

THE CATALYST

Q2 SUPPLEMENT

FOAM TRANSITION: IS IT AS SIMPLE AS "FOAM OUT / FOAM IN"?

by:

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JOIFF

THE INTERNATIONAL ORGANISATION FOR
INDUSTRIAL EMERGENCY SERVICES MANAGEMENT

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The Catalyst is always pleased to publish detail that will provide a Shared Learning Training opportunity for JOIFF members and its many readers around the World who are non-members of JOIFF.

At the JOIFF Foam Summit that took place in London, United Kingdom on 10th February 2020 the speakers provided a large amount of very important technical information and there was an open and frank exchange of views.

Following the JOIFF Foam Summit JOIFF contacted one of the speakers at the JOIFF Foam Summit, Dr. Ian Ross – Senior Technical Director & Global PFAS Lead for Arcadis, and asked for a holistic article on their perspective on the current position of FireFighting Foam which discusses in greater detail, than space would allow in the Catalyst Magazine & eMagazine.

JOIFF felt that the detail provided was so important that it should be shared as a service of JOIFF's Shared Learning.

The length of the article made it appropriate to publish it

as a supplement to The Catalyst - which is a historic step forward for us as it is the first supplement published by The Catalyst in its 20 years of publication.

Disclaimer:

We would like to emphasise that JOIFF, as a truly Independent organisation has no commercial interest in Foam, but has a major interest in informing and educating its members and is truly independent in the debate about Foam.

The statements, views and opinions are of the authors of the Article.

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CONTENTS

3. INTRODUCTION
4. WHY PFASs ARE A ISSUE
6. CURRENT GLOBAL REGULATORY POSITION
10. THE EFFECTIVENESS OF F3 FOAM
11. AFFF MANAGEMENT & FOAM TRANSITION
13. CLEAN OUT CHALLENGES
14. DECONTAMINATION CASE STUDIES
15. CONCLUSION

FOAM TRANSITION:

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TRANSITION

IS IT AS SIMPLE AS “FOAM OUT / FOAM IN”?

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INTRODUCTION

Dramatically escalating scientific, regulatory, public, political and press attention to the environmental and human health effects of per- and polyfluoroalkyl substances (PFASs) is leading to the development of increasingly conservative (low) regulatory levels for PFAS in drinking water [1-3]. As an increasing number of drinking water supplies are discovered to be impacted with PFASs above levels deemed to be safe, numerous impacted communities are instigating litigation against end users and manufacturers of aqueous film forming foams (AFFF) and fluoroprotein foams. As a result, the ongoing use of firefighting foams containing these “forever chemicals” is under significant scrutiny [4].

As an increasing number of PFASs, including both long chain (C8) and shorter chain (C6, C4 etc.) are regulated in drinking water, surface waters, soils and groundwater [5, 6] and the application of firefighting foams containing PFASs are being curtailed in multiple jurisdictions, many

foam users are transitioning to using fluorine free firefighting (F3) foams [7, 8]. The historical regulatory focus has been on three individual “long chain” highly bioaccumulative PFASs, namely perfluorooctane sulphonic acid (PFOS), perfluorohexane sulphonic acid (PFHxS) and perfluorooctanoic acid (PFOA). However, an expanding range of PFASs are now regulated in many locations [9-35].

The effective use of F3 foams in most fire protection scenarios is supported by a growing body of independent testing data on increasingly larger scale applications. For example, independent tests performed by LASTFIRE demonstrate comparable performance between F3 and PFAS-based foams such as the “C6-pure” AFFF in some large diameter tank fire simulations [36]. LASTFIRE continues to expand testing to include other hazards and scenarios. After having carried out extensive testing and due diligence on alternatives to AFFF, Equinor (formerly Statoil), a major Scandinavian petrochemical company, switched completely to F3 foams in 2013 for both its onshore and offshore (North

Sea) operations [8].

As firefighting activities represent one of the most environmentally emissive uses of these extremely persistent and highly mobile anthropogenic chemicals, through both training exercises and incident response, the uses of PFASs in firefighting are perceived to cause an increased potential for environmental contamination. Historical and ongoing use of AFFF and fluoroprotein foams can generate long term soil or concrete highly concentrated ‘source areas’ of PFASs, which can potentially generate large plumes of PFASs dissolved in groundwater and/or impact surface waters meaning PFASs can travel well beyond the original source area, with some PFAS plumes impacting more than 250 km² of groundwater [37].

From a waste management perspective, treating foam concentrates and spent foam mixtures resulting from AFFF and fluoroprotein foams used in fire incidents is not possible using biological treatment processes. That is, conventional wastewater treatment plants will not breakdown non-biodegradable PFASs. Discharge of these wastes to sewer is therefore not an effective treatment

FOAM TRANSITION

option. Whereas, some F3 foams have been identified as containing readily biodegradable ingredients, thus can potentially be treated biologically via conventional wastewater treatment. A GreenScreen Certified™ process is now available for F3 foams to mitigate concerns from end users regarding their environmental profile [38].

One growing concern is effective decontamination of fire suppression systems as fluorosurfactant PFASs adhere to surfaces and can form multiple layers. This means the interior of fire suppression systems can be coated with a significant mass of PFASs which cannot be removed with repeated water rinses. This behaviour can result in significant rebound of PFAS into F3 foams, causing regulatory concerns and potentially negating the benefit of transitioning to PFAS-free foams. Fortunately, effective decontamination of fire suppression equipment and infrastructure is achievable using recently developed approaches, often eliminating costly equipment replacement.

As an accelerating number of foam transitions projects start, where AFFF and fluoroprotein foams are replaced by F3, there is a need for a competent and experienced team of fire and environmental engineers that can effectively decontaminate fire suppression systems, engineer minor suppression system modifications, ensure compliance with fire safety and insurance requirements and manage regulatory expectations [39].

This article introduces PFASs as a group of emerging contaminants, describes updates considering their fast-evolving regulation including those relating to environmental media and their use in firefighting foams. It then provides an overview of recent large-scale fire extinguishment tests, demonstrating the efficacy of F3 foams vs AFFF and describes how successful foam transition and decontamination of fire suppression systems has been implemented. The challenges to overcome when transitioning away from AFFF and fluoroprotein foams are described to highlight that when changing out foams it is not as simple as "Foam out / Foam in". However successful foam transitions are possible using an experienced team with a combination of fire and environmental engineering skills, with the lesson learned

from foam transition projects described.

WHAT ARE PFASs AND WHY AN ISSUE?

Some PFASs also termed fluorosurfactants were introduced for use in firefighting foams in the early 1960's. These foams were designed to extinguish liquid hydrocarbon Class B fires and include AFFF, film forming fluoroprotein foam (FFP) and fluoroprotein foam (FP) [40]. These foams have been used for decades at oil terminals and refineries for repeated fire training events, in fire suppression systems at oil storage tank farms and used to extinguish fires of various sizes relating to incidents.

PFASs are a broad group of some 4,730 anthropogenic (human-made) xenobiotics (foreigners to the biosphere) [41, 42]. As bulk manufactured chemicals, PFASs have been used in a wide array of commercial goods and products since the 1940's. The term PFASs includes many thousands of individual compounds each with their own acronyms, which can initially be very confusing. This article attempts to highlight the acronyms of importance considering firefighting foams and provide a brief overview of the importance of a few differing compounds. The term PFAS or PFASs refers to all the compounds in this class, i.e. those in both C8 and C6 firefighting foams [43].

PFASs are thermally stable and repel oils and water with impressive surface tension levelling properties. They are extremely persistent in the environment and have been characterised as "forever chemicals" [44] as they show no sign of being amenable to microbial metabolism and thus are not considered to be biodegradable [45]. PFASs are usually highly mobile and many bioaccumulate within various species including humans and the edible portion of some plants [39, 46-51].

PFASs are a diverse class of chemicals, united by the common

structural element of a fully fluorinated carbon (alkyl) chain, known as the perfluoroalkyl group which is typically 2 to 18 carbon atoms in length. The whole PFAS molecule may be either fully (per-) or partly (poly-) fluorinated, but each compound always contains a perfluoroalkyl group. The number of carbons in the perfluoroalkyl group denotes whether certain PFASs are termed as C8 or C6 for example.

Perfluoroalkyl substances have previously been referred to as perfluorinated compounds (PFCs) but are now more commonly termed perfluoroalkyl acids (PFAAs). The PFAAs include PFOS, PFOA, PFHxS and perfluorohexanoic acid (PFHxA).

Polyfluoroalkyl substances comprise thousands of compounds synthesised for a broad array of commercial uses. In addition to the perfluoroalkyl group, polyfluorinated compounds contain carbon to hydrogen bonds, such as fluorotelomers, but also may have more complex functional groups which can be neutral, or charged (anionic, cationic or zwitterionic), which changes how they are transported in the environment. None of the thousands of PFASs can biodegrade. However, the polyfluorinated PFASs, can transform in the environment to create the perfluorinated PFASs, collectively termed perfluoroalkyl acids (PFAAs), as shown in Figure 1. Polyfluorinated PFASs can be described to biotransform or abiotically transform in the environment and biotransform in higher organisms [52] to create PFAAs and are thus termed PFAA precursors or "precursors".

The polyfluorinated precursors produce "dead end" perfluorinated daughter products (PFAAs) as the terminal

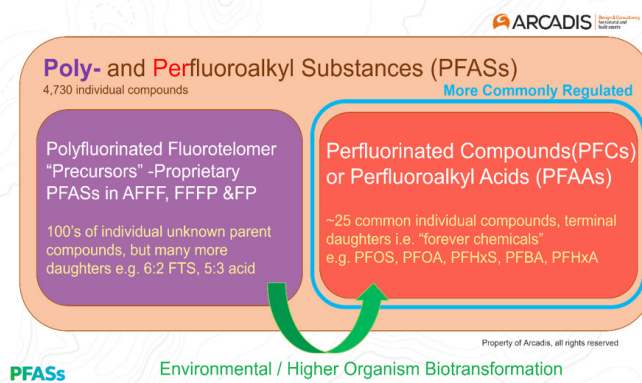


Figure 1. Regulated PFASs and their Precursors in Firefighting Foams

products of transformation. Firefighting foams contain multiple fluorotelomer-precursors, which are proprietary molecules, and for which no analytical standards are available. These “parent” PFASs can therefore go undetected until they transform in the environment or higher organisms to form the regulated terminal “daughter” PFAAs. Little research has been done considering the toxicology of these unregulated parent fluorotelomer precursors in AFFF or their transient environmental transformation intermediates. More advanced analytic tools such as the total oxidizable precursor (TOP) assay will reveal their presence and is able to quantitatively estimate the concentration of PFASs containing a detectable perfluoroalkyl group. Studies have shown that some fluorotelomer precursors are 10,000 times more toxic than the terminal daughter PFAAs they transform into [53].

PFAAs may also be subdivided into two broad classes, short-chain PFAAs and long-chain PFAAs, with long chain examples including PFOA, PFHxS and PFOS [43]. Studies have been conducted that indicate long-chain PFAAs have a higher potential to bioconcentrate and bioaccumulate through trophic levels as compared to shorter-chain PFAAs [54]. They are described as exhibiting biopersistence, which describes compounds that tend to remain within an organism, rather than being expelled or broken down. The short chain PFAAs have been described not to exhibit significant potential to bioaccumulate above relatively high threshold levels [55], however they are significantly more mobile than long-chain PFAAs and thus significantly more difficult to remove from water using many treatment technologies and also extremely persistent meaning they have the potential to form very large “mega” plumes [37] and circulate around water bodies for thousands of years to come i.e. indefinitely, making them a potentially larger threat. The mobility of organic compounds was recently described to be of significant importance when considering protection of drinking water supplies [56].

However the risks posed by short-chain PFASs (i.e. all “C6-chemicals” in AFFF, not just PFAAs) are often mischaracterised

by referral to select studies focussed on PFHxA [57] failing to mention the toxicity or bioaccumulation potential of the parent fluorotelomer precursors and the myriad of intermediate PFASs they can form. Intermediate transformation products include the 6:2 fluorotelomer sulphonate (6:2 FTS) and 5:3 acid which are described to bioaccumulate in marine invertebrates and rats respectively, and the final transformation products, the short chain PFAAs are shown concentrating in the edible portion of crops [39, 46-48, 50, 51, 53]. Recent articles have highlighted a “flawed focus on PFHxA as a reference chemical for short-chain PFAS class” and highlighted scientific studies undertaken by independent scientists working for the U.S. Food and Drug Administration (FDA) which highlighted the issue of the potential bioaccumulation of short chain PFAS as being an “elephant in the room” [58, 59].

The long-chain PFASs, including PFOS, PFOA, PFHxS bioaccumulate in humans through consumption of impacted drinking water, and increasingly low drinking water standards are being promulgated globally. Whilst an increased understanding of the toxicology and bioaccumulation potential of the myriad of PFASs associated with fluorotelomer precursors is evolving it is clear that daily repeat exposure to PFASs in drinking water would cause them to generate a steady state (equilibrated) concentration in an exposed population. This is because even if PFASs have short retention half-lives and can be excreted, if they are still being consumed in drinking water used every day, the exposure remains at the same level. In the last year an expansion of the impacts from PFASs from drinking water to foodstuff has been observed with dairies in Maine and New Mexico reporting detections of PFASs in cow’s milk [60, 61], with biosolids used as fertilizer emanating from wastewater treatment plants implicated as a potential source of PFASs in Maine [62]. This may be a sign that further industries could be impacted, with data from a study evaluating differing PFASs in beer and cider reporting up to 49 ng/L of PFOA and 37 ng/L PFHxA in beer with 33 ng/L of a precursor to PFOS reported in cider

[63].

WHICH PFASs ARE IN FIREFIGHTING FOAMS?

Firefighting foams containing PFASs include all AFFF, FFFP and FP formulations. If a foam is classified as a fluoroprotein or film forming it will contain PFASs, the only current exception is the recently developed fluorine free film forming firefighting (F5) foam by Angus termed Jetfoam [64]. High expansion foams are not expected to contain PFASs but an exhaustive survey of their chemical components has not been published.

Older formulations of AFFF (1964-2003) contained significant concentrations of PFOS. The sale of firefighting foams containing PFOS ceased in 2003 [65], but many AFFFs marketed as “short-chain” (C6) firefighting foams still contained PFOA (C8) and it’s precursors [66]. From the 1970’s until 2015, there were also fluorotelomer-based AFFF formulations available that contained significant amounts of precursors to PFOA. In 2004 it was reported that AFFF was not a likely source of PFOA [67], but subsequent analysis of C6 based foams revealed that approximately 20% of the PFASs present were PFOA precursors and therefore have the potential to form PFOA in the environment, with the remainder being precursors to short-chain PFAAs [68-70]. As a result of the US EPA PFOA stewardship program between 2006 and 2015 [71], the amount of PFOA or PFOA related substances (i.e. precursors) in firefighting foams was diminished to achieve a maximum of 50 mg/kg in C6-pure foams by 2015 [72]. The current AFFF formulations, referred to as “C6-pure” mainly contain PFASs with six or fewer fluorinated carbons and thus will not result in the release of PFOS, but can form a myriad of short-chain PFASs, including PFHxA in the environment and should contain minor amounts of PFASs that are precursors to PFOA (i.e. <50 mg/kg as fluorine PFOA-precursors).

There are many more proprietary PFASs present in firefighting foam than are regulated. These polyfluorinated precursors evade detection by common analytical methods but in the environment

FOAM TRANSITION

will be transformed to the increasingly regulated perfluorinated PFASs. Firefighting foams, comprise hundreds of individual PFASs which have not been accounted for until recent analytical advances have enabled the total mass of PFASs to be estimated using a novel technology termed the total oxidisable precursor (TOP) assay [69, 73]. In the environment, these polyfluorinated PFASs will slowly transform to create PFAAs, such as PFOS, PFHxA and PFOA. Recognising the science behind this process, regulators in Australia have recently adopted this advanced analytical tool for sampling environmental matrices and compliance. The TOP assay is widely available commercially and may be considered best practice for assessment of PFASs in firefighting foams [40, 74]. However, recent analytical guidance in the U.S. from the Fire Fighting Foam Coalition (FFFC) recommends use of standard analyses [75] to assess PFASs in firefighting foam concentrates, such that the vast majority of PFASs in the fluorotelomer-based firefighting foams would not be detected [40, 76].

ADVANCING REGULATIONS



The increasing detection of PFAS in drinking water above very low regulatory thresholds informed by the available toxicological research, suggests, according to Patrick Breyse, director of the U.S. Center for Disease Control's National Centre for Environmental Health that PFASs are "one of the most seminal public health challenges for the next decades" [77].

Globally, environmental regulations, generally focused on the PFAAs, are rapidly being proposed to very conservative (low) levels. After initial regulatory attention in the late 1990's environmental concerns considering PFASs from the U.S. Environmental Protection Agency were acted on in 2000, when on 16th May it was announced that PFOS, would be withdrawn from sale [78, 79]. Whilst PFOS sales continued until 2003 [65], it took until 2009 before PFOS production and uses were restricted by the Stockholm Convention which classed PFOS as PBT [80]. The Stockholm Convention listed PFOA, as a POP, in 2019 [81] [82] with PFHxS also currently under consideration [83]. There has been a dramatically accelerating focus on PFASs by environmental regulators in the last five years. For example, in 2016, the detection of PFASs in drinking water in the USA, combined with the U.S. Environmental Protection Agency (US EPA) issuing a long-term health advisory level of 70 ng/L (for combination of PFOS and/or PFOA)[84], led to 6.5 million people's drinking water being considered unsafe [85].

There have been calls for a complete ban of the whole class of PFASs [86] [87], but so far this has only been instigated by Denmark in relation to food packaging [88] [11], with Washington State also proposing the same approach [89]

It was noted that the Stockholm Convention Persistent Organic Pollutants Review Committee recently recommended "not to replace fire-

fighting foam that contained or may contain PFOA, its salts and PFOA-related compounds with short-chain per- and polyfluoroalkyl substances (PFASs) due to their persistency and mobility as well as potential negative environmental, human health and socioeconomic impacts"[90].

Advances considering the regulation of firefighting foam use, which also place restrictions on PFASs via limiting use of AFFF, FFFP and FP are also being proposed in multiple countries with regulations in specific US states [91] and Australia [92] proposed or promulgated in the last few years.

REGULATORY RATIONALE

When assessing the environmental or human health impact of anthropogenic chemicals, the following terms are often used to describe how they behave:

- Persistence (P): Compounds that do not break down in the environment over long periods of time (i.e. they do not readily biodegrade).
- Bioaccumulative (B): Compounds that build up and are retained in organisms at a faster rate than they can be removed or expelled.
- Mobility (M): Compounds that can travel long distances in groundwater or surface waters from their point of release.
- Toxicity (T): Compounds impart an adverse health effect to an organism at a relatively low concentration of exposure.
- Biopersistence: Compounds that tend to remain inside an organism, rather than being expelled or broken down.
- Biomagnification: The increased concentration of a compound, such as a toxic chemical, in the tissues of organisms at successively higher (trophic) levels in the food chain.

The use of these terms in relation to environmental risk assessment of differing chemicals has led to the development of criteria and regulations which restrict their production. Historically the global regulations used to assess and restrict use of xenobiotic chemicals has been via Stockholm Convention on Persistent Organic Pollutants. The Stockholm Convention aims to classify xenobiotics as persistent organic pollutants (POPs) using criteria related to their Persistence

(P), Bioaccumulation (B) and Toxicity (T) [93]. The objective of the Stockholm Convention Treaty being to protect human health and the environment from POPs, by assessing their PBT properties to establish which chemicals should be eliminated from use by restricting their production. However, this process is usually focussed on individual chemicals, can take an extensive period of time to assess each single molecule and the PBT criteria have been described to be only marginally effective for protection of drinking water supplies [94], as the PBT criteria seemed aimed to protect the food chain.

Europe

To protect drinking water supplies the mobility of chemicals has been identified as of significant importance [94], this criterion also potentially influences



how difficult it can be to treat water to remove pollutants. There are additional emerging methods to evaluate environmental hazards posed by PFASs. These include assessing persistence, mobility, and toxicity (PMT) and the assessment of very bioaccumulative and very persistent (vPvB) compounds and [95] [31]. Criterion to identify PMT and very persistent and very mobile (vPvM) compounds to protect drinking water supplies were recently published under European Union (EU) Regulation REACH (EC) No 1907/2006 [96]. The

use of these additional criteria to assess environmental effects of PFASs will potentially lead to the identification of a far wider range of PFASs to be restricted under future environmental regulations. Across Europe, the most stringent drinking water guidelines are found across Scandinavia, with Denmark's set at 100 ng/L for the sum of 12 PFASs [34] and Sweden's set at 90 ng/L for the sum of 11 PFASs [35], and certain states in Germany such as Bavaria with 13 individual PFASs regulated to varying acceptance criteria between 0.1 µg /L and 10 µg /L [32]. Lower levels are being proposed by Denmark, with a temporary level of 3 ng/L for PFOS being considered.

There are concerns that these very low levels are potentially higher than some detections in major rivers, such as the 238 ng/L of PFOS reported in the river Severn in the U.K., 32 ng/L PFOS in the river Rhine in Germany, 97 ng/L PFOS in the river Seine in France and 1,371 ng/L of PFOS in the river Krka in Slovenia [97]. A 2018 study of multiple PFASs in 10 major rivers in Asia, Europe and the U.S., where as combination of long and short-chains PFASs were assessed, revealed that the river Thames contained the highest concentration of PFASs with 118 ng/L detected [98].

Given growing evidence of human health risks and potential ecological harm from multiple PFASs, many jurisdictions are now regulating an increasing number of PFASs including both long and short-chain varieties and their precursors [5]. While the short-chain precursors are still commonly used as commercial replacements (e.g. in "C6-pure" fire-fighting foams). Many short-chain (C4-C7) PFASs, introduced as replacements for C8, have also captured the attention of environmental regulators, with short-chain PFASs regulated in Sweden, Denmark, Germany, Italy, Belgium, Switzerland, Canada, and 12 U.S. states. A limited number of the PFAA precursors are now themselves regulated, such as in Sweden, Germany, Denmark, Canada and Switzerland. The regulatory trend is to consider an increasing number of individual PFASs and apply increasingly lower target concentrations. However, as regulations considering PFASs become more comprehensive by addressing a greater

number of individual compounds and become more stringent, the reality of the existing widespread detections or "background" concentrations needs to be appreciated. There have been reports of PFAS detections in rain falling on the island of Malta, with up to 6.3 ng/L PFAS reported, potentially reflecting the potential for certain PFASs to be volatile and travel some distance from a point source [99].

The European Chemicals Agency (ECHA) has recently proposed a European Union (EU) wide restriction that will prevent and reduce the emissions of PFHxA, its salts and related substances within the EU [100]. As PFHxA (along with other short-chain PFAAs) is one of the terminal environmental transformation products of the fluorotelomer PFASs used in C6 fire-fighting foams this restriction has direct impact on the ongoing use of AFFF, FFFP and FP foams. The rationale for the proposed restriction is that PFHxA fulfils the P-criterion and vP-criterion and has mobility and long-range transport potential, with unpredictable and irreversible adverse effects on the environment or human health over time. Exemptions are proposed over a 5 year period for emergency use of fire-fighting foams but there is no exemption for fire testing and training, unless the whole release is contained. However containment without appropriate treatment allowing discharge will be a significant challenge, as is mentioned in later sections, biological treatment is not effective for any PFASs. There is also a 12-year exemption in place for Class B fire-fighting foam user to protect storage tanks, with a surface area above 500m². The proposed restriction was described as being practical because it is affordable, implementable, enforceable and manageable.

European regulations implementing restrictions of PFOA (its salts) at and PFOA-related substances in products will be applicable from 4 July 2020 [101]. PFOA and its salts shall not be used when the concentration of PFOA including its salts exceeds 25 parts per billion (ppb or ug/L) or the concentration of one or a combination of PFOA-related substances exceeds 1000 ppb (or ug/L) in the production of, or placed on the market in: another substance, as a constituent;

FOAM TRANSITION

a mixture; any part of an article. There is a question of whether C6-pure foams contain PFOA-related substances i.e. precursors, below the 1000 ug/L (1 mg/L) threshold, with the target for C8 content (i.e. PFOA and PFOA precursors) from the C8 stewardship program being 50 mg/kg [72] so significantly higher than that restrictions being imposed in Europe in 2020.

The Nordic Council of Ministers recently performed a socioeconomic analysis of environmental and health impacts linked to exposure to PFAS to determine the cost of inaction. The reported estimates for annual health-related costs were €2.8-4.6 billion for the Nordic countries and €52-84 billion for all European Economic Area (EEA) countries [102, 103].

United States

In the U.S. since 2016 the drinking water guidelines focussed on long-chain PFASs, such as PFOS, PFHxS and PFOA have fallen sharply to ever lower target levels. New Jersey is finalising maximum concentration levels (MCLs) for PFOS at 13 ng/L and proposing a 14 ng/L target for PFOA [104], with these levels approved in April 2020 by New Jersey Department of Environmental Protection [105]. These levels were also adopted by the State of California [106], but the California Division of Drinking Water's (DDW) adopted lower notification levels at 6.5 ng/L for PFOS and 5.1 ng/L for

PFOA [107] and the State of New York is finalising MCLs of 10 ng/L for PFOS and PFOA [108] [109]. Vermont has applied a standard of 20 ng/L to a combination of five PFAAs including both long and short-chain PFASs [110], whilst New Hampshire recently announced targets of 12 ng/L for PFOA and 15 ng/L for PFOS [111], Michigan announced a 16 ng/L health based value for PFOS and 8 ng/L for PFOA [112]. During 2019 an increasing number of drinking water supplies have been identified to be affected by PFAS in the U.S. [113, 114], with other businesses such as dairy farms also impacted [61].

In the US regulations addressing the use of firefighting foams containing PFAS have so far been proposed or enacted in 11 States. There are some differences between States, with the main elements of the restrictions in differing States are outlined below [91, 115, 116].

Washington

A new bill was signed into law that expands existing restrictions on PFAS-containing foams. The measure eliminates exemptions included in the state's 2018 law that banned most applications of AFFF, FFFP and FP [115]. The new law will phase out exceptions for the continued manufacture, sale, and distribution of the foams for use in chemical plants, oil refineries, and oil terminals in 2024, unless a waiver is secured. It also would eliminate exemptions for continued

use of the products where required by federal law, effective two years after those federal requirements drop off.

California

The Proposition 65 regulations (Safe Drinking Water and Toxic Enforcement Act) include three routes of exposure for PFAS: Occupational, Consumer and Environmental. With listing of PFOA as developmental toxicant in 2018, discharge prohibition came into effect in 2019.

Colorado

Law prohibits the use of Class B firefighting foam that contains PFAS for training purposes, and violations may result in imposition of a civil penalty. There are limits on the sale of PFAS-containing foam, which requires manufacturers to notify their customers of this law.

Arizona

In 2019, the law prohibiting discharge or other testing or training uses of PFAS-containing Class B foam carves out usage "required by law or federal regulation."

Virginia

As of 2019, there are restrictions on the use of PFAS-containing foams for training and testing while allowing continued use for real world fires.

Kentucky

As of 2020, there is a ban on uncontained release of PFAS-containing foams, unless



it's an emergency.

Georgia

There is a 2019 house bill ruling to restrict the use of PFAS-containing foams for training and testing, while allowing continued use for real world fires.

New York

In 2019, a law banned the use of PFAS-containing Class B foams for training purposes, and will prohibit their manufacture, sale, or distribution two years later. There are certain exemptions, such as when the products' use is required by federal law or to fight fires at oil refineries or chemical plants.

Minnesota

A 2019 law prohibits PFAS-containing Class B foam for testing or training, unless required by federal law, but excludes from this ban use of AFFF in emergency firefighting and fire prevention activities. Any release of PFAS-containing Class B foam must be reported within 24 hours.

Wisconsin

A 2020 law bans the use of PFAS-containing foam for training purposes. The foams will be allowed for use in emergency firefighting and testing purposes, although testing facilities must implement "appropriate containment, treatment, and disposal or storage measures to prevent discharges of the foam to the environment." Legislation will take effect on 1 September 2020 [117].

Michigan

In 2019, a bill was proposed that would ban the use of PFAS-containing foam during firefighting training, beginning on 31 December 2023. And until that date, firefighters would need to be instructed on the proper use, handling, and storage of the foams, as well as on containment and proper disposal. Further bills outlines the "best health practices" for using, handling, and storing the foam, including decontamination of a firefighter's body and equipment and would require that fire departments submit a written report to the State within 48 hours of using an AFFF.

Australia

In Australia the key pieces of legislation guiding the management of firefighting foam include the PFAS

National Environmental Management Plan (NEMP) and the Queensland Environmental Management of Firefighting Foam, Operational Policy. The regulation of PFAS in Australia is undertaken by the regulatory agencies in each state or territory. However, an intergovernmental agreement on a National Framework for Responding to PFAS Contamination has been signed by each Australian state and territory. A key action item of the agreement is the implementation of the PFAS NEMP which has been endorsed by the Heads of EPAs in Australia and New Zealand (HEPA). While this legislation does not provide specific guidance on foam transition or include recommendations for acceptable concentrations of PFAS in AFFF or other foams, it provides guidance on the assessment, management and remediation of PFAS contaminated sites and materials, and references key criteria protective of the human health and the environment which do apply to the management of foam fire suppression systems.

In 2016, the Queensland Department of Environment and Science (DES) introduced a policy for the management of firefighting foam, including the phase out of PFOA and PFOS-based AFFF. The compliance for the policy came due on 07 July 2019, in which foam users were required to comply with the policy or provide justification and a compliance plan to avoid non-compliance. [118].

For foam concentrates, the policy stipulates a limit on fluorinated organic compounds in concentrates equivalent to <10 mg/kg PFOS+PFHxS and <50 mg/kg C7-C14 as fluorine, based on TOP Assay. For foam mixes and wastewater generated from foam system testing and decontamination, the Interim Contaminated Water (waste) criteria stipulates a limit on foam-water mixtures of 1.0 µg/L for C4-C14 perfluorinated carboxylates plus C4-C8 perfluorinated sulphonates following oxidation using the TOP Assay. A limit of 0.3 µg/L also applies to each of PFOS and PFOA measured in accordance with US EPA Method 537.1. These criteria apply to any liquids released from the foam system including foam mix discharged during a test or fire event, fire water supply, and concentrate should there be loss of containment.

Given foams are typically proportioned with between 1-10% concentrate by volume, it is possible to use a concentrate that is compliant with the Queensland Foam Policy but produces a foam with PFAS concentrations above the interim PFAS contaminated water criteria.

The policy provides also outlines further requirements for the off-site disposal of waste foam concentrate and contaminated water. Specifically, the policy states that "Notwithstanding that firefighting foams containing PFOS and PFOA must not be held or used, water contaminated by fluorinated organic compounds must not be released to the environment if the levels of fluorinated organics exceed 0.3 µg/L PFOS, 0.3 µg/L PFOA and 1.0 µg/L for sum of TOP Assay C4-C14 plus C4-C8 sulfonates."

In January 2018, the South Australian government amended the Environment Protection (Water Quality) Policy 2015 under the Environmental Protection Act 1993 to ban the use of potentially hazardous fluorinated firefighting foams.

Under this legislation, all PFAS containing firefighting foams are banned and there is no maximum allowable concentration for PFAS in operational foams used in South Australia.

Summary

As environmental regulation advance to include multiple PFASs, including both long (C8) and short (C6) chain varieties, it seems prudent that owners and operators of high-hazard facilities that require the use of PFAS-containing Class B foam products may need to consider the environmental liabilities associated with the continued or historical use of these foams. Additionally, training and use of some AFFF, FFFP and FP foams may still be an ongoing activity at high-hazard sites.

It may be wise to consider the future potential environmental liabilities of the historical and continued use of all PFAS-containing foams. This may be particularly important if the high-hazard site is situated on an aquifer used as a drinking water supply or used by a business that manufactures foodstuffs, such as a dairy. Over the last two years, there has been a rise in the number of firefighting foam related sites that are being investigated

FOAM TRANSITION

to evaluate environmental and human health impacts thus requiring potential future clean up via remediation. The opportunity to transition to F3 foams as soon as practicable appears to be a wise commercial decision considering the fast pace of advancing environmental regulations addressing PFASs and those restricting use of AFFF, FFFP and FP.

THE EFFECTIVENESS OF F3 FOAM

Environmental and public health concerns regarding PFASs have been developing since 2000 and has stimulated significant innovation to create F3 foams. As a result over the last 20 years, firefighting foams and their delivery systems have evolved to be far more effective, without a need for PFASs in most circumstances [36, 119, 120]. The new generation of F3 foams have been available since the early 2000's and are increasingly being used globally [7]. The first F3 foams were successfully tested at large scale in 2002 [32], with evolving improvements in performance.

AFFF is essentially a technology developed in the 1960's, [121] that has now been replaced by many users, with more modern, next-generation F3 foams.

Testing of new generation F3 foams is ongoing with an extensive number of foam manufacturing companies now providing F3 foams, the performance of which has steadily improved as they continually evolve and are optimised. Currently, the following foam vendors supply F3 foams for multiple commercial application systems for use on several different fire scenarios: Perimeter (Solberg/ Auxquimia), National Foam, Angus, Dr Sthamer, Bio-Ex, Novacool, Fomtech, 3F, Chemguard, Aberdeen Foam, FireRein, FireFreeze Worldwide, Orchidee Fire, Pyrocool Technologies, Verde Environmental Inc, Tyco, VS Focum and FoamFatale.

The industry group LASTFIRE, which is funded on a non-profit basis by fuel storage companies, develops best practice guidance for storage tank protection, free from the often commercial bias of foam manufacturers [122]. LASTFIRE has carried out an extensive series of tests using "new

generation" foams of both C6 and F3 types. These tests were aimed specifically at storage tank related scenarios but have relevance to all foam applications. Fire tests have involved a range of incident scenarios including tank fires, dike area fires and general spill fires as well as standard test protocols such as EN1568 and LASTFIRE. The LASTFIRE standard test protocol was developed, initially by Mobil Research and Development Corporation but finalised by LASTFIRE, specifically to evaluate foam performance for the critical application of tank fires – an example of a test simulating a specific application, as all performance-based tests should be for critical situations. The work of LASTFIRE is ongoing but the most recent large-scale tests involved 40m x 7m spill fires with JetA fuel and were carried out in cooperation with Airport Research and Training Facility.

LASTFIRE are keen to emphasise that the research is ongoing and further tests are planned. Conclusions regarding foam performance should not be generic, as there are examples of varying levels of effectiveness and performance for each foam category on the market. The results show that F3 Foams can successfully extinguish both spill and tank fires using standard application rates – and indeed at more critical application rates too, given the correct application

conventional aspirating foam pourer. Comparative testing with conventional application devices was carried out on tank scenarios as part of the overall series.

LASTFIRE have also developed a "best practice" covering assurance protocol involving all stages of foam procurement, application, management and ultimately disposal. Again, this is aimed specifically at storage tank application but the principles and most of the detail is applicable to all foam application including aviation. The work of LASTFIRE is complemented by that of the Etank Project carried out by RISE in Stockholm which included the use of F3 foam on water soluble fuels.

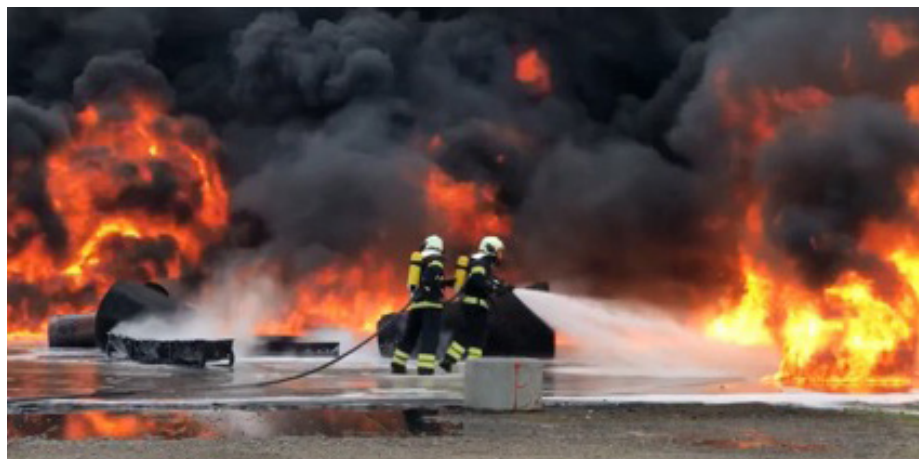
Fires need to be extinguished quickly to limit the damage and harm to people, environment and assets. For large Class-B fires there is the perception of uncertainty regarding the performance F3 foams, however there is also uncertainty regarding the performance of C6-pure AFFF as these foams are also untested for large scale fire extinguishment. However, firefighters have been choosing foam containing PFAS, when both C6-pure foams and F3 foams offer comparable extinguishment performance.

In the Oil and Gas sector, Equinor



techniques and foam quality. Application techniques tested have included both forceful (monitor) and gentle (pourer) conventional proprietary aspirating and "non-aspirating" devices. An interesting part of the work is testing of alternative application methods including CAF and Self Expanding Foam. In the DFW test for example, the 40-m long test pan with Jet A fuel was efficiently and effectively extinguished using a CAF foam pourer at 50% of the application rate of a

(formerly Statoil) are responsible for ~50% of total production in the North Sea totalling some 2.5 million barrels a day, and comment "We regard the new fluorine-free foam as a fully acceptable and even better replacement for AFFF" [8]. Other oil companies have transitioned to F3 foams for some applications and are committed to doing so completely when further testing is completed



Feedback regarding the performance of F3 foams from Graeme Day (London Heathrow Airports Fire Service Compliance Manager), following successful transition of F3 foams at Heathrow Airport, included that F3 foam has “no operational problems and performs perfectly in an ARFF setting”, and “environmental impact and consequential remediation and clean-up costs of using a fluorine-free foam compared to AFFF, FFFP, or FP are effectively zero and firewater runoff can be discharged directly to ground or drainage systems”. Graeme continued “Since purchasing our fluorine free foam, we have used it on two separate aircraft fires (an A321 and a 787) and it worked perfectly. Furthermore, the clean-up costs from these incidents were zero as following tests of the fire ground water runoff by the UK Environment Agency and local water company, we were given permission to wash the foam solution into Heathrow’s surface water drainage system. This meant that the affected runways were available for use very quickly which had obvious financial benefits for Heathrow.

The Royal Danish Airforce has been using F3 foams for several years, with an ethos of “Train as you Fight”, as the Danish Airforce trains with the same firefighting foams and fuels as encountered in real life incidents, with their confidence extinguishing fires using F3 foams evident as a result. Lars Andersen the Fire-Chief stated that “my experience is that fluorine free foam works flawlessly” [123, 124]. Following recent testing exercises with F3 foams Lars stated “Put yourself in the place of a crewmember trapped in a fuselage engulfed in flames. Ask yourself a

question; would I trust the fluorine free foam? I would” [125].

F3 FOAM ENVIRONMENTAL PROFILE

Clean Product Action have recently developed a GreenScreen Certified™ standard for firefighting foams. Certification depends on foam manufacturers providing a full product inventory to Clean Product Action under a confidentiality agreement. Clean Product Action then reviews all the relevant environmental and human health data. The data requirements vary by certification level and include: GreenScreen List Translator™ scores and GreenScreen Benchmark scores; product-level acute aquatic toxicity data for fish, aquatic invertebrates and algae; ingredient-level aquatic toxicity and fate data meet USEPA Safer choice criteria (Master criteria or Direct Release criteria). The restricted ingredients include: organohalogens, PFASs, siloxanes, alkyl phenols & alkylphenol ethoxylates and chemicals listed under the Manufacturing Restricted Substances List (MRSL). There are three levels of certification: Bronze, Silver and Gold. The first four companies with certified products are Angus Fire Ltd, BIOEX, National Foam Inc., and Verde Environmental, Inc.

To assist with ensuring that all brands of F3 foams do not pose a future environmental hazard it is suggested that foam suppliers confirm that all organic components of the foams, irrespective of concentration can be confirmed to be readily biodegradable as per Organization for Economic Cooperation

and Development (OECD) guidelines [126]. They should also confirm that there are no carcinogenic, mutagenic and reprotoxic substances (CMR) in the F3 foam formulations to help ensure the safety of the foams to firefighters. Consideration of the very comprehensive Queensland Department of Heritage and Environmental Guidance Policy regarding Firefighting Foams [127] [128], could help guide policy in many jurisdictions.

To verify that F3 foams are fluorine free and do not contain PFAS it is recommend that test are performed with TOP Assay and Total Organic Fluorine (TOF) by Combustion Ion Chromatography (CIC) as both methods are now commercially available [129].

AFFF MANAGEMENT AND TRANSITION

When considering foam transition one of



the firefighting foam stocks and classify them based on occurrence of PFOS, PFOA, 6:2FTS, PFOA and PFHxA-precursors (C6 foams) or dominantly 6:2 FTS and PFHxA precursors (C6-pure foams). There may be a perceived priority to remove PFOS- and PFOA-containing AFFF from stock as C6-pure foams can sometimes pose less current liability than legacy AFFF stocks. However there are concerns that the short chain PFASs and precursors present in these foams are increasingly being regulated. Best practice at this time includes at a minimum, eliminating fire training and nozzle/coverage testing with AFFF, complete containment during proportioning testing, and proper clean-out of equipment to limit environmental releases of the new foam, which contain short chain PFASs that are proposed to

FOAM TRANSITION

be regulated.

Decontamination of firefighting and fire suppression equipment is essential to limit carryover of PFASs from old foam usage. Triple rinse with water is not sufficient and leads to a significant volume of decontamination water that requires treatment. Arcadis recommends using specialized biodegradable cleaning agents such as V171 to effectively remove PFAS residuals from fire suppression systems to limit future liabilities and cost associated with PFAS contaminating F3 foams as a result of inadequate decontamination.

The transition to F3 foam will require foam supply system modifications, but more and more stakeholders are recognizing the benefits of eliminating PFAS from fire suppression and firefighting strategies.

FOAM TRANSITION TEAM

One of the first issues to address in planning for transition from AFFF and fluoroprotein foams to F3 is bringing

fire engineering, fire service contracting, and environmental engineering into the process from the beginning. Failing to bring a team with the required skill set could result in a project which delivers fire protection equipment that is incompatible with the new foam, a fire protection system that does not meet accreditation requirements for insurance and regulators, cross contamination of the F3 foam with PFAS and undocumented and irregular disposal of PFAS-impacted waste. Neglecting to assemble a comprehensive team is likely to result in a rework of the fire protection system at significant additional cost.

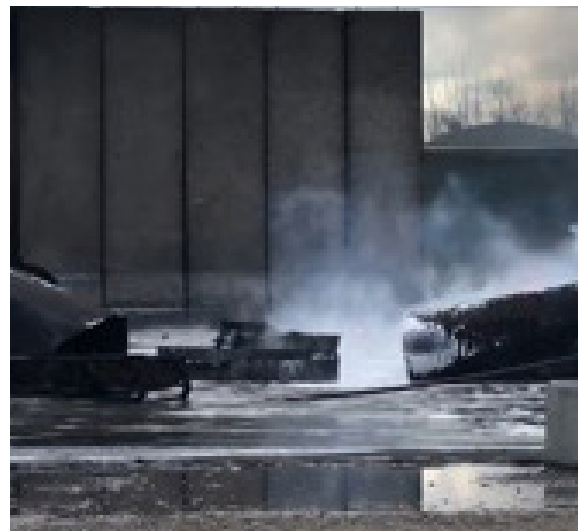
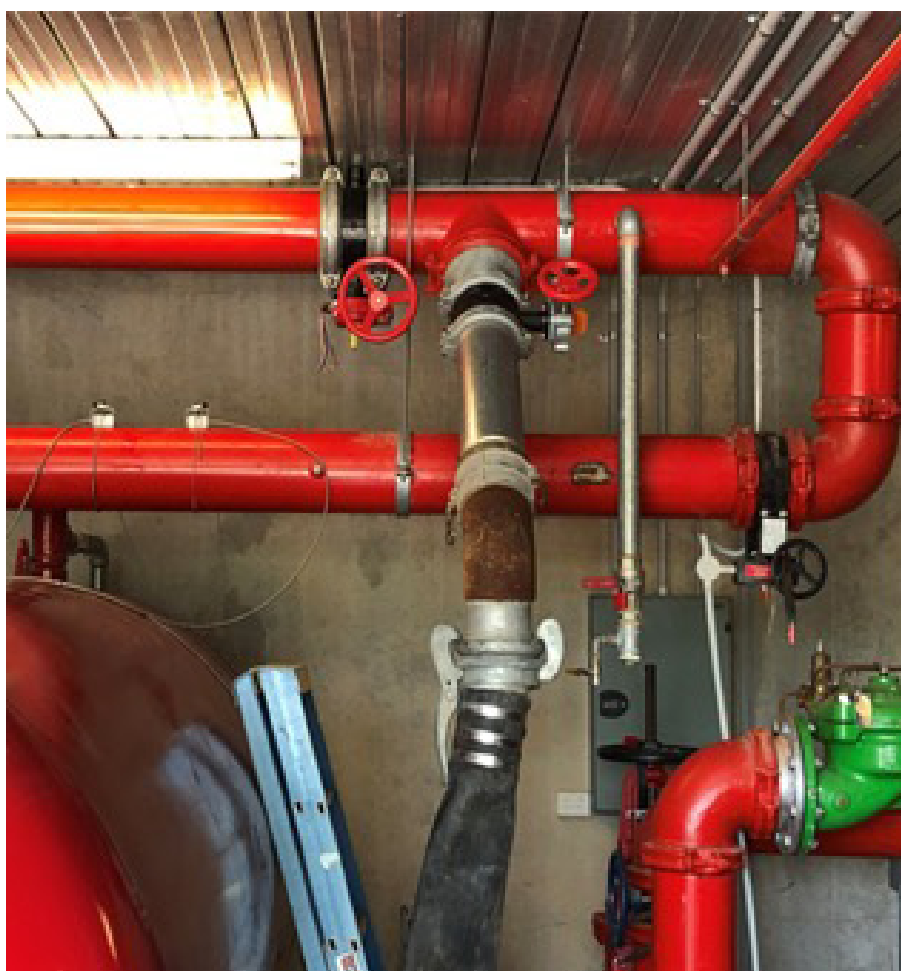
Successful foam transition projects often start with fire and environmental engineers working closely with the end users to select the best F3 foam to meet the project needs. Then, collaboration on a cost benefit analysis that balances the feasibility to replace equipment with the viability to cleanout and manage residual PFAS, will result in a more cost-effective transition. Effective designs must address containment and management

of foam mixtures to meet the fast-changing environmental regulations and reduce future environmental liability. Environmental policy and regulations are changing more rapidly than fire protection codes and standards. Therefore, the collaboration of fire and environmental engineering from the beginning can help avoid lengthy delays in approvals of foam transition plans and the final commissioning of fire protection systems.

Minor modifications to existing fire protection systems are commonly required with F3 foam replacements to ensure appropriate standards for proportioning and flow requirements are achieved, and often to maintain accreditation for insurance coverage. To ensure proper performance, it is now common practice for existing foam proportioners to be replaced with units tested and accredited with the replacement foam. For most cases, performance requirements cannot be achieved without the tested and certified proportioner. Foam application rate and discharge duration are often impacted by the differing physiochemical properties of the replacement foam. One clear example is kinematic viscosity, which will affect the performance of pumps and storage volumes of concentrate. The switch to aspirated discharge devices typically increases replacement foam performance and reduces the need for more extensive system modifications.

CLEANOUT CHALLENGES

The PFASs used in firefighting foams are high-performance surfactants. They



FOAM TRANSITION

water systems occur. Therefore, the investigation of fire water systems should be included as an important component of foam transition planning.

EQUIPMENT REPLACEMENT VERSUS CLEANOUT AND RETAIN

Underground or elevated piping conveying concentrate or foam mix can be very costly to remove and replace. Therefore, decontamination and reuse or abandonment in place can be the more cost-effective solution. From experience with multiple fire suppression systems, valves of all types can potentially be difficult to clean and therefore the replacement of such components as deluge valves, alarm check valves, and solenoid valves, can help avoid PFAS rebound. As mentioned previously, a thorough cost benefit analysis by a team of fire and environmental engineers can identify those components best retained

and those best replaced.

DECONTAMINATION CASE STUDIES

Arcadis developed and then successfully applied cleaning agents to remove PFASs from surfaces at field scale in Australia in 2017. When a foam concentrate was released to a sewer system, the complete network of piping, pump stations, and concrete wet wells was shut down, and then decontaminated to remove residual PFAS. During this process, more than 600 waste tanks were cleaned to remove PFAS residual from surfaces. Since then, several successful piping system decontamination projects have been implemented in Australia, Europe and the U.S.

Arcadis has used cleaning agents to remove PFASs from the surface of PVC pipes, stainless-steel tanks and hangar sprinkler piping and is currently progressing completion of a foam change out using the agents at multiple

large commercial hangars. The initial PFAS cleanout project in 2017 used a sequential series of aqueous rinses, high-pH flushes and application of the cleaning agent as shown in Figure 3. presenting Sum of PFAS (28) TOP Assay results. The results demonstrated that water and high pH are ineffective for removal of PFASs from surfaces, as demonstrated by the relatively low concentrations of PFASs measured in these flush solutions. The elevated concentration in the cleaning agent demonstrated significantly greater PFAS mass removal even after multiple flushes of water and caustic solution. Further work to clean PFASs out of a 20-m³ foam concentrate tank was conducted and results are presented in Figure 4. This application demonstrated that soaking with the cleaning agent, followed by high-pressure washing can be effective. The importance of using TOP assay for analysis of PFASs was revealed

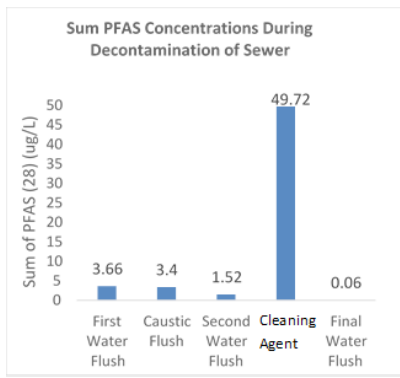


Figure 3 Sum of PFAS Concentrations During Decontamination of AFFF-Impacted Sewer System

during this work as it was shown that this method is essential to detect PFASs associated with AFFF, with conventional

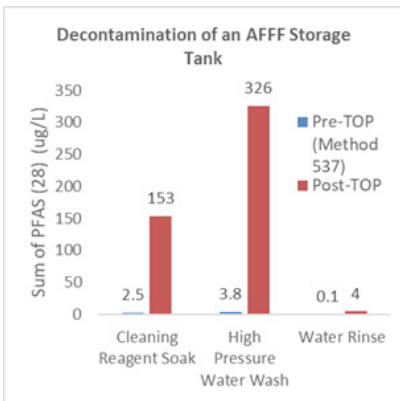


Figure 4 Sum of PFAS Concentrations During Decontamination of 20-m³ Concentrate Tank

analysis only detecting approximately one-percent of the PFASs identified using the TOP assay.



WASTE MANAGEMENT

From a waste treatment perspective, wastes generated during foam transition include AFFF, FFFP, or FP concentrate, foam mix from proportioning test work, fire water drainage, decontamination solutions, and solid waste in the form of impacted piping, components, and tank bladders.

If all the organic components of a firefighting foam are assessed to be readily biodegradable, they could be effectively managed using a biological wastewater treatment plant (WWTP). For example, discharge to a sewer system for a biodegradable foam mix generated from a proportioning test considered, with regulatory and utility approval, as an appropriate disposal method. The converse is true for any foam containing PFASs, such as AFFF, FFFP and FP, as they are extremely persistent organic compounds which do not biodegrade so cannot be treated using sewerage and conventional WWTPs. Alternative treatment systems such as the use of granular activated carbon (GAC) for the long chain PFASs and ion exchange resin (IX) for the short chain PFASs could be

applied to treat firewater impacted with PFASs. However, the performance of GAC and resin treatment systems can be severely compromised by other organic compounds in the foam matrix (e.g. natural organic matter, glycols) which can coat adsorption sites, and inorganics (e.g. natural anions) which compete with PFAS for binding capacity. Foam fractionation is one alternative treatment process that will not be impacted by co-contaminants.

There are significant challenges and costs associated with disposal of fluorinated firefighting foam concentrates i.e. AFFF, FP, FFFP and their (alcohol resistant) AR-variations. The use of incineration has recently been questioned in the U.S. as a result of the uncertainty relating to complete destruction of PFASs when incinerating liquids, potentially resulting in aerial emissions of fluoro-organics such as tetrafluoromethane and perfluoroisobutylene. Other waste treatment alternatives such as cement kilns as demonstrated in Australia show promise as a practical destruction process because of the high temperatures, long residence time, and excess calcium that takes up fluorine. However, along with incineration, cement kilns may also require comprehensive assessment of organo-fluorine compounds in air emissions.

Arcadis has furthered the development of destructive methods for PFASs which operate effectively at ambient temperature, using ultrasound. This approach is termed sonolysis and it can destroy PFASs, mineralising them to form fluoride and carbon dioxide, at temperatures around 30oC. This technology is being scaled up and

adapted with pre-treatment technologies to address firefighting foam concentrates, so PFASs in these foams can be destroyed without aerial emissions.

CONCLUSIONS

Due to reputational risks, regulatory changes and potential litigation, many foam users are transitioning away from oams containing PFASs including both the C8 and C6 products. F3 foams are widely available and used across multiple sectors due to their effective fire protection in most situations. Increased confidence in F3 foam performance and developing environmental concerns regarding C8/C6 foams has accelerated foam transition.

Balancing fire safety by using effective F3 foams to alleviate environmental liabilities is now generally perceived as essential [130], as regulatory agencies begin to appreciate the risk and cost to society imposed by firefighting with PFASs.

In the next few years the pace of transition to F3 foams will accelerate. Ensuring that the replacement F3 foams are not contaminated with PFASs as a result of residuals coating the interior of fire suppression systems will become increasingly important, especially taking into account the diminishing regulatory criteria for PFASs.

A webinar with more details describing the performance of F3 foams, with examples of foam transition projects is available at http://theic2.org/ic2_webinar_ffff.



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