organic components in the formulations such as sugars, carbohydrates, solvents and biodegradable surfactants.
- The potential for BOD to deplete oxygen in waterways is of far greater significance than acute toxicity as expressed by the OECD 203 toxicity test method which uses artificial aeration.

Given the significant potential for acute, short-term impacts by BOD a review of levels of a diversity of firefighting foams was undertaken to characterise and compare all types of foams (70+ foams) based on data that is publically available. The review also compared foams containing fluorinated compounds with non-persistent (fluorine-free) foams to assess general claims of differences in acute impacts, BOD being a primary contributor to acute impact effects. Obsolete foams no longer in general use, such as 3M Lightwater, a PFOS foam, were excluded from the review and comparison.

The review found that both fluorinated and non-persistent foams had 5-day BOD and notionally final 20-28 day BOD average values that were of a similar order. Fluorinated foams had on average slightly higher BOD₅ and BOD₂₀₋₂₈ values and a wider upper and lower range than fluorine-free foams (Figure 2.2.1).

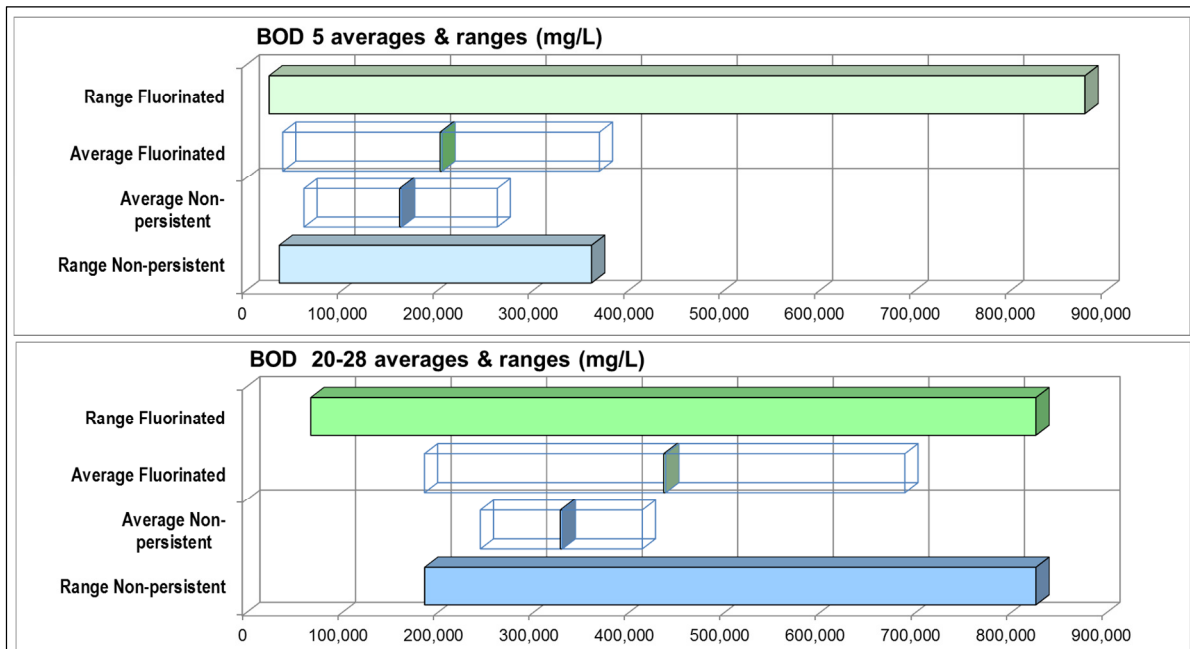


Figure 2.2.1
Comparison of BOD₅ and BOD₂₀₋₂₈ for ~70 fluorinated and non-persistent foams. Standard deviations (SD_n) shown in outline relative to the average values.

The differences between the BOD values of foam types, and even between particular products, are largely academic from an environmental management perspective as it is clear that all foams have high to very high BOD with significant potential to cause acute adverse impacts in water

bodies through oxygen depletion. The naturally low dissolved oxygen levels in water bodies (6 to 10 ppm) means that even after significant dilution of firewater the impacts of BOD from foam can be substantial.

With this demonstrated overlap and similarities in BOD characteristics across foam products as the primary characteristic of concern for acute impacts, the broad statements about differences in impacts for foam types that have been made do not stand up to scrutiny. Even when the BOD values for specific products are compared the high to very high BOD for all foams renders the issue moot as all foams can have significant adverse environmental impacts.

2.2.2 Impacts of firefighting foam BOD on water bodies

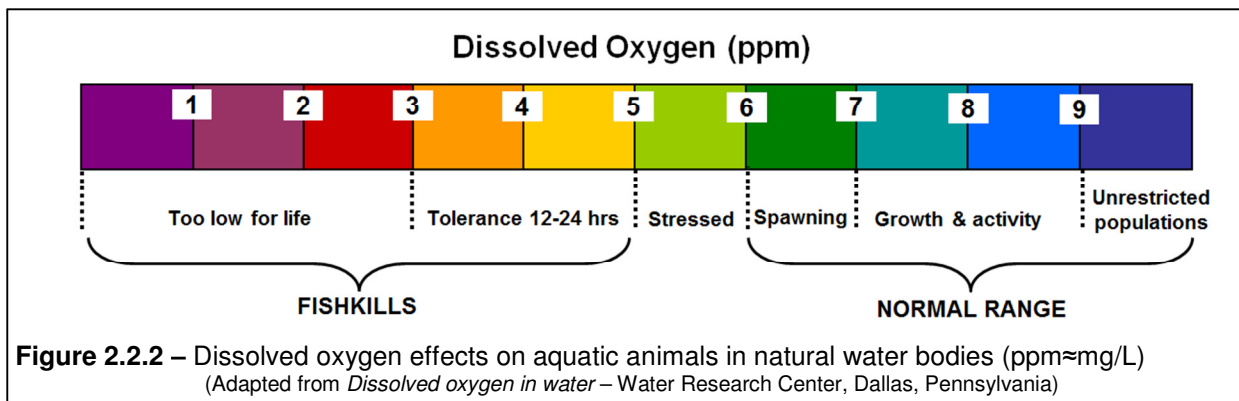
The natural dissolved oxygen concentrations in bodies of water are relatively low, generally in the range of 6 mg/L to 10 mg/L (ppm - parts per million w/w) with only a small capacity of a few parts per million “spare” to buffer for oxygen depletion due to pollution or natural variability before fish are stressed and fish kills occur (Figure 2.2.2).

While the BOD and acute chemical toxicity of foams are tested for separately using the relevant laboratory methods the potential for overall acute effects is a result of their combined effects. In this equation BOD is by far the greatest contributor towards the potential for short-term adverse effects.

BOD Impacts of Firefighting Foam on Water Bodies – Key Issues:

- Dissolved oxygen in water bodies is naturally low and can be easily depleted by pollutants.
- Very high BOD for all foam types is the main cause of short-term (acute) adverse impacts on water bodies through depletion of dissolved oxygen resulting in asphyxiation of aquatic organisms.
- High BOD results from the degradation of organic components in the foam, this adds to, but far outweighs, any direct acute chemical toxicity effects by foam.
- Provided there are no persistent toxic compounds present BOD can be managed by on-site biodegradation or treatment through a wastewater treatment plant.
- BOD can also have adverse and lasting effects on groundwater quality creating anaerobic conditions that affects other water quality characteristics and suitability for beneficial uses.

In addition to the effect of BOD due to firefighting foam it should also be remembered that in incidents that involve spills or a fire the firewater may already be oxygen depleted due to high temperatures, and it may contain combustion products and other contaminants that will further add to the BOD and further depletion of available dissolved oxygen.



- **The naturally low levels of dissolved oxygen in waterways mean that there is significant potential for environmental harm even from the release of firewater derived from finished foam at 1% to 6% dilutions, particularly in confined bodies of water with limited water volume and turnover to dilute and disperse contaminants.**

From the foam user’s perspective, as well as for the incident responder, when planning for responses involving fires or foam use it is highly desirable to put in place procedures and

measures to contain and prevent or minimise the release of firewater with high BOD (e.g. by containment in ponds, bunds or drains) for a sufficient period (e.g. 28 days or more) to allow degradation to occur before possible release such that the elevated BOD potential (or other contaminants) have minimal or no impact on the adjacent bodies of water.

Unsurprisingly the very high BOD of foam is the greatest influencing factor for possible short-term adverse effects in waterways through depletion of the dissolved oxygen levels in the water column. As outlined above, the normal range of dissolved oxygen is about 6 to 10 ppm with a reduction of only a few parts per million likely to cause acute oxygen stress for most aquatic life.

While some components of foam such as surfactants, solvents and biocides can have acute toxicity effects this is far outweighed by the effects of BOD by two or three orders of magnitude. For example, where dilution in a waterway is sufficient to ameliorate the effects of oxygen stress caused by high BOD the dilution will also be sufficient to largely negate acute toxicity effects as well.

At the very least the values for COD, BOD₅ and BOD₂₈ should be cited in the SDS for foam concentrate to provide an indication for users and responders of:

- Immediate effects (\approx BOD₅), i.e., acute oxygen stress.
- Overall likely oxygen demand (\approx BOD₂₈ or if longer BOD_n), i.e., a measure of the degradation burden.
- Overall biodegradability for each BOD_n period as a proportion of COD.

If the progressive natural degradation of the foam product is unusual, i.e., not simply exponential or mono-phasic, then the SDS should cite a range of BOD values, e.g. 5, 10, 15, 20, 28 day up to 99% of BOD progression if it is more than 28 days, alternatively the degradation BOD characteristics can be represented by a graph of BOD against the relevant time periods [56].

2.3 Biodegradability

In many cases where pollution occurs there is reliance on dilution and natural degradation processes to break down toxic compounds. The focus on biodegradability has mostly been on the breakdown of the toxic components to non-toxic end-products such as salts, water and carbon dioxide, a process known as mineralisation.

Biodegradability–Key Issues:

- Biodegradation can naturally reduce some toxic pollutants to non-toxic end products.
- Some toxic pollutants only partially degrade resulting in toxic daughter or end-point products.
- Persistent toxic compounds are not readily broken down naturally and can have long-term effects.
- Biodegradability can have adverse effects in water bodies through BOD-related oxygen depletion.

However, while biodegradation can reduce the concentrations of particular toxic components, the process and rate of biodegradation also has other aspects that need consideration including:

- Depletion of oxygen in waterways by BOD is a major effect of biodegradation.
- Generation of toxic intermediate or transformation compounds can occur.
- Some compounds are not degradable or only partially degradable.
- End-point compounds that may be toxic.

For example the well-known persistent legacy pesticide DDT eventually biodegrades but DDT first breaks down to the similarly toxic and persistent daughter products DDE and DDD¹ extending and complicating the pathways to eventual mineralisation. Accordingly the biodegradability of a compound must also be considered in terms of intermediate toxic breakdown or transformation products on the way to end-point compounds or mineralisation.

¹ DDT–DichloroDiphenylTrichloroethane, DDE–DichloroDiphenyldichloroEthylene, DDD– DichloroDiphenylDichloroethane

Assessment of biodegradability of contaminants is closely tied to BOD progress compared to COD which describe the approximate rates and extents to which the organic components in a product will break down through natural processes in the environment and therefore the extent and duration of potential impacts of those components until they degrade to a non-toxic state.

In combination with BOD₅, BOD₂₈ and BOD_(n-100%) the overall biodegradability of a product is an important consideration for contingency planning, incident response and incident recovery in terms of providing a guide to the likely timescale and progression of natural degradation of the related organic components in wastewater. This provides a means for assessing the likely progression of potentially harmful conditions under various timeline, dilution and containment scenarios. For example, predicting and managing the impacts of unavoidable releases to waterways, discharges to sewer for treatment or on-site containment and treatment until such time as a non-toxic end-point state is reached if this is possible.

2.3.1 Biodegradability of firefighting foam

A significant proportion of the compounds in firefighting foam are degradable organics such as glycol ether solvents, hydrocarbon surfactants, proteins, carbohydrates and complex sugars which result in moderate to high overall biodegradability as judged from the ratio of BOD_n to COD (Figure 2.2 C).

The overall biodegradability of a product or waste under environmental or biological treatment conditions is generally determined as the ratio of the 28 day biochemical oxygen demand (BOD₂₈) to the total chemical oxygen demand (COD) of dichromate-oxidisable organics, expressed as a percentage (BOD₂₈/COD x 100). However, this assumes that all the organic components are able to be oxidised using the standard COD method, this is not the case for persistent organic compounds including fluorinated organic compounds.

It should be noted that for fluorinated foams neither BOD or COD takes into account the non-degradable fluorinated organic compounds that cannot be readily oxidised as these compounds are chemically extremely stable and resistant to oxidation biologically or by acid dichromate [49].

Partial biodegradative breakdown of fluorotelomer compounds, as used in many fluorinated foams, is known to produce a range of intermediate transformation products, which may themselves be toxic, such as fluorotelomer unsaturated acids and aldehydes before yielding highly persistent end-point compounds such as perfluorocarboxylic acids (PFCAs) including PFOA, as terminal highly stable end-product with unfavourable PBT characteristics.

For example a product that initially contains no PFOA but contains an 8:2 fluorotelomer will generate PFOA when the 8:2 fluorotelomer transforms through partial degradation involving the un-fluorinated di-methylene “spacer” group (Figure 2.1 B)

Where the foam contains persistent toxic organic compounds or related transformation products it cannot be described or implied as being readily (>95%) or fully (>99%) biodegradable even when the overall persistent organic compounds are <5% w/w in the concentrate or <1% w/w of the total organic components respectively. Under the REACH Regulations any substance giving rise to PBT products on degradation must itself be classified as PBT [12].

The comparison of data for different foams from various sources shows that all are of concern with the potential to adversely impacts waterways through oxygen depletion, even at high dilutions of the finished foam solution. The incomplete biodegradability of the organic content of some foams under natural conditions, 10% to 80% non-degradable in some cases (Figure 2.3.1) [57] further emphasises the issue of whether or not any of the relatively non-degradable organic components have long-term chronic toxicity characteristics that could be of concern.

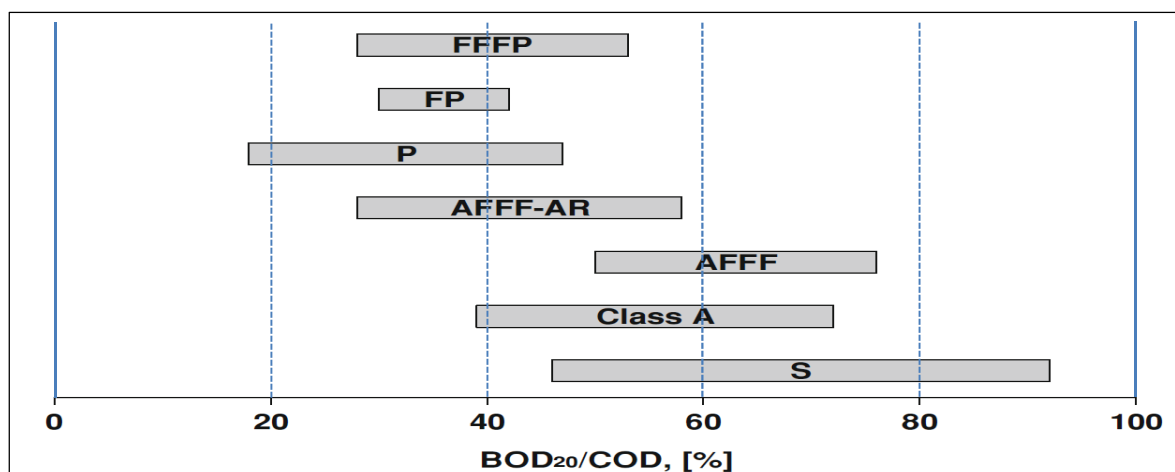


Figure 2.3.1 Range of biodegradability of 40 foam concentrates [57]

(FFFP=Film-forming fluoroprotein, FP=Fluoroprotein, P=Protein, AR=Alcohol resistant, AFFF= Aqueous film-forming foam, Class A, S=Synthetic(fluorine-free))

The use of the term “*biodegradable*” without qualification to describe foams where there are any persistent toxic components or their precursors present is misleading for users, responders and regulators who could assume from a product statement of “...*biodegradable*...” that this infers that the product is completely biodegradable to mineralisation with no persistent residues that need to be considered.

Users bear the ultimate responsibility for the selection, use and impacts of the foam they choose and should ascertain clearly what the full characteristics of the product are beyond non-specific product information for all relevant aspects.

2.3.2 Definitions of biodegradability for firefighting foam

In the light of the highly variable use and very loose definition of “...*biodegradable*...” with the term normally being applied to a wide range of products, most of which do not contain toxic highly persistent components, there needs to be a clear distinction and context for the term “...*biodegradable*...” as applied to firefighting foams that is meaningful for assessing risk and liability given that foam is frequently used in large volumes and under potentially highly environmentally dispersive operational conditions.

Biodegradability of Firefighting Foam–Key Issues:

- “*Biodegradability*” as a term has been used very ambiguously when applied to firefighting foam.
- “*Biodegradable*” should only be applied to firefighting foam that does not contain persistent toxic compounds such as fluorinated organics, siloxanes, or similar compounds or their precursors.
- *Readily biodegradable* means >95% biodegradable in 28 days or another stated period.
- *Fully biodegradable* means >99% in 28 days or another stated period for fully biodegradable foam.

The usefulness of a clear definition of biodegradability for users and regulators is:

- Assurance as to what extent the product organic content will degrade to mineralisation (i.e., to carbon dioxide, water and inorganic ions).
- Clear disclosure about whether there are persistent organic compounds present.
- Predicting and planning for how wastes will need to be managed.

For the purposes of classifying and stating biodegradability (derived from BOD and COD values) for a non-persistent firefighting foam as being *fully biodegradable* or *readily biodegradable*, the organic compounds in its composition must degrade under normal environmental conditions within 28 days or over a similar stated period from the time of its release to water with the meanings:

- *Readily biodegradable* (>95% in 28 days)
- *Fully biodegradable* (>99% in 28 days), OR

- *Readily biodegradable (>95%) in ## days*
- *Fully biodegradable (>99%) in ## days.*
e.g., “Fully biodegradable (>99%) in 45 days”

Otherwise the biodegradability of foam that does contain persistent toxic compounds such as any fluorinated organics cannot claim to be readily biodegradable or fully biodegradable and should state biodegradability as:

- *Non-persistent organic components ##% biodegradable in ## days.*
e.g., “non-persistent organic components 88% biodegradable in 28 days”.

To limit the downstream extent and duration of acute toxicity impacts on the environment rapid and complete biodegradability of a released contaminant is desirable where there is the potential for toxic contaminants to be released to the environment with the potential for long-range transport, even if this implies elevated BOD in the short term. High BOD for the majority of foams is of overriding concern compared with the ranges of acute toxicity across firefighting foam types which is narrow and at the lower end of the impact scale.

2.4 Acute (short-term) toxicity

Acute toxicity refers to the immediate or short-term effects from the direct toxicity of contaminants; usually the effects occur within hours or days of exposure. Acute toxicity testing observes the effects of a contaminant over a short period, e.g. over 96 hours, relative to a single exposure at the beginning of the test procedure or the effects of exposure to particular concentrations [58].

Concerns regarding acute toxicity of pollutant releases to the environment focus on the potential to cause harm to aquatic organisms in bodies of water. Tests for acute toxicity need to involve a spectrum of aquatic test species such as crustaceans, algae and fish that are relevant to the location or at least tests that use standardised test species across the relevant groups.

Acute (short-term) Toxicity – Key Issues:

- Acute toxicity is of greatest concern in regards to aquatic organisms in water bodies.
- Relevant test species should be used, not just the most robust or least sensitive.
- Toxicity testing must be done and reported for the as-used product, not for single components.
- Acute toxicity test methods may negate or mask the far greater effects of acute BOD impacts because the test maintains 60% artificial aeration of the test water.
- Acute toxicity must be considered in conjunction with potential BOD effects as would occur in the environment.
- Acute toxicity testing does not take into account potential long-term (chronic) effects of persistent toxic compound on human health or the environment.

Toxicity testing should be conducted in accordance with standards and methodologies, such as those accepted and recognised in Australia, the USA, Canada, New Zealand and OECD, by an independent laboratory or organisation. Australian or equivalent test species should include fresh water and marine species, for example but not limited only to:

- 48-hour acute (immobilisation) test using a freshwater species, e.g. the daphnid *Ceriodaphnia dubia* (using USEPA 2002 method) or Australian or equivalent test species.
- 72-hour micro-algal growth inhibition (cell yield) tests using, e.g. freshwater alga *Selenastrum capricornutum* (using USEPA Method 1003.0) or Australian or equivalent test species.
- 96-hour fish imbalance tests using a freshwater fish species, e.g. Rainbow fish *Melanotaenia splendida splendida* (based on OECD Method 203) or Australian or equivalent test species.

- 72-hour micro-algal growth inhibition tests using *Isochrysis aff. galbana* or *Nitzschia closterium* (based on USEPA Method 1003.0 and Stauber *et. al.* 1996 for the National Pulp Mills Research Program) or Australian or equivalent test species.
- 96-hour acute toxicity tests using juvenile tiger prawn *Penaeus monodon* (based on USEPA OPPTS 850.1045), or the amphipod *Melita plumulosa* should tiger prawns not be available or Australian or equivalent test species.

When assessing acute toxicity care must be taken to ensure that the test species is relevant to the particular location where the product might be used and not just the most robust or least sensitive test species.

In addition to assessing the toxicity of a product against the most and least sensitive relevant species an overall or average acute toxicity value should be determined using a method that favours the most sensitive species. For example an average toxicity based on toxicity test results for relevant fish, crustaceans and algae calculated as:

$$\text{Average Toxicity} = \frac{3}{\left[\frac{1}{\text{Tox1}} + \frac{1}{\text{Tox2}} + \frac{1}{\text{Tox3}} \right]}$$

(96 hour LC₅₀ or EC₅₀) [49]

2.4.1 Acute (short-term) toxicity of firefighting foam

In terms of the potential effects on the environment of a release of firefighting foam there needs to be consideration of the duration and severity of the effects of toxic compounds. However, it needs to be kept in mind that the oxygen depleting effects from BOD in water bodies are more significant, will manifest in similar ways and may be related to relatively non-toxic degradable organic components. In any event the acute toxicity effects are coincident with BOD and for the most part are inseparable.

Acute (short-term) Toxicity – Key Issues:

- Current foam types generally fall within similar short-term (acute) toxicity ranges of 100 mg/L to 10,000 mg/L (Rated as: *Practically Nontoxic* to *Relatively Harmless*).
- Note that BOD has a concurrent effect to acute toxicity (Section 2.2.1) and the acute toxicity test is not representative of the combined effects.
- Acute toxicity testing does not take into account long-term (chronic) effects to health or the environment of fluorinated or other persistent organic compounds.
- Any test results must be for the effects of the as-sold product not just selected components.

Some claims have been made that non-persistent foams overall have twice to 40 times the acute toxicity impact of fluorinated foams. When acute toxicity levels of significance are considered this has not been substantiated by any verifiable evidence or in the research literature.

A comparison of the acute toxicity of firefighting foams published by industry (2006) [59], summarised in Figure 2.4.1, and the review of other more current acute toxicity data, where available from product information, found that fluorinated and non-persistent foams are of the same order of acute toxicity ranging from *Slightly Toxic* to *Practically Non-toxic* as categorised according to the US Fish and Wildlife Service toxicity scale (Table 2.4.1) [60]. Differences between toxicity values spanning these low toxicity categories are not of consequence.

Note that these categories are for short-term toxicity only and do not take into account long-term chronic toxicity for persistent compounds. Also note that the comparison in Figure 2.4.1 pertains to only two species of fish, it is a comparison that is ten years old making it somewhat out-of-date (2006) and as such is not likely to represent fairly the characteristics of current generation foams across the spectrum of potentially affected biota (e.g. fish, crustaceans, algae, etc.).

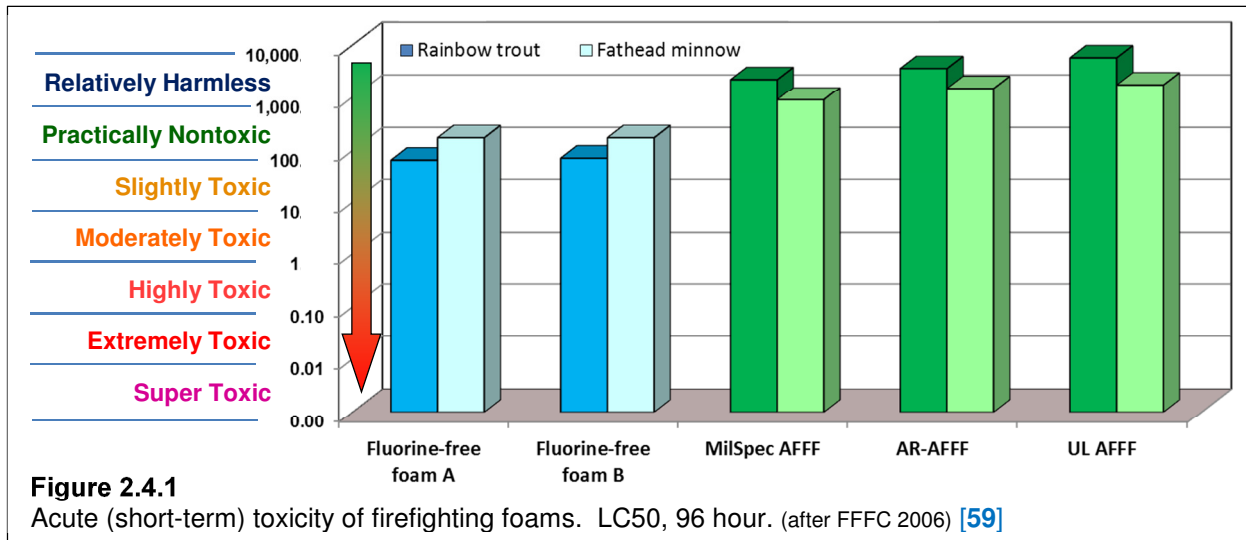


Table 2.4.1–US Fish and Wildlife Service toxicity scale [60]
Aquatic EC or LC50 (freshwater)

Toxicity Category	Range (mg/L)
Super Toxic	< 0.01
Extremely Toxic	0.01 –0.1
Highly Toxic	0.1 –1
Moderately Toxic	1 –10
Slightly Toxic	10 –100
Practically Nontoxic	100 –1,000
Relatively Harmless	> 1,000

An assumption that is often made is that the acute toxicity values will provide a means for assessing the short-term impacts of the release of a contaminant on aquatic organisms. This is erroneous without consideration of BOD which is high to very high for all foams.

Assessing and ranking the real-world immediate acute impacts of foam releases to waterways needs to consider the effects of BOD-induced oxygen depletion in conjunction with direct toxicity effects. The acute toxicity test does not take into account BOD effects because:

- the *OECD 203* test protocol (fish toxicity) **requires artificial maintenance of the dissolved oxygen level to at least 60%** of air saturation in the test media by aeration for the duration of the test (96 hours) [61].

The effect of this artificial aeration is that for the 3 day duration of the test it negates, or at least very significantly masks, the substantial “toxic” effects of BOD from the breakdown of degradable organic foam components such as solvents, carbohydrates, HC-surfactants and complex sugars.

This means that the acute toxicity test results by themselves are of very little use and are very likely misleading for indicating the real acute impact of releases to waterways where the short-term effects on biota will actually be from the combined effects of BOD-induced oxygen depletion plus a much lesser contribution from direct acute toxicity.

In terms of managing potential environmental impacts in water bodies, where there is sufficient dilution or treatment to mitigate the effects of BOD then it follows that the far lesser acute toxicity effects will also be mitigated.

Note that information on the combined effects of BOD and acute toxicity has so far rarely been provided in product information to allow practical assessment of the overall effects.

The environmental management of foam Policy stipulates the standard test methodologies and information that must be made available so that users, regulators and incident responders have a standardised basis for assessing the acute toxicity risks they face and for making appropriate comparisons, decisions and choices. The Policy includes guidance on relevant test species and best-practice test methods. It should be noted that sensitivity to toxins is variable across species and assumptions cannot be made even between species within related groups such as fish and crustaceans [62,63].

Significant problems have arisen for foam users, environmental regulators and incident responders in that acute ecological toxicity test data and information reported in foam product information and safety data sheets are rarely adequate, often only citing single components, and data may even be completely absent, making it difficult or impossible for the user to make an informed judgement or decision in regard to a balanced environmental risk assessment for response planning or incident management.

Quite often acute ecological toxicity information cited in the SDS and product information only relates to selected components of the foam and not to the final product formulation. It is well recognised that the overall toxicity of a mixture may be very different from its separate ingredients [64,65] through largely unpredictable synergistic effects between components. This is particularly pertinent for firefighting foams where the surfactants are very likely to facilitate the entry of other chemicals into the organism's cells through the effects of surfactants on cell membranes.

For acute toxicity test results to be relevant the tests must be done for the final product formulation and at the usage concentration. It is not sufficient, and is very often misleading, only to report on selected components in isolation.

Manufacturers/suppliers should consider providing additional information in SDS and product technical information beyond that required by the Policy, GHS and Codes. Equally, users may need to seek further information relevant to particular or unusual circumstances that they face or for the environment in which the foam will be used (such as the near-shore marine environment) before deciding how best to address their needs and obligations. For example, information relevant to the OSPAR marine species test suite and protocols [66,67,68].

2.5 Persistence

The presence of any persistent toxic compounds, or persistent compounds of relatively low acute toxicity but with unknown long-term effects, in releases to the environment is of concern. Toxicity effects on health and the environment by persistent compounds can be exerted over a long period with the added possibility that increasing concentrations, long-term exposure, bioaccumulation and long-range dispersal may occur [69,70,71,72,26]. The term *persistence* in the Policy is used to mean environmental persistence; it should not be confused with bio-persistence (see Section 2.8).

Persistence – Key Issues:

- Persistence of toxic compounds is of significant concern where there are releases to the environment, especially where there is evidence that adverse health and environmental effects from long-term exposure and bioaccumulation could occur. See Chronic (long-term) toxicity.
- Persistence raises the issue of potential increasing exposure through increasing concentration, biopersistence in organisms, bioaccumulation from the environment and bioconcentration through the food chain.
- The persistence of toxic intermediate, transformational, breakdown and end-point compounds must also be considered and not just the compounds present in the original product.

Firefighting foams are often used in situations where containment may be difficult or impossible, so it is likely that there will be releases to the environment and dispersal under a variety of circumstances. This could occur on a large or small scale during incidents and normal operational activities. Where persistent toxic compounds are present, care must be taken to

ensure that the likely environmental risks and impacts are *fully understood* and such products are only used with appropriate containment and controls in place.

Many pollutants released to the environment can be expected to naturally degrade over time or to become immobilised, for example, by adsorption to sediments, microbial degradation, oxidation, reduction, hydrolysis, UV photo-degradation, hydroxyl attack in the atmosphere, etc. However, persistent fluorinated organic compounds (PFCs) do not naturally diminish in this way as expected for other compounds due to their extreme persistence. Their characteristics also include chemical stability, high solubility, high mobility, high acid strength (low pKa), dispersible volatile precursors or transformation products in air (such as FTOHs or short-chain perfluoroalkyl derivatives from landfill or WWTP emissions). This applies for PFCs in surface water, groundwater and in soil [73,74,22,75,76,33]. PFCs do bind to an extent to organic matter in soil [77] but there is potential for re-release as some or all of that organic matter decays given the persistence of PFCs.

Extreme persistence in itself is not generally considered a primary problematic characteristic, however, it is well established that even without known significant bioaccumulative and toxicity characteristics if the concentration of a persistent compound, particularly in groundwater, is highly dispersible and is likely to increase over time, thereby increasing potential human health and environmental exposure, the compound should not be discharged [78]-; this especially applies when a compound's characteristics are largely unknown or there are emerging evidence and concerns about adverse effects [5,6,7,79,80] and for compounds or classes of compounds regarded as “main pollutants” such as persistent organo-halogen compounds and substances which may form such compounds in the aquatic environment [81].

Persistence becomes particularly problematic and of-concern where the compounds or their degradation products are also toxic, highly dispersible, and may be biopersistent and bioaccumulative, or are suspected of being so thereby triggering the *Precautionary Principle*.

Even compounds that have short-term low to moderate acute toxicity require very close scrutiny for their potential to cause adverse health and environmental effects over the longer term making a conservative approach to their management necessary, i.e., through the application of the *Precautionary Principle* [49,3] [6,5,7,8]. Environmental persistence increases the risks of long-term toxic effects, long-range transport (LRT), biopersistence, bioaccumulation, bioconcentration and biomagnification occurring.

An organic compound is considered environmentally *persistent (P)* or *very persistent (vP)* under *Annex XIII of REACH (EC 2011)* when its half-life, including that of its degradation products with similar characteristics or effects, is greater than those shown in [Table 2.5 A](#) for each environmental compartment.

Table 2.5 A – Criteria for identifying Persistent (P) and Very Persistent (vP) substances [82]			
Persistent (P) degradation half-life		Very Persistent (vP) degradation half-life	
Marine water	>60 days	Marine water	>60 days
Fresh or estuarine water	>40 days	Fresh, or estuarine water	>60 days
Marine sediment	>180 days	Marine sediment	>180 days
Fresh or estuarine sediment	>120 days	Fresh, or estuarine sediment	>180 days
Soil	>120 days	Soil	>180 days.

2.5.1 Persistence of fluorinated organic compounds

Many firefighting foams are heavily reliant on longer-chain (>C6) fluorinated organic compounds for their firefighting performance and these foams have been extremely effective in a range of firefighting applications with few alternatives available until recently.

Persistence of Fluorinated Organic Compounds – Key Issues:

- All fluorinated organic compounds are extremely persistent or eventually result in extremely persistent transformation or end-point compounds.

Since about 2000 there has been growing and significant evidence of the adverse health and environmental effects of poly- and per-fluorinated organic compounds released from various sources including fabric protectants and manufacturing processes as well as firefighting foams. Perfluorinated organic compounds are well known to be extremely persistent in the environment, with no known natural processes whereby they will degrade [44,30,24,73,83,26].

The extreme persistence of perfluorinated organic compounds can be described as “geological” to the extent that rock strata in the distant future, formed from current contaminated sediments, are likely to contain un-degraded perfluorinated organic compounds from releases in the last few decades as complete mineralization is not expected to occur under natural conditions [84,85]. In addition, fluorinated organic compounds are also likely to be still circulating in the environment after similar very long periods of time. For example, the simplest perfluoroalkyl compound, fluoro-methane (CF₄), has an estimated half-life in the upper atmosphere of >50,000 years [86].

The carbon-fluorine bond in fluorinated organic compounds is extremely strong and stable, it is the strongest bond in organic chemistry [25,22,87,88], enhanced by overlapping electron shells and a short C-F bond length [76]. This gives extreme durability to perfluorinated organic compounds under all but exceptional chemical and physical conditions. It is not surprising that perfluorinated organic compounds do not undergo biotic or abiotic degradation under environmental conditions given that even thermal degradation only occurs at temperatures of 1,100°C and above with at least 2 seconds residence time at that temperature [89,46,90,91].

Normally persistence or degradation in the environment is described in terms of a compound’s *half-life*, being the time it takes for 50% of the original amount or concentration of the compound to degrade. The environmental half-life of PFOA has been described as “*challenging or even impossible to measure*” with an estimate of PFOA’s half-life under artificial hydrolysis conditions in the laboratory of about 92 years [44]. Even under these artificial conditions the expected degradation of PFOA to a residual amount below 1% of the original concentration would be seven half-lives or about 644 years.

Another estimate puts the half-life of PFOA under hydrolysis at about 235 years [72] giving an expected time to degradation below 1% of initial amount of about 1,645 years. These estimates should not be cited as expected environmental half-lives as they are purely notional. PFOA persistence, and that of all similar perfluorinated organic compounds, is expected to be effectively indefinite under environmental conditions.

2.5.2 Precursors and partial transformation of fluorinated organic compounds

Foam formulations currently contain complex combinations of many fluorinated organic compounds, principally perfluoroalkyl and fluorotelomer compounds of various carbon chain lengths and with a broad diversity of functional groups (Table 2.1). On release to the environment compounds can transform into various intermediate and eventually end-point compounds with similar adverse effects. Other compounds such as fluoropolymers and fluoro-siloxane compounds may also occur in foam formulations and can be regarded in the same way.

Fluorinated Organic Compounds Precursor & Transformation Products – Key Issues:

- Fluorinated foam formulations use a broad diversity of complex fluorinated organic compounds.
- FOCs can produce a range of different toxic intermediate, transformational, partial breakdown and end-point compounds.
- The toxicity and characteristics of transformation and end-point compounds must also be identified and be considered in addition to the compounds present in the original product.

While fully fluorinated end-point *per*-fluorinated compounds such as PFOS and PFOA will not degrade under environmental conditions, many of the compounds that are in use are more complex and on release to the environment will transform to various intermediate compounds on the way to becoming end-point compounds (generally carboxylates such as PFOA or sometimes sulfonates such as PFOS).

This means that not only must the adverse effects of the initial compounds be considered but also the behaviour and adverse effects of any toxic intermediates (largely unknown and potentially very different in nature) as well as the effects of the final end-point compounds. To an extent the transformation process can also occur prior to use in storage and in foam delivery systems over the long service-life of the product depending on conditions.

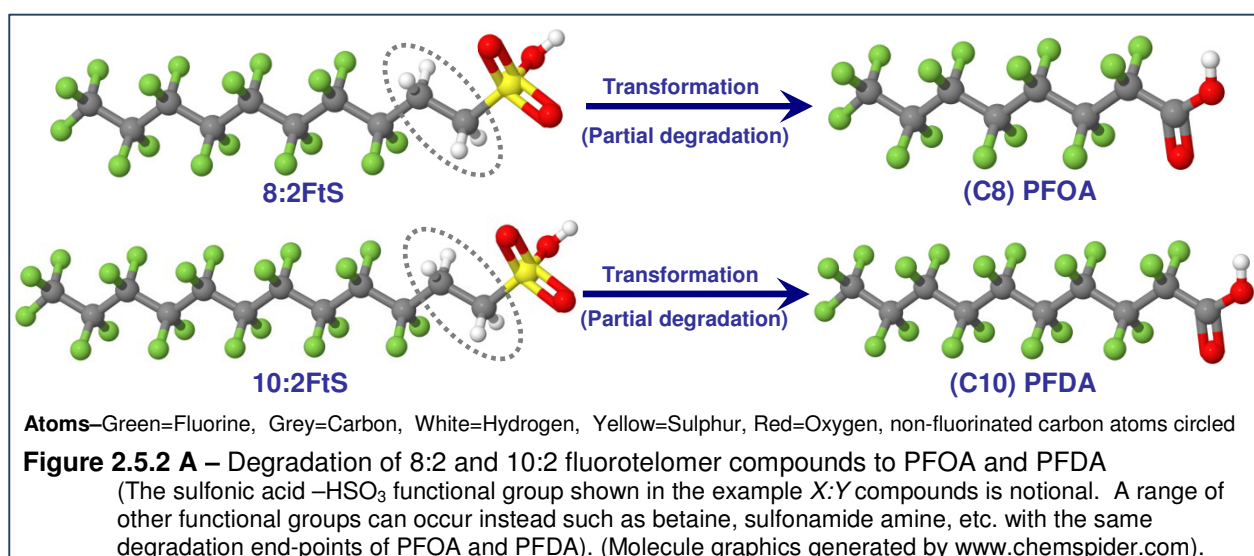
The process of transformation for *perfluoroalkyl* compounds where the carbon backbone is fully fluorinated may involve a simple change of functional group for one that is more stable. For example *perfluorooctyl sulfonamido amine* (PFOSA) is likely to replace the *sulfonamide-amine* group with a *sulfonate* thereby transforming to more stable PFOS. Compounds not based on a *perfluoroalkyl sulfonamide* would transform mainly to an end-point carboxylate, e.g. *perfluorooctyl amido betaine* would lose the *amido betaine* and transform mainly to PFOA.

For fluorotelomers (X:Y Ft) such as 8:2 Ft betaine that have part of the carbon chain that is not fully fluorinated (the dimethylene “spacer” group, Figure 2.1 B) on release to the environment they will transform or *partially degrade* through a loss of the non-fluorinated part of the molecule including the dimethylene spacer and the functional group, including some limited dehydro-fluorination [92]. For example *8:2 fluorotelomer sulfonamido betaine* would transform to mainly to PFOA.

In any event, the end-point degradation products for all PFCs are still highly persistent perfluorinated compounds related to the fully fluorinated part of the carbon chain (Figure 2.5.2 A) [43,47], for example:

- In the case of a variety of 8:2 fluorotelomers the end point is mostly the carboxylic acid PFOA, after the non-fluorinated -CH₂-CH₂- dimethylene group is lost.
- For higher homologue 10:2 fluorotelomers the end point is perfluorodecanoic acid (PFDA).
- For compounds such as *perfluoroalkyl sulfonamides* the partial degradation end-point is likely to be a sulfonate such as PFOS (C8) or PFHxS (C6) depending on the precursor compound carbon chain length.

From an environmental standpoint it is highly misleading to describe fluorinated organic compounds as “*degradable*” which implies in general parlance to the non-specialist end-user that the product *fully* degrades and therefore it might be assumed that there are no residual persistent end-compounds of concern. This is not the case.



The “*degradation*” of fluorinated organic compounds under environmental conditions is better referred to as “*transformation*” as it only refers to the *partial degradation* or loss of the non-fluorinated carbons (usually a C2 dimethylene group) from some compounds and also, under specific conditions, limited partial de-fluorination adjacent to non-fluorinated carbon atoms, ultimately (and possibly through multiple intermediate steps [93]) leaving behind a persistent end-

point *per*-fluorinated compound [93]. This process may also involve a transformation where the functional group also changes, e.g. a sulfonamide is replaced by a sulfonate.

The eventual end-point compound left behind by transformation is a highly persistent *per*-fluorinated compound which does not degrade under environmental conditions [94,83,76]. The partial degradation/transformation steps and their intermediate compounds (and their half-lives) that lead to the eventual end-point compound, and the environmental behaviour of each of these compounds, are also not well understood. This applies to both long-chain and short-chain compounds [36,50,83] [95].

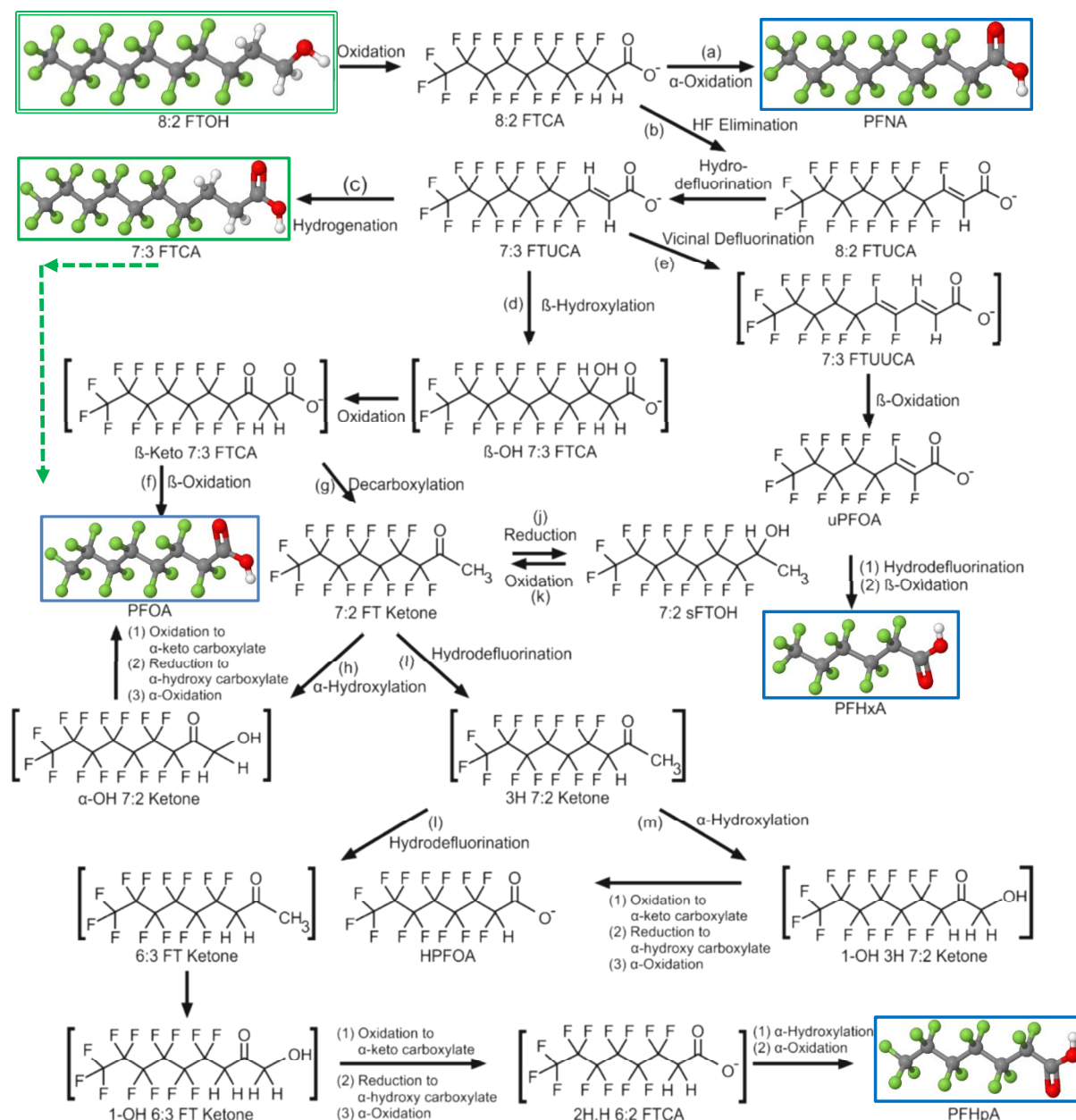


Figure 2.5.2 B – Possible biotransformation pathways for 8:2 fluorotelomer alcohol (8:2FTOH), a precursor compound (top left) to multiple transformation [xx] and end-point compounds (blue boxes) including PFOA, PFNA, 7:3 FtCA, PFHxA and PFHpA. Bracketed compounds are proposed intermediate transformation compounds. (After Washington, Jenkins & Weber, 2015 [93] – 3D Molecule graphics generated by www.chemspider.com)

Foams containing significant concentrations of PFOA precursor compounds such as 8:2 fluorotelomers effectively leave the user unwittingly exposed to the liability of having released foam that relatively quickly generates PFOA (and many other transformation compounds) with a very significant potential to cause human health and environmental impacts.

Similarly, those foams with significant concentrations of longer-chain fluorotelomers, such as 10:2FtS and 12:2FtS or equivalents ([32,47] and Tables 2.1 A, B & C), will transform to C10 perfluorodecanoate (PFDA) and C12 perfluorododecanoate respectively. These are higher homologues of PFOA which are orders of magnitude more toxic and more bioaccumulative [71].

Given the variable but relatively rapid degradation of 8:2 fluoroteleomers to PFOA in the environment the release of foam that contains these precursor compounds is effectively regarded as a release of PFOA to the environment as the PFOA precursor compounds can have relatively short half-lives (e.g. as short as 10.3 days for 8:2 fluorotelomer stearate monoester [96]). Similarly perfluorooctyl sulfonamido amine in a foam is likely to degrade to PFOS as do at least 96 other PFOS precursor substances [76].

It is evident that the original composition of some fluorinated foams rapidly loses relevance once the foam is put into use due to the relatively rapid transformation of compounds. The complexity of the biotic and abiotic transformation pathways means that not only do the effects of the original and end-point compounds need to be considered but also the numerous intermediate compounds and whether or not conditions are anaerobic which can favour persistence of precursors.

For example the potential transformation pathways and products of the initial 8:2 fluorotelomer alcohol (8:2 FTOH) [93] illustrated in Figure 2.5.2 B involves:

- Sixteen intermediate transformation compounds.
- Four perfluorinated end-point compounds (PFOA, PFHxA, PFHpA, PFNA).
- A 7:3 fluorotelomer carboxylate which may have further transformation potential to PFOA.

The issue of concern that arises from this is what are the potential effects of each of these 21 very different, largely unknown, complex transformation compounds. Such complexities are commonly not addressed with only the original single precursor and possibly one or two end-point compounds such as PFOS and PFOA being considered.

When this single example is applied to each of the large number of complex fluorotelomer and other compounds so far identified (with many more likely to emerge) the scale of the issue increases very significantly, especially in terms of the almost complete lack of information concerning potential health and environmental effects.

Effectively the fluorinated foam produced from concentrates advertised as “*PFOA and PFOS free*” may not remain free of PFOS or PFOA and their higher homologues for very long once it is put into systems or released to the environment and the transformation of precursors through partial degradation occurs. For example perfluoroalkyl sulfonamide-based compounds can transform to sulfonates such as PFOS and non-sulfonamide C8 compounds including 8:2 fluorotelomers can transform to PFOA (Table 2.1).

Additionally, end-users should be aware that their current foam stocks may contain PFOS, PFOA, their precursors and higher homologues due to contamination of newer replacement stocks of foam by legacy residues and breakdown products left over in tanks and pipework in systems that have not been adequately decontaminated.

Under the Policy foams containing PFOA and/or its precursors and their higher homologues are required to be withdrawn from service as soon as it is practicable and disposed of properly. It is recognised that a significant number of firefighting foams in service are currently dependent upon PFOA precursor and related fluorinated organic compounds (as well as on very significant levels of the more toxic longer-chain C10 to C14 compounds [32,37]) and that a reasonable time to transition to alternative foams will be required with interim containment measures implemented as soon as practicable; this will vary according to the complexity of the particular circumstances.

The potential for adverse health and environmental effects by PFOS has been well understood for some considerable time. Firefighting foams that contain significant levels of PFOS (>10 mg/kg), its higher homologues and their precursors are of **very significant concern** for human health and the environment world-wide and as such the Policy requires that they are not to be used and should be withdrawn from service **as soon as possible**, secured and plans put in place

for proper disposal [89,97]. Care must be taken to ensure that systems that have contained PFOS foam are properly decontaminated to prevent PFOS and associated compounds from contaminating replacement products.

2.6 Bioaccumulation

Bioaccumulation is the general and continued uptake of substances from the environment through contact, with nutrient uptake through diet resulting in an increasing concentration within the organism which enhances the potential for health and environmental harm substantially, especially in the case of toxic, highly persistent compounds that are not metabolised or are slow to be eliminated from animals.

In a general sense the term bioaccumulation also encompasses the related terms of bioconcentration (where uptake exceeds elimination), and biomagnification (increased concentration via uptake from the food chain) (see Policy Definitions).

Bioaccumulation – Key Issues:

- Where toxic compounds are also persistent bioaccumulation can occur resulting in adverse health and environmental effects from long-term build-up in plants and animals. See Chronic (long-term) toxicity.
- Fluorinated organic compounds are highly persistent with many having significant potential to bioaccumulate.

The persistence of any compound in the environment increases the exposure of organisms to the compound, and that is of particular concern for chemicals that bioaccumulate (as well as bioconcentrate or biomagnify). Especially, for example, if the compound has an affinity for a particular compartment in biological systems, or it associates with fats or proteins in blood serum or is concentrated in a particular organ, such as iodine is in the thyroid [69,70,98,25]. Given that firefighting foams can be released to the environment under various circumstances, care must be taken to ensure that the behaviour of any potentially bioaccumulative compounds are well understood, especially those that are toxic and persistent.

Various long-chain fluorinated organic compounds are known to bioaccumulate and have been detected world-wide in various organisms [99,69,100]. Uptake of PFOS and PFOA is known to occur for plants growing in contaminated soils and has also been found in food products including fish, meat and milk products [73].

Testing with aquatic species suggests that PFOA is “*not highly bioaccumulative*”, however it should be taken into account that PFOA is highly soluble and aquatic species used in standard tests have an additional mode of elimination via the large surface area of their gills that terrestrial animals do not have. That is to say, the gills are an added way that aquatic animals can more readily excrete contaminants from their bodies back into the water so tests using aquatic species should be viewed with caution in respect of their applicability to species without gills.

Also, given the potential for long-range transport (LRT) and uptake via various pathways for animals and humans the overall bioaccumulative potential of PFOA and its precursors is supported by the weight of evidence for its nomination as a candidate substance of Very High Concern under REACH (SVHC) due to its CMR (Carcinogenic, Mutagenic, toxic for Reproduction) and PBT (Persistent, Bioaccumulative, Toxic) properties [18,101] as well as indications of potentially genotoxic properties for PFOA, PFOS and other PFCs [102].

PFOA is also only one of a wide diversity of compounds that are used, occur in or are derived from foam, with very little known about their behaviour in the environment [32,22,31]. Some compounds can persist for years to decades [103,104] before partially breaking down to end-point compounds such as PFOA and PFHxA.

It is worth noting that standard assessment of bioaccumulation potential using the N-octanol-water partitioning coefficient (K_{ow}) is not valid for surface active substances (surfactants) including

fluorosurfactants as they do not tend to accumulate in storage lipids but rather associate with proteins and concentrate primarily in the blood and liver among other tissues [66,71,98,99,70].

Assessment of the bioaccumulative potential of substances against existing regulatory criteria for bioconcentration factors (BCFs) and bioaccumulation factors (BAFs), such as those developed under CEPA 1999, need to be applied cautiously and take into account that these threshold criteria may not be applicable as they are based on historical experience with neutral, non-metabolised organic substances in freshwater aquatic systems, with particular reference to lipophilic substances [72,30,98] which, unlike fluorinated organics, primarily partition into fats.

Fluorinated organic substances depart in their characteristics and behaviour from the traditional assumptions made regarding BCFs and BAFs in a number of significant respects, as well as there being indications of bioaccumulation occurring in a number of terrestrial and marine animals for both long and short-chain PFCs [105,106] [107,72,69,42]. There are also indications that typical BAF default (conservative) values of one may greatly underestimate the risk [105] and that both long and short-chain PFCs may bioaccumulate and enter the food chain [106] including C4 to C7 compounds.

The unusual nature and behaviour of persistent toxic organic compounds, including per- and poly-fluorinated organics, strongly suggests that a conservative approach to management must be taken given that many show indications that they or their breakdown products may be bioaccumulative.

For example, in earthworms (a primary trophic group) exposure to PFOS, PFOA and 6:2FtS gave similar bioaccumulation factors for PFOS (BAF 2.6) and 6:2FtS (BAF 2.4) suggesting undegraded 6:2FtS bioaccumulates to a similar extent as PFOS and PFOA [107].

2.7 Chronic (long-term) toxicity

Where a contaminant is persistent in the environment the long-term, chronic toxicity must also be considered, how it may become transformed to other toxic daughter compounds and how all of them may behave in biological systems. For persistent pollutants, such as fluorinated organic compounds, the degree of persistence and their toxicity, even for those with low acute toxicity, are very significant considerations in assessing the chronic toxicity risk posed to human health and the environment [108,58,100].

Put simply, persistent pollutants, even if they have relatively low acute or immediate toxicity, have a very long time over which they can exert their effects, especially if there are any indications that environmental concentrations may increase [109] and bioaccumulation, bioconcentration and/or biomagnification could also occur or if there is slow elimination from the body [110,70,72].

Chronic (long-term) Toxicity – Key Issues:

- Where persistent toxic compounds are present the potential for long-term exposure and effects also needs to be considered in detail especially with regards to environmental persistence where concentrations could increase over time, biopersist or bioaccumulate in organisms.

Comparisons have been made between the toxicity of fluorinated and fluorine-free foams, however, such comparisons are almost always in regards to short-term acute toxicity with rarely any mention of long-term chronic toxicity. When considering the potential adverse effects of toxicity the short-term toxicity of a product is only one characteristic that should be considered and is not directly relatable to long-term toxicity.

Short-term toxicity is the most often cited characteristic in foam product information and SDS, it is misleading to assess and compare the potential effects of foams on this basis alone, especially when some products may contain persistent and bioaccumulative compounds with subtle, but nonetheless, toxic long-term effects.

2.8 PBT (Persistence-Bioaccumulation-Toxicity)

The overall potential for a firefighting foam to cause adverse environmental effects needs to be assessed in terms of its Persistence-Bioaccumulation-Toxicity (PBT) profile. This needs to take into account both the short-term and long-term impacts of the final formulation. Each component needs to be weighted appropriately in arriving at the overall evaluation.

Where there is insufficient information on a particular foam formulation, or the principle components of concern, a conservative approach to PBT assessment and product management is mandatory in line with the *Precautionary Principle*. This is especially the case where there are compounds in use for which there are indications that long-term effects may be expressed through biopersistence, bioaccumulation, bioconcentration or biomagnification or where there is the potential for long-range transport and there are known occurrences of contaminants in biota that are very unlikely to be the result of direct exposure [42,72,111].

Persistence-Bioaccumulation-Toxicity of Foam – Key Issues:

- All fluorinated organic compounds are highly persistent, dispersive, toxic to varying degrees and many have significant potential to biopersist and bioaccumulate.
- There is a lack of comprehensive information on the chronic toxicity potential for most PFCs but strong indications of potential adverse effects across all classes.
- PFOS and PFOA meet the PBT criteria according to the *Stockholm Convention on Persistent Organic Pollutants*.

The general *persistence* of a compound refers to its overall persistence in the environment subject to degrading influences such as photolysis, oxidation, hydrolysis and biodegradation. The more specific terms *bio-persistence*, *bio-accumulation*, *bio-concentration* and *bio-magnification* refer to biotic processes within or involving living organisms.

The term *biopersistence* has been frequently misused in general publications and marketing information e.g. “*biopersistence in the environment*” has been used incorrectly where *environmental persistence* is more accurate and appropriate. *Biopersistence* specifically refers to how long a compound, once taken up by the organism, persists in the body of the organism. This largely depends on the rate that it is cleared or eliminated [49,58] e.g. by respiration, excretion or metabolism (*bioelimination*). Bioelimination rates and mechanisms vary widely between organisms and may also be subject to sex-specific hormonally controlled differences within species.

When assessing the potential for adverse effects by bioaccumulation of the components of a complex mixture such as a foam concentrate factors that need to be taken into account include:

- Particular compounds that may bioaccumulate or are similar to those that are known to.
- Breakdown products or metabolites if they are similar substances or have similar effects.
- Solvents and detergents present in formulations that affect cellular uptake and metabolism.

While it is important to assess the effects of the combined formulation of any product, for practical purposes an initial assessment of bioaccumulation potential should focus on the compounds most likely to be involved (and their breakdown products) and which are significantly environmentally persistent.

That is, an assessment of all those compounds that persist long enough to bioaccumulate and with potential to exert adverse effects on health and/or the environment. These might include fluorotelomers, fluoropolymers, siloxanes [112], heavy metal chelators or similar compounds and their breakdown products.

Given that the formulations of firefighting foams are by commercial necessity trade secrets, this puts the onus on the manufacturers to review the compounds in their formulations, including probable breakdown products, and provide the relevant information to the user even if the compounds are only publically identified in a generic way in SDS and product information.

For example, in addition to any statements about the ≤C6 purity of the fluorinated organic compound content it would be sufficient to state “*Contains fluorinated organic compounds known to persist in the environment and may bioaccumulate in living organisms – Do not discharge to the environment*”.

The octanol-water partition coefficient $\log(P_{ow})$ can in some cases be used to estimate the bioconcentration factor of a compound but this is not appropriate for surfactants [71,98] so a more direct measure of the bio-concentration factor (BCF) will need to be done for persistent organic compounds [49].

In general, the potential for bioaccumulation (and bio-magnification) should be assumed as many poly- and perfluorinated organic compounds belong to a class of substances known to have a potential to accumulate in living organisms, there are indications from structural features and there is no mitigating property such as hydrolysis [113] [114]. Individual BCFs for aquatic organisms are in any case only part of the overall trophic bio-magnification that can occur in food-chain, especially in higher predators [49]. While the focus for bioaccumulation has been on the longer-chain PFCs there are now indications that short-chain C3-C4 compounds are more mobile in soils and groundwater [115,77] and more readily taken up by plants [37] with the potential to enter the food chain through crops and stock.

The PBT profiling system proposed by the UK Civil Aviation Authority (Figure 2.8 A) which is currently being considered by the Bavarian State Environment Agency provides a sound basis for a simplified PBT assessment and guide for incident responders in keeping with the *Precautionary Principle* mentioned elsewhere in these *Explanatory Notes*. For complex products this may need to be informed by a more detailed risk assessment similar to the Hazard Index method [65].

Environmental Impact – Chronic Effects – Persistence, Bioaccumulation, Toxicity (PBT)		Significance
PERSISTENCE (Note – $t^{1/2}$ = half-life)		
0 Low ($t^{1/2}$ < 28 days)		Of little concern
1 Moderate ($t^{1/2}$ 1 - 12 months)		Caution required
2 High ($t^{1/2}$ > 1 year) (ALL PFCs)		Extreme concern
BIOACCUMULATION		
0 Low (BCF < 50)		Of little concern
1 Moderate (BCF 50 – 500)		Caution required
2 High (BCF > 500)		Serious concern
TOXICITY (CHRONIC)		
0 Low (>100 mg/L)		Low risk
1 Medium (1 – 100 mg/L)		Environmental damage likely
2 High (< 1 mg/L) (PFOS)		Containment essential
GROUNDWATER/CONTROLLED WATERS		
X Discharge forbidden (ALL PFCs)		Organohalogenes (fluorosurfactants)

Figure 2.8 A – PBT simplified classification [49] Under consideration by Bavarian State Environment Agency

2.9 Health, safety, amenity and economic considerations

While the Environmental Management of Firefighting Foam Policy focusses primarily on the actual and potential impacts of firefighting foam on environmental values, questions have arisen regarding the potential health impacts of releases of persistent toxic compounds on the public, workers, firefighters and other responders as well as the broader effects on public amenity values, reputation, economic resources and costs to industry.

As background to this the EP Act also regards “*people and communities*” as part of the environment with environmental values including “*a quality or physical characteristic of the environment that is conducive to ecological health or public amenity or safety*” (EP Act §8 & 9) [13] and clearly there is a responsibility for all government regulatory agencies to consider the wider environmental, health, economic and amenity implications of related effects.

Health, safety, amenity and economic considerations – Key Issues:

- All firefighting foams have the potential to cause short-term impacts on health and amenity.
- The release of persistent fluorinated foam compounds can result in very wide spread and potentially long-term impacts to environmental, health, economic and amenity values.
- Pollution incidents often incur very significant cleanup costs with potentially very adverse broader social implications such as loss of confidence in industry and regulators, loss of amenity, loss of income, perceived contamination of produce and reduced land values for affected areas.

Common environmental effects of all foams are varying degrees of detergent toxicity and elevated biochemical oxygen demand that can have immediate adverse effects on biota in the aquatic environment. Furthermore, some foams may contain compounds that can have long-term effects on worker health, public health, the environment and other values. Of particular concern are toxic compounds that are persistent, bioaccumulative and with long elimination times from animal species including the human body [116,117,70,110,103].

Since their first development and use fluorinated organic compounds are now found widely in the environment, plants, animals and the human population [23,72,80]. All foams contain a mix of various compounds in their formulations, often in a combination that is unique for each foam.

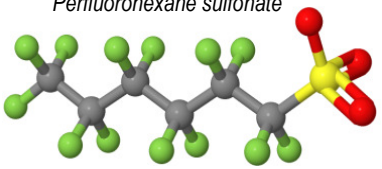
There is now very significant evidence for adverse effects in mammals for many classes of fluorinated organic compounds and indications of similar problems for most others. The elimination half-lives for a range of fluorinated organic sulfonate and carboxylate compounds are variable across different mammals but are particularly long in humans [69,117,70,110,26,118] [119] with elimination half-lives ranging from 1.5 years to 21.7 years (Table 2.9 A).

In the context of a person receiving a significant dose of PFOS (C8 compound) or PFHxS (a C6 short-chain PFC that behaves like a long-chain C8 PFC), a number of half-lives may be required to reduce the concentration of the compound in their body to acceptable levels below which acute or chronic effects could occur; this may amount to a period of up to several decades.

This emphasises that it is all the more important to prevent significant exposure to responders, the public and the environment in the first place especially in the light of the indications of long-term adverse chronic effects for both long-chain and short-chain compounds such as immune suppression [120,121,122,123], neurotoxicity [124], genotoxicity, cytotoxicity [125,126], endocrine disruption [122], cancer susceptibility/promotion [126], compromised embryonic development [127], with evidence for effects at low doses or close to ambient levels [122,127,128,123].

Compound	Half life
C6, PFHxS	8.5 years (2.2 to 27 years)
C8, PFOA	3.8 years (1.5 to 9.1 years)
C8, PFOS	5.4 years (2.4 to 21.7 years)
C9, PFNA	2.5 years (1.7 to 3.2 years)

Perfluorohexane sulfonate



(PFHxS – Perfluorohexane sulfonate, C₆F₁₃O₃S, structure at right, other structures for PFOS, PFOA and PFNA are shown elsewhere)

2.9.1 The costs of incidents involving firefighting foam

Generally the focus on risk management for firefighting is on the immediate priorities of rapid and effective suppression or extinguishment of fire. In addition to this, and in particular during the contingency planning stages well before any incident occurs, there needs to be consideration of the practicalities and costs of the recovery phase especially with regards to potential long-term effects of incidents or normal operations. This is now the standard contingency planning approach for incident management.

The Cost of Incident Involving Firefighting Foam – Key Issues:

- There are numerous examples of contamination by fluorinated foam emerging world-wide with exceedingly high soil, water and groundwater cleanup, remediation and compensation costs.
- Day-to-day operations and incident contingency planning must include proper long-term management and forward planning provisions appropriate to the products in use and the particular circumstances.

Wherever possible there should be pre-planning that seeks to minimise the unnecessary costs and impacts of general operations and incident response. Planning for containment and control of firewater and contaminants produced during incidents is an aspect that is often deficient or simplistic in emergency response plans despite the obvious implications for long-term costs.

For example one current response plan for a facility using fluorinated foam has release of firewater to the adjacent waterway as a management measure. The potential outcomes of this approach are clearly unacceptable from human health and environmental protection perspectives as well as downstream economic and amenity values.

Incidents often generate very large quantities of contaminated soil and firewater, and the cost of treatment can be very significant under some circumstances with damage to adjacent values beyond the site also being considerable. There are very limited options for treatment of wastewater and soils contaminated with persistent contaminants and most are expensive with materials having to be transported to distant treatment facilities and subjected to high temperature destruction methods such as incineration in a cement kiln, plasma-arc destruction or subjected to chemical immobilisation [90,129,130,91,89,33].

The determination of overall risk is based on *Probability X Consequence (AS/NZS 31000:2009 Risk Management–Principles and guidelines)*. While the probability of a large-scale incident resulting in a significant release is unlikely, the lasting consequences when it does occur can be catastrophic with few options available during the emergency to control or prevent releases beyond the site that could result in impacts. This makes the overall risk High.

For example, the 2005 fire at the relatively small Buncefield bulk hydrocarbon storage facility in the UK necessitated the use of about 750,000 litres of fluorinated foam concentrate during the response. The incident generated about 55 million litres of firewater, most of which was released to the environment (just 16ML was recovered) with groundwater drinking water supplies for north London also compromised [131].

At Coode Island in Melbourne in 1991 about 200 tonnes of firefighting foam concentrate were used [132] on a dock-side hydrocarbon chemical storage facility fire and most of the firewater was released to the adjacent waterway. The foam used was most likely 3M Light Water AFFF (PFOS). Based on the two most likely formulations the release of fluorinated organic compounds is likely to have been very substantial at between 3 tonnes and 30 tonnes (Table 2.9.1 A).

This represents a release during the Coode Island fire of up to about 30,000 kilograms of fluorinated organic compounds, about a third of which was PFOS [36]. The potential for significant effects on the environment, health of responders and the public from the perspective of the foam chemicals released was not recognised at the time and was not investigated.

Table 2.9.1 A – Coode Island fire, FOCs released based on 200 tonnes of concentrate used [132]

Foam type	3M Light Water FC-203 CE (1991)	3M Light Water FC-203 FC
Composition from MSDS	<i>alkyl sulfate salts... 5%, amphoteric fluoroalkylamide derivatives... 5%, perfluoroalkyl sulfonate salts... 5%</i>	<i>amphoteric fluoroalkylamide 1–5%, residual fluorochemicals <1%, PFOS salts 0.5-1.5%</i>
Fluorinated organic compounds	30,000 kg (PFOS 10,000 kg)	3,000 kg to 15,000 kg (PFOS 1,000 kg to 3,000 kg)

Any large-scale release of fluorinated organics would be on top of and exacerbate the existing chronic low-level but nonetheless cumulative releases to waterways from domestic sources, such

as carpet and fabric cleaning, inappropriate fluorinated waste disposal, and leaching of contaminated soils from adjacent facilities where foams have not been fully contained.

Investigations of the longer-term fate of some relatively small releases and spills of perfluorinated organic compounds, (Toronto 2000, 330-1,650 kg PFCs [104,133] and Amsterdam 2008, ~572 kg PFCs [134]), have found elevated levels of fluorinated organic compounds persisting for at least 15 years in the aquatic environment, especially in sediments and fish [26] highlighting the potential for spills to have longer-term effects on environmental and fisheries values with a significant health risk posed to the public consuming seafood.

On-site cleanup costs for fluorinated organic compound contamination can be very substantial [135], for example, the ECHA [12] lists some examples of the costs of cleanup for a few of the many impacted sites in Germany where soils and/or water required remediation (Table 2.9.1 B).

Exposure concerns are not just limited to PFOS, PFOA and higher homologues but also include the shorter-chain compounds such as PFHxS (perfluorohexane sulfonate) that have been found in humans and associated with consumption of contaminated drinking water and fish [26,118].

While PFHxS should not be present in, or result from current and proposed alternative “6:2 fluorotelomer-based” firefighting foams which will generate PFHxA, it is possible to produce PFHxS through transformation of precursor C6 perfluorohexyl sulfonamides currently found in various foams [39,34,31]. There may well also be legacy contamination of PFHxS in inadequately cleaned systems from legacy PFOS foam use as it is a homologue of PFOS and is present as a contaminant from production.

Incident details	Costs (\$AUD)
Fire in chemical waste treatment plant, disposal of firewater.	750,000
Fire event , 42m ³ foam used, soil contamination and 2 km plume in groundwater.	estd. Millions
Fire training ground Dusseldorf airport, three groundwater plume spreading towards Rhine River.	~150 million
Relocation of fire services base to prevent further contamination risks	1.2 million
Illegal disposal of PFCs in sludge to agricultural land, cost so far and ongoing for soil and water cleanup.	1 million/10ha 9.3 million 1-1.4M/yr
Fire training ground Nurnberg airport, high groundwater contamination, contaminated soil disposal	~150,000 soils only
Single truck fire , soils and firewater disposal, groundwater remediation	1.2 million

A large-scale release of contaminated firewater from a large hydrocarbon storage facility incident, a hydrocarbon shipping tanker fire or even cumulative smaller releases to waterways and the marine environment would potentially impact those values not only by direct contamination of seafood resources and aquaculture stocks but also by generating the *perception* of contamination which is very likely to severely affect public opinion and local and overseas market purchases of local seafood produce.

For example, Queensland hosts commercial fisheries to the *annual value* about \$436 million with aquaculture valued at \$103 million and recreational fisheries valued at about \$73 million [136]. In Moreton Bay alone, adjacent to Brisbane, the value of commercial and recreational fisheries to Queensland’s economy is between \$44 million and \$54 million per year [137].

Various marine oil spills and port dredging activities over the last decade, involving less persistent, and even undefined contaminants, compared to those associated with some firefighting foams, are examples where strong public and industry concerns have been expressed regarding pollution impacts on economic, amenity, cultural and recreational values [138,139].

If the pollution included indefinitely persistent and well recognised pollutants, such as fluorinated organic compounds, the damage to that industry, and to the recreational fishing sector and the

state's reputation through actual or perceived contamination, might then extend for years to decades raising issues of who would be responsible for compensation for that period.

Where a large-scale incident involved non-persistent, fully biodegradable contaminants including organohalogen-free foam and hydrocarbons the extent of damage would be limited to largely acceptable short-term acute impacts from which the environment and resource values would recover with no risk of long-term harm or the perception of persistent pollution.

2.9.2 Human health and safety implications

While the very valid issues of responder and firefighter safety are recognised as a primary high priority in assessing the effectiveness of firefighting foam to provide protection against immediate threats during incidents the long-term health and safety aspects of exposure to users and the public also need to be seriously considered as well.

Human Health and Safety Implication – Key Issues:

- Associations between fluorinated organic compound exposure and a wide range of long-term adverse health effects are rapidly emerging including concerns regarding low-level exposure.
- Environmental management decisions and incident contingency planning also needs to take into account potential downstream long-term human health effects.

Subject to type, concentration, duration and frequency of exposure, some foam chemicals may represent a significant health risk for users who do not take appropriate personal protective measures such as wearing of respiratory protection against inhalation and ingestion of contaminants in aerosols [140]. For example, fine, easily dispersed and inhaled aerosol particles are well known to be produced by bursting bubbles. Oral (and by inference respiratory) PFOS and PFOA exposures are readily absorbed (90%) and distributed through the body in blood serum. Excretion pathways, such as in bile, can be confounded by reabsorption, such as in the gastrointestinal tract [26]. Irrespective of composition and toxicity inhalation of surfactant aerosols, can damage lung structure and function and should be avoided by using respiratory protection.

Various fluorinated organic compounds have been identified in the blood of the general human population, PFOA and PFOS are the most frequently detected compounds and of significant concern for human health [84,141,118] with adverse effects possible at current low levels of PFCs [142,123,143]. However, the prominence of PFOS and PFOA as research subjects may not provide a balanced indication of overall PFC exposure as other less well-known compounds have not been as widely researched and reported and probably many more remain as yet unidentified in humans [38,36].

PFOA and PFOS both have long residence times in human blood of more than 1,000 days [99] and other fluorinated organic compounds may behave similarly. Fluorinated organic compounds have not been detected in reference databank human serum samples taken prior to when fluorochemicals were first manufactured and used commercially shortly after World War II [144] suggesting that exposure is specific to releases from commercial manufacture and use since then.

High levels of PFOS and PFOA have been shown to be toxic for reproduction and the development of the foetus and are potentially carcinogenic and tumour promoting in animal tests [26] [109]. In addition, 8:2 fluorotelomer phosphate diesters, 8:2 fluorotelomer alcohols, and PFOA show endocrine effects in different *in-vitro* and *in-vivo* tests. PFOA and PFOS are also associated with reduced humoral immune response in early childhood immunizations [99,26].

Probable associations have been found between exposure to PFOA, PFOS and other fluorinated organic compounds and health effects in humans including hyperuricemia, high cholesterol (hypercholesteremia), ulcerative colitis, thyroid diseases, testicular cancer, delayed puberty, asthma, kidney cancer, liver damage, preeclampsia, ADHD (attention deficit hyperactivity disorder), endocrine disruption, breast cancer and elevated blood pressure during pregnancy [99,110,26,117,145,118] [146,109].

Given the length of time that has elapsed since the potential for various PFCs to have adverse environmental and human health effects was recognised there have been remarkably few published peer-reviewed studies conclusively supporting the notion that continued use of PFCs, their release to the environment and effects on human health is benign.

Even those studies associated with major PFC producers [147,148,149,150], where the researchers presumably had greater access to relevant information than independent researchers are reserved in their findings. Most tend to argue that in absolute terms there is “no conclusive evidence” or “no causal link” of PFCs causing a particular disease but then accede that further or follow-up studies are needed to “provide additional insight into whether these compounds affect cancer risk in humans” [147], or that while a C6 compound “was not carcinogenic” [150] other effects were noted [109] as well as the expectation that “environmental loading” of the compound would increase with use and that AFFF capture and destruction is needed [148,151]. To a significant extent the very narrow focus on whether or not there is “conclusive evidence” for PFCs directly causing cancer is artificial and misleading given the growing emergence of associations with causation or promotion of a range of other adverse health effects.

Even a manufacturer of PFCs while asserting that there is no absolute proof of a particular effect acknowledges that a “probable link” to a disease is an indication that it is “more likely than not” to cause the disease [146]. In particular they cite the six categories for which the C8 Science Panel who investigated the potential for PFOA to cause disease and conclude that there was a “probable link to... high cholesterol, ulcerative colitis thyroid disease, testicular cancer, kidney cancer and pregnancy induced hypertension”.

In terms of the properties of various PFCs as having a “probable link” to or being “more likely than not” the cause or promoter of a disease or adverse effect this is more than enough to trigger the *Precautionary Principle* for regulators and product end-users even without the considerable and rapidly growing evidence of other associations or “probable links”, more likely than not having adverse effects including effects at low levels such as immune suppression [152,120,121,142,153,109,143].

Many of these PFC studies that found no particular associations acknowledge the results are inconclusive and are also limited in the inferences that can be drawn from them in that their investigation was limited to the effects of single compounds on a single animal or cell model and as such was limited in application.

By contrast there is now an overwhelming and growing weight of evidence and scientific concern for the growing number and concentrations of combinations of PFCs being found in the environment [154] likely to be exerting additive synergistic effects. The net effect being that these unknown and untested complex mixes in formulations and combinations of transformation products in the environment may have the potential to exert human health effects not yet recognised [128,122,127].

For occupationally exposed users the clear correlations with possible adverse health effects, biotransformation in the body, long body-residence times and lack of definitive information on the behaviour and un-researched effects of the diversity of (largely unknown) compounds and combinations mean that special care needs to be taken to prevent exposure to fluorinated organic compounds as part of day-to-day operations as well as during incidents where responders or workers unfamiliar with the issue may be unwittingly exposed.

For example, ingestion and inhalation of aerosols created by sprays, wind, heated vapours and bursting bubbles can result in direct contaminant intake including foam chemicals.

2.10 Applying the *Precautionary Principle*

All firefighting foams need to be assessed in terms of their environmental acceptability. A primary consideration is that their use in many if not most cases is highly dispersive with the potential for far-reaching adverse effects both spatially and temporally from its components and

transformation products. Unlike the use of a product in a small-scale, closed industrial process there is a high probability that firefighting foam together with contaminated firewater will be released or leach to the environment without proper control or containment.

Applying the *Precautionary Principle*–Key Issues:

- Consideration of the *Precautionary Principle* is mandatory under the Inter-Governmental Agreement on the Environment (IGAE) and the principles of Ecologically Sustainable Development. This has been emphasised in recent legal judgements.
- The *Precautionary Principle* places key obligations on end-users and decision makers including regulatory agencies.
- Where there are any doubts about the long-term safety or environmental impacts of a product or activity a conservative approach to environmental management must be taken.

The potential for effects from the release of firefighting foam chemicals needs to be considered not only in terms of a single large release such as during incidents, but also in terms of chronic numerous smaller releases that occur as regular spills during maintenance or testing and training activities which often add up to very large quantities over time.

For example, a total of about **1.28 million litres** of fluorinated foam concentrate is estimated to have been discharged over 25 years at the Oakey air base in Queensland. Of this amount about **1.21 million** litres of PFOS-containing foam was used (1970s to 2002) with a total fluorinated organic compound content estimated at 6,066 kilograms of which about 4,920 kilograms was PFOS and precursors [155]. This represents a very substantial release of PFCs of very high concern for a relatively small facility resulting in a plume of contaminated groundwater extending more than five kilometres downstream.

Both large incident and chronic release scenarios have already resulted in many significant pollution events worldwide and need to be considered in the same way against the *Precautionary Principle*. Experience in Germany indicates that the majority of serious incidents of PFC contamination of soils, surface water and groundwater have occurred through operational and training use of firefighting foam [12], or from using wastewater treatment plant contaminated biosolids for agricultural soil improvement.

The primary triggers for the *Precautionary Principle* for a product or activity is whether there is:

- “A threat of serious or irreversible environmental damage, and;
- Scientific uncertainty as to the nature and scope of the threat of environmental damage” [5].

When considering foams, all have the potential to cause environmental harm and it is the likely degree and timescale of effects that determines whether the *Precautionary Principle* must apply. Where a product is shown to be non-persistent and fully biodegradable over the short term with only localised impacts the *Precautionary Principle* does not need to be applied. However, considering the current polarisation of opinion in the foam industry, for completeness it is worthwhile to compare and contrast persistent and non-persistent foam types against the elements of the *Precautionary Principle*.

In terms of persistent compounds a particular focus of attention for adverse impacts from both legacy and current firefighting foam use has been the presence of highly fluorinated organic compounds and their terminal breakdown products with unknown or unacceptable PBT characteristics. It should be noted that any product containing persistent toxic compounds would need to be assessed in the same way, e.g. siloxanes and partially fluorinated organo-siloxanes.

Table 2.10 summarises the current assessment of persistent and non-persistent firefighting foams against the elements of the *Precautionary Principle*.

Of particular concern is the incompleteness of published information and scientific knowledge in regards to the identity, properties and environmental and human health effects of fluorinated chemicals used in firefighting foams. Overall it can be said available information is severely limited for the great majority of foams in terms of declaring what compounds are present,

assurances of their safety and their potential to have adverse human health or environmental impacts. However, there are indications, emerging evidence and significant evidence that adverse effects have or may well occur.

Table 2.10 – Assessment of firefighting foams against the *Precautionary Principle* elements

Assessment element	Persistent toxic compounds	Non-persistent toxic compounds
Spatial scale of the threat	Local, regional, state-wide, national & global threat via dispersion and long-range transport. Wide dispersal over the long-term through air, soils, surface water & groundwater.	Immediately adjacent areas likely to be adversely affected. Wider dispersion & impacts limited by short half-life and rapid biodegradation.
Magnitude of possible impacts	Wider environment & human health impacts through high-level or enduring low-level exposure & increasing build-up over time or by bioaccumulation/bioconcentration.	Local aquatic environment impacts & short-term direct exposure risks. Mitigation by rapid biodegradability.
Perceived value of the threatened environment	High perceived values for natural environment including food-chain, economic values & long-term human health.	High perceived value for local natural environment. No significant lasting health implications.
Temporal scale of possible impacts	Long-term exposure – Effects lasting decades to inter-generational.	Short-term – Weeks to months.
Manageability of possible impacts	Very difficult to impossible to manage once chemicals have been released. Very high cost of remediation. Flow-on economic & social impacts at local & broader levels. Small spills contribute to build-up & wider exposure in the long-term.	Local relatively short-duration treatment or natural biodegradation & recovery processes. Low to moderate costs.
Public concern & scientific evidence	Worldwide established concerns & mounting scientific evidence of adverse human health and environmental effects for PFCs. Uncertainty about the identity & safety of proposed alternative fluorinated & other persistent compounds with rapidly growing evidence of adverse effects.	Limited concern based on well-established evidence & knowledge of the behaviour & effects of components.
Reversibility of possible impacts	Not reversible, very long-term or high cost for remediation where possible.	Reversible with basic remediation or natural recovery.



Figure 2.10 – Notional levels of *scientific uncertainty* under the *Precautionary Principle*.

Naturally the “trade secret” nature of foam formulations has meant that the exact compositions are not revealed, nor is this expected or necessary for environmental acceptability assessment. Trade secret considerations are not an impediment to general testing of products and making available information on the overall potential environmental and human health effects of the final formulations in their as-sold product form which is potentially equivalent to the ‘as-released’ material. Despite this in many cases even basic information is limited, absent or is listed as “not available” as allowed under the very loose provisions of the GHS for SDS [64] and other related SDS guidelines.

3 Treatment and disposal of wastes

Firewater that contains firefighting foam requires appropriate treatment and disposal based on its composition. The comments below refer to treatment and disposal firewater or wastewater that only contains firefighting foam. Any firewater or wastewater that contains other contaminants such as hydrocarbons, chemicals or products of combustion from a spill or incident needs to be considered in terms of the particular combination of contaminants as well as the firefighting foam content.

Treatment and Disposal of Wastes–Key Issues:

- Firefighting foam and firewater wastes inevitably contain components that class as regulated wastes that require special handling, treatment and disposal (*EP Regulation 2008*).
- Regulated wastes must only be disposed of to a facility licenced to take such wastes.
- The generator of the waste retains responsibility for the waste if it is not appropriately disposed of.

All solid and liquid wastes that contain fluorinated organic compounds and surfactants (e.g. concentrates, firewater, wash-water, run-off, soils, absorbents, etc.) are regarded as regulated wastes and must only be disposed of through a facility that is licensed to take regulated wastes.

3.1 Firewater and wastewater treatment

Firefighting foams that are fully biodegradable can be disposed of by wastewater treatment using on-site treatment plant, degradation in holding ponds, irrigation to suitable land for degradation, or by discharge to sewer for treatment at a municipal sewage treatment plant.

Appropriate consideration must be given to what site and systems/methods are to be used for treatment and/or disposal of fully biodegradable foam and whether these are appropriate for the purpose and do not have a potential for releases that might cause environmental harm.

Firewater and Wastewater Treatment – Key Issues:

- Wastewater containing fluorinated organic compounds must not be discharged to sewer.
- Wastewater containing fluorinated organic compounds must not be discharged to soils, water bodies or groundwater.
- Discharges to sewer of fully biodegradable wastewaters must be with the agreement of the wastewater treatment plant service provider after provision of full composition details.
- On-site treatment and disposal of fully biodegradable wastewaters must meet local approval conditions.

For firefighting foam containing persistent compounds such as fluorinated organic compounds the wastewater must be fully contained if operationally possible and not released to waterways or other bodies of surface water, stormwater, soils, groundwater or to sewer.

Municipal sewage treatment plants are not capable of treating or destroying fluorinated organic compounds such as PFOS, PFOA or the shorter-chain substitutes [46,156,100,24,40] [115] with the result that fluorinated organic compounds are released to water bodies or land in treatment plant effluent as well as contaminating the sewage sludge or biosolids fraction that is subsequently sent to landfill or distributed for soil improvement, i.e., agricultural “top dressing”, leading to further leaching, release to the environment and uptake by plants [73] [143].

Discharges of foam, firewater or wastewater to sewer for treatment and disposal must be by permit or agreement with the authority accepting the discharge of the waste to sewer for treatment. Firefighting foams, wastewater or firewater containing significant levels of fluorinated organic compounds (see *Policy Section 6.4.2*) or similar persistent and potentially toxic or bioaccumulative compounds must be disposed of to a facility approved for the treatment of such wastes.

Foams that contain any persistent toxic compounds, including fluorinated organic compounds, are not regarded as biodegradable for the purposes of the Policy; all are, or will result in non-degradable persistent, end-point compounds. Special consideration needs to be given to the potential for environmental damage associated with treatment and disposal of any persistent toxic compounds.

Waste managers accepting fluorinated organic compounds as concentrates, firewater, wastewater or in other wastes must ensure that they are fully contained and properly disposed of in such a way so as to completely immobilise or destroy them. Established methods for destruction include dedicated high temperature thermal incineration, for example, in a cement kiln [90,129,130,91], where the fluorine component is ultimately captured by scrubbing of the flue gasses to remove hydrogen fluoride (HF) or immobilised in the cement matrix as inert and environmentally neutral calcium fluoride (CaF₂).

Other forms of high temperature destruction such as the plasma-arc furnace are equally effective but significantly more expensive. Such waste disposal facilities would need to be specifically licensed and appropriate conditions imposed for this type of activity in most jurisdictions.

Fixation of contaminated soils and solid materials with an appropriate immobilisation reagent may be feasible to the point where the wastes can be disposed of to a licensed landfill, [a number of products are under commercialisation](#). Criteria to define what levels of contamination would require treatment and what levels of immobilisation/leachability for landfill [157] would be acceptable are under consideration.

Landfills (and WWTP) have been shown to be sources of small volatile fluorinated species capable of diffusing into the upper atmosphere [158] dispersing to distant areas and may have global warming potential (GWP).

3.2 Foam concentrate disposal

Firefighting foam concentrates that are fully biodegradable can be treated and disposed of by a range of general waste disposal facilities subject to relevant waste acceptance criteria.

Foam Concentrate Disposal – Key Issues:

- Foam containing fluorinated organics must be disposed of to a licensed regulated waste facility.
- Foam containing fluorinated organics must be destroyed by high temperature incineration.
- Fully biodegradable foam must be disposed of to a facility licensed to receive such wastes.

Firefighting foam concentrates that contain persistent contaminants such as fluorinated organic compounds must be disposed of by methods that ensure their complete destruction, i.e., by mineralisation, or immobilisation [91,129,90]. Disposal by high temperature incineration using plasma-arc destruction or injection into cement kilns is favoured for liquid wastes. Destruction in a cement kiln may also be feasible for contaminated soils.

Disposal of regulated wastes containing persistent organic pollutants for potential release elsewhere such as by gifting or on-selling potentially to be dispersed globally from another location is neither responsible nor acceptable. The evidence that fluorinated organic compounds are of significant world-wide concern from both environmental and health perspectives is well established as is their extreme persistence, increasing environmental concentrations, very high mobility and dispersive behaviour once released to the environment leading to long-range transport which can be over thousands of kilometres.

3.3 Infrastructure contamination

Infrastructure such as pipework, rubber or polymer seals, flexible hoses, pumps, tanks, the floors of hangars and the surfaces of sealed and unsealed fire-training pads that have been exposed to foam containing fluorinated organic compounds have become to be recognised as potentially

significant and ongoing sources of contamination (e.g. of new infrastructure and stormwater) by residual fluorinated organic compounds leaching out of such items.

Infrastructure Contamination – Key Issues:

- Legacy foam residues or incomplete decontamination of persistent organic compounds can result in replacement foam stocks becoming significantly contaminated.
- The leaching of contaminants from legacy infrastructure can result in ongoing release to the environment beyond the site boundaries well after persistent foam use has changed or ceased.

For example, concrete and bitumen areas used for foam training have been found to retain fluorinated organics; these are difficult to remove from their matrixes and may subsequently leach out of the surfaces and contaminate stormwater. It is self-evident that the leaching of legacy contaminants would occur whether or not the site continued to be used at all or the foam type was changed to some other fluorinated foam or fluorine-free foam. It is up to the facility operator to assess and appropriately address this issue.

When carrying out maintenance, cleaning, decommissioning, stabilisation or replacement of such items the potential for short-term and long-term releases of residual contamination should be considered, risk assessments carried out regarding the potential for impact from low-level releases, and short and long-term mitigation measures adopted as appropriate.

4 Foam use issues

Firefighting foam is used across a diversity of applications that range from large-scale industrial facilities to small mobile and hand-held extinguishers. Each user group has to take into account the limitations imposed by their particular operational, health, safety, environmental and economic circumstances in choosing the type of foam and delivery systems that best meets their needs and obligations.

The following explanatory notes apply to the issues faced by some of these particular user groups in addition to general considerations regarding the use of firefighting foam.

4.1 Fire brigades

Fire brigades are called on to deal with a range of both large and small incidents involving various flammable solids and liquids with their prime consideration being safety and protection of life. Once engaged in an emergency incident response the incident controller's decisions on response actions are constrained by available resources, competing priorities and constrained timeframes for decision making and response actions.

Within the capabilities and resources available the Incident Controller will endeavour to arrange for or facilitate contaminant containment and environmental protection measures to be put into place by the site manager, their agent or other relevant resources.

Fire Brigades–Key Issues:

- The primary concerns for fire brigades responding to incidents are safety and the protection of life under the particular circumstances using whatever resources are available
- The site operator or owner bears the responsibility for incident planning, provision of appropriate resources (including foam and containment) and any effects of an incident regardless of the fire brigades response actions.
- Small-scale use of fully degradable foam can be managed by disposal to sewer or on-site degradation provided release to waterways and groundwater is prevented.

Fire brigades have on hand the types of firefighting foam that best suit the range of usual circumstances that require their use in industrial, urban and rural circumstances. Day-to-day fire brigade use of foam on spills and fires is sporadic and at unpredictable locations, most involving small-scale incidents such as at vehicle roadside spills, industrial incidents and vegetation fires.

For small incidents foam will generally minimise the amount of firewater generated and therefore limit the potential spread of other contaminants.

As a matter of course, each incident is assessed by the Incident Controller for the potential for contamination impacts on human health and/or the environment, whether from the foam itself or from spilled chemicals, fuels or fire residues, and for the need to take practical containment or clean-up measures in the context of the overall incident response.

A primary response action where any release of contaminants may occur, including foam, is to put into place temporary bunding or ensure existing bunding is secure to contain firewater, foam and other contaminants. Once the emergency phase of the incident has been resolved by the fire brigade the site owner, operator or their agent is responsible for the further recovery measures necessary including maintaining containment and waste treatment or disposal.

When brigade appliances attend incidents at facilities where foam stocks and application systems are already present they have very little control over what foam type or equipment is available and how it will be applied. As a matter of course they will have to use the foam stocks and delivery systems that are present. If the Incident Controller has the opportunity, and it is safe to do so, it would be preferable to use fluorine-free foam stocks before using fluorinated foam where there is the potential for risks to response personnel or a release to the environment.

When an emergency incident occurs legislative priorities as part of the emergency may apply for the duration of the incident these are defined in the particular legislation as applicable to particular circumstances. For example emergency response, disaster management and health provisions may take precedence during an emergency. However those emergency provisions primarily apply to the powers and actions of the emergency services personnel and do not negate the obligation of the facility owner/operator to have previously considered and put into place all the necessary measures and controls to deal with an incident and post-incident responsibilities.

Where Fire Brigades are required to respond to a spill or fire at a facility that has existing firefighting foam and systems available on site it is the facility owner's or operator's responsibility to have:

- undertaken a proper risk assessment of the likely scale and impact of an incident
- selected the most suitable foam for the risks and situation
- put in place management and containment measures as necessary
- made allowance for the potential involvement of fire brigade resources.

While Fire Brigades will endeavour to respond to an incident in the most effective way practicable including minimising potential harm, the facility owner/operator is fully responsible for assessing the relevant risks on and off the site and for having in place the appropriate resources, measures, plans and procedures to control, contain and manage any releases to the environment of any contaminant. This includes having appropriate detailed response plans in place and having made appropriate choices about measures such as foam products, delivery systems and containment to achieve a best-practice standard for protection of life, health, operator safety, environment and property.

Some industry operators are under the impression that once the Fire Brigade takes control of an incident that they are no longer responsible for the outcomes. This is not the case. The site operator must have taken every reasonable and practicable measure to manage properly any foreseeable incident taking into account what scale and types of resources may be required to deal effectively with the worst-case incident including the use of outside resources.

Where non-persistent (fluorine-free) firefighting foam is released to land, such as when used by an urban or rural fire brigade for ignition prevention, control, extinguishment, damping-down and training on vegetation fires, it is expected that no adverse effects will occur from the application of small amounts away from watercourses.

For example, experience with incidents since 2003 where there has been progressive application of up to 500 litres of fully biodegradable fluorine-free foam concentrate at 6% for vapour

suppression at road tanker rollover sites there have not been any noticeable detrimental environmental effects when it has been irrigated to land or left to soak in and degrade in-situ.

Similarly rural firefighting use of non-persistent foam at much lower concentrations over a much broader area would similarly not be expected to have any significant or lasting effects. Releases to watercourses or other bodies of water directly or in runoff should however be prevented and avoided where possible given the potential for adverse effects on aquatic organisms.

Concentrated and repeated applications of fluorine-free foam, such as in areas where testing or training is carried out repeatedly onto bare-earth could result in the build-up of contaminants to the point where natural degradation is impeded by factors such as elevated concentrations of toxic components, depletion of oxygen and waterlogging. This raises the possibility of contaminants persisting long enough to be washed into adjacent watercourses or other water bodies by stormwater or for it to leach down to groundwater. In these situations there should be firewater control measures in place to contain wastes and prevent immediate releases to adjacent waterways or to any place that leads to such bodies of water and to assess whether groundwater is at risk.

Where firewater not containing persistent organic compounds is generated, beyond that which can readily soak into the local soil to degrade, control measures such as bunding or ponds should be used to hold the water for at least 28 days to allow for degradation before release and/or for evaporation. Note that some firewater may require detention for longer than 28 days to properly degrade.

Fire brigades should not have on hand or intend to use any firefighting foam containing fluorinated organic compounds that is intended for application on an area where it cannot be fully contained and the wastes appropriately collected and disposed of later. For example, roadside fuel spills or rural fire brigade use on bushfires and in fact most firefighting situations that do not involve industrial facilities.

4.2 Hydrocarbon refineries and large storage facilities

Fire protection measures at large hydrocarbon refineries and storage facilities are recognised as being of paramount importance to protect life, human health, the environment and property. Many facilities are long-established with legacy-related restrictions such as their location adjacent to environmentally sensitive bodies of water, established roads and drainage layout, connections to third-party port facilities, limited space available for modification of operations and the difficulties in making changes to essential systems while continuing normal operations. This naturally complicates their ability to make changes to procedures, systems and operations to keep pace with changing health, safety and environmental requirements.

Hydrocarbon Refineries and Large Storage Facilities—Key Issues:

- Large refineries and fuel storage facilities are acknowledged as having a range of circumstances that could affect transition to best practice in a timely manner. Provisions exist to consider customised extended timeframes, milestones and interim measures for upgrading facilities to meet best practice.

Nevertheless changes need to be made over time to meet changing standards and obligations. It is recognised that for large industries significant planning and preparation needs to go into changes to essential systems associated with firefighting such as containment and control measures, delivery systems and foam type.

The emerging information regarding the previously unrecognised significant impacts of various aspects of firefighting foams on health and environmental values, as well as the occurrence of large-scale incidents such as the Buncefield (2005) and Coode Island (1991) fires, plus recent small-scale spills has culminated in the recent (but overdue) realisation that the risks of impacts from fluorinated firefighting foam releases at all scales are no longer acceptable. Experience in Germany has indicated that uncontrolled dispersive use of fluorinated firefighting foam during

operational incidents, testing and training is the major cause of serious environmental pollution. The results being that remediation and clean-up costs can be exceedingly high, e.g. Düsseldorf Airport, A\$150 million (€100 million) and rising [12].

Hydrocarbon refineries and large storage facilities by their very nature require substantial fire protection systems with the attendant risk of the release of very large quantities of foam in contaminated firewater during incidents, not infrequently amounting to tens of millions of litres of total runoff. This has the potential to have serious and long-lasting impacts on the adjacent areas, in particular in regards to damage to aquatic ecosystems that underpin a diversity of values such as ecological diversity, public amenity, recreational fishing, commercial fishing and aquaculture.

The legacy systems in place at existing large facilities almost certainly hold stock of foams such as fluoroprotein foams (FFFP) that are dependent on substantial concentrations of long-chain fluorotelomer (8:2Ft) PFOA and higher homologue precursor compounds for their effectiveness. These foams are not acceptable in the medium or long term as they effectively represent a potentially significant release of PFOA to the environment (waterways, soils, groundwater, and atmosphere). In the meantime these legacy systems must full containment of firewater in completely impervious bunding.

Hydrocarbon refineries, large storage facilities and other large industries also face significant challenges when upgrading firefighting facilities to keep pace with current best practice. The Policy recognises that such facilities will need time to design, budget for and implement the necessary changes while maintaining normal operations. The environmental legislation provides a number of mechanisms for agreed customised plans and programs based on negotiated reasonable time-frames, milestones and interim protective measures to minimise the risks.

4.3 Ports, shipping and offshore facilities

Fire protection measures for dock-side and on-water port facilities, oil and gas offshore exploration production facilities, as well as shipping face particular problems in being able to adequately protect life, human health, operator safety, the environment and property. This is especially so for shipping while at sea when the vessel must be entirely self-reliant. As economic hubs for the transit of goods into and out of Australia it is essential to ensure that normal operation of port facilities and vessels is not compromised and that any incidents are minimised in impacts, extent and duration.

Ports, Shipping and Offshore Facilities–Key Issues:

- While most ships operate under foreign flags they nonetheless have a responsibility to prevent releases of persistent and toxic pollutants.
- Ports are responsible for the proper choice and management of firefighting facilities under their control and any adverse effects of day-to-day or incident use of those facilities.
- Foams containing persistent organic compounds must not be released to the environment.
- A non-persistent firefighting foam suitable for shipboard use that meets IMO requirements is now available (IMO MSC Circular 1312).

Shipping, dock-side operations and oil and gas offshore exploration and production facilities present particular problems in regards to the release of any contaminants whether associated with wastes, chemicals, minerals, foodstuffs, hydrocarbons or firefighting foam. There are generally very limited opportunities for containing contaminants in large incidents that are not land-based, such as offshore facility fires and, offshore and grounded ship casualties. Also, the location of spills including on-deck foam releases from shipping casualties is mostly unpredictable except that it can be assumed that an environmentally sensitive aquatic environment is almost always at risk with the potential for further dispersal of contaminants to other sensitive areas.

Regulations pertaining to systems and foam that off-shore facilities and international and domestic shipping are required to comply with and procedures to contain and deal with on-board

firewater will have an effect as to what mitigation measures can be achieved practically and how much a facility, vessel or port operator may be able to influence how risks from incidents are managed. However, the Master of a vessel, the ship's owner, the vessel's insurer and the offshore facility operator are ultimately responsible for making good any damage that their vessel/facility cause in Australian waters and the port, shipping and/or offshore facility operator may have to deal with the ongoing effects of the incident.

Port, shipping, oil and gas exploration and production companies must demonstrate that their firefighting foam usage and firewater management meets ALARP environmental risk and best environmental practice.

In terms of practical management of current carriage and use of firefighting foam by vessels the risks of short or long-term adverse environmental effects could be reduced while still addressing the priority of maintaining safety at sea by:

- **Forward planning** – Contingency planning and relevant facilities to manage and prevent as far as practicable the release to the environment of firewater containing persistent pollutants, e.g. procedures to capture and hold firewater on board.
- **Incident management** – Prevent discharge of firefighting foam or related wastewater containing a persistent pollutant to the sea or any waterway unless it is unavoidable to secure the safety of a ship or to save life at sea by taking all reasonable and practicable measures during and after the incident to prevent the discharge into the sea.
- **Waste disposal** – Wastes or firewater containing persistent pollutants must be disposed of to an appropriately licenced onshore facility capable of treating and disposing of the wastes appropriately.

The large numbers, diversity of types and nationalities of ships operating in Australian waters limits the consistent and adequate application of on-board risk reduction practices. Accordingly port managers may need to consider what practical measures could be implemented locally to assist vessels to minimise the risk to their local environment where the environmental sensitivities are highest.

A misconception that has arisen from time-to-time is the mistaken belief that foam used on a body of water can be contained and recovered in the same way as an oil spill by oil-recovery booms floating on the water surface. This erroneously suggestion has even been included in some industry "best-practice" guidance material [151].

This is not the case, while the foam may superficially appear to be contained (Figure 4.3) firefighting foams are *completely water soluble* (as indicated in almost every SDS for foams) and while there may be some foam bubbles floating on the water surface the vast majority of the foam becomes dissolved in the firewater and the water column making floating booms useless for preventing release contamination of the water column.

The key issue for port, shipping and offshore facility operators to consider in assessing what are suitable firefighting measures and foam types for their purposes is that foam is inevitably released directly to the aquatic environment, that is, directly to the ocean, river or estuary from dock-side fixed and portable systems, from the deck of the vessel, offshore platform and/or from response vessels such as firefighting tugs.

Where a direct release of firefighting foam to the aquatic environment is unavoidable the use of firefighting foams containing fluorinated organic compounds of any sort is environmentally unacceptable due to its persistence, dispersal and potential toxicity and bioaccumulation in the environment.

Only fully degradable foam that does not contain any persistent and potentially toxic compounds is acceptable for applications where there is a direct release to the aquatic environment. Short-term acute impacts, even if locally severe, are far preferable to the potential for long-term impacts that cannot be remediated with persistent and possibly toxic contaminants that contribute to the cumulative pollution load in the area or by dispersal further afield through long-range transport.



For vessels needing to meet IMO requirements it is worth noting that there is now non-persistent foam available that meets IMO standards (IMO MSC/Circular 1312).

For all foams, including fluorine-free foams, there is a risk of short-term environmental impact from the acute toxicity of foam components such as the detergents and solvents combined with the very significant dissolved oxygen depletion impacts from BOD. In the case of shipping, port and offshore facility incidents the depth of water at the incident site is such that acute impacts from acute toxicity and BOD effects of non-persistent foam such as fluorine-free foam are unlikely to be significant given that dilution in the water column and dispersal by tidal flow will mitigate the risk of any immediate effects for small unavoidable releases.

While the discharge of fluorochemical-containing foam to a waterway would similarly have limited *immediate* effects the dispersal and potential *long-term effects* of the PFCs would predicate that such a discharge is not acceptable.

Any essential testing of systems for maintenance, safety proofing and certification purposes using foams that do not contain persistent and/or toxic compounds is acceptable where the foam is fully biodegradable and testing is planned and managed such that the risk of environmental harm is minimised.

4.4 Mobile plant and portable extinguishers

Mobile plant and hand-held extinguishers are relatively small-volume systems, generally only involving tens to hundreds of litres of dilute foam solution. Releases and wastes of this scale and associated contaminated soils and other materials can usually be readily captured, cleaned up and disposed of.

Mobile Plant and Portable Extinguishers–Key Issues:

- Foams containing fluorinated organics used in testing and maintenance must be captured and not be released to the environment or disposed of to the sewer.
- Foam wastes and contaminated soils or other materials containing fluorinated organics from unavoidable spills or use in fires must be collected and disposed of as regulated waste.
- Non-persistent fully biodegradable foams must not be released in a way likely to cause environmental harm, especially to water bodies or groundwater.

Mobile plant, such as large mining vehicles are required to have on-board systems for fire protection. These systems have defined specifications, certifications and other requirements including testing and maintenance at regular intervals. Given the mobility of the systems and the

relatively small volumes of foam involved it is entirely practical for controlled releases to be properly contained and the wastes collected and disposed of appropriately.

The practice of releasing fluorinated foam wastes to the ground during discharge tests of mobile plant systems is not acceptable and is a breach of environmental regulations. That is, it is a direct, wilful and entirely avoidable release to the environment of a variety of short or long-chain fluorinated compounds [32,31] that are known to be indefinitely-persistent and highly dispersible pollutants with the potential for health and environmental impacts through releases to bodies of water, groundwater, air or via contaminated soils and dust.

All foam wastes containing fluorinated organic compounds need to be collected, stored, transported and disposed of as regulated wastes with destruction by high temperature incineration or other acceptable means meeting regulatory requirements.

Similarly, biodegradable, non-persistent, fluorine-free foams that are now available for portable and vehicle systems must not be released in a way that they are likely to cause environmental harm, such as by BOD impacts and acute toxicity effects if allowed to enter a body of water or groundwater (see wildland firefighting 4.1). However, fully biodegradable foams or contaminated soils not containing persistent toxic contaminants may be able to be appropriately treated and disposed of on-site or at local waste treatment and disposal facilities. Unavoidable minor releases to ground are acceptable with no clean-up necessary provided that the spill is minor and there is no significant potential for contaminants to affect bodies of water or groundwater.

5 Assessment standards and information

Significant challenges are faced by firefighting foam users, responders and regulators when managing the various aspects of firefighting foam use. This is hampered by the general lack of current chemical, human health and environmental information as well as the lack of defined standards for key assessment elements such as test protocols. The Environmental Management of Firefighting Foam Policy sets out baseline requirements for basic testing and information disclosure on which the majority of assessments and decisions can be reasonably based.

5.1 Safety Data Sheets (SDS/MSDS)

Foam users, regulatory agencies and incident responders are heavily reliant on there being appropriate, relevant, comprehensive and accurate information readily available on which to base management and response decisions and planning.

The safety data sheet (SDS) should be the most relevant, comprehensive and readily available document for these purposes with various chemical behaviours and characteristics routinely cited plus they contain a dedicated section (Section 12) for information on environmental and ecological hazards.

Safety Data Sheets – Key Issues:

- SDS must contain up-to-date, relevant detailed information on which to base decisions.
- SDS must indicate whether there are persistent, potentially toxic compounds present in the foam or precursors that may generate such compounds.
- Ecological effects information must pertain to the effects of the final product formulation, not selected individual components.

Existing systems and requirements for SDS to be provided with products, understood by the user and held on site in a defined location, are well established. This gives users and emergency responders the best chance for access to essential information when required in an emergency. All key information regarding ecological effects should be integrated into Section 12 of the SDS. Separate product brochures and supplementary information documents are rarely ever kept with the product SDS.

Given that firefighting foam can be applied at various different concentrations, intentionally or otherwise, the information in the SDS for firefighting foam must, where possible, be clearly expressed as being for the concentrate or product as sold. This may be supplemented by additional information on standard dilutions if that is considered operationally helpful.

To date significant problems have arisen for foam users, environmental regulators and incident responders in that information available in foam product documentation and in particular SDS have been very rarely adequate for environmental assessment purposes [3,38,56] with issues ranging across:

- SDS are out of date and no longer valid (>5 years old from date of publication or last review), for copies held on site as well as from some manufacturers/suppliers web sites.
- Very limited or a complete absence of relevant environmental information.
- Omission or non-disclosure of information on presence and effects of persistent compounds.
- Claims of biodegradability inferring complete biodegradation contradicted by the presence of highly persistent and potentially toxic compounds.
- Acute toxicity tests only reporting third-party test results for selected components with no tests carried out on the final foam formulation (i.e. no assessment of the overall synergistic effects of the components when combined in the formulation).
- Omission of information on toxic compounds such as preservatives and biocides.
- Failure to pass-on and disclose toxicity, persistence and hazard warnings provided by formulation component or feedstock manufacturers.
- Non-relevance of the species used in toxicity tests.
- Non-standardised toxicity test periods (e.g. across SDS for 24, 48, 96 hours).
- Quoting of compliance with limited dangerous goods or other limited standards, worded so as to imply blanket compliance or approvals in other areas.
- Disingenuous statements that refer the user/responder to the “local EPA” as the authority for environmental impact information for a particular product where the “local EPA” will clearly not have any relevant information available for what are complex and usually “trade secret” final formulations or their effects.

Some users, and even some regulators, have assumed that safety data sheets must meet an adequate standard in terms of information content, relevance and accuracy. Many are not aware that the SDS standard set by *EC Commission Directive 91/155/EC of 5th March 1991* and under the United Nations Globally Harmonised System (GHS) of Classification and Labelling of Chemicals (Regulation (EC) No 1272/2008, REACH Annex II) is very broad in order to cover a vast range of substances and essentially only sets out the Sections that need to be included in SDS. Traditionally SDS have been documents focussed on workplace health and safety issues, and then mostly focussed on short-term acute human health impacts, with only relatively recent regard for the inclusion of even very basic environmental information [64].

The Australian National Industrial Chemicals Notification and Assessment Scheme (NICNAS) has similarly been focussed on SDSs and label information content for health and safety issues associated with use and handling and on higher order obligations such as those under the *Stockholm Convention* [159].

The Foam Management Policy sets out the required minimum standards for test and composition information that must be made available so that users, regulators and incident responders can make reasonable assessment of the environmental risks. The level of information required is not such that proprietary formulations are at risk of disclosure, although there must be general and consistent disclosure of the presence of toxic and persistent components as well as impurities where relevant.

The minimum standards set also provide a common basis for users to make appropriate comparisons, decisions and fair choices about what suits their application best when all

performance, health, environment, regulatory and cost issues are considered. Manufacturers and suppliers may choose to enhance SDS content by providing additional relevant information and users may need to seek further information to address particular or unusual circumstances they face.

The inclusion of standardised, comprehensive, verified information in product information and SDS will also be of an advantage to manufacturers and suppliers as appropriate disclosure will give the user confidence as to whether or not the product is credible and fit for purpose against all their requirements and obligations.

5.1.1 SDS preparation

Manufacturers or importers of chemicals into Australia are responsible for providing an SDS that has been prepared in accordance with the Australian Workplace Health and Safety Regulations, and should check that any SDS prepared against overseas standards meets this.

The Safe Work Australia *Preparation of Safety Data Sheets for Hazardous Chemicals—Code of Practice (2011)* [64] provides guidance on the content that should be included in an SDS. A particular note is made in this Code that “*While this Code applies to hazardous chemicals as defined, an SDS should be provided for any chemical that may adversely impact the health or safety of persons or the environment*” and that the “*SDS should reflect what is currently known about the chemical*”.

Individual jurisdictions may extend the general requirements. For example, Workplace Health and Safety Queensland has a State Code-of-Practice (2011) *Preparation of Safety Data Sheets for Hazardous Chemicals* that outlines the desirable content of *Section 12 – Ecological Information* including ecotoxicity, persistence and degradability, bioaccumulative potential, mobility in soil and other adverse effects such as endocrine disrupting potential.

Guidance on possible content for SDSs is necessarily broad to cover a very wide diversity of chemicals and substances. Inevitably there have been inconsistencies and highly variable quality-of-information across manufacturers, even for products put to very similar uses and of similar composition. The notes and the Policy now provides guidance on the essential SDS content relevant to firefighting foams.

5.1.2 Ecological information (SDS Section 12)

Section 12 – Ecological Information in the SDS is the most relevant section that *should* contain comprehensive and relevant information about environmental effects. However, the information from other SDS sections on the product characteristics and behaviour will also be highly relevant and should also be considered when assessing the potential for adverse impacts on environmental values.

Ecological Information (SDS Section 12) – Key Issues:

- The end-user ultimately assumes the liability for the use of any product’s and its effects.
- It is the user’s responsibility to obtain adequate information regarding the product’s fitness for purpose as well as any adverse effects the product may have on human health or the environment.

These *Explanatory Notes* and the *Environmental Management of Firefighting Foam Policy* provide clarification on what the basic content of at least Section 12 (and possibly other sections) of the SDS should cover and the issues that should be considered in risk assessment and decision making for management of foam.

There is very little coordinated, independent quality control or regulation of the accuracy and relevance of SDS content, especially in regards to environmental effects for firefighting foam with SDS suffering from a significant lack of disclosure of key information that would be readily available or could be easily determined [38,36,37]. It therefore falls to the end-user to seek the

necessary information to assess the product's fitness-for-purpose and any attendant liability or to choose an alternate product that has sufficient information available.

For users to be reasonably expected to assess their potential risks/benefits and liabilities for human health, user safety and the environment, make informed choices about products and put into place associated controls, plans and measures to address health, safety and environmental issues, there needs to be more comprehensive and standardised information made readily available in product information and safety data sheets produced by suppliers.

The manufacturer or producer has responsibility for providing adequate information for each of their products; after all they are the only ones who have knowledge of exactly what went into each of their products and how it measures up against the *Precautionary Principle*. The testing required by the Policy is not onerous and only needs to be carried out once by the manufacturer for each formulation and then provided to all users world-wide. This is no different to other certifications such as testing for firefighting performance for each formulation.

The end-user is not expected to undertake or duplicate the testing required by the Policy, as has been erroneously suggested to some users. However, the end user is ultimately responsible for seeking complete and appropriate information in regards to the suitability, performance and any human health and environmental effects of the product(s) they consider or use.

A good guide to general SDS content and interpretation with coverage and explanation of all the essential elements of the sections including *Section 12 – Ecological Information* has been adopted by ExxonMobil for their products in their 2011 *User's Guide to Safety Data Sheets* [160]. This guide takes into account changes resulting from both *REACH Regulation (EC) No 1907/2006* as well as the *Classification, Labelling & Packaging (CLP) Regulation (EC) No 1272/2008* that implements the Globally Harmonized System in Europe and is being adopted elsewhere.

Complementary to the *ExxonMobil Guide* is the 2012 *REACH and Safety Data Sheets* information leaflet [161] published by the UK Environment Agency as the REACH Competent National Authority which outlines the content and provision requirements for SDS.

To address their responsibilities and liability, and to ensure that there is no misunderstanding about products put into service, end-users would be prudent to ensure that they seek and receive written confirmation of any information provided to them that is additional to that in the published SDS and product information.

5.2 Analyses for fluorinated organic compounds

A diverse range of several hundred fluorinated organic compounds (FOCs/PFCs) are now known to occur in fluorinated firefighting foam and associated wastes including a range of perfluorinated, and polyfluorinated substances, such as fluorotelomers, fluoropolymers, PFCAs or PFSAAs as well as siloxanes and complexes with fluorinated side chains ranging in length from C4 to C20.

The numerous different PFCs found so far include a diversity of original, transformation and end-point compounds with even more postulated. Identification of every individual compound present in a sample is currently not feasible, nor is it useful, as little if anything is known about the behaviour and effects of most of these individual compounds.

Analyses for fluorinated organic compounds – Key Issues:

- The current standard PFC analysis suite is inadequate to detect the range of compounds found.
- The new total oxidisable precursor assay (TOPA C4-C14) is suitable for revealing PFCs not detectable by the standard suite.
- The sum of the TOPA C4-C14 results can serve as a surrogate for total organic fluorine (C4-C14) content.

Therefore to accurately assess what PFCs are present and the probable level of risk it is not sufficient to analyse only for the current limited suite of about 20 to 28 standard fluorinated organic compounds as it is highly likely that many compounds of concern and their precursors will

remain completely undetected.

An analytical method is now available that reveals the PFCs hidden to the standard analyses by oxidising them to detectable perfluorinated carboxylic acids (PFCAs) that relate to the precursor's perfluorinated chain component. This information can then be used to assess one aspect of the likely risks posed by the unidentified precursor compounds according to the chain-length which relates generally to toxicity, dispersibility and bioaccumulation.

This recently developed method is a total oxidisable precursor assay (TOPA) which is based on the oxidation of polyfluoroalkyl precursor substances to perfluoroalkyl carboxylic acids (PFCAs), and is used to quantify the precursor PFCs not detectable by standard analyses. This oxidative hydroxyl treatment transforms the diversity of oxidisable precursors to relatable and detectable perfluorinated carboxylic acid compounds [92,162,115].

While the functional group of fluorinated organic compounds can have a significant influence on their behaviour and effects [102], little is known about these effects. Biotic and abiotic transformation over time is likely in most cases to result in an end-point perfluorinated compound that probably has a carboxylate functional group (or sometimes a sulfonate for perfluoroalkyl sulfonamide precursors).

For practical identification and assessment purposes the TOPA method and associated analyses for C4-C14 perfluorinated carboxylate compounds will relate to what oxidisable precursors are present aggregated according to their perfluorinated chain length in the C4 to C14 range (Table 5.2 A). It is possible that perfluorinated compounds from C15 up to C20 are present in some older formulations but it is hoped that the longer chain length PFCs are no longer being knowingly included in any formulations by manufacturers.

For the purposes of determining and reporting the presence of fluorinated organic compounds in soil, water, foam solutions or foam concentrate, sample analyses shall be done for:

- The standard suite of PFCs (including key sulfonates), plus
- Total oxidisable precursor assay reported as the analyses for the resulting perfluorinated carboxylates for C4 to C14 carbon chain length (TOPA C4-C14, Table 5.2 A).
- The sum of the oxidisable precursors can be taken as an indication of the total fluorinated organics (C4-C14) if a total organic fluorine analysis is not available.

C-chain	Compound	Abbreviation	C-chain	Compound	Abbreviation
C4	Perfluorobutanoate	(PFBA)	C10	Perfluorodecanoate	(PFDA)
C5	Perfluoropentanoate	(PFPeA)	C11	Perfluoroundecanoate	(PFUnA)
C6	Perfluorohexanoate	(PFHxA)	C12	Perfluorododecanoate	(PFDoA)
C7	Perfluoroheptanoate	(PFHpA)	C13	Perfluorotridecanoate	(PFTriA)
C8	Perfluorooctanoate	(PFOA)	C14	Perfluorotetradecanoate	(PFTeA)
C9	Perfluorononanoate	(PFNA)			

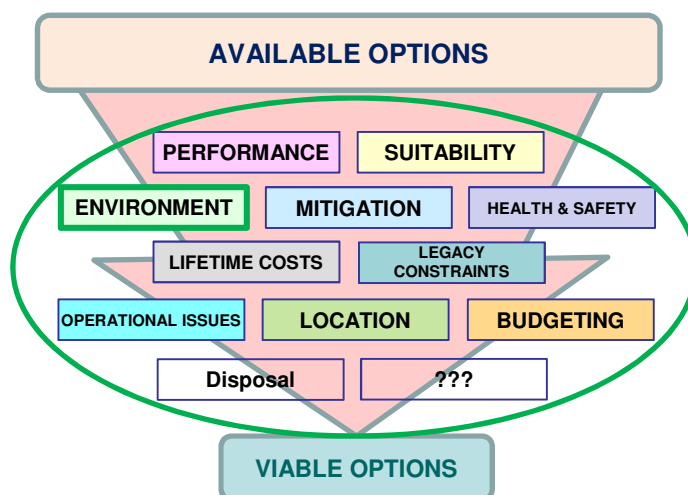
The combination of the standard PFC analysis suite and TOPA C4-C14 analyses will allow the assessment of contamination and exposure risks on the basis of individually detectable compounds that have relevant environmental or health trigger values as well as the ability to assess the levels of previously undetectable precursors present according to perfluorinated chain-length from C4 to C14.

Where other persistent organic compounds are known or likely to be present, such as siloxanes, other relevant analytical methods will be required. Manufacturers have an obligation to provide sufficient information about the presence and potential effects of such compounds for the users, regulators and responders to be properly informed.

6 Balancing considerations

Firefighting foams are a valuable and essential tool for protection of life, environment and property and incidents ranging from minor spills and fires to major incidents will continue to necessitate their use on land and at sea.

As has been pointed out in submissions, and in large part is the main purpose of the Policy, all the risks associated with firefighting foam use must be considered proactively, well before foam is put into service. This is especially important considering that during an incident the Incident Controller will have very few options open to them and very little time in which to consider them.



Balancing Considerations–Key Issues:

- The risks attached to the use of firefighting foam must be managed proactively.
- It is the user's responsibility to consider all the factors pertinent to their situation, apply appropriate weightings and arrive at a supported and balanced decision on how to manage the relevant risks.

The Environmental Management of Firefighting Foam Policy recognises that a prime consideration when choosing and procuring firefighting foam is the effectiveness of the foam for the intended firefighting application in providing adequate and evidently proven levels of performance, safety and property protection.

The system and foam options available that meet the appropriate performance standards and the user's operational needs must also be assessed in terms of a net environmental benefit analysis [163] to select the optimal combination amongst the available options that best addresses *all* requirements or fitness for purpose [3], including the relevant short and long-term environmental and human health protection standards.

All firefighting foams have the potential to cause adverse health and environmental impacts and must be managed proactively. The potential for releases, and therefore impacts, has been shown to be not only from their infrequent large-scale use on incidents but also through less obvious areas where there are less noticeable, smaller but more frequent releases.

The risks of impacts from releases range across:

- Large-scale, high-profile, very infrequent incidents where large amounts of contaminants of various types including firefighting foam are usually released.
- Accidental spills, servicing, testing and training activities where moderate amounts of contaminants are released.
- Small scale spills from accidental spills and poorly managed maintenance and testing activities.
- Use or spillage of products unintentionally contaminated by residual legacy persistent foams.
- Improper waste disposal through systems incapable of capturing and destroying contaminants, e.g. processing fluorinated foam wastes from fires or testing through wastewater treatment systems incapable of fully capturing fluorinated organic contaminants [156,100,103].

6.1 Large-scale release risks

Large-scale incidents such as the 2005 Buncefield hydrocarbon storage fire in the UK [131,164] are fortunately very infrequent, nonetheless the overall risk posed by such albeit infrequent incidents is considerable given the potential for catastrophic and wide-ranging consequences arising from the effects of the contaminants released including the firefighting foam.

Large-scale Release Risks–Key Issues:

- Although very infrequent large-scale management incidents must be adequately planned for in terms of both response and recovery issues to prevent potentially wide-spread and long-term adverse effects.

It also needs to be kept in mind that large-scale releases occur cumulatively from the many releases from smaller-scale uses that go unrecognised and unreported that contribute to the cumulative effects of some foams. This includes the cumulative contributions from releases resulting from training and poorly managed training, servicing and testing of systems of all sizes. For example 1.2ML of PFOS foam released from fire tenders over 25 years at the Oakey army airfield in Queensland [155].

A significant release of firefighting foam from a large fuel terminal, port facility or shipping incident, for example, in or adjacent to Queensland coastal waters (similar to the Coode Island incident at the Port of Melbourne in 1991 [165], involving about 200 tonnes of foam concentrate [132]), would, depending on location, have the potential to impact on a significant part of Queensland's \$436 million per annum fisheries and aquaculture sectors [136] through contamination (or perceived contamination) of seafood and loss of local and overseas markets/reputation for quality.

During the Buncefield incident about 750 tonnes of fluorinated foam concentrate were used (including significant quantities of PFOS) with about 12 megalitres (of a total of 16 megalitres) firewater still remaining to be disposed of. About the same amount was released to the environment which also resulted in part of north London's groundwater drinking water supplies being compromised.

By comparison, a large-scale incident involving foams formulated with non-persistent, fully-biodegradable compounds would be in-the-main self-remediating over a relatively short time with only short-term acute toxicity effects. In such cases the main focus would be on the impacts of the other contaminants and combustion products from the incident and not the firefighting foam.

6.2 Small-scale releases

The potential for large-scale, but very infrequent, incidents tends to dominate discussions and considerations of risks from foam use while the less obvious chronic release categories are largely ignored. This is despite small-scale spills, fires, servicing, testing, training and maintenance spills being common [107,76,38,133] [12] and contributing very significantly to the risk of adverse impacts in the long term from poorly managed and generally unnecessary releases to the environment of persistent organic pollutants.

Small-scale Releases – Key Issues:

- Small-scale frequent releases of persistent contaminants during training, testing, maintenance, and poor practices, while not individually significant, are responsible for the majority of legacy large-scale contamination through cumulative build-up and dispersal of contaminants potentially resulting in major health and environmental risks.

Recent examples of significant cumulative impacts include a rising number of cases of spills and legacy contamination from airport firefighting training areas contaminating surface and groundwater values. The Army Aviation Centre at Oakey is a current example where it has been found that a plume of groundwater contaminated by PFOS, PFOA and other PFCs released over a long period extends out of the site boundary and under the township for many kilometres down-

gradient from the source at the fire training areas with impacts on significant numbers of domestic and agricultural users accessing groundwater from bore holes in that area [166].

To put some perspective on the overall extent of such “small-scale” releases from testing and training the estimated total use of fluorinated foam concentrate at Oakey over 25 years of operation is estimated to have been about **1.2 million litres** at an approximate rate of 930 litres per week [155] releasing an estimated 6,066 kilograms of PFCs over that time.

Other instances of similar facilities with likely similar usage and contamination are now coming under scrutiny worldwide as well as at other Australian Defence air bases (e.g. Williamtown, Pearce, Townsville), fire training grounds (Fiskville), civil airports, ports and large chemical and fuel storage facilities. Cleanup, remediation costs and downstream economic impacts even for small but continued chronic releases such as training and testing areas can be enormous.

For example, costs for remediation of contamination caused by foam training and operational use at Düsseldorf Airport in Nordrhein Westfalen (Germany) have already reached \$AUD 150 million (€100 million). Even small releases related to single incidents such as roadside tanker spills can give rise to costs in excess of \$AUD 1 million (Table 2.9.1).

The risk of impacts occurring from the smaller, more frequent chronic releases is exacerbated by lack of information available to the end-user by which they can assess the risks for their particular situation and make informed decisions about appropriate management measures that they should have in place.

6.3 Considering the choices

Managing firefighting foam is not all about the potential for environmental harm. Considerations of issues such as, product performance, safety, property protection, operational practicalities and cost also have an appropriately high priority. However, the potential for environmental impact has been a consideration that has in the past been very poorly informed and largely overlooked, as have other issues such as the potential for long-term human health impacts of some chemicals.

Users need to carefully consider what combination of foam type, application systems and containment measures are best for their application and location. Achieving that balance requires consideration of a range of competing and sometimes opposing factors. What was previously an acceptable balance may change over time so this needs to be factored in to choices and planning for continuous improvement to systems in the longer term.

For example, PFOS has been an exemplary compound for firefighting for some types of fires but its serious adverse impacts on health and the environment mean that it has not been acceptable in formulations for some time. Despite the widely available knowledge of the high risks attaching to PFOS some industry users have suffered inertia and have failed to move to address the issue without regulatory intervention. Similarly PFOA and PFOA precursor compounds and their higher homologues are being found to carry unacceptable health and environmental risks and most jurisdictions recognise that moves to limit or phase out their use must occur as soon as practicable.

The lessons from the use of these and similar compounds have reinforced the need to apply the *Precautionary Principle* in the management of potential releases of contaminants, not only when adverse effects have become plain, but also when there are indications of such effects and there is insufficient information available to make a reasonable and informed assessment. It is irresponsible to release chemicals into the environment that will cause irreversible, planetary contamination unless it has been conclusively established that such chemicals are benign to the environment and human health over extended periods of time [53].

Put simply, if we have not investigated the potential for an adverse effect sufficiently then the apparent *–Absence-of-Evidence–* for the effect cannot be taken as *–Evidence-of-Absence–*; in addition the *Precautionary Principle* ensures that we do not wait for absolute proof of effects before acting to address potentially irreversible harm.

In the case of fluorinated organic substances there is now more than adequate evidence and indications that our use of products containing any such compounds should be very cautious as the releases are unrecoverable, undegradable and the adverse effects may be substantial, permanent and ongoing. From a regulatory standpoint the *Precautionary Principle* must apply placing the onus on the user/proponent to demonstrate conclusively that no adverse effects can occur even far into the future.

New generation shorter-chain C6-pure fluorinated compound-based foam products have been under development for about a decade on the basis of lower PBT characteristics and are now being brought to market. However, there is an emerging and growing body of evidence that these compounds are not benign and share many of the characteristics of the longer-chain compounds that they were intended to replace [123,143]. As such where their use is essential there needs to be careful control in terms of their purity and management as the information on their properties and effects is very limited [79,80,53] [123] with significant indications that the *per-* and *poly-*fluorinated compounds with various functional groups (as well as fluoropolymers) share properties and effects with the fluorinated organic compounds already of serious concern.

Where feedstock chemicals used in the production of foam formulations state that the feedstock materials have characteristics such as “*Toxic to aquatic life with long lasting effects*”, “*Toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment*”, or that some information is not available for key attributes such as PBT/vPvB assessment, this information must not continue to be omitted but must be disclosed as a matter of course in the final product SDS so that end-users, responders and regulators can make informed assessments and decisions.

For the end-user of firefighting foams to make informed and soundly based risk assessments and decisions they need quality information and advice to include in their considerations as to what constitutes the best-practice combination of product, systems, procedures, containment measures and response planning that can best meet their various operational needs, regulatory obligations, health and safety standards, community expectations and economic goals.

7 Use of persistent organic compounds

Fluorinated organic compounds are the largest group of environmentally persistent organic compounds known to be very widely used in firefighting foam formulations, as well as in a wide range of other consumer products and industrial processes. Other compounds, such as siloxanes, may also be environmentally persistent depending on the specific compounds in use, therefore care must be taken to evaluate their effects and fate in the environment before they are put into widespread use.

Use of Persistent Organic Compounds – Key Issues:

- There are rapidly growing world-wide environmental and human health concerns regarding the increasing exposure to persistent organic pollutants from industrial use and releases.

The major concerns with fluorinated organic compounds after they are released to the environment include:

- Diverse variety of compounds in use with little information on the potential impacts of each.
- Permanent pollutants with indefinite environmental persistence.
- Known to have various toxic effects on human health and the environment.
- Various bioaccumulate and/or biopersist in plants, animals and humans.
- Persist in the human body for a very long time (slow elimination).
- Can be transported over long distances by the air, oceans, waterways and groundwater.
- End-products will continue to circulate in the environment undegraded.
- Toxic effects may be cumulative and exerted over an extended period of time.
- Populations and environments far from the point of release have already been contaminated.

- Adverse impacts on environmental, human health, amenity and economic values may be irreversible.

Considerable world-wide human health and environmental concerns have been expressed generally in a wide range of published papers and by regulatory agencies regarding the use of fluorinated organic compounds and the lack of information on production volumes, uses, properties and biological effects of existing and proposed fluorinated alternative compounds.

7.1 World-wide concerns

In addition to the general concerns expressed regarding fluorinated organic compounds there have also been specific statements issued voicing the concerns of groups of eminent scientific experts who work on the characterization, properties, analysis, environmental distribution and adverse effects of poly- and perfluorinated alkyl substances (PFASs).

Worldwide Concerns–Key Issues:

- There are substantial and growing world-wide human health and environmental concerns about the continued use of all types of fluorinated organic compounds in any application that can result in release to the environment.
- Concerns regarding the uses of PFASs have prompted statements by eminent international scientists detailing the extent of their concerns and the current lack of action to address issues.

This includes the recent *Helsingør Statement* [80] and *The Madrid Statement* [79] which specifically raised issues directed at informing and cautioning regulators, manufacturers, distributors and end-users including:

- The world-wide occurrence of PFASs in humans, wildlife and the environment.
- The lack of decline in the occurrence of some long-chain PFASs despite regulatory controls.
- The very limited knowledge on the properties and effects of PFAS alternatives.
- The wide range of adverse human health and environmental effects attributed to PFASs.
- Less efficient fluorinated alternatives may lead to increased use, emissions, and exposure.
- Concerns about low testing requirements for mixtures of substances.
- The need for world-wide regulation of production and use of PFASs of all types.
- The persistence of alternative PFASs and their transformation products.
- Increased exposure to alternative PFASs implies increased risk of unknown adverse effects.
- The lack of toxicological data on PFASs from manufacturers.
- The limited technical capacity to destroy PFAS wastes world-wide.
- The need for tighter regulation and controls on PFAS-based products.
- Greater transparency by manufacturers on PFAS product content and potential effects.
- Ceasing use of PFAS-based products where a safer alternative exists.
- The need to develop non-persistent, non-toxic alternatives to PFASs.

The publication of these statements are a very strong indication of the high level of concern amongst a wide diversity of professional scientists eminently qualified to comment on the use and release of persistent organic pollutants based on current facts and indications of the behaviour, fate and adverse impacts on human health and the environment of these compounds.

7.2 Ongoing use of fluorinated compounds

Firefighting foam formulations that use fluorinated organic compounds are very diverse in their (largely unknown) formulations. The *Environmental Management of Firefighting Foam Policy* does not preclude the use of all fluorinated firefighting foams, however, there are restrictions on the types and purity of fluorinated compounds that can be used and the measures that must be in place to contain and manage releases.

This is in line with the general intent of the *U.S. EPA 2010/2015 PFOA Stewardship Program* which set the initial baseline principles and goals underpinning the direction to be taken for the

management of compounds of particular concern. This approach now needs to be extended in the light of the better understanding of fluorinated organic compounds that has emerged since then.

Ongoing Use of Fluorinated Compounds–Key Issues:

- Very significant environmental and human health concerns are emerging about the past and ongoing use of fluorinated organic compounds with numerous associations with a diversity of adverse effects.
- Fluorotelomers in later generation foams eventually transform in the environment to highly persistent perfluoroalkyl end-point compounds.
- Intermediate transformation compounds such as X:YFtS are significantly persistent in the environment so their effects need to be considered as well as the likely final end-point perfluorinated compounds.

Significant difficulties in being able to assess the potential human health and environmental impacts of fluorinated firefighting foams arise from the “*trade secret*” nature of foam formulations (acknowledged as a valid issue) as well as the general lack of relevant testing results for foams in their as-sold, final form meaning that there is a lack of information for users, responders and regulators to use to assess possible impacts.

While specific compound information may be necessary for human health-risk assessment the Policy does not require that detailed confidential formulations of any foam of a “*trade secret*” nature be divulged but rather that meaningful information is provided on key issues for each as-sold formulation marketed for use including:

- Acute and chronic impact test results for the final product as-sold (toxicity and BOD).
- Biodegradability that takes into account all the compounds used in formulations.
- Indications of persistence and bioaccumulation potential of compounds used in formulations.
- General classes, purity and content of fluorinated organic compounds where they are used in formulations.

Significant evidence and indications of the potential for adverse effects on human health and the environment by the wide range of both long-chain and short-chain fluorinated organic compounds used in firefighting foam are common including:

- All fluorinated organic compounds used in foams are extremely persistent or transform to extremely persistent compounds including both long-chain and short-chain compounds.
- All fluorinated organic compounds are toxic to varying degrees to human health and the environment.
- Adverse effects have been found or indicated in animal models, children and adults including developmental toxicity, neonatal mortality, carcinogenicity, kidney and liver toxicity, immunotoxicity and reproductive toxicity [118].
- Wildlife may be more vulnerable to PFCs than humans including potentially irreversible genotoxic effects from short exposures at elevated concentrations [102].
- Longer-chain fluorinated organic compounds have been shown to be bio-accumulative.
- Shorter-chain fluorinated organic compounds have been shown to have potential for bioaccumulation [107] [105,106].
- Shorter-chain fluorotelomer carboxylic acids are more acutely toxic than corresponding perfluorocarboxylic acids such as PFOA to some species [110,167].
- Fluorinated organic compounds have been found to persist in the human body with long elimination half-lives for long-chain compounds and even longer for shorter-chain compounds (Table 9.2 A – C8, 2.3 to 5.4 years, C6, PFHxS 8.5 years) increasing the potential for bioaccumulation in humans so that comparatively low exposures can result in large body burdens [69,118].

- Shorter-chain fluorotelomers such as 6:2FtS persist and continue to concentrate in groundwater a decade after use has ceased at some sites [40,168].

As an example of fluorotelomer behaviour and persistence of transformation compounds; The Tyndall Air Force Base (in the USA), which operated until 1992, used AFFF, (the foam was supplied ~1983 to 1988), for firefighting training:

- A foam concentrate sample was found to have 12,000 ug/L 6:2FtTAS and 6,000 ug/L 8:2FtTAS (TAS-thioamido sulfonate) with no 6:2FtS detectable in the concentrate.
- In 1999 groundwater samples from all four bore holes on site were found to have exceptionally high fluorotelomer sulfonate concentrations (6:2 & 8:2FtS >10,000 ug/L) [40]. These are assumed to have been derived from the partial degradation of the fluorotelomer thioamido sulfonates (X:Y-FtTAS) in the original foam concentrate (see point above).
- The fluorinated organic compounds in the groundwater samples consisted of 82% X:Y fluorotelomer sulfonates, 16% perfluoro sulfonates (probably mainly PFOS) and 2% perfluorocarboxylates (presumably PFOA and PFHxA).

This demonstrates:

- Production in the environment of 6:2FtS and 8:2FtS as transformation products of thioamido sulfonate compounds (X:YFtTAS).
- Persistence of the fluorotelomer sulfonates in the groundwater over a period of about 11 to 16 years (implying the need to consider X:Y-FtS compound effects over this extended period and not just the end-point perfluorinated compounds).
- Probably some production of PFOA and PFOS from precursor compounds.

Similar persistence of fluorotelomers as transformation products in groundwater and soils is coming to light for a range of other facilities [104,133,134,166,40,169] [93].

The effects of the various compounds on human health must also be considered not only in terms of exposure to the initial compounds but also in terms of the intermediate and end-point metabolic degradation products as the compounds interact within the various compartments and organs in biological systems [140].

This highlights the need to consider the potential for impacts on health and the environment in the short, medium and long term for fluorotelomers, intermediate partial degradation products and their end-point compounds. There is currently very little information available on the behaviour and effects of such compounds.

7.3 U.S. EPA PFOA Stewardship Program relevance

The U.S. EPA 2010/2015 PFOA Stewardship Program which was put into place in 2006 [22,94,83] obtained commitments from eight global chemical manufacturing companies who provided chemicals used in firefighting foams in many countries including Australia to:

- By 2010 – reduce product content of PFOA, higher homologues and precursors by 95%.
- By end of 2015 – eliminate PFOA, higher homologues and precursors.

U.S. EPA PFOA Stewardship Program relevance—Key Issues:

- The U.S. EPA 2010/2015 PFOA Stewardship Program set a useful initial direction but is now of limited current relevance as it has not kept pace to reflect the considerable body of information that has emerged since 2006.

The *Stewardship Program* relates to production of feedstocks and use in new products and does not take into account that there are existing feedstock materials and long shelf-life legacy stocks of products containing PFOS, PFOA, PFOA precursors, etc. still widely held by suppliers and users that could be used and be released to the environment. It also is not relevant to, and does

not provide assurances about, products sourced from other countries and made by other companies that are not party to, or supportive of the Program.

The *U.S. EPA PFOA Stewardship Program* has provided some good initial direction relevant to fluorinated firefighting foam development and control in the U.S., and by inference other countries, but it is not comprehensive and consideration of the broader issues and information that has become available since its establishment in 2006 is required.

The OECD is expected to take over the *US EPA PFOA Stewardship Program* function and is considering how best to develop, facilitate and promote national and international product stewardship programmes and regulatory approaches for perfluorinated chemicals based on their existing work programmes and in association with other participating organizations of the IOMC (Inter-Organization Programme for the Sound Management of Chemicals) [42].

The *Environmental Management of Firefighting Foam Policy* has taken into account a significant amount of much more recent information that has emerged since the agreement in 2006 and bridges the gap between production-focused controls, production by companies who did not subscribe to the U.S. EPA PFOA 2010/2015 Stewardship Program, and the immediate risks associated with the continued use of legacy products by users not recognising the risks and not voluntarily embracing the need for change.

For example, large stocks of PFOS foam are known to be still deployed potentially for immediate use in various systems on and adjacent waterways around Australia (and elsewhere) despite the current understanding of PFOS's adverse effects since at least 2000 and its listing as a Persistent Organic Pollutant under *Annex B* of the *Stockholm Convention* since 2009 [99]. An incident involving a one tonne spill of PFOS-containing foam occurred in Queensland to a body of water connected to the *Great Barrier Reef Marine Park* in January 2013.

7.4 Long-chain fluorinated organic compounds

The OECD definition of long-chain fluorinated organic compounds refers to perfluoroalkyl carboxylic acids with seven or more perfluorinated alkyl carbons (i.e., ≥ 7 totally fluorine-substituted carbons) and perfluoro-alkane sulfonates with six or more perfluoroalkyl carbons (i.e., ≥ 6 totally fluorine-substituted carbons) [99].

Long-chain Fluorinated Organic Compounds – Key Issues:

- Long-chain fluorinated organic compounds (C7-C20) are of particular concern due to their ultimate persistence, dispersibility, toxicity and bioaccumulative potential.
- Fluorotelomer carboxylic acids in newer generation foams are also of concern for aquatic ecosystems due to their enhanced toxicity.
- Almost all current generation foams still depend heavily on the presence of long-chain (C8-C14) FOCs for their performance.

The “long-chain” definitions for carboxylates and sulfonates are different in number of C atoms because a sulfonate with a given number of carbons has a greater tendency to bioconcentrate and/or bioaccumulate than a carboxylic acid with the same number of carbon atoms and therefore behaves like a long-chain fluorinated organic carboxylate (with two more carbons).

Although the OECD 2011 definition unfortunately does not include perfluoroalkyl substances other than carboxylates and sulfonates, other compounds, with functional groups such as betaines, sulfonamides, amines, thioethers, etc., with a perfluoroalkyl chain ≥ 7 are similarly considered long-chain [22,94,99] and their potential effects must be considered.

The carbon chain length is not the only factor influencing toxicity, mobility, bioaccumulation, etc. The type of functional group (e.g. fluorotelomer alcohol, sulfonate, carboxylate, thioether, sulfonamide, betaine, etc.) and whether all carbon atoms are fluorinated have a bearing and must be considered. For example, fluorotelomer carboxylic acids (FTCA) are generally more toxic to aquatic organisms by one to four orders of magnitude than the corresponding perfluorocarboxylic acids (PFCA) [62,167].

Many firefighting foams currently deployed still rely heavily for their effectiveness on the presence of long-chain fluorinated organic compounds [170,171] (e.g. 8:2Ft, 10:2Ft) which are of significant concern for human health and the environment in themselves and because of their degradation products. This means that foams that contain PFOS, PFOA, their precursors and higher homologues need to be identified and be taken out of service and disposed of as soon as practicable.

PFOS has been of particular concern for some time as a persistent organic pollutant under the *Stockholm Convention* and has well known adverse health and environmental effects. As a matter of priority PFOS foams must be taken out of service *as soon as possible* and legacy stocks must not be used. Many instances of PFOS foam still being in service in Australia are coming to light that could potentially be released directly to the environment despite well over a decade of awareness in the industry of the very significant potential for adverse health and environmental effects.

The *European Union Commission Regulation (No. 757/2010)* required that all foam containing PFOS above 10 mg/kg (0.001% w/w or 10 ppm) must not be used after 27 June 2011 and this was adopted by the UK Environment Agency in February 2011 [89,97]. Based on this benchmark:

- The maximum allowable impurity for PFOS in any firefighting foam concentrate has been set in the Policy to 10 mg/kg.
- Foams that contain PFOS above 10 mg/kg impurity limits are of greatest concern and must be taken out of service as soon as possible and must not be used operationally or for training.

Canada prohibited the use of foam containing PFOS above 0.5 ppm (mg/kg or 0.00005%) from 29 May 2013 [104,172] in Regulations that came into force on 29 May 2008. New Zealand also excluded PFOS and PFOA from use in any solid or liquid substances that are imported or manufactured for use as a fire fighting chemical in the *Fire Fighting Chemicals Group Standard 2006* under the *NZ Hazardous Substances and New Organisms Act 1996*.

Foams that contain PFOA, PFOA precursors and their higher homologues (including fluorotelomers and fluoropolymers) at overall concentrations above 50 mg/kg are of similar concern and must be taken out of service as soon as practicable and must not be used.

Relevant to the practical implementation of this is:

- Stocks of PFOA-contaminated/PFOA-precursor (and longer-chain homologues) containing foams are still in service and time will be required to properly consider replacements.
- Changes to foam delivery systems may be necessary and timeframes for replacement can be negotiated on a case-by-case basis.
- Agreed individual plans will detail how and when changeover is to be achieved.
- All PFOA-contaminated/PFOA-precursor containing foams are to be out of service by no later than three years from the Policy being approved. This provides for a changeover period beyond the anticipated timeline for the elimination of PFOA and related compounds from products by the end of 2015 under the industry agreed *US EPA PFOA Stewardship Program*.

By comparison the ECHA (European Chemical Agency) is now likely to adopt much lower limits for free PFOA of 25 ppb (0.025 ppm) and PFOA precursor compounds of 1 ppm in all mixtures and articles that *are proportionate to the risks* [20] with a 3 year general implementation timeline the same as the Policy. Recognizing manufacturing and operational issues the ECHA is currently considering a time-limited derogation of 1 ppm free PFOA and 1 ppm PFOA-precursors for firefighting foam.

Similarly the US EPA very recently (May 2016) established drinking water health advisories for PFOS and PFOA with upper limits of $0.07\mu\text{g/L}$ for each compound and their sum based on an assessment of the latest peer-reviewed science [173]. These significantly lower values replace the previous 2009 advisories of $0.4\mu\text{g/L}$ for PFOA and $0.2\mu\text{g/L}$ for PFOS [174]. This reflects the growing knowledge of and concerns about these and related compounds.

7.5 Short-chain fluorinated organic compounds

Foams based on formulations using high-purity, short-chain ($\leq C6$) fluorotelomers have been under development as alternatives to the more toxic, more bioaccumulative, longer-chain compounds. This is in line with the *U.S EPA 2010/2015 PFOA Stewardship Program* goal of elimination of PFOA, PFOA precursors and the higher homologues by the end of 2015. Note, as stated previously, this only relates only to *production* and affects only those *specific manufacturers* that signed up to the Program. It does not mean that existing stocks of products containing these compounds will not still be available and in use in legacy systems.

Short-chain Fluorinated Organic Compounds – Key Issues:

- Foams based primarily dependent on short-chain fluorinated organic compounds ($<C7$) for their performance may have undesirably high levels of PFCs.
- Emerging information indicates that short-chain fluorinated organic compounds have similar PBT characteristics and adverse effects as long-chain compounds.
- Foams concentrate using short-chain PFCs must not have more than 50 mg/kg impurity of PFOA, precursors and higher homologues and not more than 10 mg/kg PFOS, PFHxS and precursors.

While there has been progress in moving towards shorter-chain C6-based foams there are still many foams, some promoted as “*predominantly C6*”, or “*C6-based*”, which still rely heavily on a significant proportion of long-chain ($>C6$) compounds in their formulations (e.g. up to 75% C7-C9, up to 32% C8-C12) [32,31,42] [170]. Progress towards effective C6-pure foam has been significantly hindered by performance issues as outlined by a recent industry statement:

- “Until recently, aqueous film forming foams that were used for fire fighting invariably contained components, including low molecular weight fluorosurfactants and fluoropolymer surfactants having perfluoroalkyl chains where the perfluoroalkyl group was at least a perfluorooctyl group [C8 or higher]. For example, it was believed that a surfactant required at least a perfluorooctyl moiety to provide the necessary physicochemical attributes for efficient and persistent foam formation for fire fighting applications... Although C6 fluorosurfactants have been reported to be satisfactory for less demanding applications, such as cleaning solutions, the reduction in length of the perfluoroalkyl chain unfortunately leads to a decrease in the ability to form long lasting persistent foams with the properties necessary for effective fire fighting. Thus, AFFF and AR-AFFF concentrates where the perfluorooctyl surfactant is replaced by an equivalent C6 compound typically are unable to meet the requirements of the US and international standards for fire fighting applications.” [170].

There are a wide diversity of compounds with six perfluorinated carbons that are used in foam formulations (Tables 2.1 A, B & C) with no doubt more to be reported, each with different characteristics and (largely unknown) effects. Six-carbon perfluorinated compounds (and shorter) were reported to be generally less toxic and less bioaccumulative than the longer-chain compounds and therefore were been considered as potential replacement compounds when problems became apparent with long-chain compounds. Since then significant concerns have emerged about all PFCs including short-chain compounds.

The reduced effectiveness of foam relying on short-chain fluorinated C6 compounds for their performance has also meant that higher concentrations need to be added to foam formulations to attain effective performance (as per the industry statement below) with this defeating the overall purpose of reducing fluorine content and with it increasing environmental and human health risks if the compounds are released:

- “To counter this loss of activity, manufacturers have been forced to increase the concentration of fluoro surfactant in AFFF concentrates and/or to use oligomeric surfactants in which multiple perfluoroalkyl groups are covalently attached to short polymeric carrier molecules. See WO01/030873. In both instances the total concentration of fluorine atoms (calculated on a weight percentage basis) remains at an undesirably high level.” [171].

The development of C6-based foam formulations, initiated by the *US EPA 2010/2015 PFOA Stewardship Program*, has been underway for some time (since at least 2006) and has provided the opportunity to transition away from foams based on long-chain C8 compounds (and their homologues) and to develop and assess C6-pure foams of potentially lower risk.

While some *C6-pure* or *C6-compliant* foams are available so far no documented examples have yet come to light in the form of reports or publication in the technical literature of any *C6-pure* foam having been used successfully on a large fire such as a fuel storage tank.

However despite significant time having elapsed since the *US EPA 2010/2015 PFOA Stewardship Program* was put in place there is still insufficient independent information publicly available on C6-based or C6-pure foams to conduct realistic environmental risk assessments due to major gaps in information [37,118] [95,135,123] with:

- Few indications of the proposed short-chain fluorinated alternatives proposed for use with many still not publically identified.
- Identified alternatives lacking sufficient information on their behaviour, transformation products, fate and potential impacts on health and the environment.
- Proposed volumes of fluorinated alternatives that have been or might be used and released are unknown.
- Significant emerging and growing concerns regarding potential adverse impacts of short-chain fluorinated organic compounds [135,20,168,123,143] including PFHxA [168,106,105] a degradation endpoint compound for new generation 6:2Ft foams which is reported to be 3 to 5 times more acutely toxic to some aquatic species than PFOA [37].
- Uncertainty as to what the long-term environmental remediation requirements may be for short-chain fluorinated organics contamination in the light of emerging information [135].

The use of new generation fluorinated foams that have in their formulations (or will have) shorter-chain fluorotelomers (e.g. 6:2 Ft) needs to be qualified. There still needs to be appropriate management as there is a range of concerns, some which have arisen or have been better elucidated since the 2006 *US EPA 2010/2015 PFOA Stewardship Program* commenced.

Significant issues that need to be considered for short-chain fluorinated organic compounds include:

- End-point perfluorinated compounds produced by partial transformation of fluorotelomers have the same extreme persistence of all other perfluorinated organic compounds.
- The functional groups on the compounds strongly influence their properties [102] (e.g. the differences in effects between betaines, carboxylic acids, sulfonamides and sulfonic acids in acidity (pKa), acute toxicity, bioaccumulation and bioelimination characteristics).
- The partial degradation/transformation steps, intermediate products, half-lives and environmental effects of fluorotelomers are overall poorly known [83]. For example, 6:2 fluorotelomer mercaptoalkylamido sulfonate (FTSAS), common in many AFFF, is regarded as a potential source of fluorotelomer sulfonates, fluorotelomer alcohols and fluorotelomer saturated and unsaturated carboxylic acids [36]. Processes similar to the biotransformation of 6:2 FTOH may occur which involves nine intermediate products through 6:2 FTCA, PFHxA to PFBA [83].
- Many short-chain compounds still show the same PBT characteristics of longer-chain compounds albeit at reduced levels [107,40] e.g. PFHxS (C6) is regarded as having the characteristics of a “long-chain” sulfonic acid [99] and PFHxA is three to five times more ecotoxic than PFOA to at least three aquatic species [53] [95].
- Short-term acute effects are largely unknown or unpublished but there are indications of particular species sensitivities [95,62] such as perfluorocarboxylic acids (such as PFOA, PFHxA, etc) being especially toxic to microalgae [175] and that wildlife may be more vulnerable to PFCs than humans [102].

- Long-term chronic effects of short-chain fluorinated organic compounds are largely unknown, especially in combinations that would act synergistically [73,83,167] [95,135].
- In X:Y fluorotelomers the compounds include “Y” extra unfluorinated carbons in the backbone in addition to the “X” number in the perfluorinated moiety, e.g. an X:2Ft fluorotelomer is two carbons longer and until it partially degrades it behaves as a longer chain compound.
- Short-chain compounds are *not* non-toxic and not necessarily non-accumulative [107]. For example 6:2FtS is persistent in groundwater [40] and exhibits similar levels of liver and reproductive toxicity to PFOS [65].
- Mobility in soils and water (and therefore dispersal) is generally higher for the shorter-chain compounds [24,99,73,53,168] due to higher solubility in water, weaker sorption to solids and displacement in soils by other PFCs [176] with likely higher uptake into leaves, stems and fruits [53].
- Combinations of different fluorotelomers are used in foam formulations with little information available on their single or combined synergistic effects and those of their breakdown products [40] [153,177] except that the effects are likely to be additive.

Potential degradation products from the new fluorotelomer products and raw materials include the 5:3 acid, PFPeA (perfluoropentanoate) and PFHxA (perfluorohexanoate), depending on environmental conditions [178]. A study of ski-wax technicians exposed to PFCs showed that the perfluorocarboxylic acids PFHpA, PFOA, PFNA, PFDA and PFUnDA all bioaccumulated, with PFHxA having a relatively short half-life in man compared to other perfluorocarboxylic acids [179].

Measurements made of groundwater concentrations at former US military firefighting foam training sites indicate that PFOS, PFOA and 6:2 FTS all have environmental half-lives of at least a decade, with some samples still foaming 10-15 years after the sites were last used [40]. Similarly in Norway 43 airports that had previously used fluorinated foams were investigated for PFC contamination [169] with PFOS, 6:2FtS and other PFCs found to be present in soils, surface water, groundwater and biota.

Analysis of publicly accessible information on fluorinated alternatives to long-chain fluorinated compounds reveals evidence that many known fluorinated alternatives may still possess hazardous properties (persistence, bioaccumulation potential, (eco)toxicity, and/or long-range transport potential) and thus may pose risks to humans and the environment [95,135,168].

The lack of data on any alternative compounds whether fluorinated organics or not makes it unclear whether they have been fully tested and assessed before being commercialised. With this in mind the regulatory agencies have no choice but to take a conservative approach based on the available worst-case indications in the application of the *Precautionary Principle* to decisions about environmental management.

The *U.S. EPA 2010/2015 PFOA Stewardship Program* and the agreements that were entered into by the major chemical companies do not provide any guidance on what the final quality targets are for the “*elimination of PFOA, PFOA precursors and higher homologue chemicals*” from products [180] in terms of allowable impurities although there has been some progress on understanding what is desirable and what is achievable. Clearly total 100% elimination with no traces of impurities whatever is neither practical nor measurable, or even financially viable as a solution, so achievable targets need to be set and these have been considered in this Policy.

As a benchmark for achieving the Stewardship Program goals DuPont has indicated in technical information (2008 & 2012) that its C6 foam feedstock Capstone™ products (1183, 1157 & 1157D) [181,182] meet the goals of the *US EPA 2010/2015 PFOA Stewardship Program* with a PFOA impurity target below LOD (limit of detection) where LOD is referenced to a method appropriate for PFOA, precursors and higher homologues [183] with a LOD in the range *sub* µg/g (micro grams per gram) and LOQ µg/g (µg/g = mg/kg or ppm w/w). DuPont also indicated in

2009 that PFOA content in aqueous-based dispersions will be or have been reduced *to a level below 50 ppm* (~mg/kg) [184].

This limit is supported by 2010 industry estimates based on an assumption of less than 1 ppm PFOA impurity in AFFF having up to 0.5% fluorotelomer content [42] compared to older generation foams with 0.9% to 1.5% w/w of fluorinated organic compounds [75].

More recently the Dynax product information sheet for their DX5022 (2009) [185] cites this product as an “*anionic fluorochemical foam stabilizer*”... “*to be used in synthetic and protein-based alcohol-resistant fire-fighting foam agents*”... “*is made from C6 fluorotelomers containing less than 0.3% C8 and higher homologs*” (~<3 g/kg, i.e. ~<3,000 ppm). This is effectively achieving a ≤C6 feedstock content purity of 99.7%. In a C6 foam concentrate using 1% total PFCs this would be no more than 30 ppm ≥C7 impurity (3,000 ppm × 1%), below the Policy purity limit of 50 mg/kg (ppm). More recent similar products developed since 2009 would be expected to achieve at least this, if not better purity.

The foam Policy therefore considers a limit of 50 mg/kg for PFOA, PFOA precursors and higher homologues, as impurities in the foam concentrate, to be a reasonable and achievable standard for impurities in short-chain fluorotelomer-based foam formulations that is already being met using current feedstock materials. The limit on PFOS contamination as an impurity is dealt with separately.

7.6 Alternatives to fluorinated compounds

The growing recognition of the environmental and human health problems associated with persistent organic compounds such as fluorinated organic compounds has driven investigation of alternative fluorine-free and other non-halogenated compounds and formulations that may impart similar beneficial firefighting characteristics to firefighting foams, particularly those that may have the ability to form aqueous films. For example the investigation of trisiloxane surfactants [186] or fluoropolymer-siloxane composite compounds [187].

Alternatives to Fluorinated Compounds–Key Issues:

- Any product being considered for use where it might be released to the environment must have its safety and environmental acceptability tested and demonstrated conclusively by the manufacturer before being released to the market in accordance with the *Precautionary Principle*.

As with any new product the development phase must include close scrutiny of the potential adverse effects on health and the environment so as to avoid the past mistakes of putting into service unsuitable and potentially damaging products.

Siloxane surfactants have recently emerged as a promising alternative for formulation of halogen-free AFFF where the siloxane group in various carbohydrate siloxane compounds forms the hydrophobic part of the surfactant [186]. However, associated publications refer to “*environmentally-sound high-performance siloxane surfactants*” [188] and “*environmentally friendly*” [189] without any reference to, or elucidation of, the basis for stating that that the proposed surfactants are acceptable in terms of even the primary issues of persistence, biodegradability, BOD, COD, bioaccumulation or acute and chronic toxicity.

All foams have the potential to cause significant environmental harm, even if only through high BOD causing oxygen depletion combined with short-term detergent toxicity effects in water bodies. As such no foam can be validly described as “*green*” or “*environmentally friendly*”, as is sometimes claimed in sales promotional material. Environmental acceptability needs to be fully considered and openly communicated, especially with regards to the potential for long-term effects.

For example, the cyclic siloxane compounds most commonly in general use in a range of domestic products have been identified as variously being environmentally persistent, bioaccumulative, toxic, having the potential to cause health issues such as endocrine disruption, liver and lung injury and having the potential to cause ecological harm [190,191].

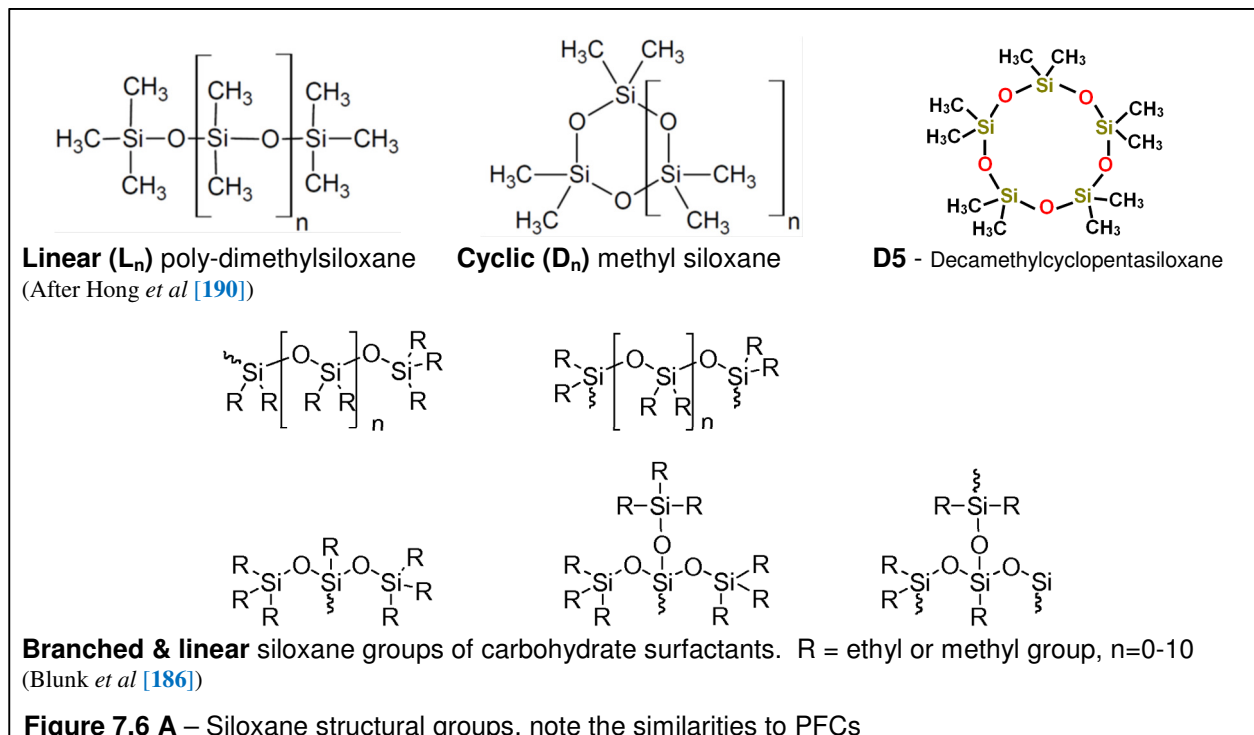
It is therefore essential that related siloxane compounds and fluoropolymer-siloxane composite compounds being considered for use in foams should therefore have their PBT properties thoroughly investigated before being considered for use.

It is important to consider the structure and behaviour of alternative compounds in terms of the similarities with existing compounds of concern. Siloxanes share a number of similar properties with PFCs in persistence, adverse effects and environmental fate as well as being considered as alternatives to PFCs in firefighting foam. Other alternative compounds with similar characteristics to PFCs and siloxanes could be considered in the same way. Although the fluoropolymer-siloxane composites would be expected to suffer from the same environmental issues as all other fluorochemicals.

Siloxanes can be grouped into three structural groups with similarities to PFCs especially in the linear and branched forms (Figure 7.6 A) [190,186,192]:

- Cyclic siloxanes, having a closed-ring structure such as methyl siloxanes expressed as D_n where (n) is the number of silicon atoms in the ring (e.g. D_4 , D_5 & D_6). The ring structure appears to confer resistance to degradation.
- Linear siloxanes compounds, expressed as L_n , having (n) silicon atoms in a chain-like structure (e.g. $L_4 - L_{17}$). This is similar to linear PFCs with persistence characteristics likely to be different to cyclic siloxanes but as yet not fully investigated.
- Branched and linear siloxanes attached to a functional group (e.g. carbohydrate). As for PFCs the functional groups are likely to influence the biological behaviour of the compound and its transformation products.

Based on chemical principles, non-cyclic siloxanes with biodegradable functional groups such as carbohydrates may be biodegradable with low or limited persistence. However, this is not evident from the published papers that were reviewed as most research has focussed on cyclic methyl siloxanes (e.g. D_n siloxanes) which exhibit various adverse effects [190,193,192,194,195].



8 Use of non-persistent foams

Given the intense focus on the problems and risks identified with foams that use fluorinated organic compounds such as PFOS, PFOA, their precursors and related compounds in their formulations much discussion has been polarised in terms of “*fluorinated*” versus “*fluorine-free*”.

While this polarisation may be valid in terms of the differences in the underlying firefighting mechanisms between the main foam types, the underlying issues from an environmental perspective, beyond the acute short-term toxicity and BOD effects applicable to all types of foam, are more correctly about the use and impacts in day-to-day operations and infrequent major incidents of foams with:

- Persistent toxic compounds or their precursors with potential to cause short and long-term adverse impacts.
- Non-persistent toxic compounds with short-term adverse environmental impacts.

Use of non-persistent foams–Key Issues:

- Non-persistent foams are those that do not have any persistent toxic organic compounds in their formulation or from contamination, this includes “fluorine-free” foams that meet that requirement.
- The primary concerns for non-persistent foams are oxygen depletion from BOD and acute toxicity impacts in water bodies from the direct effects and biodegradation of their organic components.

It is quite conceivable that either a fluorine-containing firefighting foam or indeed a fluorine-free firefighting foam could have long-term adverse impacts from the inclusion of persistent compounds or persistent breakdown products which may be toxic, such as biocides, fungicides or corrosion inhibitors.

For example, *cyclic* siloxanes, used extensively in personal-care products, e.g. D5 Decamethyl-cyclopentasiloxane (Figure 7.6 A), have been considered for use in firefighting foams but found not to be effective and have environmental persistence, bioaccumulation and toxicity characteristics that make their release to the environment highly undesirable.

Accordingly the term *fluorine-free* foam is used interchangeably to also mean *non-persistent* foam, the key issue being whether or not there are significantly persistent and potentially toxic chemicals of any kind in the formulations.

All firefighting foams can have adverse environmental impacts. There is no foam that is completely environmentally benign despite what is claimed in some marketing material. As is the case with fluorinated foams there are many diverse formulations of non-persistent or fluorine-free foams and all need to be assessed for firefighting effectiveness for the particular application as well as assessed for their potential environmental impacts against the relevant criteria.

The primary environmental impact concerns for any foam including fluorine-free foams are their high BOD when released to bodies of water and groundwater and their short-term acute toxicity, primarily due to the synthetic detergents and solvents in their composition.

The general claim from some quarters that has been circulating that “*fluorine-free foams do not work*” in terms of firefighting performance is completely disingenuous. The same high performance certification standards are applied to the testing for all foams regardless of their composition with rigorous tests carried out by independent certification organisations to the agreed standards. Foam must be selected according to the particular application. Many fluorine-free foams are acknowledged as “*meeting the toughest amongst the firefighting standards*” [42,196,45,186] and exceed film-forming fluorinated foam performance in various circumstances. Similarly the performance of AFFF is variable with some aqueous film forming foams (AFFF) failing to form aqueous films under some circumstances. For all foams, whether fluorine-containing or fluorine-free, there are of course a range of products commercially available differing in cost, applicability and operational performance.

Even a brief review has found that various fluorine-free foams from a range of manufacturers meet the independent certifications for all the major firefighting applications including the *LAST*

Fire Test, EN1568(parts 1-4), DEF(Aust)5706, ICAO Level B&C, AS5062 and reputedly *US MilSpec/UK Defence Spec* in terms of performance but not in terms of the legacy requirement in MilSpec to have a specified fluorine content or a positive spreading coefficient on a test fuel.

There are also sufficient documented examples available of the effectiveness of non-persistent foams under particular field conditions for vapour suppression and fires including large incidents involving hydrocarbon storage tanks, refineries, offshore platforms, oil wells and shipping.

Notably the US military has also specifically recognised the problems associated with the use of persistent organic compounds and has issued a *Statement of Need* [135] for the development of a fluorine-free foam that meets the performance requirements defined in the military specification MIL-F-24385F with particular attention to:

- Testing to validate persistence and aquatic toxicity of alternative materials.
- Assessment of the human health and environmental impacts of proposed ingredients, formulations, and by-products.

Performance certification authorities that undertake these independent certifications include MPA Dresden, CAAi UK, FM Approvals, Underwriters Laboratories Inc., IMO, SP Technical, Resource Protection International, SP Sweden and DNV Norway.

A cursory investigation of the extent of fluorine-free foam use around the world (with a focus on Australian use given the Policy relevance to Australia) found about 183 fire brigades, facilities and corporations that are using fluorine-free foams including at least:

- Airports – 23 Australian (predominantly Air Services Australia), 54 overseas.
- Fire brigades – 5 Australian, 19 overseas.
- Corporations – 13 Australian, 34 overseas.
- Ports – 12 Australian, overseas ports not investigated.
- Petroleum products – 7 Australian, 13 overseas (including offshore oil and gas platforms).

One of the last applications to be completely reliant on fluorinated foam for certification was hand-held and portable extinguishers. Recently a portable fluorine-free foam-type fire extinguisher has been certified as compliant with AS1841 for use in Australia. This extinguisher is based on a fluorine-free extinguisher that was earlier certified for use in the EU.

For existing legacy hand extinguishers containing fluorinated foam it is eminently practical for the small amounts of foam, contaminated materials and wastes produced in hand-held extinguisher incidents and servicing to be dealt with appropriately. This being implemented properly will largely depend on the supplier making the user aware (in Section 12 of the SDS and other product documents) of their environmental and health responsibilities and the requirement for containment and clean-up of wastes containing persistent organic pollutants.

The general marketing claim made by some that all fluorine-free foams are “*10 times more toxic*” (than fluorinated foam) is also without foundation, or at best is a claim that is out-of-date and refers to acute short-term toxicity of particular early products [59]. A brief review of acute toxicity across foam types (where there is sufficient information to do so in SDS) finds similar relative toxicity and overlap in values such as LD50 and LC50 depending on manufacturer and foam type [49].

The potential health, safety and environmental effects of each foam need to be assessed in terms of not only their acute short-term toxicity (the most basic and often-quoted measure) and BOD, which will almost always trump the short-term toxicity in importance as far as environmental impact is concerned, but also the potential for long-term chronic toxicity effects, as well as environmental persistence, which have rarely been considered so far.

There have been suggestions that surfactants in fluorine-free foams will result in the release of other contaminants through detergent effects including allowing hydrocarbons to pass through oil separators in discharges to the environment. Water soluble surfactants whether fluorinated or not are not removed by oil skimmers, neither are dissolved polar fuels that are now commonly available, making the principal consideration for releases a question of whether the discharge is

of dispersive, persistent organic long-term pollutants versus fully biodegradable compounds with limited localised short-term adverse effects.

Where there are contaminants in firewater other than the foam, such as fuels or complex combustions products, there is no distinction between the types of foam and requirement for proper containment, management, treatment and disposal according to the particular composition considering the usual elements of BOD, persistence, short and long-term potential effects.

Where a hydrocarbon fuel release to water is inevitable, and most are not practically recoverable, it is preferable to disperse it with biodegradable surfactants (as is common practice for any oil spill) to remove it from the surface where wildlife will be contacted and affected and to increase its dilution and droplet surface area to facilitate rapid biodegradation.

A further argument levelled against fluorine-free foams, again based on no consistent, verifiable or documented evidence, has been that so much more will need to be applied and more frequently in an incident. Even if or where it were to be necessary to use larger amounts (on very infrequent events), the resulting short-term, but recoverable and naturally remediating damage is preferable to permanent pollution events that have no prospect for recovery or break down of persistent contaminants and represent a long-term threat to the environment and health.

In comparison to fluorine-free foam use, the proposed alternative pure C6 short-chain fluorinated compounds reportedly may require greater concentrations of the fluorinated organics in their formulas to achieve the same firefighting performance [171,170] so it could be said that this may result in larger amounts of persistent organic contaminants being released than for legacy foams. Even ignoring the long-term issues this could therefore negate the lower (short-term) toxicity and bioaccumulation characteristics of the proposed alternative shorter-chain compounds and result in greater long-term health and environmental exposures for compounds where little is known of their behaviour but significant emerging evidence of adverse effects [79,80,171,170] [171,170].

9 Policy implementation

The *General Environmental Duty* (GED) under existing environmental legislation requires that any person, corporation or organisation carrying out an activity must take all reasonable and practicable measures to prevent or minimise the potential for the activity to cause environmental harm, having regard to *the current state of technical knowledge for the activity and other relevant matters*.

Failure to comply with the GED obligations under the legislation could result in statutory action by the regulatory authority. Similarly knowingly causing environmental harm through the release of a pollutant is an offence that can result in statutory action by the regulatory authority.

Sites that carry out their activities under licences required by environmental legislation may also have additional specific obligations to comply with licence conditions regarding how they carry out the licensed activity and what they are permitted or not permitted to release to the environment.

All firefighting foams have the potential to cause environmental harm, particularly in bodies of water through impacts by BOD, acute toxicity, chronic toxicity and release of contaminants of serious concern, including highly persistent, toxic fluorinated organic compounds. All reasonable and practical steps must be taken to manage and mitigate that risk. For firefighting foams it is now becoming clearer what constitutes the current state-of-knowledge and best practice regarding the management options, risks and potential impacts.

The *Environmental Management of Firefighting Foam Policy* takes into consideration the current state-of-knowledge as of June 2016 (including recognition of the gaps in that knowledge) to set out what is currently considered the basic environmental considerations and standards that need to be met by the suppliers and users of firefighting foam so that the user (who carries the bulk of the liability and risk) can achieve best practice and meet their obligations.

The Policy review and drafting process has taken into account the various and often competing considerations that the user faces in achieving a balanced and practical solution amongst the

options available with compromises expected in some areas. Consideration has also been given to what constitute essential and reasonable standards and timelines for users to meet the Policy requirements.

9.1 General compliance timelines

PFOS-containing foams (including foams containing PFOS precursors) represent a very significant risk to human health and the environment. Users must determine if they have PFOS foams or foam contaminated by significant levels of PFOS and if so they must be taken out of service or replaced as soon as possible and disposed of properly. Where the origin or type of foam is in any doubt the user must undertake testing to determine its general composition against the Policy standards and take action accordingly.

Foams containing long-chain fluorinated organic compounds such as PFOA, PFOA precursors and higher homologues must be replaced as soon as practicable with a fluorine-free or C6-compliant foam. While this is being implemented interim measures must be put in place as soon as possible to prevent releases of foam to the environment. Note that new generation C6-pure (99.5% ≤C6) foams must be fully contained, must not be discharged to the environment (including bodies of water, soils or groundwater) and any wastes must be properly disposed of as regulated waste.

9.2 Up to three years for facilities to comply

Where significant changes to systems are required to come into compliance with the Policy and environmental legislation a period of *up to a maximum of three years* from the date of approval of the Policy is considered reasonable to implement such changes for most facilities and in line with other international directions [20].

There is the expectation that changes will be made without undue delay within that period and the facility must be able to demonstrate that they can contain all releases from day-to-day activities and incidents in existing systems or by implementing effective interim measures.

If there are justifiable reasons why changes cannot be carried out within three years then the operator of the facility can submit a set plan for regulatory approval under the available provisions of the state environmental legislation. For example an older facility may need to implement several stages of changes to fit with operational upgrades.

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