THE GLOBAL PFAS PROBLEM: FLUORINE-FREE ALTERNATIVES AS SOLUTIONS

FIREFIGHTING FOAMS AND OTHER SOURCES – GOING FLUORINE-FREE

IPEN Expert Panel
Stockholm Convention 9th Conference of the Parties (COP9)
Geneva

April-May 2019

IPEN
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THE GLOBAL PFAS PROBLEM: FLUORINE-FREE ALTERNATIVES AS SOLUTIONS – HAS TIME RUN OUT FOR SHORT-CHAIN REPLACEMENTS FOR C8 PFAS?

FIREFIGHTING FOAMS, TEXTILES, FABRICS AND OTHER SOURCES OF PFAS DISPERSAL AND CONTAMINATION

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representing the IPEN Panel of Independent Experts

White Paper prepared for IPEN by members of the IPEN Expert Panel and associates for the meeting of the Stockholm Convention Conference of the Parties (COP9), 29 April – 10 May 2019, Geneva, Switzerland.

Cite this publication as:

IPEN 2019/Stockholm Convention COP-9 White Paper, *The Global PFAS Problem: Fluorine-Free Alternatives As Solutions*.

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for a toxics-free future

IPEN is a network of non-governmental organizations working in more than 100 countries to reduce and eliminate the harm to human health and the environment from toxic chemicals.

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This document has been produced with the financial contribution by the Swedish International Development Co-operation Agency (SIDA) through the Swedish Society for Nature Conservation (SSNC). The views herein shall not necessarily be taken to reflect the official opinion of SSNC or its donors.

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FOREWORD

At the Stockholm Convention Conference of the Parties (COP-9) in Geneva, delegates from 182 nations will meet to make critical decisions that have global implications for environmental and human health. The Conference of the Parties will decide about the listing of new POPs, including perfluorooctanoic acid (PFOA). The COP will also decide whether to close loopholes pertaining to the listing of PFOS.

IPEN respectfully presents *The Global PFAS Problem: Fluorine-Free Alternatives as Solutions*. The paper was prepared by thirteen independent experts in the fields of chemistry, environmental science, health, product formulation, remediation, engineering, fire safety, regulation and policy development. We hope that the paper is useful in informing decisions toward the global elimination of PFOA and PFOS, as well as toward the elimination of per- and polyfluorinated substances (PFAS) as a class by preventing their regrettable substitution with short-chain fluorinated alternatives. This paper builds on the findings presented in the IPEN paper prepared for the POPs Review Committee (POPRC-14, September 2018) entitled *Fluorine-Free Firefighting Foams (F3): Viable Alternatives to Fluorinated Film-Forming Foams (AFFF)*.[1] The current paper investigates additional sources and dispersive uses of PFAS, harm to public health and the environment, and socio-economic consequences.

The expert committee of the Stockholm Convention, the POPs Review Committee (POPRC), determined that PFOA is likely, as a result of long-range environmental transport, to lead to significant adverse effects on human health and/or the environment such that global action is warranted. For consideration at COP-9, the POPRC recommended the listing of PFOA. The POPRC also recommended strengthening the listing of PFOS in the treaty. Regarding a major dispersive use, the POPRC determined that fluorinated alternatives to PFOA and PFOS in firefighting foams should not be used, “due to their persistence and mobility, as well as their potential negative environmental, human health and socioeconomic impacts.” (POPRC-14/2)

The paper presents compelling evidence of the efficacy of fluorine-free alternatives to replace a major dispersive use of PFOA and PFOS in aqueous film-forming foams used in firefighting. Indeed, replacement of PFAS-based firefighting foam with fluorine-free alternatives is a moral and socioeconomic imperative given the long-term harm to environmental and public health, immensely high costs of clean up, and liability concerns.

The Stockholm Convention clearly mandates that Parties must decide on listing “in a precautionary manner.” This means prioritizing the Convention’s promise to protect human health and the environment from POPs in the listing of new chemicals, including PFOA. PFOA should be listed in Annex A for global elimination with no exemptions. This same promise also applies to evaluating the listing of PFOS and the necessity of strengthening the listing by eliminating various acceptable purposes and specific exemptions.

A recent Nordic Council of Ministers report, The Cost of Inaction: A Socioeconomic Analysis of Environmental and Health Impacts Linked to Exposure to PFAS, made significant conclusions including that “a large and growing number of health effects have been linked to PFAS exposure and evidence is mounting that effects occur even at background level exposures.” In assessing the adverse human health effects of PFOA (UNEP/POPS/POPRC.12/11/Add.2), the POPRC noted that the International Agency for Research on Cancer classifies PFOA as a Class 2B carcinogen with particular regard to testicular and kidney cancers. The Risk Profile also summarizes epidemiological evidence linking PFOA exposure with high cholesterol, inflammatory diseases, ulcerative colitis, thyroid disease, immune effects, pregnancy-induced hypertension, endocrine disruption and impaired neuro- as well as reproductive development.

In presenting testimony to a U.S. Senate hearing on March 28, 2019, Dr. Linda Birnbaum, Director of the National Institute of Environmental Health Sciences and the National Toxicology Program highlighted the immunotoxicity of PFOA and PFOS, noting that the National Toxicology Program “conducted a systematic literature review which concluded that PFOA and PFOS are presumed to be a hazard to healthy immune system function in humans.” She also stated that “approaching PFAS as a class for assessing exposure and biological impact is the most prudent approach to protect public health.”

Global action to eliminate PFOA, PFOS and the class of PFAS chemicals, is urgently needed and essential to prevent further harm.

Pamela Miller
IPEN Co-Chair

Dr. Tadesse Amera
IPEN Co-Chair

April 2019

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[1] Available at: https://ipen.org/documents/fluorine-free-firefighting-foams

THE GLOBAL PFAS PROBLEM: A NEW REPORT BY THE IPEN EXPERT PANEL

An agreed Position Paper by an Expert Panel assembled on behalf of IPEN for presentation to the Stockholm Convention COP-9 meeting in Geneva, April-May 2019. The panel was convened as the result of an initiative by the International POPs Elimination Network (IPEN) (Pamela Miller and Dr. Tadesse Amera, Co-Chairs of IPEN), a global network of approximately 500 NGOs worldwide. The panel members were tasked to provide expert opinion and an agreed position to inform COP-9 on the issue of pollution by PFAS relevant to current deliberations including PFOA, PFOS and PFHxS from diverse sources that are having growing, widespread and considerable socio-economic, health and environmental impacts due to the extremely persistent, dispersive, toxic, bio-accumulative, fluorochemical (PFAS) content.

Apart from the well-known, contentious and problematic use of PFAS in firefighting foam PFAS use commonly extends across a very wide range of other applications including textile and leather treatments, food wrappers, paint additives, electronics, automotive, hydraulics, metal plating, photoresists, stain resistant coatings, polishes, cleaning agents and surfactants in various industrial processes. All of these uses can eventually result in releases to the environment due to the difficulty of containment and the indefinite persistence of PFAS. The early PFAS applications using PFOS and PFOA have mostly been replaced by a vast and growing diversity of related fluorotelomer and fluoropolymer compounds that are of no less concern in their own right as well as eventually transforming to end-point compounds related to PFOS and PFOA.

While much of the recent attention and research on the PFAS problem has focussed on the effects of large-volumes of PFAS firefighting foam there has been the realisation that the less obvious, diffuse sources of PFAS pollution by the thousands more PFOA related compounds, as outlined above and extensively in the scientific literature, are of equal or greater scale and significance. The research and learnings from firefighting foam PFAS pollution are directly applicable to and a sound model for dealing with the broader problem of assessing overall PFAS release sources and pollution.

The IPEN Expert Panel brought together for this White Paper has the breadth of knowledge and experience to provide valuable insights into the overall and less obvious problems of PFAS pollution in the context of the Stockholm Convention across all PFAS sources. The Panel's experience and expertise also provides practical direction on the assessment and management of the socio-economic, health, contamination, remediation and environmental problems attached to legacy and current PFAS use.

The expert panel consists of the following members together with their areas of expertise:

Dr. Thierry BLUTEAU

Leia Laboratories, Ormskirk UK and Essertines-en-Donzy (Lyon) France, PhD chemist; foam formulator and developer; formerly Croda-Kerr and Bio-Ex; developed Ecopol™ fluorine-free foam: also solvent-free and fluorine-free firefighting foams. free foam; he graduated in Paris University with a Masters in biochemistry, followed by a PhD in pharmaco-chemistry; he initiated work in firefighting technologies in 1992, as laboratory manager at Croda Fire Fighting in France; 6 years later, he created Bio-Ex, a company which specialized in firefighting foams, where he launched one of the first commercial Class B fluoro-free foams (Ecopol); in 2012 he started collaborating with 3FFF Ltd to design a new line of foams; later on, he joined Leia Ltd, where he has dedicated his time to creating innovative foams and as well as advising customers on specific firefighting projects; his latest achievement was presented by 3FFF Ltd in 2015 with the launch of Smart Foams™, a range of new foams totally free of fluorinated materials and solvents, with highly favourable ecological profile.

Dipl. Ing. Martin CORNELSEN

Qualified water treatment engineer; Dipl.Ing., MSc; development of a technically simple multi-tiered small filter system for the treatment of polluted water to drinking water in underdeveloped rural areas of advanced materials and processes for water and wastewater treatment using functional nanocomposites (BMBF - Federal Ministry of Education and Research, 2012-2013); development of a cost-effective adsorption process to purify water contaminated by PFAS (BMWi - Federal Ministry for Economic Affairs and Energy, 2010-2011); development of a liquid product (no adsorbent) for the cost-effective cleaning of water contaminated by PFAS (BMWi, 2013-2015); development and manufacture of textile adsorbant material for the remediation of water contaminated by chromates (BMWi, 2014-2016); recovery of precious metals from the waste streams of metal processing industries with the aid of fibre-fixed adsorbants (BMBF, 2016 until probably 2018); development of methodology for eliminating PFAS from water polluted by fire extinguishing agents (BMBF, 2016 -2018). Martin is bilingual in German and English.

Graeme DAY

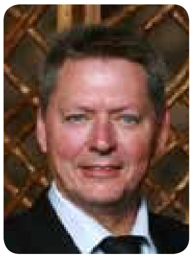
Fire Service Regulation & Oversight Manager Operations, London Heathrow Airport; Kent Fire & Rescue Service 1979; operated at a strategic management level in the Fire and Rescue Service since April 2001; completed the Civil Aviation Authority (CAA) Airport Fire Officer (Grade 1) course and the UK National Level 4 Strategic Fire Command and Control course; liaison officer to Gatwick Airport with the (then) BAA fire service, Civil Aviation Authority (CAA), Air Accident Investigation Branch (AAIB) and Royal Air Force; represented West Sussex Fire and Rescue Service at local, national and international levels; developing partnerships with a variety of private sector organisations contributing to the development of firefighting procedures, i.e., the fire service operational manual relating to aviation incidents; ARFFWG and the pan-Europe Aviation Regions Conference (ARC); chair Gatwick Airport Resilience Planning Group; Training and Support Resilience Working Groups; Master of Business Administration (MBA); Fire and Rescue Service's Search and Rescue Team 1999; Turkish earthquake as Field Commander 2003; Chemical, Biological, Radiological and Nuclear (CBRN) Cadre Officer; WSFRS Principal Leadership Team; Chief Operations Officer WSFRS; NEBOSH Diploma; Fire and Resilience Directorate (FRD); Enhanced Command Support (ECS) vehicles, ECS training, procedures and support mechanisms to the Fire and Rescue Services (FRS) of England; EU Community Mechanism for Cooperation in Civil Protection University of Rome; currently the Regulation and Oversight Manager for Heathrow Airport's Rescue and Fire Fighting Service (RFFS); liaising frequently with the European Aviation Safety Agency (EASA) and UK Civil Aviation Authority; member of the CAA RFFS Vehicle Rollover Group; chair UK Airport Operators Association (AOA) RFFS Working Group; represents Heathrow Airport on the USA National Fire Protection Association (NFPA) RFFS Technical Committee, NFPA foam sub-committee; International Civil Aviation Organisation (ICAO); managing the change from AFFF to an ICAO Level B compliant fluorine and organo-halogen free firefighting foam; member EASA Rule Making Task Group (RMT 0589); chair RFFS working group Airports Council International (ACI) Europe.; member of the UK National Fire Chiefs Council (NFCC) Operational Guidance Forum and Strategic Engagement Forum; UK Defence Fire & Rescue Management Board; ISO 9002 qualified auditor.

Nigel HOLMES

Nigel Holmes is Principal Advisor Incident Management for the Queensland Department of Environment and Science (DES), the regulatory body for pollution management in Queensland; his role is as a state-wide resource advising on policy, standards, risk assessment, preparedness and response for incidents involving a diversity of hazardous materials. He also has over 30 years' multi-disciplinary experience in consulting and government roles across environmental, geotechnical and contamination assessment, regulation and policy development for land, marine, freshwater and groundwater pollution assessment, industry licensing, remediation, aquaculture and geotechnical assessment; since 2012 he has been the project coordinator for the review, development and drafting of the Queensland Environmental Management of Firefighting Foam Operational Policy supported by extensive advice and input from a very wide range of Australian and international subject experts; provision of expert advice on risks of fluorinated organic compounds: to foam end-users, suppliers and regulators across Australia on the practical assessment and management of risks posed by existing and proposed use of firefighting foams; Liaison with interstate and overseas agencies on consistency of regulatory measures: Promoting consistency in the practical, achievable and economic regulation of PFAS; Facilitation of new analytical methods for PFAS risk assessment: Promoting the refinement of the total oxidisable precursor assay (TOP-A) and incorporation into Policy as a more comprehensive method than the limited standard PFAS suite; Queensland foam Policy implementation and compliance plan: Identification of industry sectors with PFAS firefighting foam and development of strategies and guidance on the practical transition to best-practice for foam use; expert witness to the 2015 Victorian Parliamentary Inquiry into CFA Fiskville PFAS contamination.

Dr. Roger A. KLEIN

Panel coordinator; currently independent consultant; trained as a medical doctor and PhD physical chemist (Cambridge); formerly Universities of Cambridge and Bonn; County Scientific Adviser, Cambridgeshire Fire and Rescue Service; adviser, UK Home Office, risk assessment for the fire service; co-organiser Reebok Foam Conferences 2002, 2004, 2007, 2009, 2013, 1St National Foam Forum Adelaide Australia 2011; input to McKinsey Report on 9/11 disaster 2001; expert advice on firefighting foams and their environmental impact nationally and internationally especially in Australia; technical adviser to the Victorian Parliamentary Select Committee Inquiry into the CA Fiskville contamination; involved in an advisory role in the development of the Queensland foam management policy 2016; affiliated research faculty, John Jay College of Criminal Justice, City University New York (CUNY); chartered chemist CChem, chartered scientist CSci; Fellow Royal Society of Chemistry; Fellow International Union of Pure & Applied Chemistry (IUPAC).



Kim T. OLSEN

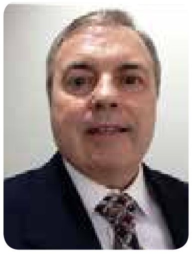
Head, Copenhagen Airport Rescue & Firefighting Academy Copenhagen Airport A/Ss, Denmark; Assistant Fire Chief, Copenhagen Airport; 9 years in the Security/Airport Police before joining Copenhagen Airports Fire & Rescue Department in 1989; member of IAFPA and ARFFWG, serving 7 years on the Board of Directors; 7 years on the Board of Directors of the ARFFWG; currently Manager for ARFFWG Section 11 also a Liaison Officer between the two organizations; involved in foam testing for Copenhagen Airport since 1995; ICAO CAFS and foam testing with the UK CAA (new standard) at CNPP, Vernon France and foam testing at DFW (Dallas Fort Worth) FTRC in 2017; member of the ACI EASA rule-making group and member of the International Airport Water Rescue Working Group; International ARFF Instructor on courses in Singapore, France, The Netherlands, Nepal, Kiribati, The Faeroe Islands, Poland and Greenland; has spoken at Aviation Safety and ARFF conferences and seminars in Denmark, Norway, Sweden, Iceland, Poland, USA, UK, Australia, Nepal, New Zealand, the United Emerita and Singapore.

JG (Gary) McDOWALL

Gary entered the industry in 1987 as the Works Engineer for the John Kerr Company based on Merseyside, which was then acquired by Croda at the end of the same year and became known as Croda Kerr. During his 12 years with Croda Kerr he was responsible for overseeing the capital investment of over £3M on this site including the transfer and development of the Monnex operation from ICI to Croda and redevelopment of the foam manufacturing facility. Working his way through management to become the Divisional Manager for Foams and Monnex dry powder and travelled extensively through the USA, Asia and Europe promoting new initiative firefighting products before forming a number of his own fire chemical related businesses including 3FFF Limited which was then formed in 2005.

During his 32 years in the industry he experienced the increased use and socio-economic impact of the fluorine chemistry used in firefighting foams and other fire protection related products and the subsequent need for change to more sustainable options. Since the turn of the century the science is has become much more understood and the legislation to inhibit the use of these materials around the world is on the increase. The company 3FFF Limited and its products under the brand known as '3F' was formed for this purpose, to innovate and develop new alternatives for the end user. These new and innovative products, some of which are both fluorine-free and solvent-free are now being approved to international standards and extensively used for many industry applications of foam. These applications also now include hand-held portable extinguishers as well as fixed fire systems, which are Gary's particular area of expertise and knowledge.

In addition to his company Directorships of four firefighting chemical businesses, he was one of the founding Directors of IAFPA (International Aviation Fire Protection Association) and currently the Chairman of the British Fire Consortium (BFC) which is one of the three main fire industry trade associations in the United Kingdom.



Ted SCHAEFER

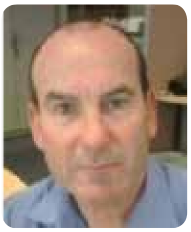
Foam formulation chemist with more than 30 years of experience, formerly of the 3M Company and Solberg Asia-Pacific (General Manager) centred in St Marys Sydney Australia; developer of the first Class B fluorine-free firefighting foams (re-healing foams or RHF™) in the early 2000s whilst at 3M; also developed Class A FireBrake™ for wildland fires, considered to be one of the most important Australian inventions in the last hundred years; University of Waterloo 1980; 3M Canada Inc. as chemist AFFF firefighting foam; early 1980's worked AFFF technology; PFOS-based fluorosurfactants key additive for Class B foams; training foam with rapid and safe burn back allowing fire fighters more training opportunities; currently the Australian Defence Force (ADF), Royal Australian Navy, Royal Australian Air Force and the civilian Australian airports (Airservices Australia) use training foam developed by THS; 1989 3M Australia to continue work on wildfire fighting foam technology; used during the largest wildfires in Australia since the early 1990s and on large bushfires in Queensland 2013; July 2001 the Australian Academy of Technological Sciences and Engineering and the Sydney Powerhouse Museum recognized FireBrake™ (a Class A foam) as one of the top 100 Australian inventions of the 20th Century; in 2000, THS investigated the feasibility of eliminating fluorochemicals from Class B firefighting foam culminating six years later in two World Patents for fluorine-free Class B foams (2003, 2006); currently seven fluorochemical-free flammable liquid firefighting foams have been based on these patents meeting global standards including ICAO, EN, UL, and LASTFIRE; he is also involved in collaborative research with the US NRL Department of the Navy; when still at Solberg October 2014 US EPA Presidential Green Chemistry Challenge Award for Re-Healing Foam for Effective Halogen-Free Firefighting; retiring in 2015, he is now consults for the Australian fire protection industry.

Dr Richard STEWART

Managing Director and Founder of Ziltek Pty Ltd, Adelaide, Australia. PhD University of Adelaide; 20 years' waste remediation experience; Science and Technology Commercialisation, University of Texas. Product Innovation course; Harvard Business School; former member of Prime Minister's Science, Engineering and Innovation Council (PMSEIC) Biodiversity Committee; Graduate Member of Australian Institute of Company Directors (AICD); developed and commercialised adsorption products for PFAS immobilisation in soil.

Michael TISBURY

Commander Mick Tisbury AFSM has been an MFB professional firefighter for almost 30 years; he is the spokesperson on PFAS for the United Firefighters' Union Australia which is a founding partner for the Global Alliance of Firefighting Unions, International Association of Fire Fighters; currently Project Coordinator MFB Firefighters PFAS Health study; Metropolitan Fire Brigade (MFB) Melbourne 1989; 29 years as an operational firefighter, training instructor and senior fire officer; development of training performance standards and a safety culture within the training environment; research into PFAS exposure for firefighters has led to the development of Operational PFAS Threshold Limits and best practice PFAS decontamination processes for firefighting appliances and equipment; commissioning a PFAS Blood Reduction Study of Firefighters; Vice President of the United Firefighters' Union; Commander Metropolitan Fire Brigade Melbourne;. Advanced Diploma of Public Safety (Firefighting Management); MFB Executive Officer Commendation; Australian National Service Medal; MFB Long Service and Good Conduct Medal; National Emergency Medal for 2009 Black Saturday bushfires in Victoria; Australian Fire Services Medal (AFSM) 2019.



Simon WEBB

30 year career in UK fire and rescue services; Head of Operational Practices in Her Majesty's Fire Service Inspectorate; responsibilities for operations, fire safety, aerodrome safety, training, performance review, policy development and health and safety; Member of the Institution of Fire Engineers; Masters in Civil Emergency; chartered membership of the Institute of Occupational Safety and Health; member and latterly the UK lead for the overseas search and rescue team and deployed to earthquakes in Turkey (1999) and Iran (2003); technical specialist UK Civil Aviation Authority (CAA); developing new firefighting foam standards (ICAO)

Kevan WHITEHEAD

Kevan Whitehead has been directly involved in the Fire Industry for over 40 years as an operational Fire Officer and more recently as the Managing Director of a specialist Fire & Rescue company. He joined Greater Manchester County Fire Service in 1978 as a Firefighter. Greater Manchester was arguably the busiest Brigade in the UK at the time, each firefighter responding on a pro rata basis to more incidents than any other Brigade in the UK. He was exposed to a wide variety of incident types varying from city centre urban environments, large Industrial sites, high speed/heavy volume motorways, docklands, major international airport and rural/moorland scenarios. The Brigade boasted 41 Fire Stations and over 2700 personnel. He quickly rose through the ranks specialising as a Fire Safety Inspecting Officer, Incident Command Trainer, and Senior Technical Officer responsible for R&D, Specification and Procurement of firefighting PPE, equipment, foams and vehicles.

He has co-organised and managed multiple international conferences on the environmental impact of Firefighting Foams, these events becoming the centre of excellence for those personnel involved in firefighting foam, be they manufacturers, end users, regulators or academics. He has also focused on firefighting PPE and was a specialist advisor to a UK Government Department on the Integrated Clothing project.

Kevan studied at the University of Bolton in the UK, achieving an MBA with a dissertation relating to marketing. During his employment, he attended TEEX in the USA to study LNG Firefighting techniques. He has delivered training to international students in Libya and Sri Lanka, and has also operated in Iraq and Kurdistan.

In 2010, Kevan joined a Fire Training Academy in the Sultanate of Oman, before forming his own Company, Unity Fire and Safety Services LLC also in Oman in 2011. The company has developed four main work streams, these being Fire Service manpower, equipment, training and consultancy. Past and present clients include BP, Shell, Petrochina, Gazprom, Lukoil and Vale. The company currently employs over 60 personnel, the vast majority being professional firefighters and fire engineers.

Lars YSTANES

Environmental specialist, Equinor (formerly Statoil), Bergen, Norway; responsible for transitioning from AFFF to fluorine-free (F3) foams for all operations, both onshore and offshore 2013-2019; environmental impact and regulations Norwegian Continental Shelf (NCS) and Norwegian North Sea (NNS) sector for oil and gas extraction and processing.

EXECUTIVE SUMMARY

The use of fluorinated organic compounds (PFAS) is widespread across many industrial and domestic applications including for textiles, food packaging, stain and oil resistant treatments, industrial processes and firefighting foam. Relatively speaking the high-profile dispersive use of firefighting foam accounts for about a third of total global production whereas the greater proportion of the other two-thirds are no less likely to be released but as less visible and diffuse releases during use and as end-of-life waste.

Alternative non-persistent products are now available for all the PFAS uses that cannot be fully contained. This includes PFAS-containing firefighting foams that represent a major source of PFAS contamination that can be easily managed by transition to the fully effective alternatives that are now readily available.

The current generation of fluorine-free firefighting foams (F3) are viable alternatives to aqueous film-forming foams (AFFF, FFFP, FP) for many operational scenarios. Where possible the use of fluorine-free firefighting foam (F3) avoids the socio-economic impacts and financial liabilities associated with costly legal action, regulatory prosecutions, infringement of license conditions, clean-up and remediation.

Any operational differences between persistent and non-persistent foams can now either be engineered out or dealt with by appropriate training. Many of the detailed arguments in support of this conclusion were covered in the IPEN White Paper presented at the 14th Stockholm Convention Persistent Organic Pollutants Review Committee meeting held at FAO Headquarters in Rome in September 2018 and in summarised form as a short invited presentation during the POPRC-14 Plenary Session.

For many end-users the discussion whether to change over to fluorine-free firefighting foam from traditional AFFF is no longer about - "*Is foam 'A' more effective than foam 'B'?*" Operational use in incidents in the real world and due diligence during the procurement process have proved beyond all reasonable doubt that fluorine-free foams perform equally well compared to AFFF under many conditions and continue to improve. This has shifted the main consideration for end-users to how much extra risk do we continue to carry with fluorinated foam, what cost will we incur in the longer term by not changing over to F3 products and what is our potential liability from damage caused by releases of foam-contaminated runoff.

The decision on foam selection and use has now matured with business decisions based on a proper and holistic cost-benefit-analysis, including the ability to maintain business continuity, avoiding reputational damage and limiting remediation and third-party harm costs. It has been realised that the true lifetime cost of firefighting foam cannot be based on just the original cost of purchasing the foam concentrate.

This White Paper expands the approach taken in the POPRC-14 IPEN White Paper entitled "*Fluorine-Free Firefighting Foams (3F) Viable Alternatives to Fluorinated Film-Forming Foams (AFFF)*" by considering other sources of fluorinated persistent organic pollutants (FPOPs) and their impact on human health, the environment and socio-economic values including societal infrastructure.

Although firefighting foams are unavoidably dispersive in the way they are used operationally by fire departments and have become the most recognisable and obvious point sources of environmental pollution, there are a number of less obvious but nonetheless important other PFAS sources that can generate PFOA or other PFAS products leading to contamination, for example diffuse PFAS sources from:

- Textile stain repellent coatings released from landfills as leachates and volatiles.
- Agricultural soil amendment by WWTP biosolids and effluent irrigation.
- Unregulated domestic fabric, PPE and furniture treatment products.
- Washing of treated textiles and fabrics with PFAS in wastewater sent to sewer.
- Treated food packaging with PFAS ending up in leachate releases.
- 'Hidden dispersive' scenarios, e.g., hand-held and portable foam extinguishers.

Current advances in feedstock C6-technology mean that products including AFFF firefighting foams recently put on the market, but not older than a couple of years, represent an unlikely source of free PFOA (best currently available fluorosurfactant feedstock < 25 ppb PFOA derivatives and precursors). This is largely not true for older foam stocks and other applications that also contain a significant proportion of long-chain PFAS up to C14 that are precursors to PFOA and its related toxic longer-chain equivalents.

Even with the use of so-called C6-pure AFFF there remains the problem of the generation of a diversity of toxic short-chain perfluoroalkyl intermediate and end-products which are extremely mobile and environmentally persistent. Short-chain PFAS contradict their supposed advantages of lower toxicity by having much higher environmental mobility than long chain material resulting in extended groundwater and soil plumes, are almost impossible to remove from drinking water and waste water effluent streams, and are known to concentrate in edible crops and grasses providing a direct contamination pathway into the food chain.

In addition, this White Paper considers the problem that contamination of the environment with end-point fluorochemical degradation products, mainly perfluorinated carboxylic acids (PFCA) or sulphonates (PFSA), never involves only one end product of degradation but also a whole range of highly persistent intermediate products of likely enhanced biological action and toxicity and bio-accumulative potential through synergism. It has been estimated that there are likely to be many hundreds of such compounds produced as the result of breakdown in the environment.

Focussing on just legacy compounds such as PFOS, PFHxS or PFOA, as so often happens, is therefore a form of tunnel vision which ignores the greater part of the problem, especially since these compounds are unlikely to be representative of the occurrence, effects and risk posed by the vast range of far more complex PFAS produced since the early 2000s. Moreover, the spectrum of perfluorinated end-products which arise even from the degradation of a single relatively simple fluorochemical such as a fluorotelomer fluorosurfactant make industry statements about the persistence, bio-accumulation and toxicity (PBT) profiles for any single breakdown product simplistic and largely irrelevant as these ignore the range of intermediate and end-point PFAS likely to be produced and the effects of combined exposure to multiple chemicals. All PFAS end-point compounds are environmentally extremely persistent with, in known instances, long half-lives in humans together with intermediate transformation compounds also persistent in their own right which may be chemically reactive and of higher toxicity than the end-point substances.

Toxicology studies for a single substance such as PFHxA do not account for possible synergism between substances for which there is, and is unlikely to be, any detailed PBT data for the vast array of compounds that can occur. With so little ever likely to be known about the effects of the diversity of PFAS exposures possible, a read-across approach is necessary from the characteristics of known PFAS and other structurally or functionally allied organic compounds using methods that identify suites of individual compounds, or can provide information about the proportions of carbon-chain precursors in such mixtures such as the total oxidisable precursor assay (TOP assay).

This situation brings into sharp focus Donald Rumsfeld's memorable phrases around the risks of what we know and don't know, as applied to the uses and effects of PFAS:

- ***"Known knowns"*** – It is well established that PFAS are persistent, toxic, bio-accumulative to varying degrees and highly dispersive.
- ***"Known unknowns"*** – We are being exposed to many more (and increasing) PFAS than the few that are recognised and can be analysed for. While we know the PFAS family is very large much is unknown about their diversity, sources, identities and effects.
- ***"Unknown unknowns"*** – We don't know the full extent of the PFAS problem but the rate and growth of new information consistently pointing to adverse effects of PFAS exposure implies that there is a large body of unknown risk and as such a conservative approach to use and management is essential.
- In other words, ***not knowing about a risk is not evidence that there is no risk*** and therefore, as has been long established for PFAS, when there are indications and evidence of adverse effects the ***Precautionary Principle*** needs to be applied with the legal ***burden of proof on the proponent*** to provide absolute proof of no adverse effects before release of the product for use, an obligation that is not currently being met.

SOMMAIRE

L'emploi de composés organiques fluorés (PFAS) est largement utilisé dans de nombreuses applications domestiques tels que les textiles, l'emballage alimentaire, les traitements antitaches, les procédés industriels et les mousses extinctrices. En relativisant, le profil élevé de dispersion imputable aux mousses extinctrices représente un tiers de la production totale, mais la très grande proportion des autres deux tiers qui n'est pas rejetée directement se retrouve finalement tout autant diffusée, mais par des voies invisibles durant son emploi ou sous forme résiduelle.

Des alternatives non persistantes sont désormais disponibles pour l'ensemble des utilisations de PFAS qui ne peuvent être récupérées. Cela inclut les musses extinctrices avec PFAS qui sont une source majeure de contamination par les PFAS et qui peuvent facilement être remplacées para les produits de substitution déjà disponibles.

Les émulseurs actuels sans fluor (F3) sont des substituts aux émulseurs filmogènes (AFFF, FFFP, FP) Pour l'ensemble des opérations anti incendie. Quand c'est possible, le choix d'un émulseur sans fluor (F3) évite les conséquences socioéconomiques et financières associées aux actions couteuses légales, les procès en cours de justice, les pertes d'exploitation, le nettoyage et la remédiation.

Les différences opérationnelles entre émulseurs Persistants et Non Persistants peuvent être calculées ou traités par des Plans d'intervention et une Formation appropriée. Beaucoup des éléments amenant à cette conclusion sont apportés dans le rapport IPEN présenté au 14ème Comité de Révision des Polluants Organiques Persistants de la Convention de Stockholm, qui s'est tenu à Rome au Siège de la FAO en septembre 2018, et ayant fait l'objet d'un résumé durant une présentation rapide pendant la session plénière du POPRC-14.

Pour la plupart des utilisateurs d'émulseurs, la discussion n'est plus de savoir s'il est possible de changer d'un émulseur traditionnel AFFF à un émulseur Sans Fluor en se demandant "*Est-ce que la mousse A est aussi performante que la mousse B?*" Les opérations faites en conditions d'intervention réelles et la bonne utilisation des moyens disponibles ont démontré sans ambiguïté ou doute que les émulseurs sans fluor sont tout aussi efficaces que les émulseurs AFFF dans des conditions variées et se sont largement améliorés au fil des ans. Cela a conduit les utilisateurs à évaluer désormais quels sont les risques consécutifs à l'emploi des émulseurs traditionnels, quels seront les couts à long terme s'ils ne choisissent pas un émulseur sans fluor (F3) et quels sont leurs risques potentiels en cas de déversement incontrôlé d'effluents polluants.

Le choix et l'emploi de l'émulseur fait maintenant l'objet d'une décision d'entreprise basée sur une évaluation affinée cout- bénéfice, prenant en compte la possibilité de maintenir son activité, d'éviter une perte d'image et de réputation, et de limiter les couts potentiels de traitement de déchets et d'indemnisation des victimes. Il est avéré que le cout réel d'un émulseur ne saurait se baser uniquement sur le cout de l'acquisition.

Ce Livre Blanc étend l'approche présentée dans le précèdent document au POPRC-14 IPEN et intitulé "*Émulseurs Sans Fluor (3F) Des alternatives viables aux émulseurs filmogènes fluorés(AFFF)*" en intégrant les autres sources de contamination par les FPOPs – Produits Organiques Persistants Fluorés – et leur impact sur la santé humaine, sur l'environnement et sur les valeurs socio-économiques présentes dans les infrastructures sociétales.

Bien que les émulseurs soient une forme de dispersion inévitable due à leur emploi opérationnel par les Professionnels de la Lutte contre les Incendies, et soient devenus la source la plus visible de contamination dans l'Environnement, il existe un grand nombre de sources de PFAS moins reconnaissables mais tout aussi importantes qui peuvent générer des PFOA et autres PFAS contaminants, comme par exemple :

- Les traitements antitaches pour textiles relâchés dans les sites d'enfouissement d'ordures via les fuites d'effluents liquides et d'émission volatiles
- Le compost Agricole et les eaux d'irrigation fournies par les stations d'épuration
- Les produits de traitement de meubles, de tissus et textiles non contrôlés.
- Le lavage des textiles traités avec des PFAS et relâchés dans les égouts
- Les emballages traités avec des PFAS y qui finissent dans les effluents émanant des dépôts d'ordures.
- Les rejets cachés, telles que le contenu des extincteurs.

Les dernières avancées technologiques de la production de C6 signifient que les produits AFFF mis récemment sur le marché ces deux dernières années sont supposés ne pas libérer de PFOA (le meilleur produit fluoré disponible à ce jour contient moins de 25 ppb de dérivés ou précurseurs du PFOA). Ceci est totalement faux pour les stocks anciens d'émulseurs et autres applications qui contiennent des PFAS à longue chaine – jusqu'à 14 Carbones – et sont autant de précurseurs du PFOA et ses équivalents toxiques à longue chaine.

Malgré l'emploi d'un supposé "pur C6" dans les AFFF, la question reste posée du devenir el de l'impact de ces résidus toxiques à chaine courte qui sont extrêmement mobiles et tout autant persistants dans l'environnement. Les PFAS à chaine courte sont contradictoires car, s'ils offrent un avantage supposé de toxicité réduite, ils sont beaucoup plus mobiles dans l'environnement et envahissent rapidement les eaux souterraines et les couches superficielles du sol, sont pratiquement impossibles à éliminer de l'eau potable et des eaux traitées en stations d'épuration, et sont identifiés pour se concentrer dans les récoltes et les végétaux trouvant ainsi une voie de contamination directe dans la chaine alimentaire.

De plus, ce Livre Blanc pointe le problème de contamination environnementale des produits issus de la dégradation des composes perfluorés, en particulier les Acides Perfluorocarboxyliques (PFCA) et Perfluoorsulfoniques (PFSA), ce qui représente une quantité importante d'intermédiaires et autres dérivés, ce qui augmente les risques de toxicité et de bioaccumulation par synergie. It est estimé qu'il existe plusieurs centaines de ces composés dégradés dans l'environnement.

L'attention concentrée sur les produits majeurs tels que le PFOS, le PFHxS ou le PFOA, comme c'est souvent le cas, donne une vision avec des œillères qui ignore une grande partie du problème, surtout parce que ces composés PFAS méconnus, parfois complexes, produits depuis les années 2000, présents en faible quantité individuelle, présentent néanmoins autant de risques non évalués. De plus, la diversité des résidus issus de la dégradation d'un seul et relativement simple télomère tensioactif perfluoré rend les affirmations des fabricants concernant l'impact PBT – Persistant, Bio accumulable et Toxique - d'un seul produit de dégradation exagérément simpliste et largement inapproprié car les études fournies ignorent les centaines d'autres résidus PFAS et les effets combinés de l'exposition à ces cocktails chimiques. Tous les résidus PFAS sont extrêmement persistants, et selon les études scientifiques reconnues, ont des temps très longs de demi vie dans le corps humain avec des intermédiaires potentiellement réactifs et de toxicité supérieure aux produits absorbés.

Les études toxicologiques d'une seule substance, comme le PFHxA, ne prend pas en compte les synergies potentielles avec d'autres PFAS associés pour lesquels il n'y a -et certainement n'aura jamais - aucun résultat d'étude PBT pour l'ensemble énorme des substances présentes. Avec aussi peu d'information disponible sur les effets de l'exposition à cette diversité de PFAS, il est nécessaire de faire une étude transversale à partir des caractéristiques de PFAS connus et autres composés de structures et fonctions proches pour identifier des familles de composés, et qui peut donner des informations sur les proportions relatives de certains précurseurs carbonés dans ces mélanges tel que la méthode TOP Assay (Précurseur Oxydable Total).

Cette situation met en application ces phrases célèbres de Donal Rumsfeld sur ce que nous savons et ignorons, concernant l'emploi et les effets des PFAS:

- ***"Connaissances Connues"*** – Il est reconnu que les PFAS sont Persistants, Toxiques, Bio-accumulables à un certain degré et facilement dispersés
- ***"Connaissances Inconnues"*** – Nous sommes exposés à beaucoup plus (et en quantités croissante) de PFAS que les quelques produits connus et analysés. Alors que nous savons que la famille PFAS est largement inconnue dans sa diversité, son origine, ses membres et ses effets.
- ***"Méconnaissance Inconnue"*** – Nous ne connaissons pas l'étendue du problème des PFAS mais la quantité grandissante des informations récentes pointe du doigt les effets négatifs de l'exposition aux PFAS ; cette méconnaissance d'un risque inconnu doit nous inciter à une approche prudente des utilisateurs et à une gestion responsable.
- En d'autres termes, ***la méconnaissance du risque ne signifie pas qu'il n'y a pas de risque*** et ainsi, comme cela est connu pour le PFAS, quand il existe des preuves d'effets toxiques, le ***Principe de Précaution*** doit être appliqué avec la ***Démonstration Légale de la Preuve*** à la Charge du fabricant qui doit apporter l'information avant de fournir le produit, une obligation qui n'est aujourd'hui pas appliquée.

RESUMEN EJECUTIVO

El uso de los compuestos orgánicos perfluorados (PFAS) es extenso en numerosas aplicaciones industriales y domesticas, incluyendo los textiles, los embalajes para la comida, los tratamientos anti mancha, los procesos industriales y los espumógenos contra incendios. De forma relativa el perfil de dispersión muy elevado de los espumógenos cuenta como un tercero de la producción mundial, sin embargo la gran proporción de los otros dos terceros también están rechazados pero con poca visibilidad durante su uso o después de ser desechados.

Los Productos alternativos y no persistentes están disponibles hoy en día para todos los usos de PFAS que no podrían ser retenidos. Esto incluye los espumógenos con PFAS que representan una fuente importante de contaminación de los PFAS que podrían ser fácilmente cambiados con alternativas eficaces ahora disponibles.

La generación actual de los espumógenos sin flúor (F3) es una solución alternativa viable a los espumógenos formadores de film (AFFF, FFFP, FP) para muchos escenarios de intervención. El posible uso de los espumógenos Sin Flúor (F3) evita el impacto socioeconómico y las consecuencias financieras asociadas con las acciones legales, los procesos judiciales de regulación, las perdidas de actividad, la limpieza y descontaminación de los sitios contaminados.

Cualquier diferencia de operaciones entre los espumógenos persistentes y no persistentes pueden ser calculadas y operadas con la capacitación adecuada. Casi todos los argumentos detallados para respaldar esta conclusión se encuentran en el Libro Blanco IPEN, presentado a la 14ta Comisión de la Convención de Stockholm sobre los Contaminantes Orgánicos Persistentes hecha en Roma en la Sed social de la FAO en septiembre 2018, y de forma resumida presentada durante la sesión Plenaria del POPRC-14.

Para la mayoría de los usuarios la pregunta para decidir elegir un espumógeno Sin Flúor que reemplace un espumógeno tradicional AFFF no seria mas que '*'La espuma A es mas eficaz que la espuma B?*" El uso operacional durante accidentes reales ocurridos en el mundo y la reacción apropiada para la intervención ha demostrado sin ambigüedad o duda que los espumógenos Sin Flúor tienen una eficacia idéntica a los AFFF en la mayoría de las situaciones y siguen mejorando. Esto ha cambiado la consideración principal de los usuarios al riesgo debido al uso de espumógenos con Flúor, y de cuales serían las consecuencias y los costos asociados a largo plazo al NO cambiar para productos F3, que pudieran ocasionar daños potenciales generados por la emisión de espumas contaminantes en el medio ambiente.

La decisión de elegir el espumógeno hace parte ahora de las decisiones de empresas basadas sobre un análisis real y documentado del balance Costo/Beneficio, incluyendo la posibilidad de mantener la actividad, evitar el daño de imagen y reputación, y limitar los costos de descontaminación y daños a terceros. Se ha demostrado que el costo real del espumógeno no solo se limita al costo de la compra inicial, sino que lleva consigo costos asociados.

Este Libro Blanco alarga el contenido del Libro precedente POPRC-14 IPEN denominado '*'Espumógenos Sin Flúor (F3) Alternativas Viables a los Espumógenos con flúor (AFFF)*" considerando otras fuentes de Contaminantes Fluorados Orgánicos Persistentes y su impacto para la Salud Humana, el Medio Ambiente y los Valores Socioeconómicos e infraestructuras sociales.

Aunque los espumógenos son una fuente inevitable de dispersión debido a su uso por los Bomberos, son por lo tanto una Fuente muy reconocida y obvia de contaminación al medio ambiente, Existen otras fuentes de PFAS escondidas pero importantes que generan compuestos PFOA y demás PFAS provocando contaminación, como:

- Tratamiento de alfombras dando fugas y compuestos volátiles desde basureros
- Fertilizantes derivados de bio solidos e irrigación de estaciones de depuración
- Productos de tratamiento de textiles, ropas y muebles
- Limpieza de textiles tratados con PFAS y enviados a la alcantarilla
- Embalajes de comida con PFAS dando emisiones a los basureros
- Emisiones escondidas, como las descargas de los extintores portátiles

Los últimos avances en la tecnología de los PFAS C6, significan que los productos como los espumógenos AFFF vendidos reciente en el Mercado, pero de no mas de dos años, no representa una Fuente de PFOA libre (el mejor tensoactivo fluorado tiene un contendido inferior a los < 25 ppb de PFOA derivados y precursores). Esto no aplica para los espumógenos adquiridos anteriormente y demás productos fluorados, que contienen una proporción significativa de PFAS de cadena hasta 14 carbones y que son precursores del PFOA y sus equivalentes de larga cadena.

El uso del así llamado C6-Puro AFFF no responde al problema de la generación de una diversidad de productos perfluorados tóxicos de cadena corta, que se demuestran móviles y persistentes en el medio ambiente. Los PFAS de cadena corta contra dicen su supuesta ventaja de menor toxicidad por su propiedad de movilidad aumentada en el medio ambiente – en comparación con los productos de cadena larga – resultando en una presencia mas elevada en las aguas subterráneas y los suelos superficiales, y que son prácticamente imposibles a remover del agua potable y de las aguas tratadas en la estaciones de depuración, las cuales se concentran en los vegetales y cereales presentando así una vía de contaminación directa en la cadena alimentaria.

Adicionalmente, el Libro Blanco considera que el problema de la contaminación en el medio ambiente es debido a los productos finales de la degradación de los compuestos fluorados, con una mayoría de Ácidos perfluorocarboxylicos (PFCA) y Sulfonatos (PFOS) (PFSA), nunca generan solamente un producto, sino una cantidad importante de productos intermediarios muy persistentes con capacidad de aumentar su acción biológica y potencial toxico y bio acumulativo de forma sinérgica. Se estima que existen unas centenas de estos productos resultando de la degradación en el medio ambiente.

Concentrando su atención solamente en los compuestos emblemáticos como el PFOS, PFHxS y PFOA, como pasa siempre, es una forma de tener una visión en un túnel ignorando una gran parte del problema, en particular porque esos pocos compuestos no representan todos los riesgos y efectos incurridos por la mayoría de los demás PFAS, a menudo mas complejos, producidos desde los años 2000. Además, el espectro de los compuestos de degradación derivados de un solo fluoroquimico tan sencillo como un tensoactivo fluorado telomer, deja las afirmaciones de los fabricantes a propósito del perfil Persistente, Bio acumulativo y Toxico – PBT – de un único producto de degradación exageradamente simples e inaplicables porque no toman en cuenta todos los productos PFAS producidos y los efectos combinados de los mismos. Todos los compuestos PFAS y sus productos derivados son muy Persistentes en el medio ambiente y, en casos conocidos, tienen un tiempo de media vida en los humanos contando con una transformación rápida en otros compuestos también persistentes y potencialmente capaces de reaccionar y de tener una toxicidad superior a los productos finales.

Los estudios toxicológicos de una sola sustancia como PFHxA no toma en cuenta la sinergia posible con otras sustancias para las cuales no existe – y nunca existirá – la información PBT por la cantidad enorme de esos productos. Con tan poca información sobre los efectos de la diversidad de PFAS existentes, un estudio transversal se necesita a partir de las características de los productos PFAS conocidos y otras estructuras y químicos similares con las mismas funciones usando métodos para identificar familias de compuestos individuales, y dando la información de las proporciones de los precursores en esas mezclas, como el método del precursor Total Oxidable (TOP Assay)

La situación presente da sentido a los famosos dichos de Donald Rumsfeld a propósito de lo que se sabe y no se sabe, en cuanto a los uso y efectos de los PFAS:

- ***"Conocimientos Sabidos"*** – Esta establecido que los PFAS son Persistentes, Tóxicos y Bio acumulativos a varios grados, y altamente dispersivos.
- ***"Desconocimientos Sabidos"*** – Estamos expuestos a mucho mas PFAS que los pocos ya reconocidos y analizados. Aunque sabemos que la familia PFAS es muy extendida, no sabemos mucho de su diversidad, fuentes, identidades y efectos.
- ***"Desconocimientos Desconocidos"*** – No sabemos la extensión del problema de los PFAS pero la velocidad de crecimiento de la información mas reciente siempre apuntando a los efectos adversos de la exposición a los PFAS significa que existe un riesgo desconocido pero amplio y que solamente una actitud conservativa del uso y de la gestión del problema es esencial.
- En otras palabras, ***Desconocer un riesgo no es una evidencia que el riesgo no existe*** y además, como ya demostrado para los PFAS, cuando existe evidencias e indicaciones de efectos adversos, el ***Principio de Precaución*** se debe de aplicar , con la ***Carga de la Evidencia para el Proveedor*** a demostrar con evidencia incuestionable que no existen efectos adversos ANTES de proponer el uso de su producto, una obligación incumplida hoy en día.

摘要

氟化有机化合物(PFAS)广泛应用于许多工业以及家庭应用，包括纺织品、食品包装、染色和耐油处理、工业生产和灭火泡沫。相对而言，引人注目的分散灭火泡沫的使用约占全球总产量的三分之一，而其他三分之二的泡沫类型在使用和作为终端废物过程中，因为其使用过程中不那么明显和扩散导致其不太可能被释放。

现在非持久性产品可使用于氟化有机化合物（PFAS），从而得以污染控制。比如含有PFAS的消防泡沫，它是PFAS污染的一个主要来源，可以很容易过渡到新型更有效的非持久性产品的应用。

目前生产的无氟灭火泡沫塑料(F3)在许多应用中都是水成膜泡沫塑料(AFFF、FFFP、FP)的可行替代品。使用无氟灭火泡沫塑料(F3)可以避免昂贵的法律诉讼、监管起诉、违反许可证条件、清理和补救所带来的社会经济影响和财政负担。

持久性泡沫塑料和非持久性泡沫塑料之间的任何操作差异现在都可以通过适当的培训消除掉。2018年9月在罗马粮农组织总部举行的第14届斯德哥尔摩公约持久性有机污染物审查委员会会议上发表的白皮书以详细的参数支持了这一观点，并且在POPRC-14全体会议期间做特邀报告。

对于许多最终用户来说，讨论是否从传统的消防泡沫转向无氟灭火泡沫不再是关于“泡沫‘A’是否比泡沫‘B’更有效?”。在实际应用中，对事故的操作使用和采购过程中的调查已毫无疑问地证明，在许多情况下，无氟泡沫塑料的性能与AFFF一样好，而且还在不断改进。这使终端用户更多的考虑如果继续使用氟化泡沫更不改用F3产品的话，我们将承担多少额外的风险，费用以及潜在的因为使用氟化泡沫污染造成的责任。

泡沫塑料的选择和使用决策现在已经和商务决策融合，正确和全面的成本效益分析，包括业务持久性、避免声誉损害、限制补救和第三方损害成本的能力。人们已经认识到，灭火泡沫的实际寿命成本不能仅仅以购买泡沫浓缩液的原始成本为基础。

POPRC-14 IPEN峰会上发表的“无氟灭火泡沫塑料(3F)替代氟化成膜泡沫塑料(AFFF)的可行方案”白皮书扩考虑了氟化持久性有机污染物(FPOPs)的其他来源及其对人类健康、环境和社会经济价值(包括社会基础设施)的影响，从而扩展了在峰会上发表的采取措施。

虽然消防泡沫在其由消防部门使用过程中的不可避免的分散性，造成显著的环境污染问题，但是还有其他不明显的生成全氟辛酸及其盐类(PFOA)或其他PFAS产品导致的污染来源，例如PFAS扩散:

- 以渗滤液和挥发物的形式从垃圾填埋场释放的纺织品防污涂料。
- 通过污水处理厂生物滤液和污水灌溉对农业土壤进行改良。
- 不规范的家用织物、个人防护用品和家具处理产品。
- 处理过的纺织品和织物在污水中使用PFAS进行洗涤。
- 经过PFAS处理的食品包装最终会释放出渗滤液。
- “隐性扩散”，例如手持和便携式泡沫灭火器。

目前C6技术的进步意味着最近这两年市场上的AFFF消防泡沫剂在内的产品，不太可能是免费 PFOA 的来源(目前可用的最佳氟表面活性剂原料 < 25 ppb PFOA 衍生物和前体)。这在很大程度上并不适用于较老的泡沫塑料和其他应用，因为这些应用程序也含有相当大比例的长链 PFAS (长链至C14)，这些长链 PFAS 是 PFOA 及其相关有毒长链当量的前体。

即使使用所谓的C6纯AFFF，仍然存在产生多种有毒短链全氟烷基中间体和最终产物，它们具有极强的流动性和环境持久性。相比于长链材料对地下水和土壤的渗透破坏，几乎不可能从饮用水和废水去除,和渗透于食用作物和牧草从而导致食物链的污染；短链PFAS的优点在于它们的低毒性和高效环境溶解性。

此外，白皮书指出环境污染的终端氟化物降解产物主要包含了主要是全氟羧酸(PFCA)或磺酸盐(交换树脂)，从来都不是只有一种， 而是包含了一系列高顽固中间化合物，这些产物通过积累合成具有更强的生物行和毒性。据估计，由于环境的破坏，可能会产生数百种这样的化合物。

2000 年初，对于这些遗留化合物， 比如 PFOS， PFHxS, PFOA， 因为隧道视野的关系，经常发生；特别是因为这些化合物不太容易表现出来， 人们更多的是关注由于 PFAS 所带来的危害。 此外，由于单个氟化物如氟调聚物降解所产生的有氟终端产物，使行业侧重于任何单一化合物的持久性,生物积聚和毒性 (PBT)， 从而忽略了这些忽略中间产物的范围和终端 PFAS 的产生可能性以及对其他多种化学物质的影响。 所有PFAS 终端化合物在环境上都具有极强 的持久性， 在已知的情况下， 半衰期很长， 而且中间转化化合物本身也具有持久性， 它们可能具有化学反应性， 毒性比终端产物更强。

针对单一物质(如PFHxA)的毒理学研究，没有考虑到化合物之间的合成，没有详细PBT数据支持庞大的化学合成物。对于PFAS 暴露的多样性了解甚少，有必要从PFAS的特征以及其他的结构或者功能上类似的有机合成物，用单个个体识别的方法，或者可以提供混合物中的碳链前体合成比例信息，比如总的可氧化前体报告（TOP报告）

唐纳德·拉姆斯菲尔德(Donald Rumsfeld)的“已知和未知的风险”名言，在这种情况下很适合用来描述PFAS的用途和效果:

- **“已知的已知”**--PFAS具有持久性、毒性、不同程度的生物累积性和高度分散性。
- **“已知的未知因素”**--我们接触到的PFAS(而且还在增加)远比我们能识别和分析的少数PFAS多。尽管我们知道PFAS家族非常庞大，但对他们的多样性、来源、身份和影响仍知之甚少。
- **“未知的未知因素”**--我们不知道PFAS的全部问题,但新信息的出现始终指向PFAS的副作用，这意味着会有大量的未知风险，因此使用和管理PFAS是至关重要的。
- 换句话说，未知的风险并不说明没有风险，因此当有迹象和副作用出现，产品的使用原则是必须有绝对的证据证明没有副作用，很遗憾的是， 这一原则还没有被执行。

ИСПОЛНИТЕЛЬНОЕ РЕЗЮМЕ

Использования фторсодержащих органических соединений (PFAS) широко распространено во многих промышленных и бытовых приложениях, включая текстиль, пищевая упаковка, пятно и масло выводящие, промышленные процессы и противопожарная пена. Условно говоря, высщее дисперсионное использование противопожарной пены расчитанно примерно для трети всего мирового производства в то время как большая часть других вероятно была выпущена, две трети не менее но менее видимым и диффузных выбросов во время использования и как конец жизни отходов.

Альтернативные непостоянные продукты теперь доступны для всех видов PFAS практических предложений, которые не могут содержаться полностью. Это включает в себя PFAS содержащая противопожарная пена, которая представляет собой основной источник PFAS загрязнения практических предложений, которые могут легко управляться переходом к полностью эффективным альтернативам, которые теперь легко доступны.

Нынешнее поколение пенообразующих противопожарной пены (F3) являются жизнеспособные альтернативы водной пленкообразующей пены (AFFF, FFFP, FP) для многих оперативных сценариев. Там, где это возможно, использование пенообразующей противопожарной пены (F3) позволяет избежать социально экономические последствия и финансовые обязательства, связанные с дорогостоящими правовыми действиями, регулирующие судебное преследование, нарушение лицензионных условий, очистке и восстановлению.

Любые оперативные различия между постоянными и непостоянными пены, могут теперь быть инженерии или заняться соответствующей подготовки. Многие из подробных аргументов в поддержку этого вывода, были защищенны в Белой книге IPEN, представленной на 14 Стокгольмской Конвенции Стойких Органических Загрязнителей Обзор Комитета совещания, состоявшегося в штаб-квартире ФАО в Риме в сентябре 2018 и в краткой форме как короткое приглашение, презентация в ходе POPRC-14 Пленарной сессии.

Для многих пользователей обсуждалось, следует ли изменить пенообразующие противопожарной пены от уже более традиционных AFFF как « пена ‘A’ более эффективна, чем пена ‘B’?». Оперативные использования в ходе инцидентов в реальном мире и должной осмотрительности во время процесса закупок оказались разумными, без сомнений, пенообразующие пены выполнять одинаково хорошо по сравнению с AFFF во многих условиях и продолжают улучшаться. Это изменило основное внимание для конечных пользователей, сколько дополнительной опасности мы продолжаем нести с фторированной пены, какую цену мы заплатим в долгосрочной перспективе, не изменяя F3 продуктов и наша потенциальная ответственность от повреждений, вызванных релизы пены загрязненных стоков.

Решение при выборе пены и использовании, теперь созрела в бизнес-решении основанного из надлежащих и целостных затратах выгодного анализа, включая способность поддерживать непрерывность бизнеса, избегая репутационный ущерб и ограничения восстановления и сторонних вредных расходов. Было понятно, что истинная стоимость жизни противопожарной пены не может основываться на только первоначальной стоимости приобретения концентрата пены.

Этот технический документ расширяет подход в Белой книге POPRC-14 IPEN под названием «Пенообразующие противопожарной пены (F3) жизнеспособные альтернативы фторированные пленкообразующие пены (AFFF)», рассматривая другие источники фторированные стойких органических загрязнителей (FPOPs) и их влияние на здоровье человека, окружающей среды и социально экономического значения, включая социальные инфраструктуры.

Хотя противопожарные пены неизбежно дисперсионные они используются пожарным департаментом и стали наиболее узнаваемым и очевидным точечным источников загрязнения окружающей среды, существует целый ряд менее очевидных, но тем не менее важно, что другие ПФАС источники, которые могут генерировать PFOA или другие продукты практических предложений, ведущих к загрязнению, например диффузные источники ПФАС :

- Защита от пятен покрытия текстильные освобожден от свалок как поступления и летучих.
- Сельскохозяйственные почвы WWTP поправка очистных сооружений сточных вод и твердых веществах биологического происхождения, орошения.
- Нерегулируемый внутренние ткани, PPE для обработки мебели, обработка продуктов.
- Мытьё обработанного текстиля и фабричных тканей в сточных водах, выброшенные в канализацию.
- использованная пищевая упаковка PFAS оседают в фильтрате релизов.
- “Скрытый дисперсионные” сценарии, например, карманные и портативные пены огнетушителей.

Текущий прогресс в сырье, C6-технологии означает, что продукты, включая AFFF противопожарной пены недавно на рынке, но не старше, чем пару лет,вряд ли представляют собой бесплатный источник PFOA (лучших имеющихся в настоящее время Перфторуглеводороды сырья < 25ppb PFOA производных и прекурсоры). Это во многом не верно для старых запасов пены и других приложений, которые также содержат значительную долю длинноцепочечных PFAS до C14, которые являются прекурсорами PFOA и его связанные токсичных эквивалентах дольше цепи.

Даже с использованием так называемых C6-чисто AFFF остается проблема поколения, разнообразие токсичных короткоцепные перфторалкильных промежуточных и конечных продуктов, которые являются чрезвычайно мобильными и экологически стойкими. Короткоцепные PFAS противоречат их предполагаемой меньшей благополучной токсичности, имея гораздо выше экологическую мобильность, чем длинная цепь материала, что приводит к расширениию подземных вод и шлейфовпочвы, почти невозможно удалить из питьевой воды сточных вод и известных сосредоточиться в съедобных культурах и травы, обеспечивая прямой путь загрязнения в пищевой цепи.

Кроме того, этот технический документ рассматривает проблемы, что загрязнение окружающей среды с концевой фтористые деградации, главным образом перфторированных карбоновых кислот (PFCA) или сульфанатов (PFSA), никогда не предполагает только один конечный продукт деградация, но и целый ряд весьма стойких промежуточных продуктов, вероятно укрепление биологического действия и токсичность и био накопительный потенциал благодаря синергизму. Было подсчитано, что есть вероятно, сотни таких соединений, производимых в результате пробоя в окружающей среде.

Акцентирование на просто старых соединениях, такие как PFOS, PFHxS или PFOA, как это часто бывает, форма туннельного видения,которая игнорирует большую часть этой проблемы, тем более, что эти соединения вряд ли будут представлять воникщие эффекты и риски, связанные с широким спектром гораздо более сложных PFAS производстведенных с начала 2000-х. Кроме того спектр перфторированные конечных продуктов, которые возникают даже от деградации одного относительно простых флуорхимических например fluorotelomer Перфторуглеводороды, промышленности делают заявления о стойкости, биоаккумуляции и токсичности (PBT) упрощать профили для любого единичного продукта в большинстве неуместно, так как они игнорируют спектр промежуточных и конечных практических предложений, может производиться и последствия комбинированного воздействия нескольких химических веществ. Все конечные соединения PFAS экологически крайне стойкие, в известных случаях, долгий полураспад в организме человека вместе с промежуточным преобразованем соединения также постоянные, в их собственном праве, который может быть химически активным и более высокой токсичности, чем конечное вещество.

Токсикологические исследования для одного вещества такие как PFHxA не расчитаны для возможного синергизма между веществами, для которого является и вряд ли может быть, какие-либо подробные данные PBT для огромного массива соединений, которые могут произойти. В связи с этим, мало когда-либо, повидимому, известно о последствиях разнообразия PFAS возможном воздействии , через чтение необходимо исходить из характеристик известных практических предложений и других структурных и функциональных союзных органических соединений, используя методы, идентифицировать комплекты индивидуальных соединений, или может предоставить информацию о пропорциях углеродной цепи прекурсоров таких смесей, как assay всего окисляемые прекурсоров (TOP проба). Эта ситуация подводит к Дональду Рамсфелду вокруг запонинающейся фразы того, что мы знаем и не знаем, в приложении для использования и воздействия практических предложений:

- **«Известные известные»** – это хорошо установлено, что PFAS стойкие, токсичные, биологически накапливающиеся в различной степени и высоко дисперсионные.
- **«Известные неизвестные»** – мы подвергаемся воздействию много больше PFAS чем некоторые, которые признаны и могут быть проанализированы. В то время как мы знаем, что семья PFAS в большем количестве их разнообразии неизвестно, источники, самобытность и эффект.
- **«Неизвестные неизвестными»** – мы не знаем, в полной мере PFAS, но скорость и рост новой информации, постоянно указывает на неблагоприятные последствия воздействия PFAS подразумевающие, что существует большое тело неизвестного риска и таким образом использовать консервативный подход и Управление имеет важное значение.
- Другими словами **не зная о риске не имея доказательства того, что нет никакого риска** и поэтому, как давно было создано для PFAS, когда есть показания и доказательства побочных эффектов **Принцип предосторожности**, должен применяться легальным **правом доказать инициативу**, обеспечить абсолютное доказательство без побочных эффектов до выпуска продукта к использованию, обязательства которое является в настоящее время неудовлетворительными.

ملخص تفصيلي

إن استخدام المركبات العضوية المفلورة (PFAS) منتشر على نطاق واسع في العديد من التطبيقات الصناعية والمنزلية بما في ذلك المنسوجات ، وتغليف المواد الغذائية ، ومعالجات مقاومة البقع والنفط ، والعمليات الصناعية ورغوة إطفاء الحريق. ومن الناحية النسبية فإن الاستخدام العالي والمتبدد للرغوة في مكافحة الحرائق يمثل نحو ثلث إجمالي الإنتاج العالمي ، في حين أن النسبة الأكبر من الثلثين الآخرين لا تقل احتمالية إطلاقها ولكن كإنبعاثات أقل وضوحا ومنتشرة أثناء الاستخدام وكنفايات منتهية الصلاحية.

المنتجات البديلة غير الثابتة متاحة الآن لجميع استخدامات PFAS التي لا يمكن احتواؤها بالكامل. ويشمل ذلك رغاوي مكافحة الحريق المحتوية على سلفونات مشبعة بالفلور والتي تمثل مصدراً رئيسياً لتلوث حامض السلفونات المشبع بالفلور أوكتين التي يمكن إدارتها بسهولة بالانتقال إلى البدائل الفعالة بالكامل التي أصبحت متاحة الآن بسهولة.

الجيل الحالي من رغاوي مكافحة الحرائق الخالية من الفلورين (F3) هي بدائل بدائل ممكنة ويمكن الاستعانة بها بدلا عن الرغاوي المكونة والمشكلة ل (AFFF ، FFFP ، FP) للعديد من السيناريوهات التشغيلية. حيث أن استخدام رغوة مكافحة الحرائق الخالية من الفلورين (F3) يجنب الكثير من الآثار الاجتماعية والاقتصادية والالتزامات المالية المرتبطة بالإجراءات القانونية المكلفة والملاحقات التنظيمية وانتهاك شروط الترخيص والتنظيف والمعالجة.

ان أي اختلافات تشغيلية بين الرغوات الثابتة وغير المستمرة يمكن الآن إما تصميمها أو التعامل معها عن طريق التدريب المناسب. تمت تغطية العديد من الحجج التفصيلية الداعمة لهذا الاستنتاج في الورقة البيضاء IPEN المقدمة في الاجتماع الرابع عشر للجنة استعراض الملوثات العضوية الثابتة في اتفاقية استكهولم التي عقدت في المقر الرئيسي لمنظمة الأغذية والزراعة في روما في سبتمبر 2018 ، وفي صورة ملخصة على شكل عرض قصير مقدم خلال لجنة استعراض الملوثات العضوية الثابتة -14 الجلسة العامة.

بالنسبة للعديد من المستخدمين النهائيين ، لم يعد النقاش حول ما إذا كان التغيير إلى رغاوي مكافحة الحريق الخالية من الفلور من AFFF التقليدي قد انتهى - ”هل الرغوة“ أ ”أكثر فعالية من الرغوة“ ب ”؟ أثبت الاستخدام العملي في الحوادث في العالم الحقيقي والعناية الواجبة أثناء عملية الشراء أنه ليس هناك شك معقول في أن الرغاوي الخالية من الفلور تعمل بشكل جيد بالمقارنة مع AFFF في العديد من الظروف وتستمر في التحسن.

وقد أدى هذا إلى تحويل الاعتبار الرئيسي للمستخدمين النهائيين إلى مقدار المخاطر الإضافية التي ما زلنا نحملها مع الرغاوي المفلورة ، وما هي التكلفة التي سوف نتحملها على المدى الطويل من خلال عدم التغيير إلى منتجات F3 وما هي مسؤوليتنا المحتملة عن الأضرار الناجمة عن تلك الرغاوي ومدى تأثيرها على صحة الإنسان والبيئة والقيم الاجتماعية والاقتصادية بما في ذلك البنية التحتية المجتمعية.

لقد نضج القرار بشأن اختيار الرغوة واستخدامها الآن مع قرارات العمل على أساس تحليل التكلفة والفوائد المناسب والشامل ، بما في ذلك القدرة على الحفاظ على استمرارية العمل ، وتجنب الأضرار الناجمة عن السمعة والحد من تكاليف العلاج وتكاليف الضرر من طرف ثالث. لقد تم إدراك أن التكلفة الحقيقية لرغوة إطفاء الحريق لا يمكن أن تستند فقط إلى التكلفة الأصلية لشراء مركزات الرغوة.

يوسع هذا الكتاب الأبيض النهج المتخذ في الورقة البيضاء IPCR-14 IPEN المعنونة ”رغاوي مكافحة الحرائق الخالية من الفلورين (F3) البدائل الصالحة للرغوات المغلفة بالفلور (AFFF)“ من خلال النظر في المصادر الأخرى للملوثات العضوية الثابتة المفلورة (FPOPs) و تأثيرها على صحة الإنسان والبيئة والقيم الاجتماعية والاقتصادية بما في ذلك البنية التحتية المجتمعية.

على الرغم من أن رغاوي مكافحة الحرائق متفرقة بشكل لا يمكن تجنبه في الطريقة التي يتم استخدامها من قبل إدارات مكافحة الحرائق بشكل عملي ، وقد أصبحت المصادر الأكثر وضوحًا وضوحًا للتلوث البيئي ، إلا أن هناك عددًا من مصادر PFAS المهمة الأخرى الأقل وضوحًا والتي يمكنها توليد PFOA أو غيرها من PFAS المنتجات المؤدية إلى التلوث ، على سبيل المثال ، مصادر PFAS المنتشرة من:

- طلاءات طلاء قماش الطلاء تنطلق من مدافن النفايات كعلامات متطايرة ومتطايرة.
- تعديل التربة الزراعية بواسطة الأنابيب الصلبة للنفايات الصلبة والنفايات السائلة.
- النسيج المنزلي غير المنظم ، معدات الوقاية الشخصية والأثاث.
- غسل المنسوجات والأقمشة المعالجة مع PFAS في المياه العادمة المُرسلة إلى المجاري.

- تغليف الأطعمة المعالجة بمادة PFAS التي تنتهي في إطلاقات العصارة.
- سيناريوهات "تشتيت مخفي" ، على سبيل المثال ، أجهزة إطفاء الرغوة المحمولة باليد والمحمولة.

إن التقدم الحالي في C6-feedstock يعني أن المنتجات التي تشمل رغاوي مكافحة الحرائق في AFFF التي تم طرحها مؤخراً في السوق ، ولكن ليس أقدم من عامين ، تمثل مصدراً غير محتمل ل PFOA المجاني (أفضل المواد المتاحة فلورسورفاكتانت المتاحة حالياً <25 ppb مشتقات وسلائف PFOA) . لا ينطبق هذا إلى حد كبير على مخزونات الرغاوي القديمة والتطبيقات الأخرى التي تحتوي أيضًا على نسبة كبيرة من السلاسل طويلة السلسلة من PFAS حتى C14 والتي هي سلائف لـ PFOA وما يرتبط بها من سلاسل سمية أطول.

حتى مع استخدام ما يسمى AFFF نقية C6 لا تزال هناك مشكلة في توليد مجموعة متنوعة من المنتجات السائلة قصيرة الأجل perfluoroalkyl السامة والناتجة التي هي متحركة للغاية وبيئيا المستمرة. تتناقض سلسلة PFAS قصيرة السلسلة مع ما يفتقر إليها من سمية منخفضة من خلال وجود حركة بيئية أعلى بكثير من المواد ذات السلسلة الطويلة مما يؤدي إلى زيادة المياه الجوفية وأعمدة التربة ، ويكاد يكون من المستحيل إزالتها من مياه الشرب ومياه الصرف المتدفق ، ومن المعروف أنها تركز في الصالحة للأكل المحاصيل والأعشاب توفير مسار تلوث مباشر في السلسلة الغذائية.

وبالإضافة إلى ذلك ، يعتبر هذا الكتاب الأبيض أن تلوث البيئة بمنتجات التدهور الفلوري-الكيميائي في نهاية المطاف ، ولا سيما الأحماض الكربوكسيلية المشبعة بالفلور (PFCA) أو السلفونات (PFSA) ، لا ينطوي أبداً على منتج نهائي واحد فقط من التدهور ولكنه يشمل أيضاً مجموعة كاملة من المنتجات الوسيطة المستمرة للعمل البيولوجي المحسن المحتمل والسمية واحتمال التراكم الأحيائي من خلال التآزر. وتشير التقديرات إلى أنه من المحتمل أن يكون هناك مئات عديدة من هذه المركبات التي تنتج نتيجة للانهيار في البيئة.

إن التركيز على مركبات قديمة مثل سلفونات الأوكتين المشبعة بالفلور أو PFHxS أو PFOA ، كما يحدث في كثير من الأحيان ، هو بالتالي شكل من أشكال رؤية الأنفاق التي تتجاهل الجزء الأكبر من المشكلة ، خاصة وأن هذه المركبات من غير المحتمل أن تكون ممثلة للحدث والآثار والمخاطر. تشكلها مجموعة واسعة من PFAS أكثر تعقيدا بكثير أنتجت

منذ أوائل 2000 وعلاوة على ذلك ، فإن الطيف من المنتجات النهائية المشبعة بالفلور والتي تنشأ حتى من تدهور مادة كيميائية فلورية بسيطة نسبياً مثل fluorosomfactant fluorotelomer ، تجعل بيانات الصناعة تتعلق بمواصفات المثابرة والتراكم الحيوي والسمية (PBT) لأي منتج تفكك فردي بسيط ومبتكر إلى حد كبير. لا أهمية لها لأن هذه العوامل تتجاهل نطاق ال PFAS الوسيطة والنقطة النهائية التي يمكن إنتاجها وآثار التعرض المشترك لعدة مواد كيميائية. جميع مركبات نقطة النهاية PFAS مثبته بيئياً للغاية ، في حالات معروفة ، فترات نصف العمر الطويلة في البشر مع مركبات التحويل الوسيطة أيضاً ثابتة في حد ذاتها والتي قد تكون تفاعلية كيميائياً وذات سمية أعلى من مواد نقطة النهاية.

لا تتناول دراسات علم السموم لمادة مفردة مثل PFHxA التآزر المحتمل بين المواد التي توجد ، ومن غير المرجح أن تكون ، أي بيانات مفصلة لـ PBT عن المجموعة الكبيرة من المركبات التي يمكن أن تحدث. مع وجود القليل جدا من المرجح أن تكون معروفة حول آثار تنوع التعرضات PFAS ممكن ، يكون من الضروري اتباع نهج للقراءة من خصائص PFAS المعروفة والمركبات العضوية المتحالفة الأخرى الهيكلية أو الوظيفية باستخدام طرق تعرف مجموعات من المركبات الفردية ، أو يمكن أن توفر معلومات عن نسب سلائف السلسلة الكربونية في مثل هذه الخلائط ، مثل مقايسة السلائف الأكسدة الكلية (مقايسة TOP).

إن هذا الوضع يجسد عبارات دونالد رامسفيلد البارزة حول ما نعرفه ولا نعرفه ، في التطبيق على استخدامات وتأثيرات PFAS:

- "**المعروفات المعروفة**" - من الثابت جدا أن PFAS ثابتة وسامية وبيولوجية تراكمية بدرجات متفاوتة ومتناثرة بشكل كبير.
- "**المجهول المعروفة**" - نحن نتعرض للعديد من (أو زيادة) PFAS أكثر من العدد القليل المعترف به ويمكن تحليله. في حين أننا نعرف أن عائلة PFASكبيرة جدًا ولا نعرف الكثير عن تنوعها ومصادرها وهوياتها وتأثيراتها.
- "**مجهول مجهولة**" - نحن لا نعرف المدى الكامل لمشكلة PFAS ولكن معدل ونمو المعلومات الجديدة تشير باستمرار إلى الآثار السلبية للتعرض PFAS يعني أن هناك مجموعة كبيرة من المخاطر غير معروفة وعلى هذا النحو نهج متحفظ لاستخدام وإدارة أمر ضروري.
- وبعبارة أخرى ، فإن عدم معرفة المخاطرة ليس دليلاً على عدم وجود مخاطر ، وبالتالي ، كما هو معمول به منذ فترة طويلة بالنسبة لنظام تقييم الملاريا ، عندما تكون هناك دلائل وأدلة على تأثيرات ضارة يتعين تطبيق المبدأ التحوطي مع العبء القانوني الناجم عن ذلك. إثبات على مقدم الاقتراح تقديم دليل مطلق على عدم وجود آثار ضارة قبل إطلاق المنتج للاستخدام ، وهو التزام لا يتم استيفائه حاليًا.

1. INTRODUCTION

At their recent meeting held at UN FAO headquarters in Rome in September 2018, the UN Stockholm Convention Persistent Organic Pollutants Review Committee (POPRC-14) made recommendations for consideration by the Conference of the Parties (COP9) to be held in Geneva April-May 2019, recommending the removal of most current exemptions for use of long-chain PFAS as well as highlighting the unsuitability of short chain poly- and perfluoroalkyl substances (PFAS) as replacements for those based on C8 or longer chemistry or containing C8 derivatives that could act as precursors for PFOA:

> *"...The assessment indicated that alternatives to PFOS-based firefighting foams are readily available in many countries and have been demonstrated to be technically feasible and economically viable but some have potential negative environmental and health impacts. On this basis, the Committee recommends that the acceptable purposes for the production and use of PFOS, its salts and PFOSF for firefighting foams be converted to a specific exemption for the use of firefighting foams for liquid fuel vapour suppression and liquid fuel fires (Class B fires) already in installed systems including both mobile and fixed systems, and with the same conditions specified in paragraphs 2 (a)(d) and 3 of the annex to decision POPRC-14/[...] on PFOA, its salts and PFOA-related compounds.* ***The Committee recognized that a transition to the use of short-chain per- and polyfluoroalkyl substances (PFASs) for dispersive applications such as firefighting foams is not a suitable option from an environmental and human health point of view and that some time may be needed for a transition to alternatives without PFASs..."***

and,

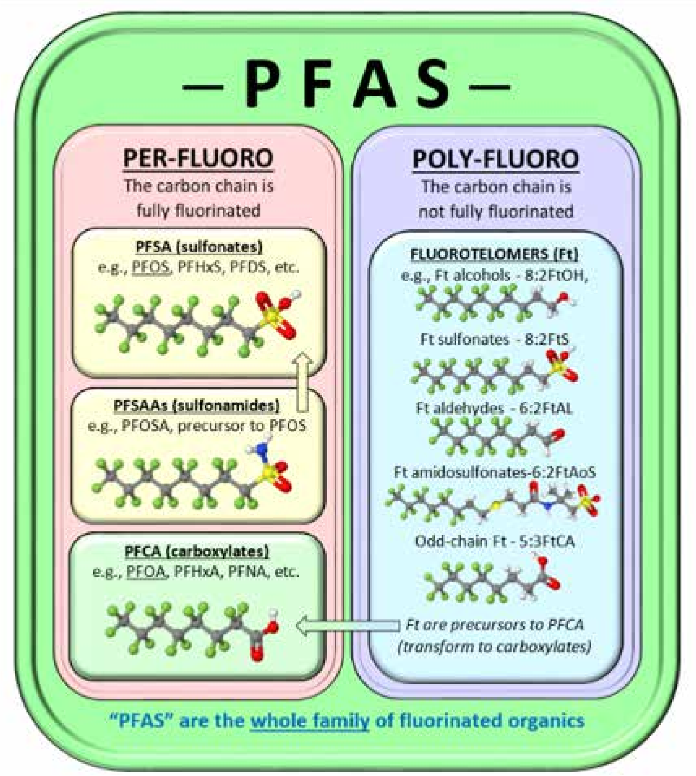
> *"...Recommends to the Conference of the Parties that it consider encouraging Parties* ***not to replace firefighting foam that contains or may contain PFOA, its salts and PFOA-related compounds with short-chain PFASs due to their persistency and mobility as well as potential negative environmental, health and socioeconomic impacts....***"

This IPEN White Paper addresses the key issue raised by POPRC-14 in Rome September 2018 of whether or not short-chain PFAS derivatives can be considered suitable replacements for foam formulations containing PFOA or PFOS and their related long-chain substances, especially in dispersive applications such as firefighting foam or in the treatment of textiles and food packaging that eventually also result in releases of PFAS contamination via litter, wash-water and landfill leachates.

Moreover, this White Paper reinforces the arguments presented in the previous White Paper presented to POPRC-14 in Rome September 2018 that non-persistent, fluorine-free firefighting foams (F3) have been proven to be viable alternatives to fluorinated AFFF type firefighting foams based on operational performance criteria, environmental and socio-economic grounds. The same can be said for most other PFAS applications where there are fluorine-free alternatives available.

1.1 PFAS, BEHAVIOUR AND FATE

A common misconception is that there are only a handful of PFAS compounds in use or of concern. This has been fostered by the narrow focus in the media and by some regulators on legacy compounds such as PFOS, PFHxS and PFOA. The reality is that there are thousands of PFAS being used plus their transformation products in the environment generating many more related variants, all very



similar in structure, behaviour and effects (Barzen-Hanson et al., 2017).

The acronym PFAS covers all fluorinated alkyl organic substances including perfluorinated, polyfluorinated, fluorotelomer and fluoropolymer compounds. PFAS are highly dispersive subject to long-range transport and occur globally in all environmental compartments.

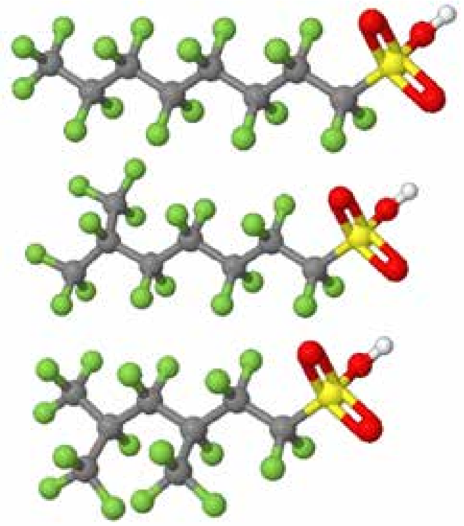
The naming-system for fluorinate organic compounds is complex with considerable misuse and confusion surrounding the meaning of terms, indeed papers have been published in attempts to standardise the naming of and abbreviations for PFAS compounds (Buck, et al, 2011). Individual compounds are usually abbreviated to acronyms as their chemical names are unwieldy, e.g., PFOS is short for perfluorooctane sulfonic acid, full chemical names are even worse. For most purposes fluorinated organic compounds can be considered in the following way:

- **PFAS** - encompassing ALL the fluorinated organic compounds commonly under discussion (derived from "**P**er and poly **F**luoro **A**lkyl **S**ubstances" – "PFAS").
- **Perfluoro** – a subset of PFAS that have fully fluorinated carbon chains and are mostly end-point sulfonate (e.g., PFOS, PFHxS) or carboxylate (e.g., PFOA, PFHxA, PFDA) compounds.
- **Polyfluoro** – a subset of PFAS where the carbon chain is *not fully fluorinated* with at least one of the carbons having hydrogens attached instead of fluorines. This includes the thousands of fluorotelomers and fluoropolymers that will eventually transform to perfluorinated carboxylates like PFOA and its related compounds.

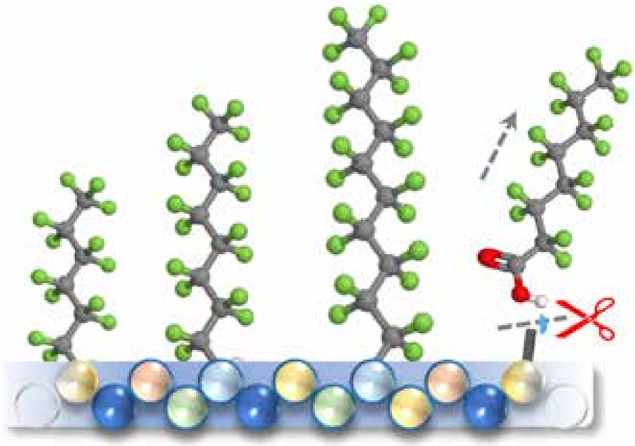
Accordingly, the broadest term to use is "PFAS" unless there is a need to refer to the sub-groups (e.g., fluorotelomers, sulfonates, carboxylates, fluoropolymers) or to specifically refer to the individual compounds (PFOS, PFHxS, PFOA, 8:2FtS, etc.).

For completeness it is also worth knowing that there are isomers of the perfluorinated compounds with the same number of atoms but arranged in a different configuration of molecular joins. The simplest way to visualise most PFAS is as straight-chain molecules, however for some there are non-linear forms. For example, PFOS has different branched isomers that can occur. This has implications for how they can partition and be transported differently compared to the straight chain PFOS.

Similarly, there are side-chain polymers (derived from fluorotelomers or perfluoroalkyl sulfonyl fluorides) that can have perfluorinated groups attached to a non-fluorinated polymer backbone. These are used as textile finishes that are of no particular concern in the polymer form, however, they can eventually break down during use or at end-of-life disposal to release various perfluorinated molecules resulting from the release of the fluorotelomer and perfluorinated side chains. Fluoropolymer compounds are very hard to characterise in terms of analyses and their eventual behaviour in the environment.



PFAS isomers. From top: linear PFOS, 6-PFOS, and 3-5-PFOS (all $C_8F_{17}SO_3H$).



Notional fluoropolymer structure. Polymer backbone with various chain-length PFAS side chains. Breakdown can release persistent perfluorinated side chain molecules (e.g., PFOA on right).

An important and obvious aspect common to all PFAS is the presence of the fully fluorinated carbon chain (CF_3-CF_2-CF_2→...), this is clearly evident in the various figures. PFAS are often described in terms of the length of the per-fluoroalkyl carbon chain (e.g., C_8) which is a general indicator of:

- **Mobility** – Short-chain PFAS are far more mobile in soils, surface water and groundwater and have been found to be taken up by grasses and the edible portions of plants to enter the food chain.

- **Toxicity** – Toxicity decreases with chain length but short-chain PFAS are not non-toxic, with exposure and the potential for adverse effects increasing along with their rising environmental concentrations from ongoing releases. Also note that the original parent fluorotelomers in many current products have overall chain-lengths of more than 6 carbons, for example 5:3 and 6:2 fluorotelomers have chains 8 carbons long, plus complex functional groups. Little is known about the behaviour and effects of these longer-chain molecules.
- **Bioaccumulation** – For perfluorinated PFAS longer chain length means greater bioaccumulation potential. For fluorotelomers that are usually the parent compound in products they also have additional carbons in the chain with the potential to influence toxicity and bioaccumulation.

Clues to the length of the perfluorinated chain can be found in the names of the compounds that follows regular hydrocarbon chain (alkyl) naming, for example:

- **Carboxylates** - PF**B**A (butanoic C4), PF**Pe**A (pentanoic C5), PF**Hx**A (hexanoic C6), PF**O**A (octanoic C8), PF**N**A (nonanoic C9), PF**D**A (decanoic C10), etc.
- **Sulfonates** - PF**B**S (C4), PF**O**S (C8), PF**D**S (C10) etc., as above.
- **Fluorotelomers** - **8**:2FtS (C8:2), **6**:2FTAB (C6:2), **7**:3FtAL (C7:3).

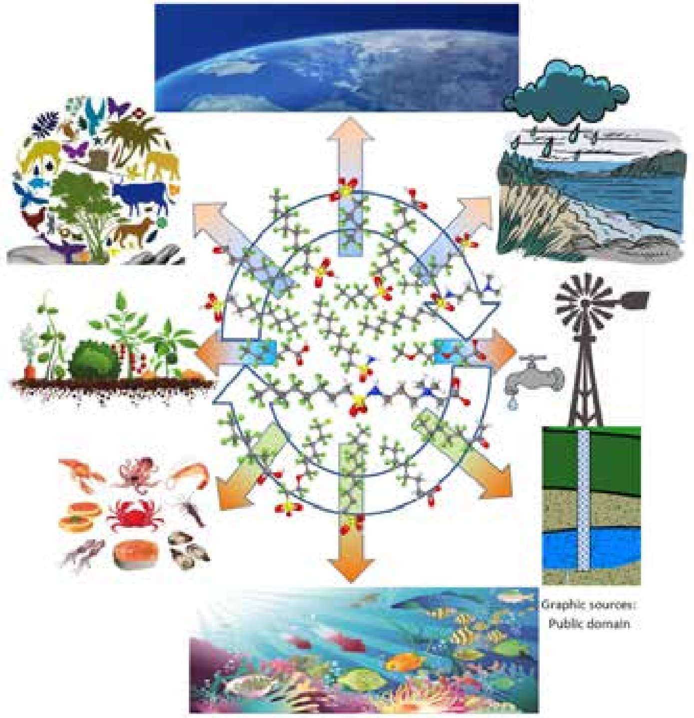
There are multiple sources of potential PFAS contamination of the environment with risk of direct and indirect human exposure. These include not only those obvious, highly-dispersive applications such as the operational use of firefighting foam at an incident but also less obvious, indirectly dispersive sources such as:

- **Landfill leachate and volatiles releases** including fluorotelomer alcohol and short-chain volatiles to atmosphere with significant global warming potential from treated textiles and food packaging at end-of-life disposal.
- **Furniture and floor coverings** in dwelling and office spaces treated with PFAS generating PFAS contamination in dust, wash-water, aerosols and volatilisation to air of the fluorochemicals.
- **Laundry wash-water** contaminated by PFAS from domestic and commercial sources from washing of treated clothing and other fabrics.
- **Releases of PFAS at elevated temperatures** from personal protective clothing such as firefighter and industrial kit with potential direct vapour and skin exposure.
- **Aerosol spray cans** for domestic and specialist fluorochemical treatment of all-weather clothing or snow ski waxing leading to direct PFAS inhalation exposure.
- **Fabric treatment wastewaters** discharged to sewer from commercial bulk treatment of fabrics for manufacture.

Once released to the environment the thousands of different PFAS are ultimately highly persistent and mobile in soils, surface water, groundwater and the atmosphere, depending on the compound. PFAS contamination can now be found in all environmental compartments and will continue to migrate through physical and biological systems.

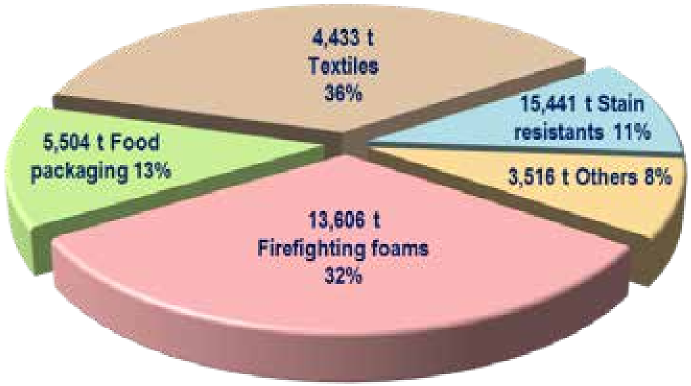
PFAS exposure risk assessment not only needs to consider the eventual end-point compounds (e.g., PFOS, PFOA, etc) but also to take into account the original complex PFAS (e.g., 8:2 FtTSAB) and probable environmental and metabolic conversion of the original fluorotelomer PFAS into numerous other very different intermediate compounds, e.g., by oxidation, photolysis and microbial action in the environment or by enzymes in the body in organs such as the liver.

Estimated annual production of PFAS as fluorotelomers is considerable with the potential for a large proportion to be released to the environment directly or in wastes. Production estimates are unlikely to include that of many devel-


Graphic sources: Public domain

PFAS are highly mobile and now found in all environmental compartments.

oping countries or reflect the diversity of newly developed PFAS such as fluoropolymers, GenX, F53 and Adona. In addition some countries are still producing perfluorinated compounds including PFOS and PFHxS that have been phased out elsewhere.



Projected fluorotelomer production and use in 2019 of 42,500 tonnes. After Global Market Insights, 2016. Projected compound annual growth rate of 12.5% from 26,500 tonnes in 2015 for Middle East and Africa.

2. FLUORINE-FREE FIREFIGHTING FOAMS ARE VIABLE ALTERNATIVES TO AFFF

A major use of PFAS and source of large-scale direct releases to the environment has been in Class B firefighting foams used to suppress vapours and extinguish fires on liquid fuel spills and fires. These fluorine-containing foams are commonly referred to as AFFF (aqueous film-forming foam) but also include FFFP and FP fluoroprotein foams.

The original and primary use of PFAS as an active ingredient in foam formulations was to form a film between the fuel surface and the foam blanket for two-dimensional hydrocarbon pool-fires. Film formation does not confer any particular advantage for three dimensional fires such as those encountered in the refinery and chemical process sectors – so-called 'in depth' fires around pipework, tanks and vertical surfaces. Moreover, recent developments in fluorine-free, non-AFFF foams indicate that film-formation is not absolutely necessary for fire extinction performance.

There are significant overall cost advantages plus reductions in risk and liability for end-users who transition to non-persistent, fluorine-free foam (F3) across a wide range of operational scenarios in both the short and long-term versus AFFF.

The alternatives to AFFF are Class B fluorine-free, non-persistent firefighting foams (F3); this technology is not new but has advanced considerably over the last 5-10 years since the realisation of problems associated with PFAS. Originally introduced as "*re healing foam*" (the RF series), by Ted Schaefer then working for the 3M Company, this technology has progressed considerably and now offers comparable firefighting efficiency to aqueous film-forming foams (AFFF), as shown by F3 achieving the same high standards of effectiveness reflected in internationally accepted certifications and approvals, i.e., EN1568 Parts 3 & 4 1A/1A, UL162. FM, ICAO Level B and C, ISO7203, LASTFIRE, EN3, AS/NZS/150 (2009), IMO-MSC.1/circ. 1312 (2009).

A spurious argument that F3 foams cost more than AFFF is not valid with cost per litre of foam concentrate for fluorine-free foams and AFFF are now virtually identical quality-for-quality with the cost of high fluorosurfactant 1% AFFFs far exceeding those for fluorine-free equivalents as shown below. Similarly, unfounded claims driven by commercial competition that F3 foams are more "costly" to use have been disproven even to the extent of use in recent incidents demonstrating:

- A similar or less cost per litre of concentrate for F3 compared to AFFF.
- Less firewater is generated by F3 use and therefore there is less firewater to treat with a reduced risk of bunds overtopping leading to contaminated firewater releases.
- Significant cost advantages for F3 in that firewater and recovered fuel is not contaminated with POPs and can be treated/reprocessed by conventional means not involving high temperature incineration.
- Expensive remediation for POPs contamination is not necessary for F3 foams.
- F3 foam only has local and temporary adverse effects that at worst can be left to naturally bio-degrade in the environment.

As a result of end-user market pressures, a significant number of foam manufacturers now offer both fluorine-containing AFFFs and high-performance fluorine-free F3 products in order to satisfy customer demand and the need for environmental and health protection, including but not exclusively:

> Angus (Respondol); Bio-Ex (Ecopol Premium); Dr Sthamer (Moussol-FF); Orchidee (BlueFoam); 3F (Freedol); Solberg (RF6, RF3x6ATC, RF1 series); Fomtec (Enviro); Tyco (Skum3x3); National Foam (Universal F3 Green); Auxquinia (Unipol); and VSFocum (Silvara).

Many end-users at high-risk facilities have already transitioned successfully in whole or in part to Class B fluorine-free foams (F3) for liquid hydrocarbon fires, including the AR variants for use on polar solvent spills and fires. Industry sectors that have managed this change successfully and have demonstrated F3 effectiveness in incidents include aviation rescue and firefighting (ARFF), the petrochemical and oil and gas offshore and onshore industries, civilian and military fire services, etc.

A market analysis of an anonymised typical end-user database for fluorine-free products is shown in the pie-chart with application-critical users prominently apparent.

Transitioning from AFFF to fluorine-free (F3) firefighting foams is currently most notable for the European and Australasian markets with moves in the US gaining momentum prompted by state and federal government recognition of the need to address the risks associated with PFAS contamination.

Many organisations have conducted extensive testing prior to transitioning to F3 products to prove for themselves that F3 are operationally fit-for-purpose as part of exercising due diligence in the risk management and procurement processes, including partnering with industry in the development of new products such as a high-performance, low temperature (24°C) protected and low viscosity 1% fluorine-free foam concentrate specifically for offshore installations as a means of reducing storage-space requirements. Transitioning to F3 is not just a recent phenomenon with organisations such as the Queensland Fire and Emergency Service (QFES) using Class B F3 foams satisfactorily for more than a decade.

As described in one of the Appendices by Lars Ystanes (Equinor) a major Scandinavian petrochemical concern has switched completely to fluorine-free firefighting (F3) foam for both its onshore and offshore (North Sea) operations, after having carried out extensive testing and due diligence on alternatives to AFFF before changing over.

The number of offshore rigs operating in the North Sea sector is the largest in the world even exceeding the number of those in either the Gulf of Mexico or the Persian Gulf as indicated by statistics for January 2018 provided on the website < www.rigzone.com >. Equinor are responsible for ~50% of total production in the North Sea totalling some 2.5 million barrels a day, and 80% of all operations on the Norwegian Continental Shelf (NCS).

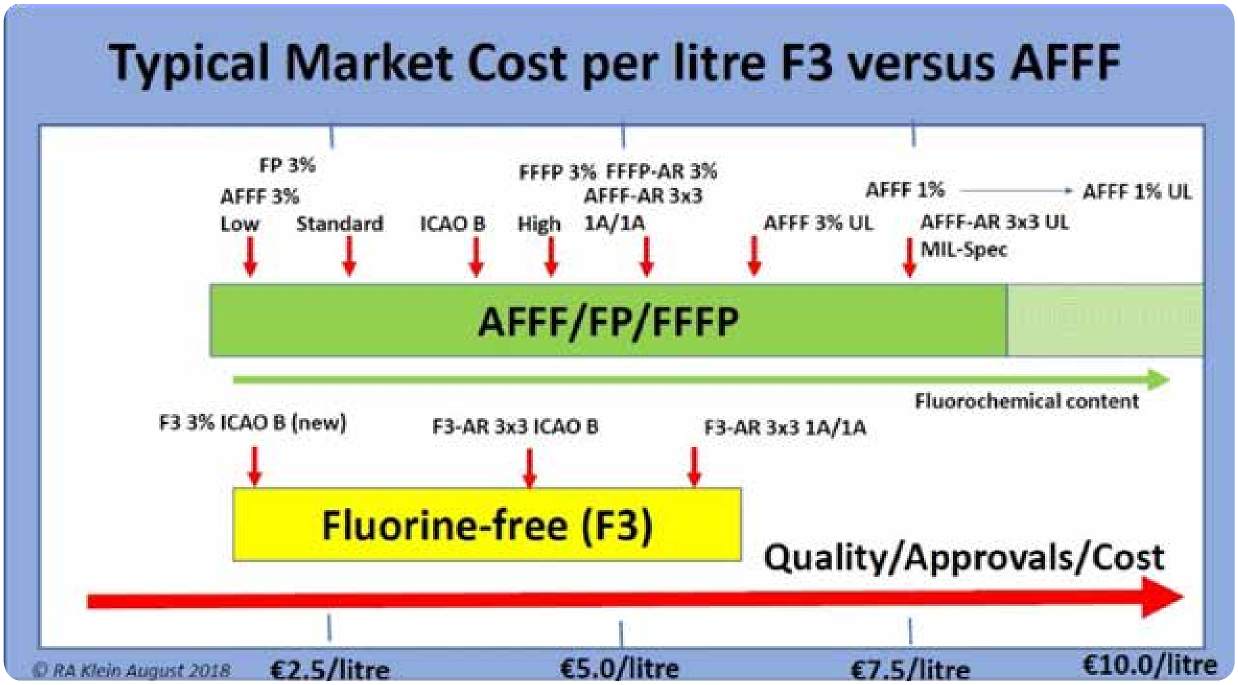
A comprehensive list of known end-users of fluorine-free firefighting (F3) foams was given in the IPEN White Paper presented at the UN Stockholm Convention POPS Review Committee meeting in Rome in September 2018. This list is reproduced below.

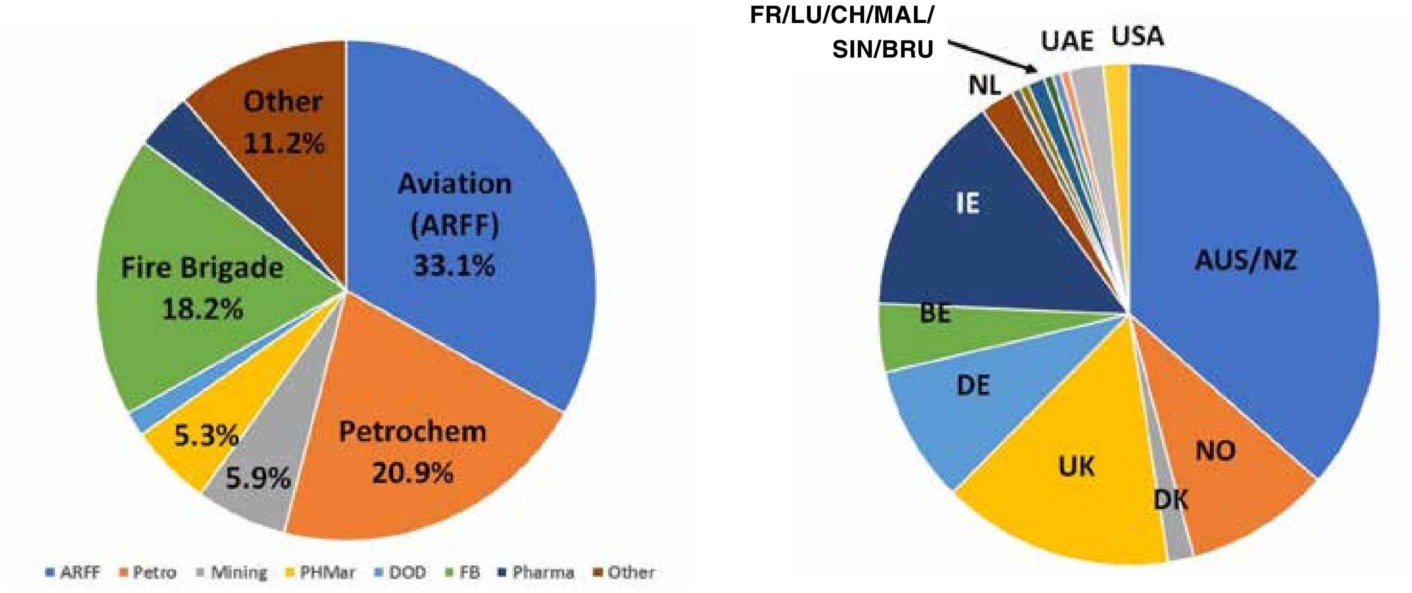
> *All of the 27 major Australian airports have transitioned to fluorine-free firefighting (F3) foams, as have the following major hub aiports: Dubai, Dortmund, Stuttgart, London Heathrow, Gatwick, Edinburgh, Manchester, London City, Leeds-Bradford, Copenhagen, and Auckland, and elsewhere in Europe such as Billund, Guernsey, Bristol, Blackpool, Köln-Bonn. Private sector companies using F3 foams include: BP, ExxonMobil, Total, Caltex, Gazprom, Statoil, BHP Billiton, Bayern Oil, 3M, BASF, Chemours, AkzoNobel, Stena Line, Pfizer, Lilly, Weifa, JO Tankers, and ODFJEL. In the oil and gas sector, F3 foams are being used extensively, with Statoil in Norway having transitioned to F3 foams throughout all of its operations. Some military users, including the Danish and Norwegian Armed forces, have moved to F3 foams.*

Commercially motivated attempts at discrediting Class B fluorine-free firefighting foams have often relied on unfounded and unsubstantiated claims based on no evidence, documentary or otherwise, that doing so would endanger life safety. Claims of reduced F3 performance compared to AFFF continue to rely on out-of-date misinformation derived from old data for early first-generation products and take no account of modern advances in foam technology within the past decade as evidenced by the broad choice of F3 foams now available for all uses.

The advantages of using a high-quality F3 foam in terms of long-term environmental and socio-economic benefits with reduced legal and financial liability, as well as lower clean-up and remediation costs, are being seen by end-users as obvious and far outweighing the costly contamination and management issues associated with the dispersive use of highly persistent fluorinated AFFF type foams of equivalent performance.

Experience has shown that discharges of fluorine-free foam contaminated runoff can be allowed to degrade naturally without long term damage to the environment so long as the immediate area is not hydrologically or biologically



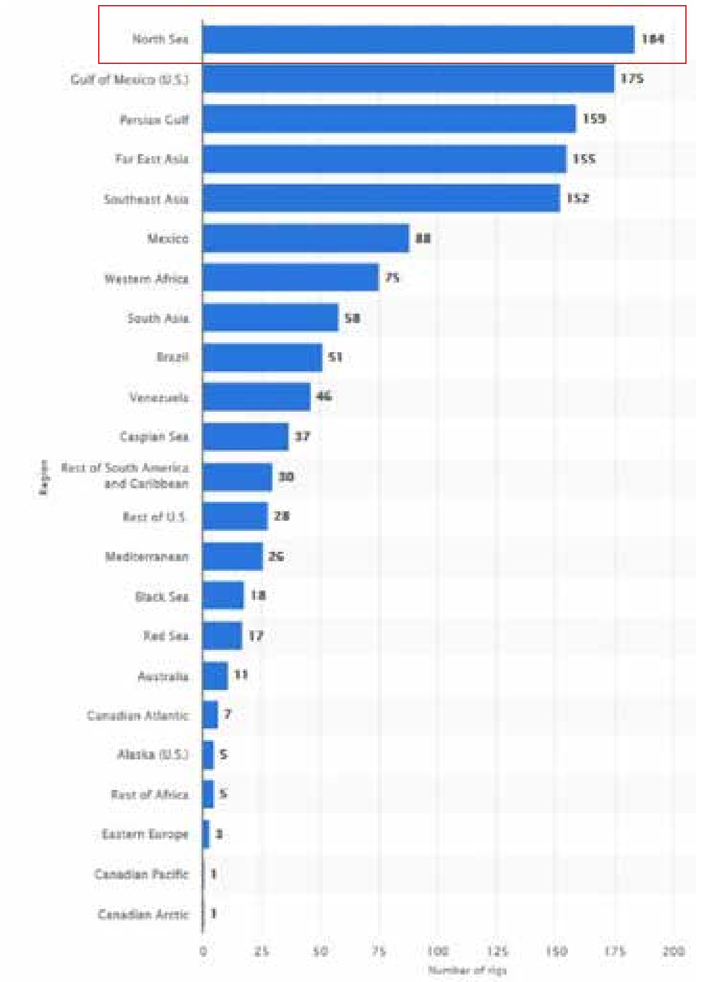


Fluorine-free foam use by sector and country.

sensitive. Although data is sparse in the public domain, a recent extended investigation of the BOD out to 60 days for a commercially available 3x6 ATC fluorine-free foam has shown that the foam degrades with a half-life of ~8-9 days ultimately reaching a genuine 100%. A similar Class A/B fluorine-free 1% firefighting foam demonstrated rapid biodegradation to 97% in 7 days and 100% degradation within 21 days.

The common assertion in safety data sheets (SDS) for AFFF - or FP and FFFP for that matter - that the product is '*readily biodegradable*' is disingenuous and highly misleading putting the end-user at considerable risk of causing permanent pollution by misapplying a biodegradation threshold of "60%" intended for single chemicals in isolation that is not relevant to mixtures including POPs, and totally failing to declare that the persistent organic fluorochemical content in the mixture will not biodegrade to mineralisation and will yield highly persistent perfluorinated end-point compounds such as perfluoroalkyl carboxylates (PFCA) such as PFOA or perfluoroalkyl sulphonates (PFSA) such as PFOS.

In summary, it is clear with the current state-of-the-art and development of newer generation fluorine-free firefighting (F3) foams that they are indeed viable as much lower-risk alternatives to AFFF in most situations, with significant progress underway to confirm their effectiveness for very large-scale uses, primarily for large fuel storage tanks protection. Detailed explanation in support of this has been presented at some length in the previous IPEN Expert Panel White Paper (WP1) presented to the Stockholm Convention Persistent Organic Pollutants Review Committee meeting (SC POPRC-14) in Rome last year 17-21 September 2018, which should be referred to for further detail.



Offshore oil rigs by region.

3. CURRENT C6 ALTERNATIVES TO LEGACY C6/ C8 TECHNOLOGY AFFFs

Older generation C6/C8 fluorotelomer technology AFFF firefighting foams, including many stocks still in use, contain substantial proportions of C8 perfluoroalkyl derivatives such as 8:2 fluorotelomers. The long-chain C8 fluorotelomers (8:2, 10:2, 12:2) are of significance as sources of PFOA and related long-chain compounds through transformation in the environment.

Based on information in the early patent literature (referred to previously in the first White Paper), the chain length distribution in the fluorinated feedstocks used could be as much as 20-40% C8 with higher homologues present as well such as longer-chain C10, C12, etc..... This has been confirmed more recently by analytical studies on a range of AFFF foam concentrates (Place and Field (2012)). All fluorotelomer C8 derivatives (e.g., 8:2 FtS, 8:2 FtTAoS, etc.) represent a source of PFOA by transformation once exposed to environmental conditions.

Products promoted as "C6-based" are not necessarily C6-pure and many contain significant proportions (10%-40%) of long-chain PFOA related compounds.

The C8 and higher components were required in foam to achieve effective performance especially as regards burn-back resistance. Claims by the industry that fluorotelomer AFFF products were always 'C6 based' and that pure C6 fluorosurfactants were available as early as the 1970s or 1980s are disingenuous and misleading as the fluorosurfactants used were a mix of C6 plus significant C8 content. Moreover, any claim that pure C6 technology for AFFF provides equivalent performance to the older C6/C8 technology should be treated with caution as C6 foams have struggled to achieve adequate performance:

> (Manufacturer's patent WO 2014144988 A2, 2014) *".,,,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 firefighting applications....".*

This issue of C6-pure under-performance was originally raised by Thierry Bluteau in 2009 at a Reebok foam seminar, and is discussed further in an Appendix, at first vehemently denied by the industry and then admitted in an article from a fluorosurfactant feedstock manufacturer in the technical press:

> (Industrial Fire Journal Q3 2010) *"...From the fast knock-down and extinguishment point of view, C6-based fluorosurfactants perform better than longer-chain molecules. But they suffer on the burn-back side, which means there has always been a trade-off between faster extinguishment and burn back resistance. In fact, some of our fluorosurfactants products are therefore a blend of C6 and C8....".*

Over the years the C8 component has been progressively reduced by the foam industry especially since the introduction of the 2010/2015 US EPA PFOA Stewardship Program. Commendable efforts by fluorochemical feedstock manufacturers mean that the currently best available fluorosurfactant feedstocks for firefighting foam contain PFOA, its salts and PFOA-related substances at less than 25 parts per billion (<25 ppb or < 25 µgm per litre). However, feedstock manufacturers subscribing to the PFOA Stewardship program are not the only suppliers of PFAS feedstocks and foam manufacturers are not legally obliged to use only pure C6 materials.

The PFOA problem has not gone away in spite of the USEPA 2010/2015 PFOA Stewardship Program and assurances from the industry. Major western manufacturers still offer old C8 technology AFFF, FP and FFFP foams which are potential sources of environmental contamination with PFOA.

Although modern *high purity* C6 fluorotelomer foams are now substantially free of PFOA and its precursors, there are still unresolved performance issues compared to the older C6/C8 and "C6-based" technology, such as the inability to use pure C6 products for sub-surface injection in fuel storage tanks. More importantly the C6 fluorosurfactants will ultimately transform to yield highly persistent, highly mobile C6 and shorter chain perfluorocarboxylic acids (PFCA) including perfluorohexane carboxylic acid (C6 PFHxA), perfluoropentane carboxylic acid (C5-PFPeA) and perfluorobutane carboxylic acid (C4-PFBA). These perfluorinated end-point products are environmentally extremely persistent as are all PFCAs, although less toxic and bioaccumulative than PFOA and longer chain PFCAs, but with these supposed advantages contradicted their other characteristics of higher mobility and uptake.

In particular and of increasing concern is that these short chain PFAS (<C7 chain length) are much more mobile in the environment than their longer-chain homologues resulting in:

- **Larger contamination plumes**, far wider than PFOS and PFOA.
- **Rapid leaching from soils** down to groundwater.
- **Greater long range transport** potential in air and water.
- **Greater difficulty in removal** from drinking water and waste effluent streams.
- **Greater difficulty for soil remediation** by stabilisation and fixation.
- **Preferential up-take** into the edible portions of crops, vegetables and grasses.

This will ultimately lead to wider distribution of contamination, increasing environmental concentrations, increasing exposure and presence in the food chain with evidence emerging that short-chain PFAS are not benign.

4. ARE SHORT CHAIN PFAS SUITABLE REPLACEMENTS FOR OLDER C8 PFAS?

As pointed out in the Introduction referring to the Review Committee's recommendations at POPRC-14, it was concluded that short chain alternatives were considered as unsuitable replacements for longer chain PFAS. These concerns do not just apply to firefighting foams which are an obvious, highly-dispersive use, but also to other fluorochemical uses such as textile treatments and food packaging which can ultimately result in environmental contamination via landfill leachates, or human exposure.

For short-chain PFAS evidence has emerged and is growing rapidly that these highly persistent and mobile PFAS are of similar concern to long-chain PFAS with the distinction between them largely academic and adverse effects likely, especially with increasing exposure from ongoing uncontrolled releases.

The problems associated with substituting older C6/C8 fluorochemical technology for short-chain replacements are considered in detail in the Appendices to this White Paper. However, the issues rising from switching to shorter chain fluorochemical technologies may be summarised briefly here:

- **Longer chain PFAS are commonly present** in current "C6-based" fluorotelomer products although C6 purity has improved dramatically amongst those suppliers subscribing to the 2010/2015 USEPA PFOA Stewardship Program (but not necessarily elsewhere), with PFOA related contamination now achieving > 25 ppb in the best available, and most expensive, feedstock currently available in the western world.
- **Toxicological studies** have inadequately focussed on a single degradation product of C6 fluorotelomers – C6 perfluorohexanoic acid or PFHxA ignoring the potential effects of the source compounds and the numerous intermediate transformation products including aldehydes, ketones and unsaturated acids.
- **PFHxA is extremely environmentally persistent** as are all perfluoroalkyl carboxylic acids, although it is less toxic and bio-accumulative than longer chain homologues it is not non-toxic with environmental concentrations continuing to increase. Data is limited to industry supported publications that do not address combined exposure to the multiple chemicals such as original fluorotelomer products, transformation compounds plus the commonly occurring diversity of other PFAS.
- **PFHxA was being considered as a SVHC** (substance of very high concern) due to its behaviour, difficulties associated with removal and the potential for adverse effects. In spite of 17 EU member states' support, in the face of opposition from the UK and Finland, this proposal was withdrawn. Germany is now preparing a restriction proposal for PFHxA. Because PFHxA can be produced by degradation of 6:2 fluorotelomers they should be considered in the same way.
- **Other short-chain transformation products** arising from C6 fluorotelomers have not been examined for biological effects leading to uncertainty.
- **Toxicological profiles are unknown** for the range of other short-chain PFAS alternatives such as diPAPs, perfluoroalkyl ether or chloro-perfluoroalkyl ether derivatives.
- **Long-range transport and dispersal** of all extremely persistent perfluoroalkyl end-point or partial degradation products are of concern not only locally but globally whether short or long-chain.
- **Exposure will increase** with continued release of persistent short-chain PFAS with inexorably higher environmental concentrations which will be practically impossible to remove from soils, effluent, biosolids and drinking water.
- **Short chain PFAS are more mobile, volatile and soluble** and much more difficult, if not impossible to remove from effluent waste streams than their longer chain homologues.
- **Increased mobility results in extended long-range transport** and much more extensive contamination plumes reaching sensitive receptors and resources at a distance.
- **Unknown long-term toxicity and bio-accumulation** profiles for short chain PFAS related to compounds with known adverse effects immediately triggers the application of obligations under the *Precautionary Principle* for end-users, regulators and manufacturers. Especially when they are known to be present in complex mixtures of PFAS transformation and partial-degradation products.

These problems apply not only to the highly dispersive use of firefighting foams but also to a wide range of other fluorochemical applications such as textile and fabric treatments, paper and food packaging, leather treatment, etc., which, although not so obviously dispersive in their application, still represent a hidden or masked source of potential environmental contamination only apparent when the entire life cycle of a product is considered with eventual release in effluent, biosolids, volatiles and landfill leachate. Realistically there are very few PFAS applications where it is possible to effectively capture the wastes or to destroy them in the long term.

5. DECONTAMINATION OF FIRE APPLIANCES

Decontamination of installations, storage vessels and pipework that have held fluorinated firefighting foams (AFFF, FFFP, FP) is a non-trivial task that can be both costly and time consuming but is necessary to avoid retaining toxic residues and to avoid contamination of new stocks. Decontamination is a necessary part of the transition of facilities to non-persistent, non-fluorinated foams or when uncontaminated third-party brigade appliances have been forced to use on-site PFAS contaminated foam stocks during a large incident.

Decontamination of equipment that has held fluorinated firefighting foam may, at first sight, appear costly but is eminently achievable with considerable long-term benefits in the reduction of potential personnel exposure and liability for releases to the environment and remediation.

Some brigades have already adopted strict policies of refusing to pass PFAS foams through their appliances even in emergencies, reducing the ability of external resources to contribute to incident response at fixed facilities still using AFFF. Alternatively, brigades using fluorine-free foam have made it clear that the AFFF foam owner will be responsible for the considerable cost of decontaminating or replacing contaminated appliances and equipment.

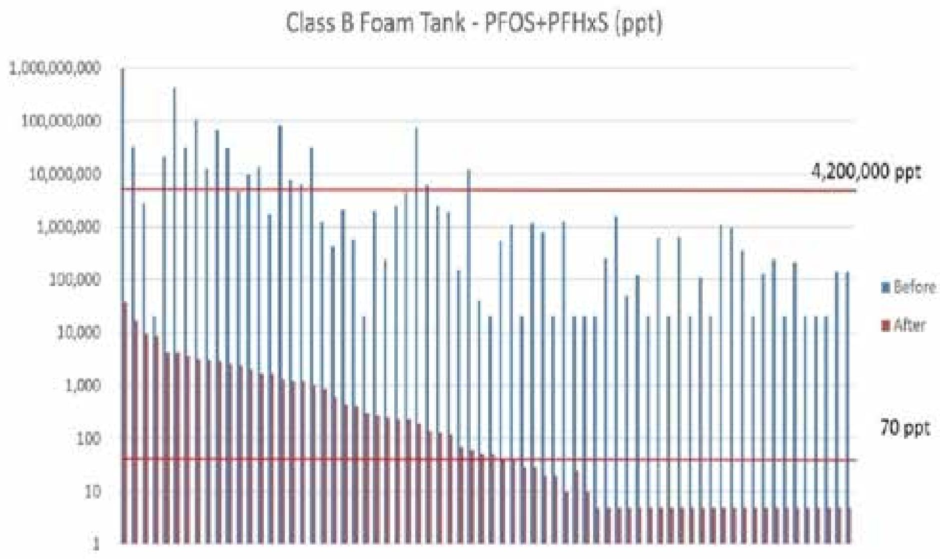
Moreover, decontamination for transitioning to fluorine-free foam or after an incident (as above) may necessitate taking equipment off the run or out of service for some time or even in some cases investing in completely new equipment so as to ensure that newly procured fluorine-free foams are not contaminated with residual PFAS residues. The only really reliable and fool-proof way to monitor possible cross-contamination from legacy fluorinated material remaining absorbed to vessel walls, pipework and valve gear is to carry out total organic fluorine (TOF) analysis of samples during the decontamination process.

In this paper two examples of such decontamination problems are given as case studies. The first described below involved the decontamination of fire appliance foam tanks, pumps and pipework, carried out by Melbourne Metropolitan Fire Brigade (MFB). The second described in one of the Appendices is for the onshore and offshore installations in Norway and on the Norwegian Continental Shelf run by Equinor, formerly Statoil. Another similar example is that of London Heathrow airport transitioning from FFFP to a fluorine-free foam (F3) which involved the procurement of new and hence previously uncontaminated fire appliances.

Due to PFAS adhering to various equipment surfaces, replacement of AFFF by fluorine-free (F3) concentrate requires any storage vessel or pipework to be replaced or properly cleaned in order to prevent carry-over PFAS contamination.

Complete cleaning of fire appliance foam tanks and associated equipment with solvent mixtures prior to refilling with fluorine-free foam (F3) concentrate is time-consuming and challenging, for example, a number of wash cycles will be required with specialised waste disposal. Moreover, provision must be made for the requirement that fire appliances and equipment have to be taken offline or 'off the run' in order to be decontaminated. The data shown shows PFAS levels before and after cleaning fire appliance foam tanks and comes from recent work carried out for Melbourne Metropolitan Fire Brigade (MFB) in which an acceptable level after cleaning of 70 ppt (ng/L) PFOS+PFHxS was the target.

PFAS levels before and after decontamination.



6. CONCERNS OVER FIREFIGHTER EXPOSURE TO PFAS IN CLASS B AFFF FOAMS

Firefighters and their representative organisations worldwide have expressed serious concerns over legacy and ongoing exposure to PFAS during training and operations as shown by various studies in the literature correlating firefighters exposed to firefighting foam during training and operations with elevated PFAS levels in their blood. Levels for PFOS, PFHxS and PFOA in the blood of a significant proportion of firefighters are well above levels in the general population raising concerns about potential consequences for human health. Of particular concern is the increased likelihood of certain cancers developing or being promoted given that firefighters are also exposed to a combination of other chemicals that can have adverse health effects that may be enhanced synergistically by PFAS exposure.

The exposure of the workforce and in particular firefighters to PFAS is of growing concern globally with evidence emerging that this is not just a legacy issue for earlier generations of workers but a continuing issue with no obvious source.

Occupational exposure to PFAS for firefighters has resulted in unacceptably high blood PFAS levels with the potential to contribute to adverse health effects.

To an extent it was assumed that PFAS exposure for firefighters was a thing of the past with "safer" PFAS foams brought into use together with better personal protective equipment and procedures. However, instances of high PFAS levels in firefighters' blood samples (including PFOS) continue to appear even for relatively recently employed firefighters who have not had long-term, legacy or obvious recent exposure. The alternative later-generation foams replacing PFOS/PFHxS foams are now known in some cases to contain long-chain PFAS that are precursors to PFOA and its homologues that may be sources of recent exposure. Other potential sources of PFAS exposure include occupation of PFAS contaminated fire stations and PFAS treated or contaminated items of fire kit, which are now also being investigated.

The following comparison of average population blood levels is taken from the Parliament of Victoria's Environment, Natural Resources and Regional Development Committee final report on the Inquiry into the CFA Training College at Fiskville (2016).

Alongside this data are shown some representative results for PFAS plasma levels in firefighters exposed to AFFF foams (Laitinen et al. 2014; Rotander et al. 2015).

Apart from confirming the low HBM-I HBGV (HBM Health-Based Guidance Values) values for PFOA as 2 ng/ml (µg/L; ppb) and for PFOS as 5 ng/L (µg/ml; ppb) in blood plasma as levels below which there is no risk of adverse health effects, there are comments on range of associated health effects and the value of time-series measurements to track progress of exposure (German Federal Environment Agency; Apel et al (2017); Buekers et al (2018)). There are no HBM HBGV available for PFHxS, in spite of it being a substance of very high concern (SVHC) and classified as very persistent and very bio-accumulative (vPvB).

For levels between the HBM-I value and the estimated HBM-II values adverse health effects cannot be excluded any more with sufficient certainty and a follow-up examination should be performed to determine whether there is a continued elevated exposure. If repeated measurements confirm the initial result a search for potential sources of exposure should be undertaken.

In summary, the Germen Federal Environment Agency HBM Commission rates effects in the subsequent areas as well proven, relevant, and significantly associated with an exposure to PFOA and/or PFOS:

1. Fertility and pregnancy
2. Weight of newborns at birth
3. Lipid metabolism
4. Immunity after vaccination, immunological development
5. Hormonal development, age at puberty/menarche
6. Thyroid metabolism
7. Onset of menopause.

The serial testing for PFAS blood levels in occupationally exposed populations is both meaningful and useful to establish baseline levels, exposure factors and exposure/ elimination trends, quite contrary to the improper advice being given by certain government departments and agencies.

The highest levels of PFOS and PFHxS in Australian firefighters were an order of magnitude higher compared to the general populations in both Australia and Canada (Rotander *et al.* 2015).

6.1 AUSTRALIAN FIREFIGHTER PFOS BLOOD LEVELS

Concerns are emerging and growing about occupational exposure of firefighters to PFAS contamination with blood PFAS levels well above the general population. In a large cohort of fire service personnel (Study A 2017; >500 individuals) who had their blood tested for PFOS 93 out of 542 (17%) had PFOS levels in excess of 20 ng/ml, with some between 100-200 ng/ml. Nearly a quarter of those tested (23%) had PFOS blood levels more than tw0 standard deviations above the Australian population mean for PFOS, see below.

A similar study (Study B, 2017) showed not only elevated PFOS blood levels in firefighters, with one extreme value of 1600 ng/ml, but an extremely good correlation (Pearson correlation of 0.9844) for the ratio of PFHxS to PFOS levels in blood, as also observed by Rotander *et al.* (2015 - second figure below).

In both of the figures the horizontal and vertical dashed red lines represent the median values for PFOS and PFHxS respectively as observed for the general Australian population (Rotander *et al.* 2015).

The point at which the dashed red lines intersect in the figure represents the average median combined PFOS/PFHxS blood concentrations for the general Australian population.

Moreover, it has been realised that there are many other novel PFAS in addition to those usually considered, i.e., PFOS or PFOA, that firefighters are exposed to occupationally from using AFFF foams or from contaminated firewater runoff, for example, perfluorohexane sulfonic acid, PFHxS, the C6 homologue of PFOS (Rotander *et al.* 2015).

6.2 PFOS BLOOD LEVELS IN AUSTRALIAN AVIATION (ARFF) FIREFIGHTERS

Aviation firefighters across Australia have been found to have up to 20 times the normal level of toxic chemicals in their blood in testing conducted by Airservices Australia in 2013 (as reported by ABC News, Elise Kinsella, posted 30 Jul 2018). Measurements of blood PFAS levels for 20% (149 out of 731) of ARFF personnel in this study (Rotander *et al.*, 2015) showed that PFOS and PFHxS levels were markedly elevated, increasing with length of service and age, i.e., potential for exposure, as might be expected for contaminants with long biological half-lives (PFOA 3-4 years; PFOS 4-5 years).

For PFHxS the estimated serum elimination half-life in humans is higher than other PFAS with an average half-life of 8.5 years (USEPA 2017)) resulting in bio-accumulation with continued exposure when uptake exceeds clearance from the body.

This increase in blood levels for firefighters reaches a maximum concentration after 20-30 years of service followed by levelling out or even a slight drop-off, perhaps due to decreased operational exposure with increased seniority / length of service and as well as tighter health and safety standards than those observed early in their careers. Notably, levels for those in this study with more recent service of 0-10 years and who were likely to have been less exposed due to more rigorous use of personal protective equipment, are close to the general population average.

6.3 PFHXS AND PFOS BLOOD LEVELS ARE ASSOCIATED AND OF CONCERN

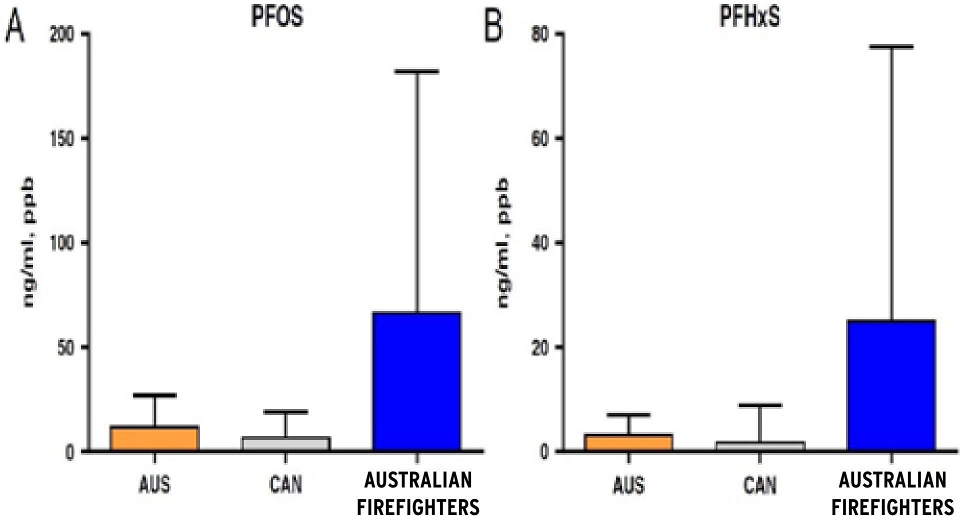
PFHxS was of particular concern to the Stockholm Convention Persistent Organic Pollutants Review Committee (POPRC14) at its recent meeting in Rome in September 2019 especially because of its long biological half-life in humans, being slower to eliminate even compared to PFOS. The Committee decided:

> *"...that perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds are likely as a result of their long-range environmental transport to lead to significant adverse human health and environmental effects such that global action is warranted...".*

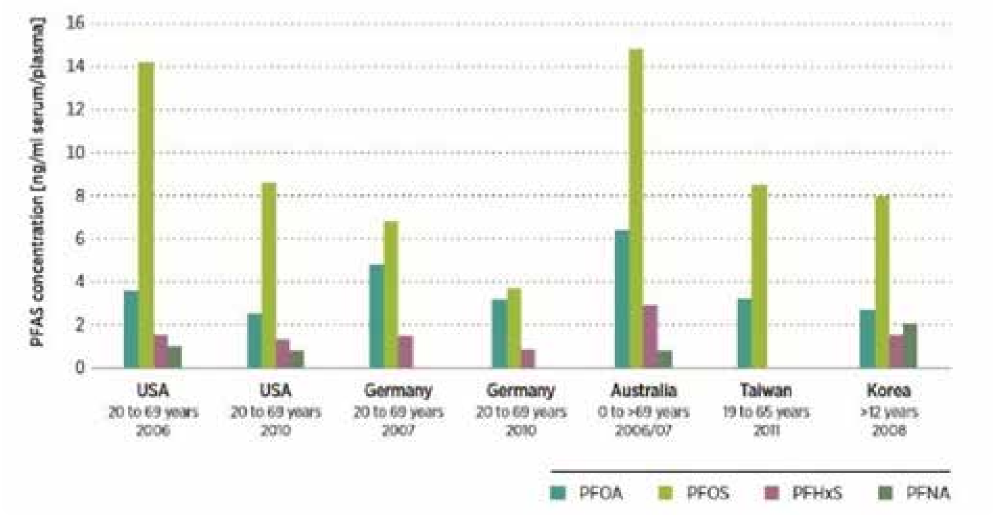
The Risk Profile for PFHxS (UNEP/POPS/POPRC.14/6/Add.1) on which the POPRC based their decision indicated adverse effects for liver, reproduction, thyroid, cholesterol, embryo development and immunisation:

> *"...PFHxS affects liver function, lipid and lipoprotein metabolism and activates the peroxisome proliferating receptor (PPAR)-alpha. In studies on rodents, increased liver weight as well as marked hepatocellular hypertrophy, steatosis and necrosis have been observed. Furthermore, alterations in serum cholesterol, lipoproteins, triglycerides, and alkaline phosphatase have been observed in rodents after PFHxS exposure. Effects on lipid metabolism and serum enzymes has been observed in human epidemiology studies. Effects on reproduction (decreased live litter size) have been observed in mice after PFHxS exposure. PFHxS binds to the thyroid*

PFAS levels in blood for Australian firefighters versus general populations.
Source: After Rotander *et al.* 2015



International comparison of four PFAS levels in blood from the general population.
Source: Umweltbundesamt (UBA) 2015 presentation



> *transport protein, and has been associated with changes in serum thyroid hormones across species. Some evidence suggests that exposure to PFHxS may affect the developing brain and immune system. Effect on the antibody response to vaccination has been shown in epidemiology studies…".*

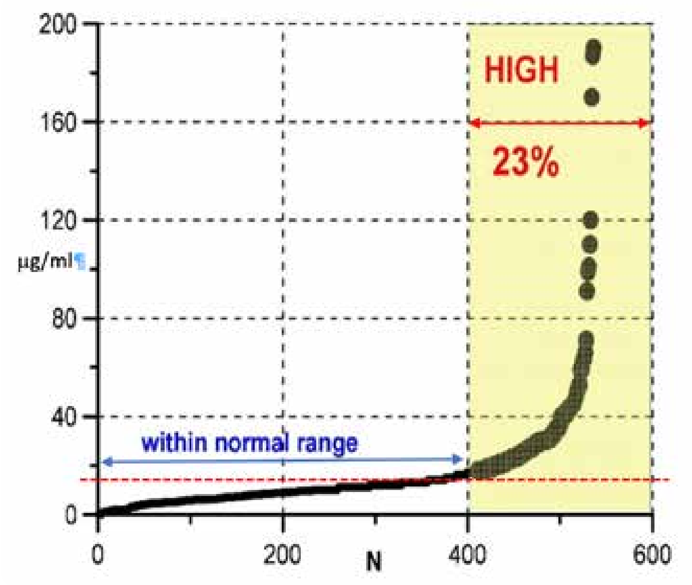
Recent studies by both Melbourne Metropolitan Fire Brigade (MFB) and the South Australian Metropolitan Fire Service (SAMFS) have demonstrated unequivocally in the results for a large cohort of occupationally exposed personnel that many individuals have blood concentrations of PFOS far in excess of the Australian population average (between 10-20 ng/ml).

Thus, finding elevated associated PFOS and PFHxS levels in firefighters due to essentially avoidable occupational exposure is of particular concern. The correlation between PFOS and PFHxS blood levels suggests that both were present in PFOS-based firefighting foams, as has been indicated by the analyses of PFOS legacy foams. The particular concern about PFHxS is that it is considered to have similar or greater toxicity and bio-accumulative potential than PFOS, plus elimination of PFHxS in humans is slower than for PFOS.

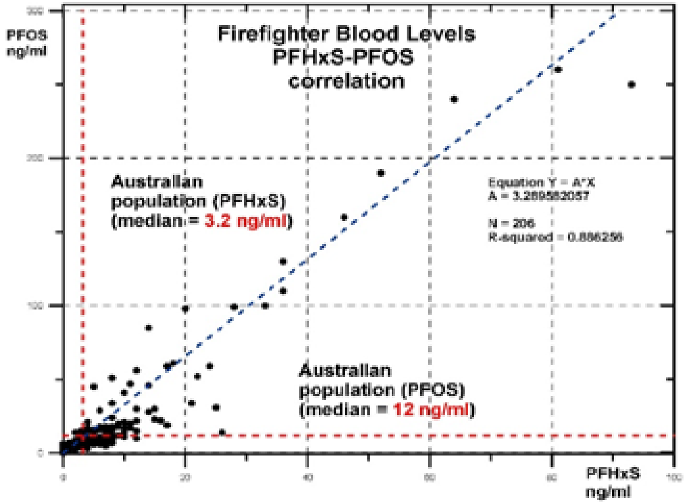
These findings have prompted further studies of PFAS in occupationally exposed firefighters to further monitor levels, explore the extent of exposure and determine possible factors affecting elimination and reduction in blood levels.

In the United States in July 2018, President Trump signed into US law H.R. 931, the "*Firefighter Cancer Registry Act of 2018*", this establishes and maintains a voluntary registry

PFOS levels in Firefighters' blood.

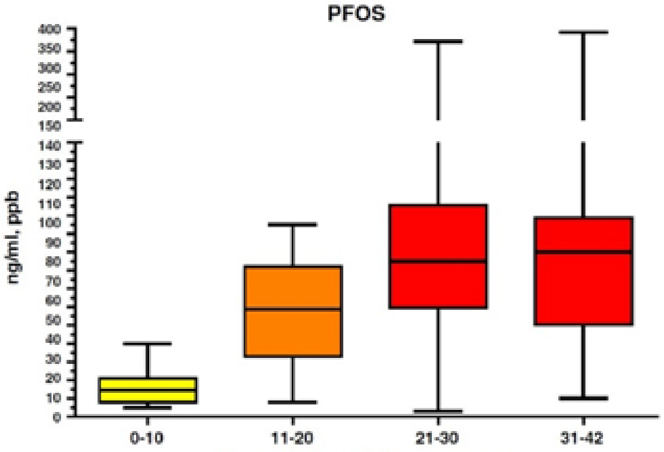


PFOS and PFHxS correlation in firefighters' blood: this implies that exposure to PFOS is likely to mean concurrent exposure to PFHxS.



of firefighters to collect data on cancer incidence. Culminating after more than two years of intense lobbying and hard work by the IAFF and its leadership, the Firefighter Cancer Registry Act of 2018 (H.R. 931) means that the US Federal Government has taken the first steps towards establishing a one-of-a-kind national cancer registry specifically for fire fighters.

Years of jobs with AFFF exposure. Source: A. Rotander et al., Environment International 82 (2015), 28-34



7. KNOWN AND PROBABLE HEALTH EFFECTS OF PFAS EXPOSURE

There is considerable confusion and misunderstanding surrounding the differences between the two toxicological mechanisms, i.e., direct "cause-and-effect" or epidemiological "probable links", which can result in adverse health effects for any chemical exposure, especially pertaining to PFAS whose effects can be subtle, synergistic and range across a very wide range of adverse health and environmental effects. From a Stockholm Convention perspective the Precautionary Principle is embedded within the convention's rationale forming a very important mechanism in terms of the management of POPs releases and pollution. The context around the relevance and significance of "direct causation" or "probable links" is relatively simple:

- **For direct causation** it is *technically* correct to say that there is "very little evidence of direct cause-and-effect by PFAS with any specific disease" and this statement is often used to deflect attention, deny liability and/or defer action (e.g., as was done for smoking and asbestos as causes of cancer). However, this is disingenuous as it defers action until "absolute proof" is available which will never occur given that PFAS effects cannot be tested deliberately and directly on humans to provide the required level of proof.
- **For probable links and associations with adverse conditions**, which are well established for various PFAS, the exercise of obligations under the Stockholm Convention are predicated in large part on the *Precautionary Principle* that is clearly triggered by the well-established and growing associations of PFAS with various adverse conditions. By contrast the burden of proof under the *Precautionary Principle* sits with ***the proponent*** (manufacturer and user) to show conclusively that their product or activity is proven not to cause adverse effects.

There is more than ample current and emerging evidence that PFAS exposure is more-likely-than-not associated with adverse health effects.

The attached recent white paper in the appendices by Chief Justice Brian Preston of the New South Wales Land & Environment Court about the *Precautionary Principle* is comprehensively and specifically relevant to PFAS. Justice Preston is a leading world authority on the jurisprudence of the *Precautionary Principle*, providing very clear guidance on its triggers, considerations and legal application in all jurisdictions with clear obligations for manufacturers, end-users and regulators in making decisions and carrying out activities. In particular it is the end-user that is also subject to the *Polluter Pays* principle as well as the *Precautionary Principle* under the ESD provisions of the Rio Declaration subscribed to by most if not all signatories to the Stockholm Convention.

For PFAS there is more than enough epidemiological evidence whereby probable links have been established between exposure to PFAS and disorders of metabolism or defined pathologies, including interference with the immune response (Grandjean *et al.* 2012, 2017). Probable links can be considered as being equivalent to an association that is "more-likely-than-not", i.e., the probable link is greater than 50%.

Industry and some government defence departments generally maintain the position that it is only necessary to act on *absolute proof of direct causation* rather than just the establishment of a *probable link* with an impact on human health from exposure to any particular pollutant such as PFOA or PFOS, especially when it comes to risk assessment or defending potential litigation. The difference between absolute proof and a probable link is an important one as summarised above with only a probable link necessary to invoke the obligations of the *Precautionary Principle*.

Establishment of cause-and-effect is clear in diseases resulting from specific exposures, for example, with blue asbestos causing pleural mesothelioma, silica dust causing lung silicosis, as well as the effects of dioxins, pesticides, or toxic heavy metals such as mercury, cadmium, or thallium, all of which have eventually been "proven" as causative agents or at least accepted as such. Probable links are more difficult to define and may be confused by other confounding exposures and factors but are nonetheless clear reasons to adopt a conservative approach to the management of any chemical.

A probable link between exposure and a particular disease is most often established progressively based on epidemiological data. Examples of established probable links include:

- Smoking and lung cancer.
- Diabetes type II and cardiovascular problems associated with obesity and high serum cholesterol levels.
- High alcohol intake and liver disease.
- Poor respirable air quality (nitrous oxides, etc.) and respiratory conditions.
- Heavy smoking and chronic obstructive pulmonary disease (COPD).
- High saturated fat intake and the development of arterial atheroma.

The general public would accept that all of the above are causes and effects beyond reasonable doubt and that they would have a high expectation that regulators would mitigate or act upon this evidence and similarly would do so in the case of PFAS exposure, *although strictly these are probable links and not absolute proof of causation.*

More general disturbances such as suppression of the immune response by PFAS may also cause predisposition to the development of conditions such as cancer in which the immune system normally provides some protection against unregulated cell multiplication and invasion.

It is important to be clear about what is meant by a probable link. To quote from a 2016 letter to the Australian Senate Inquiry into PFAS by PFAS industry representative Dr Carol Ley, Corporate Medical Director for the 3M Company:

> *"…A 'probable link' is not a 'causal' link between exposure and disease. A 'probable link' is merely a 'more likely than not' [i.e., the probability of an association is greater than 50%] association between exposure and a given disease in the cohort being studied…".*

This is significant as "*more likely than not*" for just one adverse effect, never mind such a significant range and combination of other potential adverse effects as seen for PFAS, would automatically trigger application of the *Precautionary Principle* assessment considerations and the expectation by the general public of prompt action to apply controls and protect human health values on the part of the end-user, manufacturer and regulators. There are now numerous and growing examples of litigation brought on this basis about probable PFAS effects that have been settled out-of-court for hundreds of millions of Euros rather than defended in the courts, as the weight of evidence continues to grow with courts only needing probable cause to be established and not absolute proof of adverse effects.

As pointed out in the ATSDR draft *Toxicological Profile for Perfluoroalkyls* (June 2018), a large number of epidemiological studies have examined the potential of perfluoroalkyl compounds to induce adverse health effects, with most of these cross-sectional in design and not intended or able to establish absolute causality.

Based on the consistency of findings, available epidemiological studies point to associations or probable links between PFAS exposure and at least the following conditions:

- **Pregnancy-induced hypertension**/pre-eclampsia (PFOA, PFOS).
- **Liver damage**, as evidenced by increases in serum enzymes and decreases in serum bilirubin levels (PFOA, PFOS, PFHxS).
- **Increases in serum lipids**, particularly total cholesterol and low-density lipoprotein (LDL) cholesterol (PFOA, PFOS, PFNA, PFDA).
- **Increased risk of thyroid disease** (PFOA, PFOS).
- **Decreased antibody response** to vaccines (PFOA, PFOS, PFHxS, PFDA).
- **Increased risk of an asthma diagnosis** (PFOA).
- **Increased risk of decreased fertility** (PFOA, PFOS).
- **Decreases in birth weight** (PFOA, PFOS).

The International Agency for Research on Cancer (IARC 2017) concluded that PFOA is possibly carcinogenic to humans (Group 2B). The USEPA (2016e, 2016f) had previously come to a similar conclusion that there was suggestive evidence for the carcinogenic potential of PFOA and PFOS in humans. Increased incidence of cases of testicular and kidney malignancies (cancer) has been observed in highly exposed subjects.

Other health outcomes, but with less certainty in the associations due to fewer studies or inter-study inconsistencies but nonetheless with significant implications for health, include:

- **Osteoarthritis** in women under 50 years of age (C8 PFOA & PFOS).
- **Decreased antibody response to vaccines** (C9 PFNA, C10 PFDA, C11 PFUnA, C12 PFDoA).

Less certain associations exist between PFOA and PFOS serum levels and decreased glomerular filtration rate. Increased serum uric acid levels and between serum levels of PFOA, PFOS, PFHxS, and PFNA with an increased risk of early menopause. These apparent associations may not be directly related to perfluoroalkyl toxicity.

Applying known health concerns for PFAS to occupationally exposed firefighters should be done with caution as there are many confounding factors to which firefighters may be exposed occupationally or during training such as combustion pyrolysis products, hazardous chemicals at industrial incidents and diesel exhaust fumes on station.

Unfortunately, the presence of confounding factors make litigation to seek redress for exposure difficult and often contentious, especially if direct cause-and-effect and thus absolute certainty cannot be established and the case is based on probable links, i.e., statistically likely associations, derived from epidemiological studies. However, presumptive legislation is now becoming commonplace recognising that occupations such as firefighting will experience an overall increased incidence of adverse health effects on the basis that these are "more likely than not" to occur due to various exposures rather than requiring absolute proof of particular cause and effect.

8. ARE RELEVANT SCIENTIFIC DATA ON PFAS RISKS PUBLICLY AVAILABLE?

As pointed out very recently by Richter, Cordner and Brown (2018: *Social Studies of Science 48950, 691-714*) there has been significant inertia for PFAS regulation despite the clear and growing evidence:

> *"...Despite this significant history of industry knowledge production documenting exposure and toxicity concerns, the regulatory approach to PFASs has been limited. This is largely due to a regulatory framework that privileges industry incentives for rapid market entry and trade secret protection over substantive public health protection, creating areas of unseen science, research that is conducted but never shared outside of institutional boundaries. In particular, the risks of PFASs have been both structurally hidden and unexamined by existing regulatory and industry practice....".*

Similar concerns over the public availability of historical PFAS toxicity data accumulated by the fluorochemical industry, not made public or communicated to regulatory authorities and only made public through legal discovery as part of litigation, has been highlighted by the recent legal action brought by the Minnesota Attorney General Lori Swanson (Press Release December 30, 2010 and court documents subsequently released as part of an official 2018 advisory from the office of the Attorney General), as well as a paper from Phillipe Grandjean of the Harvard School of Public Health (Environmental Health 2018: 17, 62) in which he pointed out the failure to consider data that pointed to "*more likely than not*" conclusions:

> *"...The "untested chemicals assumption", as highlighted by the National Research Council [1] has clearly been inappropriately relied upon in past risk assessments of PFASs, and these substances must now be added to the list of environmental hazards [Gwinn et al 2017] where standard risk assessment has failed. As a major reason, early evidence on PFAS toxicity was kept secret for 20 years or more, and even after its release, it was apparently overlooked .... Further, regulatory agencies relied on experimental toxicity studies and disregarded emerging epidemiological evidence. As a result, even some of the current guidelines are orders of magnitude above exposure levels at which associations with adverse effects have been reported. The PFASs therefore constitute an unfortunate example that risk assessment may be inappropriate to assess human health risks from chemical exposures when crucial documentation has not yet been published. Recognizing the weaknesses of conventional risk assessment, scientists from the U.S. EPA recently recommended to consider the full range of available data and to include health endpoints that reflect the range of subtle effects and morbidities in humans [Gwinn MR, Axelrad DA, Bahadori T, Bussard D, Cascio WE, Deener K, Dix D, Thomas RS, Kavlock RJ, Burke TA. Chemical risk assessment: traditional vs public health perspectives. Am J Public Health. 2017;107(7):1032–9]. The present summary of delayed discovery, dissemination and decision-making on the PFASs indicates that a more comprehensive assessment of adverse health risks is urgently needed and that PFAS substitutes, as well as other persistent industrial chemicals, should not be considered innocuous in the absence of relevant documentation [Birnbaum LS, Grandjean P. Alternatives to PFASs: perspectives on the science. Environment Health Perspectives 2015; 123(5): A104–5]..."*

The presumption that fluorochemicals newly introduced on the market are harmless until proven otherwise is contrary to responsible governance, given the clear read-across to the known properties of structurally similar compounds that have long been available. Failure to properly and comprehensively establish the characteristics of new products before release should no longer be accepted as the default position especially in the light of regulatory obligations under the *Precautionary Principle* as well as there being ample existing evidence for adverse effects of related chemicals in the same family.

As pointed out by Phillipe Grandjean (2018):

> *"... The PFASs therefore constitute an unfortunate example that risk assessment may be inappropriate to assess human health risks from chemical exposures when crucial documentation has not yet been published ... The present summary of delayed discovery, dissemination and decision-making on the PFASs indicates that a more comprehensive assessment of adverse health risks is urgently needed and that PFAS substitutes, as well as other persistent industrial chemicals, should not be considered*

innocuous in the absence of relevant documentation… " and that the setting of regulatory 'safe levels' for drinking water should not rely on toxicological data that may be orders of magnitude higher than that derived from epidemiological studies "… Further, regulatory agencies relied on experimental toxicity studies and disregarded emerging epidemiological evidence. As a result, even some of the current guidelines are orders of magnitude above exposure levels at which associations with adverse effects have been reported…".

It is worth noting that, over the years, 'safe' drinking water levels set by various regulatory agencies have shown a marked decrease in keeping with an increase awareness of these issues but are still in excess of the BMDL values derived epidemiologically (US data from Grandjean 2018).

9. POLITICAL MOVEMENT IN THE USA

Although PFAS chemicals are not currently regulated, in February 2019 three members of Congress from Michigan introduced the PFAS Action Act, legislation that would classify these chemicals as hazardous substances and make polluters liable for their clean-up in line with the *Polluter Pays* principle. The PFAS Action Act, which would enable PFAS chemicals to be cleaned up through the Superfund program, would change that — and could potentially cost the military heavily. A bipartisan task force formed by the US House of Representatives recently to address PFAS-related issues will likely tackle disposal issues as it pushes for accountability for polluters, including the Department of Defense.

In the US the Center for Disease Control (CDC) are now directed to undertake the collection of detailed data on the occurrence of cancer in fire fighters. The data will provide scientists with specialized information needed to research the relationship between these diseases and the job, strengthening understanding of probable links between firefighting and cancer and thus potentially leading to better prevention and safety protocols.

In 2018 Washington State Legislature took action to restrict some uses of PFAS that have contributed to contamination of food and water supplies. One law restricts PFAS use in food wrappers if safer alternatives are available (ESHB 2658), another law prohibits the use of PFAS-containing firefighting foams for training purposes and restricts the use of PFAS in firefighting foams, but with some exceptions (ESHB 6413): URL: <**https://www.doh.wa.gov/CommunityandEnvironment/Contaminants/PFAS**>.

10. HAND-HELD AND PORTABLE FIRE EXTINGUISHERS

Portable foam fire extinguishers represent a substantial source of fluorochemical contamination of the environment. Many extinguishers in current use for domestic premises, residential accommodation, shops, restaurants and office premises contain AFFF. This represents an example of commercially driven 'over engineering' and a quite unnecessary potential source of PFAS given that relatively benign carbon dioxide, dry powder or pressurised water extinguishers would be suitable for most applications as domestic premises, residential accommodation, shops, restaurants and office premises do not in general contain any significant Class B liquid hydrocarbon risks.

Maintenance and misuse of hand-held and portable foam fire extinguishers represents a previously unrecognised and substantial hidden source of PFAS releases resulting in environmental contamination.

In addition, maintenance requirements for regular discharge and re-filling of hand-held foam extinguishers makes it likely that the AFFF will be disposed of incorrectly to the environment or public drainage system. The scale of the problem is considerable.

- **Large overall volumes**. Millions of small portable and mobile extinguishers.
- **AFFF containing portable hand-held and wheeled extinguishers, containing 6L/200L**.
- **Inappropriate disposal** by extinguisher maintenance staff to the environment or sewers.
- **Test discharges by mining industry vehicles** directly to the ground of tens to hundreds of litres of AFFF.
- **Minor incidents beyond regulatory control** and education of users, small businesses and domestic releases with inappropriate waste management.

11. THE REAL LIFETIME COSTS OF USING FLUOROCHEMICAL-CONTAINING AFFF

The original expenditure involved in purchasing the foam concentrate is far outweighed by the real lifetime costs of fluorinated firefighting foam through purchase, maintenance, decontamination, waste disposal and very high cost of site remediation. It is the end-user as the polluter that must cover the lifetime costs. The foam industry has shown little inclination for either informing the end-user reliably of the potential impacts and costs of releasing fluorochemical containing products to the environment, or for covering the remediation and other costs that result from contamination with a product that was promoted as benign and 'safe'.

Fluorine containing firefighting foams (AFFF, FP, FFFP) have substantially greater lifetime costs than fluorine-free foams (F3) due to extreme persistence, difficulties in remediation and cost of PFAS waste destruction.

More recently the foam industry has persisted in claiming that current levels of contamination, for example, with PFOS or PFOA, are harmless in terms of human health despite clear disease associations in spite of ever lowering of acceptable levels in drinking water set by regulators and contrary evidence in the scientific literature. An article in the technical literature (Klein, R.A., Industrial Fire Journal Q4 2013), quoted extensively in the Stockholm Convention POPRC papers for the Rome meeting in Rome last September, which deals extensively with the topic of lifetime costs for firefighting foam is provided for reference in Appendix XI.

The holistic lifetime costs of discharging foam to the environment, however, can be summarised as follows and are especially relevant for fluorochemical containing foams:

- **Cost of the foam concentrate** – few thousand dollars per 1000 litres (1 tonne).
- **Cost of disposal** by high temperature incineration at >1100°C of unused foam concentrate or collected runoff, e.g., from training areas, as regulated industrial waste.
- **Clean-up and remediation** of contaminated soil and groundwater in affected areas on-site.
- **Legacy contamination** at sites previously used for AFFF foams, especially former training areas.
- **Analytical and consultancy costs** associated with remediation and clean-up.
- **Liability for causing environmental contamination** using PFAS-containing foams at incidents where there is no legal defence (i.e., no danger to human life or damage to societal infrastructure) – see Appendix describing the recent German court case against the Fire Service.
- **Legal liabilities and risk of prosecution** by regulatory authorities.
- **Infringement of operating license conditions**, fines and loss of license.
- **Reputational loss** and brand image damage, loss of public confidence.
- **Political consequences**, loss of trust in government institutions.

A small incident at an Australian airport in 2017 caused by corrosion of a pressure gauge, in which a storage system accidentally discharged 22,000 litres of fluorinated AFFF to the drainage system, resulted in environmental contamination and remediation costs running to about $60 million. The airline involved is suing to recover $53 million from the foam system's manager and has transitioned to fluorine-free foam (F3) country-wide.

12. SOCIO-ECONOMIC IMPACT OF PFAS CONTAMINATION

There are very considerable socio-economic costs associated with fluorochemical contamination of either soils or the aquatic environment (groundwater and surface waters, rivers, lakes, estuaries and the marine environment).

Socio-economic costs of PFAS contamination are considerable globally and are growing with contamination affecting a broad range of resource, health and environmental values.

These socio-economic costs of PFAS contamination include the following:

- **Loss of vital societal infrastructure** – contaminated ground water aquifers used for the drinking water, boreholes providing water for cattle and other stock, irrigation of crops.
- **Damage to fisheries** both commercial as well as recreational freshwater and marine fisheries, including shellfisheries.
- **Increasing PFAS blood levels** in the population affected giving rise to concerns over personal health and that of family members, especially for children and pregnant women.
- **Increasing food chain PFAS** concentration levels.
- **Loss in property values** and the inability to sell contaminated sites.
- **Loss of agricultural land** due to PFAS contamination by wastes and effluent.
- **Loss of livelihoods** – farming, fishing, aquaculture, etc.
- **Use of contaminated biosolids and effluent** for soil conditioning, composting and irrigation resulting in lost agricultural production and contamination of the food chain.
- **Cost of biosolids and effluent treatment and disposal**.
- **Loss of confidence in Government** departments and regulatory bodies that fail to act to prevent pollution and resource degradation.
- **Polluter Pays demands** – especially taxpayer funded departments, e.g., Defence.
- **Taxpayer-funded remediation and clean-up** with very large capital and ongoing resource expenditure (see the Jersey Airport Case Study Appendix XIII in which financial costs and political fallout are still ongoing twenty years later).
- **Loss of corporate reputation and brand image** for companies responsible for pollution.

A very recent report entitled “The Cost of Inaction” published by the Nordic Council of Ministers (19 March 2019) highlights the socio-economic problems. Up to 20 facilities in Europe are known to be producing fluorochemicals. Estimated annual health-related costs due to PFAS exposure are (i) EUR 2.8-4.6 billion just for the five Nordic countries and (ii) EUR 52-84 billion for all EEA countries. Non-health related costs for the Nordic countries are estimated to lie between EUR 46 million and EUR 11 billion, dominated by soil remediation. For the 31 EEA Member Countries the figure is between EUR 812 million and EUR 170 billion, with a best estimate of EUR 10-20 billion.

13. ALTERNATIVE SOURCES OF PFAS CONTAMINATION

In identifying other applications and sources of PFAS contamination over and above the highly dispersive use of firefighting foams, it is also necessary to identify non-fluorinated alternatives where available and their suitability and effectiveness as substitutes.

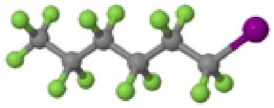
Fluorochemical feedstocks are used in a wide variety of commercial applications. Since the phasing out of PFOS-based chemistry starting in 2000, with a total ban on PFOS in the European Union from June 2011, and industry's attempts to eliminate PFOA and related compounds under the USEPA 2010/2015 PFOA Stewardship Program, most fluorochemicals now in use are derived from fluorotelomer feedstocks.

A range of fluorochemical precursors and derivatives are available and are typically used in the following applications:

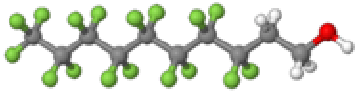
- Paper protectants, AFFF firefighting foams, coating additives and cleaners using fluorochemical iodides as the precursor to a range of other fluorochemicals.
- Paint additives and paper coatings using fluorotelomer alcohols and diPAPs.
- Surfactants and polymers using fluorochemical olefins.
- Soil, oil and stain resistant coatings for textiles, leather, and non-woven materials using fluorochemical acrylates and methacrylates.

Since the introduction of the USEPA 2010/2015 PFOA Stewardship Program industry has expended considerable efforts in reducing or eliminating as far as possible PFOA and PFOA-derivatives for products, including its higher homologues.

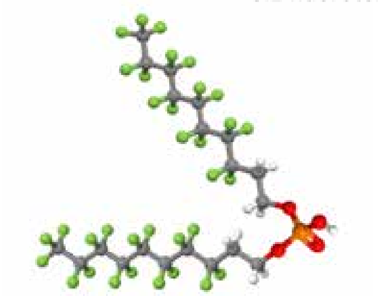
Currently the best available, and most expensive, fluorotelomer feedstocks (so-called pure C6 products) are practically/substantially free of perfluorinated chain lengths equal to C8 and above, with stated 'PFOA' levels <25 ppb. However, this does not apply to all products on the market and certainly not to legacy products still in use which often contain considerable proportions of C8 and longer chain-length fluorochemical derivatives, even to the extent of being virtually C6 free. A recent TOP assay of a commercially available C6 foam underlines the point as shown in the figure.



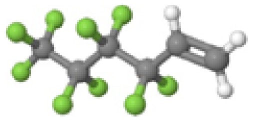
Perfluorohexane iodide



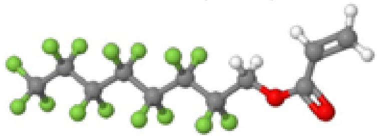
8:2 fluorotelomer alcohol



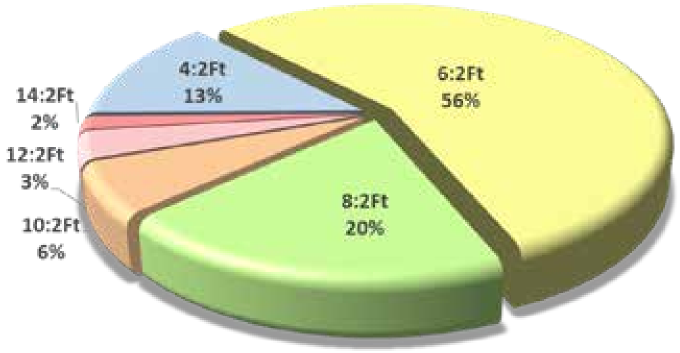
8:2/8:2 flurotelomer diPAP



Perfluorohexene (olefin)



Pentadecafluorooctyl acrylate



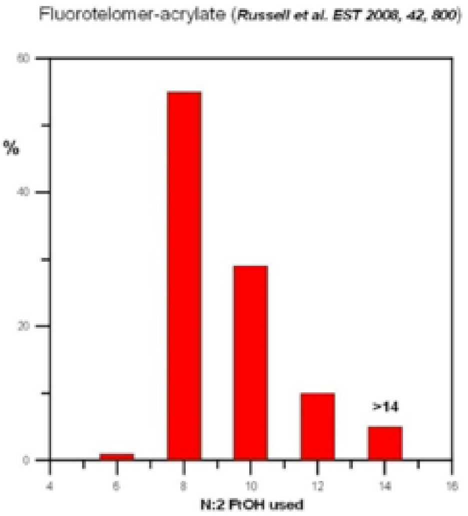
"C6-based" foam revealing long-chain (>C6) PFAS. Fluorotelomer n:2 PFAS content based on TOP assay.

14. TEXTILE AND FABRIC TREATMENT

Recent market research (GMInsights Inc. 2015) indicate that AFFF firefighting foams and textile and fabric treatments account for approximately 2/3 of the global tonnage of fluorotelomers produced. This proportion has remained stable for a number of years and the total tonnage produced is predicted to increase by 12.5% annually.

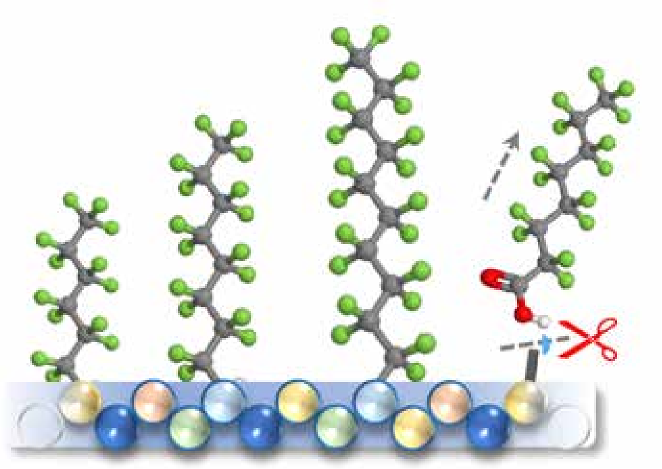
Fluorotelomer acrylate (FTAC) and methacrylate (FTMAC) are often used to form surface copolymers for textile treatment.

A typical example (Russell et al 2008) is shown below in terms of the chain lengths of fluorotelomer alcohol carbon chain lengths involved from C6 to C14. The fluorotelomer moiety is linked to the polymer backbone by an ester linkage which, in principle, is subject to relatively easy hydrolysis.



Carbon chain-length distributions of FTAC .

In other words, the polymer chain can be broken up into the related persistent perfluorinated components in the environment.



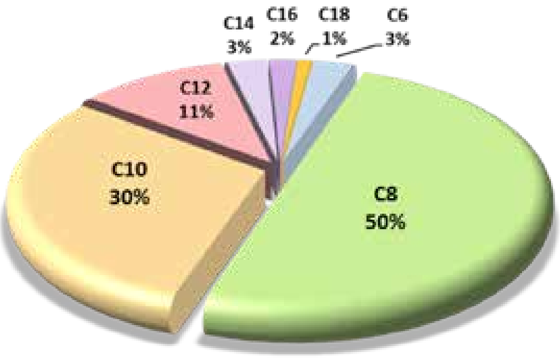
Notional fluoropolymer structure. Polymer backbone with various chain-length PFAS side chains. Breakdown can release persistent perfluorinated side chain molecules (e.g., PFOA on right).

Textile treatment with fluorotelomer derivatives gives rise to three potential sources of environmental contamination:

- **During manufacture**, when the expended fluorochemical containing treatment solutions and rinse waters must be disposed of, probably to the sewer and on through the waste water treatment plant (WWTP) to the environment (plus volatile releases to atmosphere).
- **Wastes resulting from use**, when the textile or fabric itself is washed and wastewaters sent to the sewer, passing through the WWTP and being released in effluent and appearing in WWTP biosolids.
- **End-of-life disposal**, when disposed of to landfill with the highly persistent PFAS outlasting the landfill liner and eventually being released in leachate, contaminating the water table or rivers.

A recent paper on the composition and degradation of fluoropolymers (Washington et al, 2015) found that fluorotelomers are a major component (83%) of textile treatment fluoropolymers with more than 90% of the fluorotelomers being long-chain PFAS of C8 to C18.

When the bond between the fluorotelomer side-chain and the polymer backbone degrades (half-lives from 8 to 112 years) these side-chain groups are eventually released to form fluorotelomer alcohols, aldehydes, ketones and carboxylates including PFOA and related homologues. This has implications for significant long-chain C8-C18 PFAS releases to soils, waterways and atmosphere from treated fabrics washing and eventual disposal via sewer, landfill leachate, volatilisation, WWTP effluent and biosolids.

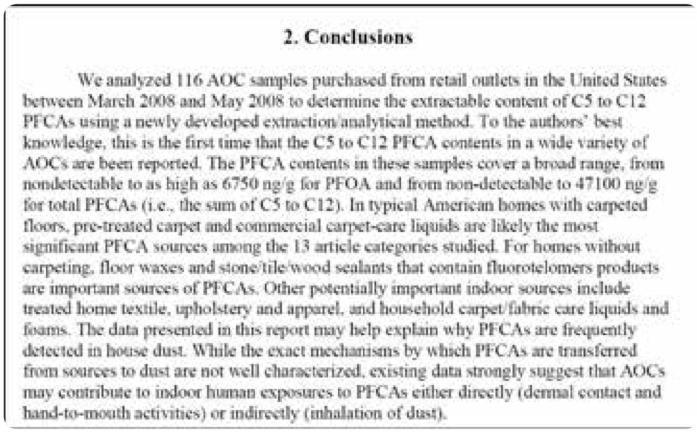


Commercial fluoropolymer textile treatment. Fluorotelomer perfluorinated chain lengths (After Washington *et al.*, 2015. FTP#4)

14.1 GENERAL ARTICLES OF COMMERCE

It has been long recognised that general articles of commerce (AOC) found in domestic environments such as used for textile and fabric treatment represent a non-trivial source of perfluorocarboxylic acids (PFCAs) ranging in chain length from C5-C12. More recent studies especially in Scandinavia have shown that house dust and respirable air contain measurable levels of PFAS contamination, providing a direct source for human exposure by inhalation.

Early measurements reported by Guo et al (2009) are of interest and are quoted verbatim below. Although more recent textile and fabric treatments would not be expected to have PFCA levels as high as those reported by Guo et al, this would only be true for recently purchased items. Many domestic items, for example, furnishing fabrics or carpets, could be expected to have a usable lifetime of 10-20 years meaning that materials treated using older technologies are still in circulation.



2. Conclusions

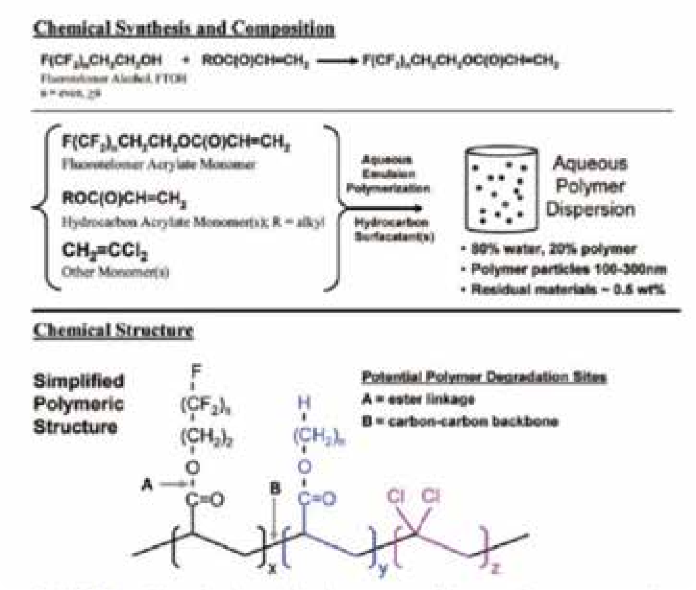
We analyzed 116 AOC samples purchased from retail outlets in the United States between March 2008 and May 2008 to determine the extractable content of C5 to C12 PFCAs using a newly developed extraction/analytical method. To the authors' best knowledge, this is the first time that the C5 to C12 PFCA contents in a wide variety of AOCs are been reported. The PFCA contents in these samples cover a broad range, from nondetectable to as high as 6750 ng/g for PFOA and from non-detectable to 47100 ng/g for total PFCAs (i.e., the sum of C5 to C12). In typical American homes with carpeted floors, pre-treated carpet and commercial carpet-care liquids are likely the most significant PFCA sources among the 13 article categories studied. For homes without carpeting, floor waxes and stone/tile/wood sealants that contain fluorotelomers products are important sources of PFCAs. Other potentially important indoor sources include treated home textile, upholstery and apparel, and household carpet/fabric care liquids and foams. The data presented in this report may help explain why PFCAs are frequently detected in house dust. While the exact mechanisms by which PFCAs are transferred from sources to dust are not well characterized, existing data strongly suggest that AOCs may contribute to indoor human exposures to PFCAs either directly (dermal contact and hand-to-mouth activities) or indirectly (inhalation of dust).

Guo, Z., Liu, X., Krebs, K.A., and Roache, N.F. (2009) Perfluorocarboxylic Acid Content of 116 Articles of Commerce (2009) USEPA and Arcadis. The Conclusions reached by these authors are quoted in full below.

14.2 MODERN TEXTILE TREATMENTS

Although modern fluorotelomer textile treatments claim to be C6-based, this is basically only partially true. As with firefighting foams C6 derivatives may or may not be the major component present but other homologues are also present with C8 and >=C10 components clearly detectable in significant amounts. These long chain PFAS components seem to be required for performance.

There are now alternative textile treatment products available not containing fluorochemicals especially for applications that do not need superior oil repellent properties.

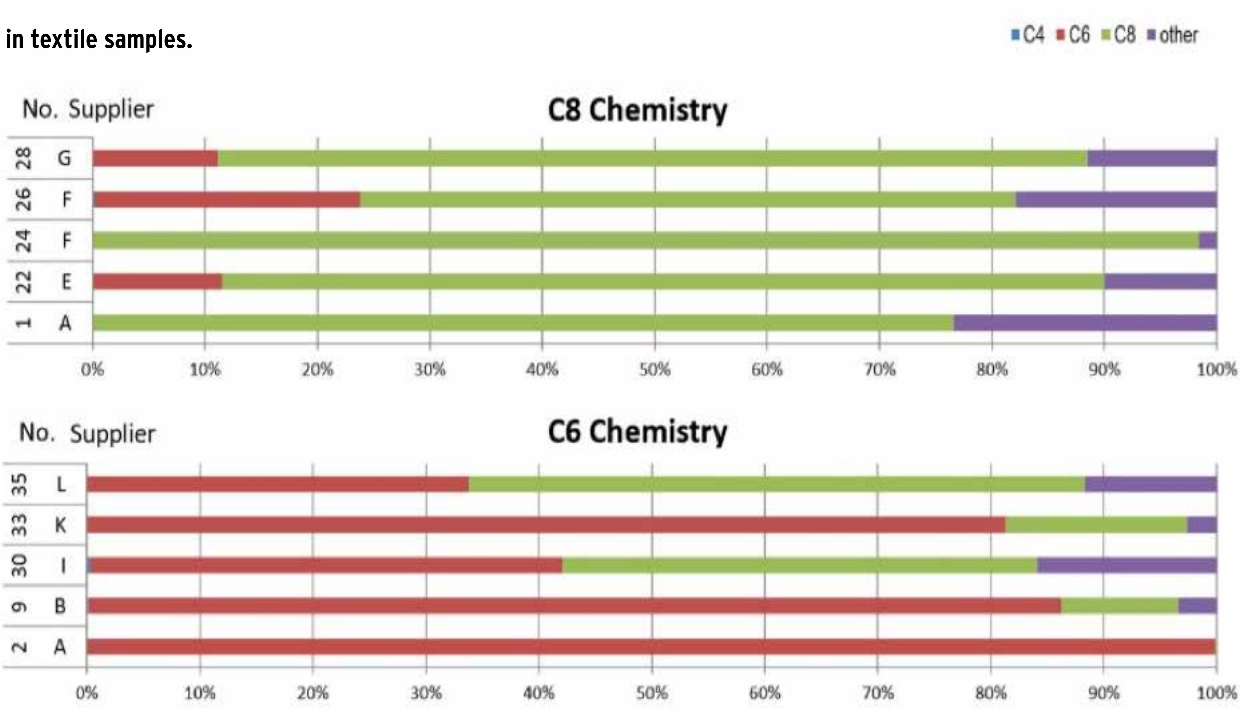


Chemical synthesis, composition and structure of a fluoroacrylate polymer product..

A good example of alternative, more environmentally friendly treatments was discussed in a recent report in *Ecotextile News* of a survey which showed that end-users of durable outdoor clothing considered price, design and water-proofing the main drivers. The point was made that for a large portion of the market use of fluorochemicals with their oil repellent properties was an example of over-engineering and therefore unnecessary.

A recent study by SWEREA showed that many textile-treatments which claim to be based on C6 chemistry contain significant levels of C8 and other chain lengths, with only one sample proving to be pure C6. The homologue distribution for PFAS in a series of textile samples with either C6 or C8 chemistry is shown in the figure (SWEREA Jönsson et al 2014).

Patterns of PFASs in textile samples.



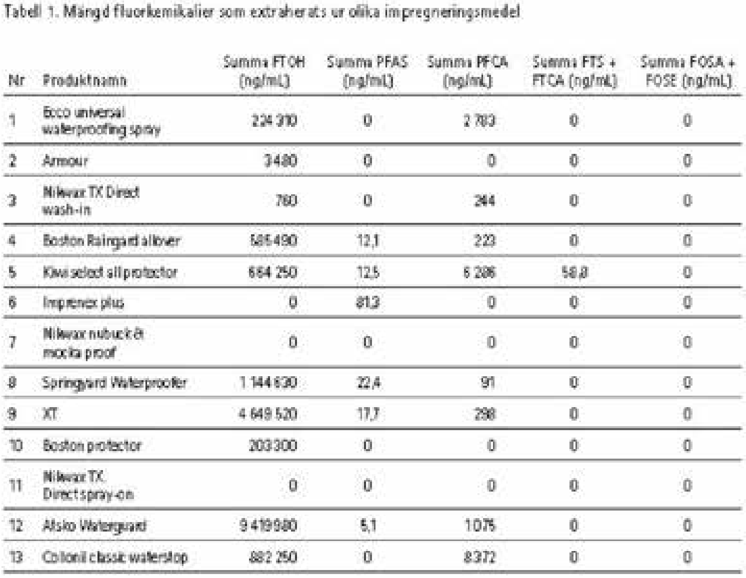
14.3 TEXTILE, FABRIC AND LEATHER TREATMENTS AVAILABLE FOR DOMESTIC USE

Aerosol spray cans are available on the market for treating outdoor clothing and footwear in a domestic environment. These represent a significant and direct human exposure pathway as respiratory protection is unlikely to be worn and inhalation of the aerosol containing fluorochemicals will result in high levels especially in blood and liver tissue. A particularly glaring example of the importance of this exposure pathway was reported by Nilsson et al (2011) for Norwegian ski-waxers applying hot fluorochemical wax to skis in enclosed spaces without any respiratory protection.

A Swedish study of commercially available aerosol spray cans containing waterproofing solution for protecting outdoor clothing and leather footwear (Swedish Society for Nature Conservation report (2006)) identified the presence of fluorotelomer alcohols (FtOH) and perfluorocarboxylic acids (PFCA) in a number of commercial products (see figure and table), some at a surprisingly high concentration. Only one brand name, Nikwax, was fluorochemical-free reflecting an acute awareness of the problem and conscious move away from the use of fluorochemicals by the company as evidenced by material on their website (<https://www.nikwax.com/en-gb/environment/fluorocarbons.php>).

Of greater significance from an environmental point of view are the quantities of extractable PFAS from treated all-weather clothing, which may end up as

Bild 2. De undersökta impregneringsmedlen

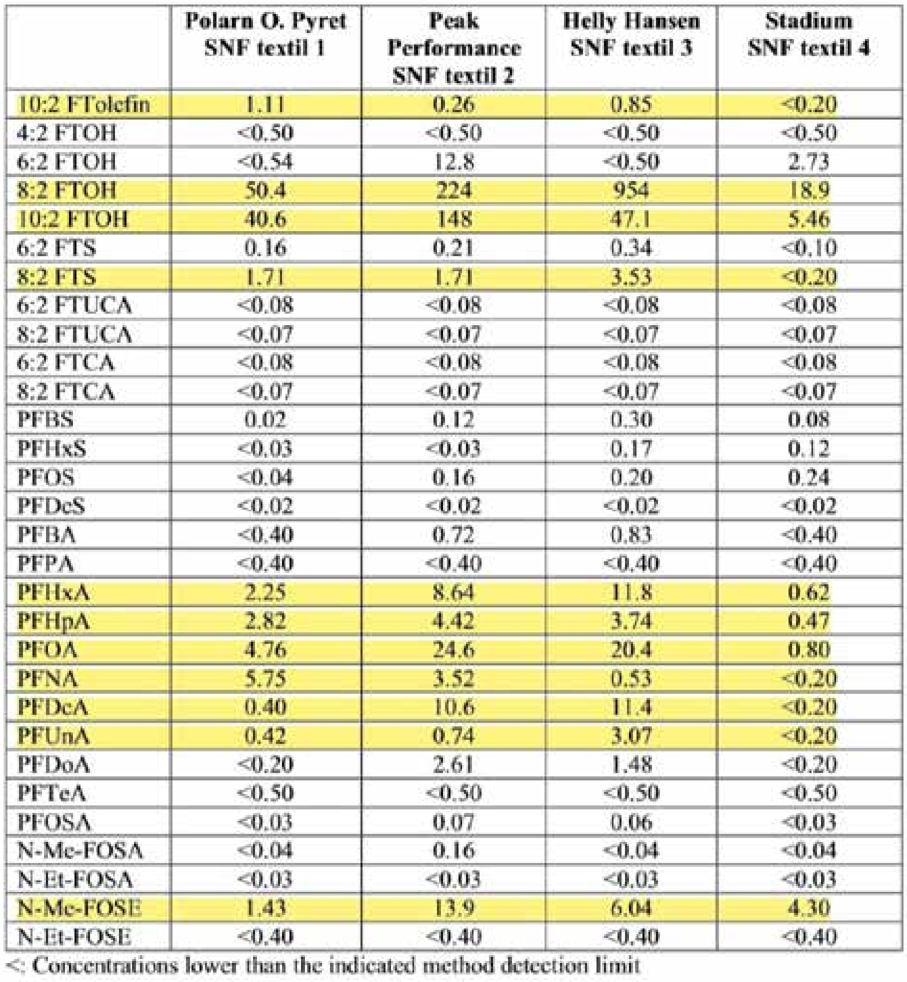


Tabell 1. Mängd fluorkemikalier som extraherats ur olika impregneringsmedel

Nr	Produktnamn	Summa FTOH (ng/mL)	Summa PFAS (ng/mL)	Summa PFCA (ng/mL)	Summa FTS + FTCA (ng/mL)	Summa FOSA + FOSE (ng/mL)
1	Ecco universal waterproofing spray	224 310	0	2 783	0	0
2	Armour	3480	0	0	0	0
3	Nikwax TX Direct wash-in	760	0	244	0	0
4	Boston Raingard allover	585 490	12,1	223	0	0
5	Kiwi select allprotector	684 250	12,5	6 286	58,8	0
6	Imprenex plus	0	81,3	0	0	0
7	Nikwax nubuck & mocka proof	0	0	0	0	0
8	Springyard Waterproofer	1 144 630	22,4	91	0	0
9	XT	4 649 520	17,7	298	0	0
10	Boston protector	203 300	0	0	0	0
11	Nikwax TX Direct spray-on	0	0	0	0	0
12	Alsko Waterguard	9 419 980	5,1	1075	0	0
13	Collonil classic waterstop	882 250	0	8372	0	0

Figures taken from "Fluorinated Pollutants in All-Weather Clothing", the Swedish Society for Nature Conservation (2006)

Concentrations of extractable fluorinated alkyl substances in rain jackets fiven in µg/m^2 (microgram extractable analyte per square meter jacket material).



	Polarn O. Pyret SNF textil 1	Peak Performance SNF textil 2	Helly Hansen SNF textil 3	Stadium SNF textil 4
10:2 FTolefin	1.11	0.26	0.85	<0.20
4:2 FTOH	<0.50	<0.50	<0.50	<0.50
6:2 FTOH	<0.54	12.8	<0.50	2.73
8:2 FTOH	50.4	224	954	18.9
10:2 FTOH	40.6	148	47.1	5.46
6:2 FTS	0.16	0.21	0.34	<0.10
8:2 FTS	1.71	1.71	3.53	<0.20
6:2 FTUCA	<0.08	<0.08	<0.08	<0.08
8:2 FTUCA	<0.07	<0.07	<0.07	<0.07
6:2 FTCA	<0.08	<0.08	<0.08	<0.08
8:2 FTCA	<0.07	<0.07	<0.07	<0.07
PFBS	0.02	0.12	0.30	0.08
PFHxS	<0.03	<0.03	0.17	0.12
PFOS	<0.04	0.16	0.20	0.24
PFDcS	<0.02	<0.02	<0.02	<0.02
PFBA	<0.40	0.72	0.83	<0.40
PFPA	<0.40	<0.40	<0.40	<0.40
PFHxA	2.25	8.64	11.8	0.62
PFHpA	2.82	4.42	3.74	0.47
PFOA	4.76	24.6	20.4	0.80
PFNA	5.75	3.52	0.53	<0.20
PFDcA	0.40	10.6	11.4	<0.20
PFUnA	0.42	0.74	3.07	<0.20
PFDoA	<0.20	2.61	1.48	<0.20
PFTeA	<0.50	<0.50	<0.50	<0.50
PFOSA	<0.03	0.07	0.06	<0.03
N-Me-FOSA	<0.04	0.16	<0.04	<0.04
N-Et-FOSA	<0.03	<0.03	<0.03	<0.03
N-Me-FOSE	1.43	13.9	6.04	4.30
N-Et-FOSE	<0.40	<0.40	<0.40	<0.40

<: Concentrations lower than the indicated method detection limit

waste in landfill. The table shows results for commercial products from this report obtained from analyses by NILU (the Norwegian Institute of Air Research).

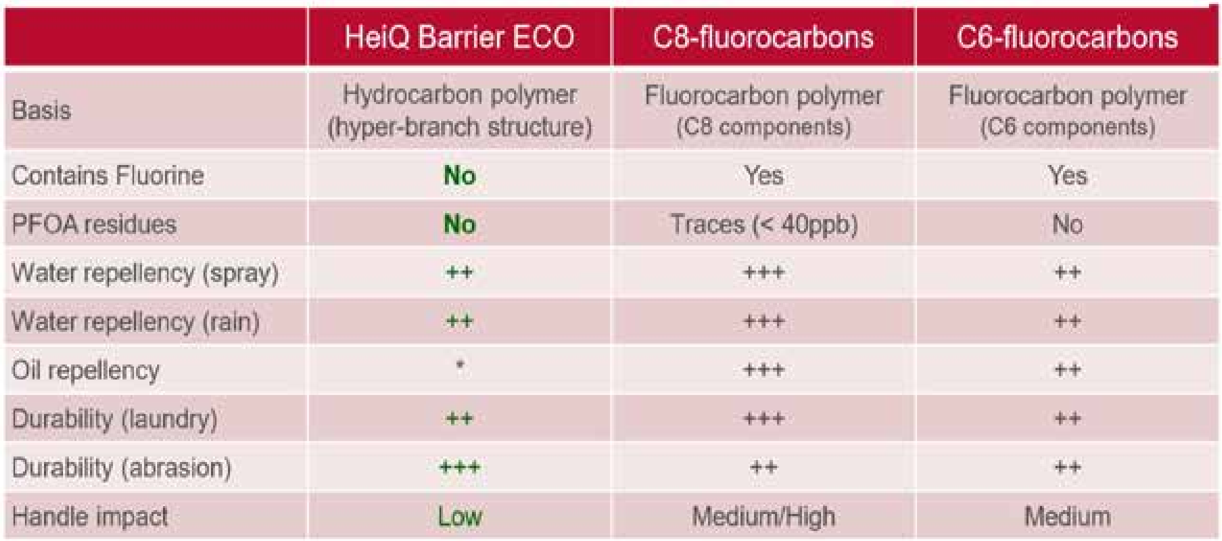
Although these results date from 2006 and earlier they are still highly relevant to the release of PFAS during laundering of treated fabrics as well as disposal to landfill at the end of their useful life, giving rise to a form of legacy contamination via long-term leaching. Notable are the high levels of perfluoroalkyl chains of C8 chain length and greater, versus the relative paucity of C6 chain lengths in treated textiles prior to the 2010/2015 PFOA Stewardship Program.

Fluorochemical treated textiles represent a substantial source of PFAS as an environmental contaminant, either via landfill leachate or wash waters used for manufacture and subsequent laundering,

14.4 NON-PERSISTENT ALTERNATIVES FOR FABRICS AND TEXTILES

Alternative fabric treatments to PFAS compounds are available including those based on paraffins, waxes, silicones, dendrimers and polyurethane (Lassen et al, 2015) which provide the equivalent resistance to water and dirt for domestic and outdoor garments that are unlikely to be exposed to oil and therefore are not dependent on PFAS treatments for oil repellence.

Specialist PPE for the petrochemical and chemical process industries as well as for firefighting kit that have a high probability of exposure to oil and solvents could still use PFAS treatments sustainably provided that there is a change in culture with wash-waters resulting from laundering and that wastes are managed properly. A related industry that probably does not dispose of wastewater appropriately is the PPE retreatment sector that uses PFAS solutions for treating fabrics.



	HeiQ Barrier ECO	C8-fluorocarbons	C6-fluorocarbons
Basis	Hydrocarbon polymer (hyper-branch structure)	Fluorocarbon polymer (C8 components)	Fluorocarbon polymer (C6 components)
Contains Fluorine	**No**	Yes	Yes
PFOA residues	**No**	Traces (< 40ppb)	No
Water repellency (spray)	++	+++	++
Water repellency (rain)	++	+++	++
Oil repellency	-	+++	++
Durability (laundry)	++	+++	++
Durability (abrasion)	+++	++	++
Handle impact	Low	Medium/High	Medium

Source: © HeiQ Materials AG, Schlieren (Zürich), Switzerland

A number of presentations from Stefan Posner and his colleagues at SWEREA IVF in Sweden have discussed the advantages and disadvantages of leather, textile and fabric treatment with fluorochemical derivatives in order to obtain durable water-repellent (DWR) coatings, together with alternative treatments.

Various alternatives to PFAS based treatments are available for textiles, fabrics and leather goods. These include:

- Siloxane and silicone polymers.
- Stearamido-methyl pyridine chloride.
- Paraffins and waxes.
- Fatty acid-modified polyurethanes and melamine resins.
- Mixtures of silicones and stearamido-methyl pyridine chloride also together with carbamide (urea) and melamine resins.
- Dendrimers; hyperbranched hydrophobic polymers and specifically adjusted comb polymers as active components with glycols added as solvents together with cationic surfactants in small amounts act as emulsifiers.
- Sulfosuccinates, e.g., sodium di-(2-ethylhexyl) sulfosuccinate.
- Reverse osmosis membranes in place of PTFE membranes.

[Source: UBA Proposal for PFHxA as SVHC: Annex XV: Fluorine-free alternatives (ECHA, 2015a; Swedish Chemicals Agency, 2015a; Swedish Chemicals Agency, 2015b; UNEP, 2012; UNEP, 2015)]

Novel technologies have been developed by industry to avoid the use of fluorocarbon based treatments for DWR all-weather outdoor clothing. Market studies have identified the end-user requirements of DWR clothing as:

- Ability to stay dry in rain and snow.
- Fabric breathability to prevent wetness from sweat and condensation.
- Flexible and light to wear.
- Environmentally acceptable footprint.

As an example of innovative product development based on mimicking mechanisms in nature which achieve water repellence, a commercially available product using duck feathers as a model combines a highly repellent surface with three-dimensional hyper-branched polyurethane polymers (dendrimers). Performance approaches that of textiles treated with C6 fluorocarbon polymers with the exception that excellent oil repellent properties can only be achieved with older C8 technology, pure C6 treatment being less effective, as shown in the table below.

15. PUBLIC CONCERN OVER PFAS EXPOSURE

Sharon Lerner, an investigative journalist for the US publication The Intercept, has published a series of articles concerned with many of the issues surrounding PFAS contamination.

As recently as October 2018 Lerner writing for The Intercept (The Teflon Toxin, Part 18) reported that

> *"….A class action lawsuit against 3M, DuPont, and Chemours was filed this week on behalf of everyone in the United States who has been exposed to PFAS chemicals. The suit was brought by Kevin Hardwick, an Ohio firefighter, but "seeks relief on behalf of a nationwide class of everyone in the United States who has a detectable level of PFAS chemicals in their blood." Hardwick is represented by attorney Robert Bilott, who successfully sued DuPont on behalf of people in West Virginia and Ohio who had been exposed to PFOA from a plant in Parkersburg, West Virginia.*
>
> *In addition to 3M, DuPont, and its spinoff, Chemours, the suit names eight other companies that produce the toxic chemicals, which are used to make firefighting foam, non-stick cookware, waterproof clothing, and many other products. While much of the litigation around PFAS has focused on PFOA and PFOS, this suit targets the entire class of PFAS chemicals, including "the newer 'replacement' chemicals, such as GenX."*
>
> *Rather than suing for cash penalties, the suit seeks to force the companies to create an independent panel of scientists "tasked with thoroughly studying and confirming the health effects that can be caused by contamination of human blood with multiple PFAS materials." Such a panel would parallel the C8 Science Panel, which was created by the earlier class action litigation in West Virginia. That panel, overseen by epidemiologists approved by lawyers from both sides in the suit, found six diseases to be linked with PFOA exposure, including testicular cancer and kidney cancer….".*

Writing in The Legal Intelligencer Joshua Cohan of Anapol Weiss (August 2018) has summarised the scale of the problem in the US:

> *"...Tens of thousands of residents right outside of Philadelphia in Warminster, Warrington and Horsham have had their drinking water directly impacted by PFCs. Some local residents have sought recourse by filing lawsuits in Bucks and Montgomery counties for the physical injuries and illnesses they have suffered as a result of unknowingly drinking and using PFC-contaminated water. A class action lawsuit has also been filed in the U.S. District Court for the Eastern District of Pennsylvania on behalf of local residents seeking medical monitoring and damages for declines in property value.*
>
> *In addition to the lawsuits that have been filed in the Philadelphia area, a number of individuals and governmental entities have also filed lawsuits in New York, Colorado, Washington and Massachusetts, seeking damages for injuries to persons and property caused by water contaminated with PFCs. The scope of the contamination is far reaching as the water at over one hundred military bases across the country has tested positive for PFC contamination...".*

Reports in the press have continued to point up increasing public concern about PFAS contamination. A Class Action brought in October 2016 by Davy and Josephine Yockey and on behalf of similarly affected Plaintiffs, targeted foam manufacturers rather than just feedstock manufacturers for the first time, including the 3M Company, Angus Fire, the Ansul Company, Buckeye Fire Protection, Chemguard nd National Foam (United States District Court Eastern District of Pennsylvania, Case 2:16-cv-05553-PBT Filed 10/24/16), marking a distinct change in emphasis from targeting the feedstock manufacturers to the suppliers of firefighting foam.

Carrie Fellner writing for the Sydney Morning Herald has made public the growing concern amongst Australians about the effects of PFAS contamination of soil and groundwater on property prices, livelihoods, and personal health in a number of detailed reports.

16. CONCLUDING REMARKS

Fluorine-free Class B firefighting (F3) foams are now completely viable alternatives to fluorochemical-containing aqueous film-forming foams (AFFF), with equivalent performance certifications and approvals. Confirmation tests and trials for particular large-scale applications to validate certification test results are underway or planned. F3 foams have been adopted and proven as effective firefighting agents operationally in the field by numerous organisations worldwide.

Market forces driven by end-user demand for a product of equivalent fire extinction capabilities but with a much-reduced environmental footprint avoiding the enormous lifetime costs of using AFFF involving disposal of waste, resource degradation, remediation of contaminated soil and groundwater, as well as prosecution and litigation for harm caused. A range of F3 foams are now available commercially from a number of major foam suppliers at comparable cost, quality-for-quality, to equivalent AFFF products.

Firefighting foams are not the only source of PFAS contamination of the environment, in spite of being the most prominent and directly dispersive of all PFAS applications. Other major sources of potential contamination include textiles, fabrics and leather goods treated with fluorochemicals to enhance oil and water repellence as well as stain resistance. These items often end up in landfill and have been characterised historically by their use of longer chain perfluorochemicals than those used in firefighting foams.

Recent efforts by the fluorochemical industry, as a consequence of the 2010/2015 USEPA PFOA Stewardship Program and regulatory changes at national and international levels, to replace older C6/C8 technologies with pure C6 technology have encountered performance issues, absence of true drop-in replacements, and environmental problems associated with short chain perfluorinated end-products of degradation.

The arguments and the evidence in this paper strongly support the listing of PFOA, its salts and derivatives, i.e., precursors, under Annex A of the Stockholm Convention with no specific exemptions allowed.

The short chain PFAS are of similar concern to the legacy PFAS being more mobile than longer-chain PFAS, producing larger more widely dispersed contamination plumes, having the potential for long-range transport, being difficult if not impossible to remove from effluent waste streams and groundwater by conventional absorption techniques, and are as equally persistent in the environment as their longer chain homologues. This underlines the recommendations made by POPRC-14 in Rome last year that short chain PFAS are unsuitable as replacements for long chain PFAS.

Given what is now known about PFAS risks, the *Precautionary Principle* obligations are that measures should be introduced so as to ensure the elimination, reduction in use, or strict control of applications using fluorochemicals, especially those dispersive applications that are likely to cause widespread and intractable environmental pollution.

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APPENDIX I

LONDON HEATHROW GOES FLUORINE-FREE

Statement from Graeme Day, Fire Service Regulation and Oversight Manager Operations, London Heathrow Airport (LHR).

Heathrow Airport Fire & Rescue Service took the decision in mid-2012 after a 15-month evaluation period to change from an AFFF firefighting foam concentrates to a fluorine and organo-halogen free concentrate for the following reasons:

- Foam concentrates containing fluorine and organo-halogen components continue to represent an unacceptable risk to the airport infrastructure because of their chronic environmental impact and the size of infrastructure investment required to contain and mitigate that risk. Fluorine and organo-halogen free foam (F3) concentrates were found to be suitable for discharge into Heathrow Airport's foul sewer as they did not contain chemicals that were of concern to Thames Water and environmental regulators. On that basis, Heathrow Airport Limited was no longer prepared to approve foam concentrates containing these materials. This decision was made as a result of discussions with environmental regulators and was in line with UK CAA thinking and best practice. The decision also took compliance with ICAO requirements, the impact of F3's acute environmental pollution and the UK Environment Agency's guidance to Fire & Rescue Services i.e. that fluorosurfactant-free foam products should be considered where performance meets the needs of the organisation, into account.
- The change to an F3 concentrate meant that Heathrow Airport Ltd could deploy an ICAO Performance Level B compliant firefighting foam if required during an emergency response that minimised as far as practicable, any pollution impact. Heathrow Airport Fire & Rescue Service personnel now train regularly using F3 foam and its associated equipment as a direct result of this change and Heathrow Airport Limited continues to demonstrate responsible management of pollution risks and sensible control measures in line with its published sustainability goals.
- Cost benefits have been realised as Heathrow Airport Limited Fire & Rescue Service now uses an F3 3% foam concentration instead of the AFFF 6% concentration previously used. This has resulted in a 50% reduction in the mount of foam concentrate purchased without compromising passenger or fire-fighter safety. Heathrow's Procurement Department managed an e-auction process to ensure that an F3 product which was ICAO Performance Level B compliant and offered the best value for money was subsequently purchased.
- Since attending the UN POPRC meeting in Rome in September 2018, I have received many enquiries about the use of fluorine-free firefighting foams from both end-users and regulators in numerous countries from New Zealand to the West Coast of the United States of America.

APPENDIX II

FLUORINE-FREE AT COPENHAGEN AIRPORTS: AN END-USER'S PERSPECTIVE ON FIREFIGHTING FOAM

Statement from Kim T. Olsen, Head of Copenhagen Airport Rescue & Firefighting Academy, Copenhagen Airports A/S, Denmark

I have been an Airport Firefighter most of my working life. After 5 years of military service in the Danish Army, I started working for Copenhagen Airport (CPH) in the Airport Security; in 1986 I moved to the Airport Fire Service and have worked my way up through the ranks in various positions, and today I am Head of the Copenhagen Airport Firefighting Academy (CARFA). Since 1995 I have been involved and responsible for testing foam at CPH.

First of all, a few words about Copenhagen Airport's foam history, including environmental issues, implementing the move over to fluorine-free firefighting (F3) foam from AFFF and the necessary investment in clean-up, remediation and containing the residual AFFF contamination.

- In 1972 CPH started to use AFFF foam. Two different products were introduced for operational use; *3M LightWater*™ and *SM*™ *AFFF* from a Swedish company.
- 1995 CPH changed to only one type of foam - the 3M LightWater™ AFFF. This was due to poor burn-back with SM™ AFFF foam.
- In 2003 CPH and Copenhagen Environment Department addressed the issue of PFOS /fluorine-containing foams in regard to run-off firewater from the CPH training area and its burn pit. This resulted in restrictions on use of AFFF.
- In 2006 all training with AFFF stopped at CPH. The Copenhagen Airport Environment Department started to establish containment measures not only the burn pit of the training area but for the whole area over which AFFF foam had been used. This was achieved with a drainage system that collected the surface water and pumped it back to the training area to prevent pollution spreading to groundwater and further afield outside of the airport perimeter.
- Ten years ago in 2008 CPH began looking for new fluorine-free foam as substitutes for AFFF. Testing the re-healing foam (RHF) from Solberg Scandinavia gave satisfactory results and was deemed fit-for-purpose. As a consequence, it was decided to change the firefighting foam used by CPH to this fluorine-free foam, which included the introduction of three new Rosenbauer Panthers. A very important issue was thus solved allow in our firefighters to resume training.
- In 2009 environmental audits indicated that both Oslo Gardemoen airport and Stockholm Arlanda airport had serious issues with PFAS contamination. Meanwhile CPH were back on the right track with solutions on how to deal with this problem by using fluorine-free foam. As the only airport in the world that had changed to this specific type of foam at the time, the Chairman of the ICAO ARRF working group was addressing his concerns about general aviation safety to the Airport Management. Documentation was required about the RHF fluorine product used. Apart from previous fire testing which had had to be done at this point, we also had to conduct tests according to the US Mil-Spec protocol., All our Panther crash tenders carrying re-healing (RHF) foam also passed, including the NFPA 403, in December 2009 with excellent results.
- In 2014 work on environmental clean-up, containment and re-construction of the Fire Training area was started. This was a huge project and Copenhagen Airports A/S invested more than 15 million EUR in this project.
- Today CARFA has a newly renovated fire training area for training firefighters from many different airports and countries from all over the world in a safer manner and an environmentally more sustainable than before.
- Copenhagen Airport Environment Department is still working on the clean-up and remediation of PFAS contamination in other areas of the airport where AFFF foam had been used. Maintenance of the drainage system around the fire training ground alone costs CPH more than 1,5 million EUR per year. This expenditure is expected to have to continue for at least the next 80 years.

We now know that the decision to change to a 3x6 ATC re-healing fluorine-free foam was the right one. We continue to be very satisfied with this as a solution and consider that this type of foam will remain sustainable in the future. Not just because of the environmental reasons, but also taking into account changes in aviation fuels with more and more bio-fuel is being added to jet-fuel, creating a need to have an alcohol resistant (AR).

The environmental clean-up from the AFFF foam will probably never stop at CPH. Basically, we are trying to prevent the pollution going outside the already polluted area. This is done with a drainage system surrounding the training site, which collects all the surface water runoff using a system of wells and pumps which return the water back on site. A large area has now been covered with concrete isolating the area from the contaminated ground. Rainwater and firewater runoff on the concrete area dos not have to be treated and can be discharged though the normal sewer system to the city's waste water treatment plant (WWTP).

Looking back at all the foam testing that we have conducted, two factors remain the most important: 1) the foam must be able to put out the fire and 2) that it is safe to work with. The ICAO foam test insures this and can be used for any type of foam. Other factors to take into consideration are the price of the foam, the environmental impact resulting from foam discharge, and long-term clean-up and remediation costs.

After many years of experience and pioneering in this field, I sincerely believe that fluorine-free foam is the future. I see no reason to keep on polluting the environment with AFFF types of foam when the fluorine-free foam (F3) is just as efficient! That being said, I must also acknowledge that there is just too much money and too many lobbyists involved in the foam business. There are people who will write and say anything to keep control over the market. The environment loses out if the aviation industry and individual airports do not play an active part on this matter.

As an end user of firefighting foams and the person responsible for the Fire Services operational capability when it comes to compliance with the law and regulations, I feel that Copenhagen Airport in Denmark has undoubtedly taken the right decisions at the right time. There is no doubt that fluorine-free foams will improve both aviation safety and the environmental impact of fire service operations. In general, almost all the firefighting foam used at airports is for testing and training. Only a very small percentage will be used operationally for actual firefighting. But this makes it just the more important that the foam provides safety of the firefighters sent directly into the danger zone in the worst case.

APPENDIX III

GOING FLUORINE-FREE IN THE PETROCHEMICAL INDUSTRY – ONSHORE AND OFFSHORE IN THE NORWEGIAN NORTH SEA SECTOR

Statement from Lars Ystanes, environmental specialist, Equinor (formerly Statoil), Bergen, Norway

1. BACKGROUND

Fluorine based firefighting foams have been identified for many years as chemicals of environmental concern. Until 2014, AFFF (Aqueous Film Forming Foam) was used onshore/offshore in Equinor (aka Statoil) operations world-wide and contain organo-halogens known as PFAS (perfluoroalkyl substances). At an early stage, Equinor pinpointed AFFF as one of our company's undesirable chemical footprints affecting the environment, with a long history of requiring chemical substitution. The process of replacing AFFF was internally driven and coordinated based on the general concerns expressed by our stakeholders such as NGOs or the regulatory authorities. Equinor aims lead in Health and Safety. Combined with significant efforts and collective internal engagement together with an inventive supplier, this resulted in replacement of a substance known to be of high long-term concern. The organo-halogens present in AFFF had been identified as priority pollutants by the Norwegian Environment Agency and other authorities since the chemicals are considered environmentally persistent, bio-accumulative and toxic.

Equinor operates 42 fields on the Norwegian Continental Shelf (NCS) representing 80% of all production on the NCS, producing 2.5 million barrels per day oil and gas, equivalent to 50% of total production for the North Sea including the Norwegian sector.

The first generation of F3 foam was a result of the R&D work performed by the supplier Solberg Scandinavian and ready for first offshore user in 2013. In parallel with this work, in 2014 the authorities required standard environmental documentation (HOCNF – The Harmonised Offshore Chemical Notification Format under the OSPAR (Oslo-Paris) Convention 1992) for all firefighting foam used in high volumes. The fact that Equinor had had success in developing a suitableF3 foam and that foam was required to be reported under HOCNF, led to general pressure driving the Norwegian market. Even if AFFF were to be still allowed, F3 is the preferred product for operators on Norwegian Continental Shelf (NCS).

Development and testing of a new, more environmentally friendly 1% fluorine free firefighting foam was carried out as a collaborative project between Solberg Scandinavian and Equinor (then Statoil) in close cooperation 2010-2012. The project was funded by Equinor enabling the supplier to complete remaining R&D activities. This was first used successfully on the offshore installation Kvitebjørn in December 2012 and the new 1% foam "Re-healing RF1, 1% foam" hereafter called RF1, was approved for use by Statoil, TRL7 (technology readiness level) in November 2013; Technical Decision Gate (TDG)4 – Approve for starting multi-use, December 2014.

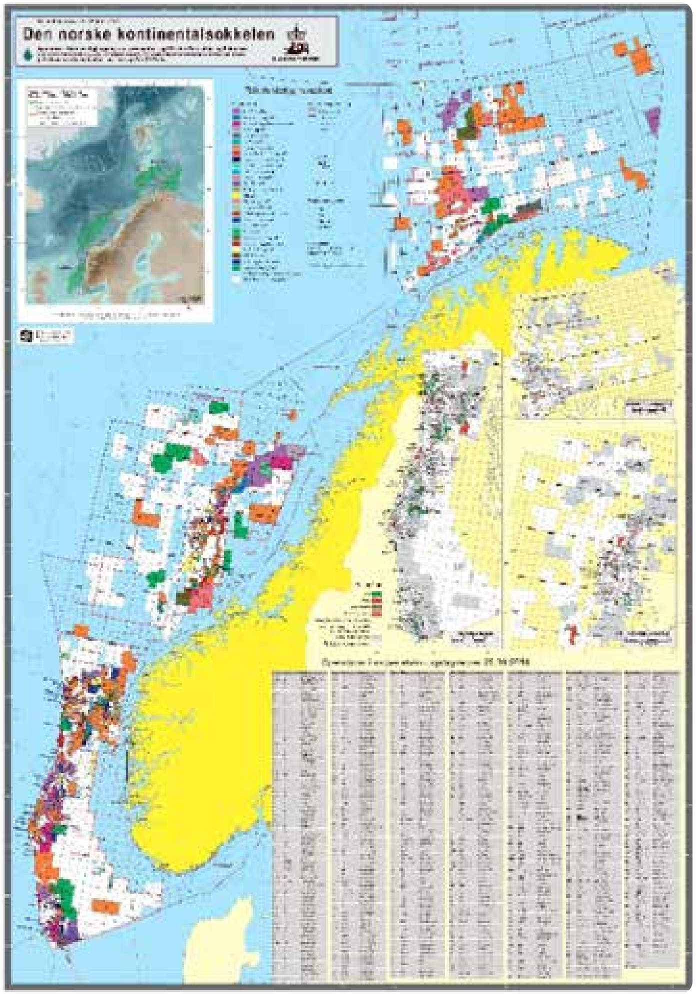


Diagram © Norwegian Petroleum Directorate.

Requirements under the HOCNF rules were an important in identifying the presence of AFFF, with its unacceptable environmental properties driving the substitution.

Today (2019) we can look back on a success story in which we removed a polluting chemical from use without compromising safety and at reasonable cost.

2. SUMMARY OF MULTI-USE ACTIVITIES

A project group was established to plan and promote implementation of the new fluorine-free foam. The group included personnel from Safety Technology, Environmental Technology, Procurement, Technology Development and Implementation. The multi-use project has been limited to Norwegian operated installations with 1% foam systems.

The following activities have been performed by the multi-use group:

- Planning of implementation together with the supplier, Solberg Scandinavian AS, of transitioning from the old to the new foam
- An information letter was distributed in 2013 to contact persons for each asset including:
    - Background for substitution
    - Information on cleaning of tanks
    - Name and contact person at supplier
    - Contact details for support team
- The support team was available upon request.
- Follow up during the substitution phase
- Follow up on technical issues including corrosion suspicions, PFOS contamination issues, etc.
- A new information letter was sent in August 2015 including information on the destruction of previously used AFFF and results of corrosion tests
- Collection and distribution of feedback from each asset at the end of the implementation phase

3. MEASUREMENTS OF SUCCESS - PLANNED AND ACTUAL RESULTS

3.1 Planned results

According to the multi-use plan, the overall success criterion was to have replaced AFFF with RF1 on all Equinor operated installations on the Norwegian Continental Shelf with 1% system by the end of 2015. The following criteria were agreed up front:

a. Proper information addressed in due time for all relevant installations

b. Implementation without accidental spills or discharges

c. Full re-cycling of AFFF during the substitution period, no new 1% AFFF to be procured by Equinor

d. Correct waste handling

e. No productions losses or unplanned cost excesses associated with the implementation

3.2 Actual results

At 31.12.2015, 29 of 32 installations had implemented RF1 substitution and since then the onshore liquified natural gas (LNG) process plant "Melkøya" has also carried out the transition. For full overview see section 5. The project concluded that the all criteria above have been fulfilled except for bullet point (c). The recycling of AFFF was stopped after discovering of traces of PFOS in some AFFF samples. For more details, see later sections. The project experienced different challenges during the execution phase, as described subsequently.

3.2.1 Equipment Breakdown

Early on in 2015 we received a general warning from one of our equipment suppliers of foam proportioning equipment, in connection with ConocoPhillips' exchange to RF1 on several installations in the Ekofisk area.

ConocoPhillips use several foam proportioners of the in-line turbine type made of bronze manufactured by this supplier. They had reported breakdown of some the proportioner bearings on the water side while using AFFF. These had subsequently been modified and strengthened.

During full-scale testing with RF1 they experienced breakdown of the foam turbine. The first conclusion was corrosion. ConocoPhillips then had a test program with Fire Protection Engineering (FPE). Further bench tests showed similar damages. Equinor was invited to these tests and our internal corrosion department was engaged. The machine supplier together with Solberg carried out additional investigations and the final conclusion was that the breakdown was caused by cavitation in the start-up of deluge caused by high water velocities and speed of turbine. RF1 had no influence on the foam proportioners.

During this period, different kinds of problems were blamed on RF1 with very little substance. It became a time-consuming exercise to investigate and deal with these criticisms which were shown to groundless. During the months of corrosion testing of RF1 in 2015, all foam substitution was halted, with some installation change-overs delayed compared to the original plan.

3.2.2 Density and viscosity

It became apparent from the project that RF1 had higher density and viscosity compared to AFFF. However, all tests performed during qualification, tests at SINTEF (including cold environment below freezing temperatures) and first use tests showed no issues with regard to density nor viscosity.

During multi-use and for some projects in engineering/construction phase it was reported that the higher density could be a problem for some installations with substandard foam pumps.

Due to environmental issues, it was decided early on to avoid full scale tests with AFFF before substitution to RF1. Such tests could have provided valuable technical knowledge on different parameters. Lack of testing with AFFF before substitution made it difficult to decide if some technical issues were already present or had been introduced/reinforced by RF1.

Most installations were able to handle the increased viscosity and density with only minor system adjustments. However, at one installation, Veslefrikk B, the pumps were not able to handle the RF1. The solution is under evaluation, and substitution until F3 is planned during 2019.

3.2.3 Contamination of AFFF with PFOS

Early in 2015, traces of PFOS (perfluorooctanesulfonic acid) were discovered in waste fractions from the Visund installation. An investigation into root causes revealed that the PFOS traces originated from AFFF in storage tanks offshore. Part of this AFFF was traced back to the reuse pool established in the RF1 implementation project and further tests revealed traces of PFOS in the reuse pool as well. The origin of the trace amounts could not be linked to original product storage samples at the vendor's site though, which in turn sparked a wider screening across all installations still holding AFFF. The AFFF re-use pool was immediately terminated and stored volumes were treated as hazardous waste.

Internal screening in Equinor revealed further challenges with concentrations of trace PFOS that were too high at several installations as shown in the adjacent figure. Exchanged AFFF volumes were treated as hazardous waste after PFOS contamination had been confirmed. The guidelines for substitution was slightly changed after PFOS became an issue, and tanks would be dry-drained rather than washed with water before refilling with RF1. Ultimately, a final verification for PFOS traces in major storage tanks was recommended and carried out, including for those tanks filled with RF1 after the exchange procedures. Verification has been based on tank screening.

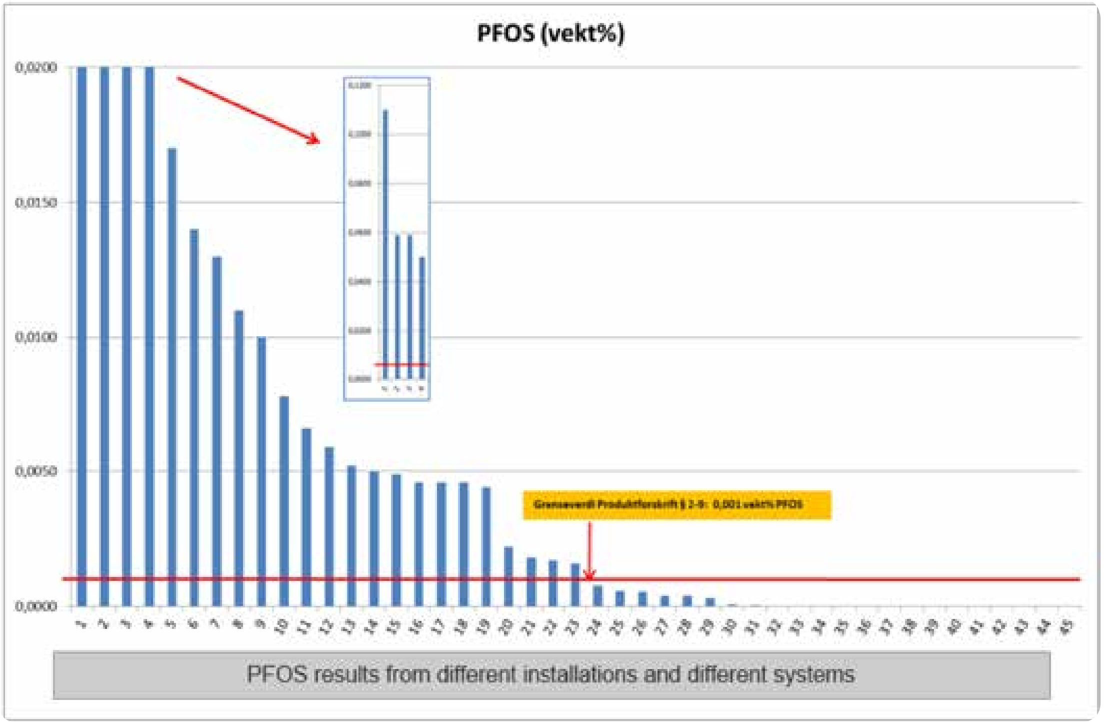
Verification results show that traces of PFCs (perfluorochemicals including PFOS) from AFFF can still be found in RF1 filled tanks. PFC concentrations are generally lower or below the detection limit for tanks that were exchanged after the latest guidelines were put in place, higher concentrations were found for RF1 at some installations where the changeover had been implemented before PFOS became a known issue. Trace levels of PFCs are expected to be present in many systems for years to come, even if RF type foam is used. Levels are below current regulatory trigger levels but will have to be checked again in line with any future changes in legislation. Selected PFCs are being considered for tighter regulation by 2020 but it is unclear whether this will affect foam stocks held in storage. When RF1 had been used from the very beginning in a new installation (Gudrun) there was no evidence of PFC contamination.

4. MULTI-USE ASSETS – STATUS

Table 1 gives the implementation status on 1 September 2016:

Installation	Substituted to RF1 yes/no	Year of substitution
Grane	Yes	2015
Gudrun	Yes	2014
Heidrun	Yes	2015

FPOS results form different installations and different systems.



Installation	Substituted to RF1 yes/no	Year of substitution
Heidrun B (FSU)	No	IMO-requirements
Heimdal	Yes	2014/2015
Huldra	No	Field closed 2014
Kristin	Yes	2014
Kvitebjørn	Yes	2013
Njord A	Yes	2013
Norne	Yes	2014
Oseberg A,B;D	Yes	2015
Oseberg C	Yes	2015
Oseberg Sør	Yes	2014
Oseberg Øst	Yes	2014
Sleipner A	Yes	2014/2015
Sleipner B	Yes	2014
Snorre A	Yes	2015
Snorre B	Yes	2015
Hammerfest LNG	Yes	2016
Statfjord B	Yes	2014
Statfjord C	Yes	2014
Troll A	Yes	2014
Troll B	Yes	2014
Troll C	Yes	2014
Valemon	Yes	2014
Veslefrikk A	Yes	2014
Veslefrikk B	Planned	2019
Visund	Yes	2015
Volve - Maersk Inspirer	Yes	2015
Volve - Navion Saga	Yes	2014
Åsgard B	Yes	2014
Åsgard C	Yes	2015

In order to consider perspectives and comments from the different business areas and business clusters involved in the Multi-use project, the project group sent out a short survey to those responsible for implementation responsible in the different units.

The original message that was sent out was as follows:

> *Has full substitution been performed?*
>
> 1. *Have there been any challenges in connection with the substitution?*
> 2. *Have you been running full scale testing of the new foam?*
>   a. *If yes: Have the tests given appropriate results?*
>   b. *If yes above: Can you please send us the corresponding reports?*
> 3. *Have you received the necessary support from the project group during the substitution?*
> 4. *Any other comments?*

The project received feedback from all Equinor-operating installations. This feedback was put together in a document in which any challenges which has occurred during the project were commented upon and any questions arising answers. The document was then distributed to those who had replied to the questionnaire.

The overall impression from the feedback received was that the substitution has been successful. 18 of 27 installations had no problems connected with the substitution; 4 of these had at that time not been testing the new foam. Some technical challenges were also reported:

- 8 out of 27 installations experienced a low mix ratio for some skids.
- One installation, Veslefrikk B, was not able to use the new foam due to the foam pumps having too low a capacity.

5. FINAL RISK EVALUATION FOR MULTI-USE PHASE

Risk assessment for the multi-use phase was part of the decision documentation. The only risk identified was a short term one, the monopoly situation whereby only one supplier was providing fluorine-free foam. This could result in price increases. In connection with renewal of foam-contract, a tender for a halogen-free foam was sent to several suppliers in 2014. Only Solberg was able to deliver on this. Even so, although the price of the foam has not increased and Equinor will keep searching for additional suppliers.

5.1 Actual schedule for Multi-use phase

By end of 2015, 29 out of 31 facilities had successfully transitioned to RF1. By September 2016, 30 of 31 assets have successfully implemented RF1.

5.2 Final cost for support in Multi-use phase

The cost for support in the Multi-use phase has been estimated to 2500 working hours in the period from August 2013 to September 2016, corresponding to a total cost of 3,5 MNOK (approx. $400,000, not including foam cost.

6. RECOMMENDATIONS FOR FURTHER BROAD IMPLEMENTATION

The 1% halogen-free firefighting foam re-healing RF1, as a substitution for Arctic Foam AFFF 1%, was tested and accepted by Equinor before implementation. RF1 holds all the necessary certificates required by Equinor for offshore installations.

6.1 Other RF-products available

Other RF products are available on the market for exchanging both 3% AFFF and ATC foams suitable for polar solvents (alcohol) for a fluorine-free alternative. RF products do not necessarily hold all certificates for just one product compared to a comparable AFFF. Certificates should be checked before implementation. Specific weight of gravity and viscosity curves should also be taken into consideration before replacement.

During the project phase for RF1 implementation, many of the Equinor operated installations with 3% system have also replaced AFFF with fluorine-free foam. This did not, however, fall within the scope for this TDI (Technology Development Innovation) and therefore is not part of this report.

6.2 Further development of RF-1

Solberg has recently modified 1% RF1 giving a version with lower viscosity at low temperatures and with a yellow environmental classification (compared to red classification[1] for RF1) called RF1-AG. This product went into operational use in 2018 for all new fields. For existing fields, aadditional tests were needed to assure that mixing of different generations of the same foam could be performed without adding any risks or unknowns. These tests have shown that the two products can be mixed in any ratio without compromising their technical properties. RF1-AG has better (lower) viscosity, excellent freeze protection and is regarded as environmental acceptable according to the OSPAR (The Convention for the Protection of the Marine Environment of the North-East Atlantic) classification system.

For older facilities, 3% foam are still used. In these cases, re-healing foam RF3, a 3% fluorine-free foam, is used.

6.3 Other potential implementation areas for the halogen free foam

Onshore facilities: Both Hammerfest liquified natural gas (LNG) terminal, Sture oil terminal, and Kårstø terminal, as well as the Mongstad refinery, have all more or less substituted AFFF for PFC-free products. Last year saw decline in PFC concentrations during receiving environment monitoring at some locations.

7. FINALISED BUSINESS CASE

With Equinor's contribution in developing, testing and implementation of fluorine-free firefighting foam, we have already contributed to a large reduction of the environmental foot print caused by the oil industry on the Norwegian continental shelf (NCS).

The Norwegian Environmental Agency has reported a 17% reduction of discharge of fluorine-containing foam from 2014 to 2015. This reduction is expected to continue over the coming years.

All the components of the second-generation fluorine-free foam (F3) have acceptable environmental classifications as far as the marine environment is concerned. This makes Equinor well prepared for any potential future requirements.

This project is, as far as we are aware of, one of its kind. With further implementation and experience transfer in the offshore industry, this can lead to a drastic reduction and potentially cessation of discharges of fluorine-containing firefighting foams from the oil industry worldwide.

We at Equinor have seen that the costs related to substitution are relatively modest, with the potential costs of continuing to use a potentially banned chemical far exceeding the relatively modest costs related to substitution and destruction of AFFF.

We have investigated and verified all aspects of the fluorine-free foam (F3) used, RF1-AG, with respect to operational firefighting efficiency, health and safety, freeze protection, aging, etc. We regard the new fluorine-free foam as a fully acceptable and even better replacement for AFFF. Since PFCs will most likely be regulated more strictly in the future, Equinor aims to remove AFFF wherever possible. We in Equinor will do this on our own but as always we see that national and international restrictions and bans helps to speed up the willingness and motivation for substitution in the industry as a whole.

It is notable that other suppliers have discovered the end-user driven market demand for replacing fluorosurfactants. On a regular basis we see concerns related to contamination and the undesirable side-effects of fluorosurfactants. We hope that the firefighting foam industry will take a lead in substituting AFFF worldwide.

FOOTNOTES

(1) Denmark and Norway have introduced an environmental colour marking system indicating for substances that should be considered candidates for substitution, BLACK > RED > YELLOW > GREEN, controlling substances for discharge. The UK publishes a list of all offshore chemicals currently register for use on the UK Continental Shelf (UKCS)that confirms whether products are, or contain a candidate for substitution.

APPENDIX IV

FLUORINE-FREE FOAMS AND THE FIRE SERVICE

Statement by Simon Webb. formerly the Head of Operational Practice for Her Majesty's Fire Service Inspectorate (HMFSI UK) and Technical Specialist for the UK Civil Aviation Authority

During my fire service career to my great shame and regret I and other fire officers were responsible for polluting the environment. The pollution was from firefighting foam used in firefighting, training exercises and from firewater run-off.

The root cause was ignorance - my own personal ignorance together with that of my colleagues and the fire services we worked for. During 1975-1990 we generally used foam knowing that it could damage the environment but the excuse given for using it was that of saving lives and property had priority. The reality was that we had little knowledge of the constituents, how they could cause environmental damage, or how planning could avoid such damage. But we were not alone.

One incident in particular that I commanded in 1995 involved a mixed petrol/diesel road tanker which overturned on the edge of an industrial estate in a large town. The tanks contained 30,000 litres of petrol and diesel. 24,000 litres of fuel together with a large amount of foam entered the drainage system which ran under the industrial estate. An extract from the report on the incident said "*The threat of pollution was extremely great, both from the fuel but also from the foam that was used. In fact, the NRA (National Rivers Authority) were more concerned about the foam, and we limited its application once the risk was controlled and the area evacuated.*" But could the pollution have been limited any earlier? There was a risk of fire but the possibility of re-ignition had been controlled. Certainly, knowing what we now know the tactics used would have been very different.

From 1990 onwards it was realised, albeit slowly, that some of our operational practices were damaging to the environment and better planning and control of operational actions needed to be exercised, mainly through the writing of simple straightforward Standard Operating Procedures (SOPs). This was an area I specialised in during the second half of my career as part of HM Fire Services Inspectorate culminating in working for the UK government in writing national operational SOPs for the UK fire and rescue services. Simple and straightforward procedures were emphasised as we had learnt from experience that complicated or right/wrong procedures were a hindrance to good decision making in a developing dynamic situation as found at an incident and these could lead to erring on the side of safety, i.e., the continued application of foam. The well-known military principle KISS – keep it simple, stupid – ensures that

One of my roles in the UK Civil Aviation Authority (CAA) was to develop operational guidance for the fire and rescue services (ARFF) at airports. I needed to learn in depth about firefighting foam as it plays a critical part in any fire involving an aircraft. It was a steep learning curve and I soon realised that the foam industry (suppliers) completely dominated the selection and procurement of foam. The sales line was that "life safety was paramount". As a firefighter for over 30 years this was ingrained in me, however, I also had years of experience telling me that this was no excuse for bad planning and certainly could not be used as a legal defence for causing pollution.

I spent a lot of my time at the CAA developing new tests to challenge the industry to develop more effective and less environmentally damaging foams. Something they kept telling me was incompatible, but quite frankly this was the result of just a lazy industry not prepared to invest in development but rather deciding to stick with a profitable product. Their trade body complained in writing about the direction of my work to my department director, the CAA Chief Executive, and the UK Government; they also wrote trade articles questioning that my work would put lives at risk. My flippant reply was that if they were complaining I was obviously getting it right.

I engaged with the UK Environment Agency (EA) technical specialist on the subject of organo-halogen (fluorine) containing foams. However, they deferred to comment in detail as the German regulator was at the time carrying out work on the subject. This attitude was particularly interesting in light of the Baden-Baden[1] fire and subsequent prosecution of the fire service for pollution and the decision of the German Federal Court. The UK EA position was that fire and rescue services should consider using fluorine-free foams (F3) where they could satisfy themselves that fire performance tests and approvals meet their needs. The clear danger was that the foam industry was dictating what their needs were, despite myself and others constantly correcting their misleading statements.

Whilst employed by the CAA I probably witnessed more firefighting foam tests than any other person worldwide at the time. In a period of seven years I commissioned, witnessed or conducted over 90 tests. In many of these tests there were direct comparisons between fluorine-containing and fluorine-free foams. Any foam that has a large amount of fluorine in it will be very effective at extinguishing a fire, particularly a hydrocarbon fire. But the question I came to ask was can fluorine-free foams be as effective?

In an aircraft fire the objective is to control the fire sufficiently so as to allow the passengers to escape unaided i.e. by chutes. This means in practice that the first two or three minutes is critical. Total extinguishment is important but secondary to control. The test protocol for aviation rescue and firefighting (ARFF)was revised in 2012 by a working group of the International Civil Aviation Organisation (ICAO) and now reflects this core objective of control.

I was also involved in progressing and developing the use of injecting compressed air into a foam stream (CAFS) as this makes for a very effective foam as well as consistent quality. In May 2012[2] a series of tests using Compressed Air Foam Systems and fluorine-free foam proved that they were operationally effective. One test, number 5, showed the fluorine-free foam purchased by Heathrow Airport at the time was effective in controlling the test fire.

In September 2013 I witnessed an ICAO fire test[3] to the highest Level C standard. The foam passed the new test which focussed on control of the fire. In the past the test required the fire to be totally extinguished, something which favoured the fluorine containing foams, allowing parts of the industry to use the pretext of life safety as a justification for the continued use of these products.

In conclusion, I have absolutely no hesitation in stating that in my experience fluorine-free foams for ARFF can be as effective as those containing fluorine; moreover, I have every confidence that with continued development their performance will improve even further. I see no reason why either any user of firefighting foam should not be using fluorine-free foams (F3), especially for ARFF incidents, or does not have a short-term plan to migrate to them expeditiously.

FOOTNOTES AND ADDITIONAL REFERENCES

(1) http://juris.bundesgerichtshof.de/cgi-bin/rechtsprechung/document.py?Gericht=bgh&Art=pm&Datum=2018&nr=84457&anz=106&pos=1&Blank=1

(2) https://youtu.be/pp8i_8rtwew

(3) https://youtu.be/Psh4YVbHGPo

APPENDIX V

HAND-HELD AND PORTABLE FIRE EXTINGUISHERS

Statement from Gary MacDowall, Managing Director 3F Corby UK and Chairman British Fire Consortium (BFC)

1. INTRODUCTION

Much of the recent debate about fluoro-free foams (F3) versus aqueous film-forming foams, i.e., fluorine containing foams such as AFFF and AFFF-AR, has been focused on a comparison of the fire extinguishing and burn-back performance for both types of products. With regard to performance standards such as EN1568 and ICAO, or even batch performance testing such as LASTFIRE, there is now sufficient evidence available in the market today to counter arguments based on previously perceived performance differences and is a testament that these differences do not in reality exist.

When the first F3 product was developed in the early years of this century, it was an invention of Ted Schaefer, one could say the father of the Class B F3 foam, whilst working for the 3M Company. This foam series, known as re-healing or RF foams, represents the foundation stone of what we see in the industry today. The introduction of the first Class B fluoro-free foam offered a new alternative to AFFF but in the early days could not match the fire performance of the well-established high ratings of film forming foams such as AFFF and AFFF-AR. This is not the case today. European legislation was introduced in 2009 banning foams containing PFOS (perfluorooctane sulfonic acid) as from June 2011. Since then the industry has seen rapid developments in the performance of fluoro-free foam (F3) technology and an opportunity to reduce and limit reliance on fluorochemical chemistry.

An increasing number of manufacturers are now claiming high performance for their Class B F3 foam concentrates with ratings such as 1A-1A in EN1568-3&4 and approvals to ICAO Level B, which in many ways is not surprising given the many changes in legislation, regulation and ongoing scientific research around the world. Politicians and regulators have been guided by the scientific community to encourage change with the aim of reducing reliance on fluorinated chemicals across a number of vital industries and in particular when and where dispersive use is an obvious outcome.

With an ever increasing number of Class B F3 foams entering the market, a significant number of fire performance claims by foam manufacturers have been independently tested in accordance with the standards by my own company. We undertake this work to verify if these performance ratings are accurate and we can confirm that the Class B F3 foams that we have tested do meet the claims published in the manufacturer's technical data. It is essential for commercial reasons that manufacturers such a 3FFF Limited, test not only the fire performance of our own products but also those of our competitors and to also verify their environmental profile to ensure such claims are validated.

In addition to performance testing to various standards which have been targeted as 'too small scale' and irrelevant by some in the fluorochemical industry, there are a number of well-placed industry sectors that have approved F3 products for large scale applications both onshore and offshore, not least in the North Sea oil and gas platform sector, representing the world's largest number of operating platforms offshore. Fluorine-free Class B firefighting foams (F3) are now being used by some of the world's largest civil airports with eight in the United Kingdom including London Heathrow, London Gatwick, Manchester Ringway, Copenhagen and Dubai, with more than twenty airports in Australia going fluorine-free including Sydney and Melbourne to name but a few. The ongoing technical debate about F3 foams being a viable alternative for large scale fires should have been over some time ago but there must be some consideration for end-users who are trying to manage change to new generation foam products, whilst avoiding what is often seen as a financial burden on their businesses. However, the financial burden of having to deal with legacy contamination issues and remediation costs associated with historic use of fluorine containing foams has a cost to business many times greater than a managed change to fluoro-free foams. In addition, the socio-economic costs already being experienced in Australia, the USA, Germany and even in the UK, following the Buncefield fire in December 2005, clearly demonstrate the true cost of an overindulgence and reliance on fluorinated products over the past five decades. In reality, the rapid change to fluoro-free foams currently being driven by market forces is rapidly becoming an old story for those end-users who have already made the transition and are now wondering what all the fuss was about.

One needs, as an example, to look at large oil tank and refinery fires or aircraft fuel fires as very rare events but the necessary training to deal with these events is something that is required on a regular basis. This is not to say that F3 foams should just be seen as foams used for training, quite the contrary. F3 foams have the advantage that they can be used both operationally and for training, whereas fluorinated foams can be used for operational use but are certainly not appropriate for training applications. In the case of aircraft fire fighting vehicles (ARFF) the same foam is, by necessity and regulations, used for operational use and training. There has been a perfectly practical operational assessment of risk and is why so many airports have made the transition to F3 without any impact to fire performance requirements.

2. HAND-HELD AND PORTABLE EXTINGUISHERS

Moving away from the large Class B fuel fires which are thankfully statistically rare events, far more attention needs to be focussed on the many 100,000's fixed foam fire suppression systems and many millions of hand portable extinguishers and trolley units that have traditionally been filled and approved with AFFF and AFFF-AR foams and are sold each year across the globe. Until recently this has been a largely forgotten area of the industry, where millions of litres of foam solution are discharged annually for one of the following reasons: (i) periodic function tests as part of the requirements contained in appropriate standards; (ii) discharge for scraping and disposal; (iii) discharge for training purposes; or (iv) the discharge of the unit or system onto a fire. Fixed systems, trolley units and hand portable pose an environmental threat if the discharges are not properly managed and rigorously controlled by the appropriate agencies.

The first fluoro-free and solvent-free foam was introduced by 3FFF Ltd on the market four years ago at Interschutz in Germany. This product met the requirements of the EN3 standard for hand portable extinguishers, EN1866-1 for foam trolley units and, most recently, for fixed fire systems with equivalent ratings to fluorinated foams on Class B fuels. Of course, other manufacturers are now introducing fluoro-free options for this type of application as demand for environmentally safer foams are increasing year on year. There are no longer any end-user applications where fluoro-free foams cannot be substituted providing equivalent performance to AFFF.

There are new challenges ahead to continually improve the sustainability of the chemicals we use to fight fire, to ensure dispersive applications such as release to land and water do not have environmental implications that impact on human and animal life. The most recent developments in foam concentrates and water-additive formulations that are both fluoro-free (F3) and solvent-free (SF), represent the next significant step in sustainability for the industry in the years ahead.

APPENDIX VI

AFFF, FLUORINE-FREE FOAMS AND DEEP-SEATED FIRES

Statement by Ted Schaefer, formerly the 3M Company and Solberg Foams, developer of Class B re-healing fluorine-free foams (RHF™) and Class A FireBrake™ for wildland fires

DID YOU KNOW...?

In the late 1970's and the 1980's, prominent firefighting foam manufacturers were stating that AFFF foams were useful for only thin skin fuel fires, and not fuels in depth. The only firefighting foam for fuels in depth and therefore storage tank fires, were fluoroprotein foams. Fluoroprotein foams emerged in the 1970's. This argument was put forth in technical papers and infomercials primarily promoted by a UK company.

Further support was given by papers published by the UK Fire Research Station, showing similar spreading coefficients (surface chemistry) and fire test results with FP, FFFP & AFFF. The data is summarized by T. Briggs in Chapter 12 Foams for Firefighting of the Surfactant Science Series Vol 57 Foams: Theory, Measurements and Applications. (RK Prud'homme and SA Khan; Foams: Theory, Measurements and Applications, Surfactant Science Series, Vol 57, Chap. 12 pg 465-506).

Historically, many technical articles were written and published on the technical superiority of FP and FFFP foams for storage tank fires. To date, there are still a significant number of Oil & Petrochemical companies still prefer FP foam in their fire protection systems, instead of AFFF products. Firefighting systems that use FP foam the Type II (foam pourers), Type III (portable monitors) and SSI (subsurface injection).

RURAL VOLUNTEER FIRE BRIGADES

In Australia there is a lot of agricultural, rural, mining, reserves and parklands in the vast open spaces, where the States are often the size of several European countries. There are not many large cities but there are small villages, townships and communities with hundreds to thousands of kilometers of roadways. With little formal infrastructure, these small villages and towns rely on volunteer emergency services organizations. The local communities offer their time, without pay, to assist in supporting through organizations like rural fire brigades.

In New South Wales, they have two Fire Brigade organizations. One is the professional full-time Fire and Rescue Service New South Wales with a presence in larger towns and villages, and the predominantly volunteer New South Wales Rural Fire Service which maintains fire stations and crews in small villages and rural communities. They respond to structural fires, road traffic accidents, community incidents, rescues, flammable liquid fire threats and wildfire threats.

The NSW Rural Fire Service has 72,000 members, 900 full time staff, and over 2000 fire stations. The over 2000 RFS stations serve as secure equipment storage, facilities, command centres, and for member training. As you can imagine, keeping up proficiency levels is always on the agenda of volunteer organizations like an RFS. With limited full-time staff on the more than 2000 stations, this means there is less than 0.5 full-time staff for each station, including administration. The economic cost of all training, including Class B flammable liquid firefighting, can be significant in order to ensure community and firefighter safety. In addition to training, there is also the management of any clean-up necessary as the result of training. Based on past history, the clean-up costs at training facilities for any of these 2000 plus stations would be an extremely significant financial and administrative burden.

Due to the nature of the ground water supplies in rural Australia, use of boreholes on properties for both human and animal needs, fire stations cannot allow firefighting chemicals to get into the water table and contaminate the drinking water supply. It is therefore important for chemicals contained in firefighting foams to be readily biodegradable and not to be persistent, especially if they are also of unknown toxicity or bio-accumulative potential. This makes the operational and training use of foams containing fluorochemicals especially challenging. Rural fire stations do not have the facilities to contain runoff in the way that professional metropolitan fire and rescue services do, either operationally or for training areas. Class B fluorine-free firefighting foams (F3) offer an environmentally acceptable solution to this dilemma.

SILOXANE SURFACTANTS IN FIRE FIGHTING FOAMS

Siloxanes have surface tension reducing characteristics that make appear to be interesting candidates for the replacement of fluorosurfactants. However, they do not have the same surface tension reducing capabilities that are lower than fluorosurfactants. The siloxanes, or silicone fluids, have a more limited capability to satisfy the initial spreading coefficient equation and therefore forming a film. Due to a slightly higher surface tension, the siloxanes have a more limited range of potential film formation on hydrocarbon fuels.

TABLE 1: SURFACE TENSION OF SURFACTANTS IN WATER

Property	Hydrocarbon Surfactant	Siloxane (Silicone Surfactant)	Fluoro-surfactant
Surface Tension (mN/m)	> 25	20-25	15-20
Activity in Organic Media	Medium	Medium	Very Good
Use Concentration (% by weight)	0.5 - 5.0	0.1 - 0.5	0.01 - 0.05

Silicone fluids are included as an effective cross-linking in aqueous firefighting foam structures (US Patent US20080196908A1) in combination with hydrocarbon surfactants. Longer foam drainage times are observed in silicone fluid containing formulations with foam quality evaluation. From the experimental data, good extinguishment times are observed for both polar and non-polar fuels, however the silicone fluid containing foam concentrates appear to have reduced hydrocarbon burn back resistance than a standard PFOS containing AFFF.

Siloxanes have been identified as emerging pollutants in a recent 2009 NORMAN Association Position Paper that was written as a follow up to the Prague meeting in May 2009. Both organosiloxanes and fluorochemical surfactants are listed as two of the emerging pollutants being found in passive environmental sampling. This has raised concerns with the growing concentrations of organosiloxane polymers being found in the aquatic environment. They are persistent.

Dow-Corning are a well-respected manufacturer of these compounds, they have flagged the environmental persistence of these polymers, stating that siloxane polymers are extremely durable in the environment. They are environmentally persistent and have been found to be bio-accumulative as identified in their technical bulletin *Degradation of Silicone Polymers in Nature* (1998).

APPENDIX VII

REPLACEMENT OF FORMER FIREFIGHTING FOAM FLUOROCHEMICALS BASED ON C6/C8 MIXTURES BY PURE C6 DERIVATIVES

Statement from Dr. Thierry Bluteau, Leia Laboratories, Corby UK, and Essertines-en-Donzy, France

1. INTRODUCTION

Ever since the 3M Company voluntarily phased out PFOS and related fluorochemicals starting in May 2000, the fluorochemical industry, mainly represented by the lobby group the FFFC (the Fire Fighting Foam Coalition), has presented telomer-based perfluorochemical derivatives as supposedly safer alternatives.

In this contribution, we consider both PFOA (C8) and PFHxA (C6) resulting from the degradation of the original fluorosurfactants and fluoropolymers used to formulate AFFF and AFFF-AR aqueous film-forming firefighting foams, which end up ultimately as chemically and physically stable, highly persistent end-point products in the environment.

Many scientific studies have shown these products cannot be considered to be a suitable and safe environmental solution. Reluctantly and many years later, the fluorochemical industry and the FFFC admitted that PFOA, also known as C8, was not safe or harmless and announced voluntary phasing-out of PFOA in 2015 as part of the US EPA 201/2015 PFOA Stewardship Program subscribed to by major fluorochemical manufacturers in the western world but not universally. However, in its place the fluorochemical industry promoted so-called 'pure C6' derivatives as the ultimate answer in addressing both environmental issues and maintaining the benefits of performance efficiency.

Most of the firefighting foams on the market have been certified according to accepted international standards such as EN1568, EN3, ICAO, IMO, UL162, LASTFIRE, over the latest 10-15 years; formulations were made with then currently available fluorochemicals, which consisted of materials containing predominantly a mixture of C6 and C8 perfluoroalkyl chain lengths. The C8 component was often a considerable proportion of the total.

It is important to remember that this change over from a C6/C8 mixture to purer C6 has been far from painless. The technology is thus far from being perfect and given product shortages, as well as significant price increases in raw material costs, the transition to high purity C6 fluorochemical feedstocks has not been smooth.

In order to promote acceptance of this change from a mixed C6/C8 product to one based on pure C6 technology, both the FFFC and individual manufacturers maintained that the firefighting performance of C6 foams were the same as previous C6/C8 formulations and that the new technology could be considered as a drop-in replacement. In order to check these claims, Leia decided to conduct studies to evaluate pure C6 fluorosurfactants as drop-in replacements in standard AFFF formulations, certified under EN1568 and ICAO, which used the older C6/C8 technology.

2. GENERAL STUDY: PART 1

The study was done using two AFFF 6% film-forming foams: one (AFFF1) certified to Class 1 under EN1568 part 3. This standard certifies the efficiency of foam in extinguishing hydrocarbon firesand uses heptane as the standard test fuel. The second (AFFF2) was certified to the international aviation standard ICAO Level B which uses kerosene as the standard test fuel.

Four samples were prepared consisting of:

a) AFFF1 with a standard C6/C8 mix;

b) AFFF1 containing pure C6;

c) AFFF2 with a standard C6/C8 mix; and

d) AFFF2 using pure C6.

The active fluorochemical component was maintained at same concentration in each formulation based on fluorine content. Formulations were also checked to ensure that characteristic physical parameters were maintained (Table 1). There were only minor changes in foaming qualities which were unlikely to affect the performance of the foam.

Fire testing was the carried out according to the relevant protocols and the burn-back resistance measured as defined in the protocol (Table 2 Leia Labs fire testing.) Extinction times are not reported as there were no clear differences seen in extinction times, i.e., efficiency.

TABLE 1

	AFFF 1 C6	AFFF 1 C6/C8	AFFF 2 C6	AFFF 2 C6/C8
Low Expansion	8.0	8.1	8.6	9.1
Drainage time 25%	3′10″	3′05″	3′10″	3′15″
Medium Expansion	55	48	55	65

TABLE 2

	AFFF 1 C6	AFFF 1 C6/C8	AFFF 2 C6	AFFF 2 C6/C8
Burnback Start	8′50″	19′20″	9′50″	37′30″
Burnback 100%	9′50″	22′20″	11′50″	38′50″

These results clearly indicate that there was a loss in burn/back resistance observed on substituting C6/C8 for pure C6 with a loss factor for AFFF1 of 56% and AFFF2 of 68%.

After this first series of tests, we reformulated the two foams (AFFF1 C6 and AFFF2 C6) by increasing the C6 content to match the performance of original formulations (C6/C8=1). C6 active matter in terms of fluorine content was increased by a multiplying factors based on the original content (C6/C8=1) as shown in Tables 3 and 4.

TABLE 3

AFFF 1	C6=1×	C6=2×	C6=4×	C6=8×	C6/C8=1
Burnback Start	8′50″	11′05″	18′00″	31′35″	19′20″
Burnback 100%	9′50″	13′50″	21′30″	35′05″	22′20″

TABLE 4

AFFF 2	C6=2×	C6=4×	C6=8×	C6=16×	C6/C8=1
Burnback Start	9′50″	17′35″	23′50″	35′05″	37′30″
Burnback 100%	11′50″	19′10″	25′15″	39′55″	38′50″

It is clear from the results in Table 3 that in order to match the C8 results, the C6 content must be multiplied 4-fold. From the results given in Table 4 in order to match the C8 results the C6 content must be multiplied 8-fold.

3. DISCUSSION AND CONCLUSIONS

These tests are based on the premise of a simple drop-in replacement, that is to say that the formulation was only modified by replacing the C6/C8 fluorochemical components with the same quantity of pure C6 material. Two different AFFF 6% formulations were tested so as to ensure as far as was possible that the results would not be influenced by the use of different raw materials apart from modifications of the content of the fluorochemical components.

The results demonstrate conclusively that:

- Pure C6 cannot be used as a straight drop-in replacement.
- Burn-back resistance is clearly adversely affected and considerably reduced when changing from a C6/C8 mix to a pure C6 formulation.

The correction factor lies between a 4 to 8-fold increase in C6 content clearly confirming that it is simply not possible to reformulate the foam as a straightforward drop-in at reasonable cost given the substantial cost of any fluorosurfactant components. Fluorochemical suppliers had recommended that it would be necessary to make modifications to former formulations in order to achieve an acceptable performance. Even so, considering the performance gap as regards burn-back resistance between C6 and C6/C8, considerable doubt remains whether it is possible to maintain a similar level of performance at no additional cost.

In 2010, Dr Chang Jho and Dr Mitch Hubert working for the Dynax Corporation, a major manufacturer of feedstocks and fluorosurfactants for firefighting foams, acknowledged in an article in the Industrial Fire Journal (referred to elsewhere in this White Paper) this C6 weakness and admitted that it was necessary to add C8 material in order to achieve satisfactory burn-back resistance!

On checking the performance certificates provided it turned out that a sizable number of foam manufacturers on the market were proudly announcing success in reformulating new C6 based foams but that, somewhat surprisingly, they were using outdated certificates obtained prior to reformulation, resulting in lack of any warranty covering the actual performance of these new and changed formulations!

The change from C6/C8 to C6 technology is not as simple as it has been presented to be. Recent work by the LASTFIRE consortium has demonstrated that there are indeed no absolute drop-in replacements for the older C6/C8 technology. The change-over needs a lot of reformulation and raises questions of demonstrated proven performance, considering that the necessary retesting has neither been reflected in market price increases nor in the availability of up-to-date certifications by approved independent test laboratories.

Needless to say, the apparent benefits of continuing to use C6-based foams are questionable at best as the product is not as eco-friendly as claimed, with degradation products that are certainly environmentally extremely persistent, widespread, more difficult to remove from effluent waste streams than their longer chain counterparts, and of unknown but potential long-term toxicity. Moreover, high performance fluorine-free foams (F3) are now widely available on the market from a range of manufacturers with certified performance equal to the equivalent AFFFs.

APPENDIX VIII

PFAS: A FIREFIGHTER'S JOURNEY – AN END-USER'S PERSPECTIVE ON OCCUPATIONAL EXPOSURE AND ITS CONSEQUENCES.

Statement by Commander Mick Tisbury, Lead PFAS Project, Melbourne Metropolitan Fire Brigade, Melbourne, Victoria, Australia, and United Firefighters' Union (UFU), Australia

On 21 August, 1991, the Melbourne Metropolitan Fire Brigade (MFB) responded to explosions at a petro-chemical storage facility on the docks of Melbourne, Victoria, Australia. This fire eventually became one of the largest fires in Victoria's history. As a young firefighter, 23 years old and believing myself to be 'bullet-proof', I was excited, if not a little apprehensive, to be fighting this blaze.

The incident including the fire followed by the fire duty, went on for weeks. Significant amounts of AFFF (200 tonnes) were used to extinguish the fire and one of the main products released by the exploding tanks was benzene. As Coode Island was on the outskirts of the central business district (CBD) of Melbourne, it naturally received significant political and media interest. Various experts offered a variety of opinions on the toxicity of the chemicals burning as well as the significant smoke plumes and how they might affect the community. But as usual, firefighters actually tackling the blaze were the last to be considered and besides we were too busy fighting the fire to worry about possible effects.

In the subsequent debriefs and investigations, particularly surrounding possible future health impacts to firefighters, the comment was made, "…don't worry, it's only benzene…". At my own fire station, several firefighters, including myself, suffered bouts of nose bleeds for approximately 6 months, however, as the advice that we had nothing to worry about came from 'experts', obviously our fears were unfounded.

Fast forward to December 2011. A major print media outlet ran an article about a 'Cancer Cluster' at the Country Fire Authority (CFA) training ground at Fiskville, in Victoria's western district.[1] As I now held a position on the United Firefighter's Union Branch Committee of Management, as well as being an instructor with the MFB who had trained extensively at Fiskville, this story caught my attention.

I commenced my own investigation on behalf of UFU members into work practices, particularly around the firefighting water quality used for drills at the facility. I was able to obtain 1000's of documents, including emails and water quality testing reports via Freedom of Information Act (FOI) processes. The CFA, along with the conservative State Government at the time, announced an investigation, however, this was only to be an historical investigation up to and including 1999. The UFU wrote to MFB, CFA, and various state government statutory authorities, including EPA and WorkSafe requesting investigations and the sharing of documentation.

It soon became apparent that rather than an inclusive and transparent investigation process, which involved all stakeholders, the priority of the investigation would become minimisation of potential litigation and denial of the problem. The United Firefighter's Union then commenced a campaign to raise awareness of the issues surrounding not only PFAS, but also the other toxic chemicals firefighters and the community were being exposed to at the CFA Fiskville Training Ground.

Because of the lack of transparency from the CFA, EPA and the Victorian Workcover Authority, concerned residents turned to the UFU for support, as there was no other organisation prepared to act as an advocate on their behalf.

After a change of State Government, the Victorian Parliament commenced a Parliamentary Inquiry into the CFA Fiskville Training Ground, so all information could be assessed and concerns from both firefighters and the surrounding community could be addressed. 100's of submissions and testimonies were received from affected firefighters, community members and witnesses.

Both the interim and final parliamentary reports into Fiskville were damning. The Chair of the Inquiry, the Hon. Bronwyn Halfpenny MP, included in the Chair's Foreword, the following:

> *"…This Report validates the testimony of everyone who gave evidence of contamination, exposure and ill health. To the question: "Could unsafe practices at Fiskville have caused my illness?"-the answer is, in all likelihood, yes. To the question: "Did CFA management and Board members know that practices at Fiskville were unsafe or contravened*

> *standards and safety regulations"-the answer is yes, some did...."*

On the 26th March 2015, the Victorian State Government shut down Fiskville permanently, after over 550 tests revealed high levels of PFAS contamination on the training site. Additionally, water testing found significant PFAS contamination 13.5km downstream of the training ground and in groundwater. Neighbouring farming properties on the CFA Fiskville site boundary were purchased by the state government, as were the livestock. Remediation works continue at the site and these are envisioned to continue for many years to come.

A recommendation that came out of the Interim Report was that firefighters were to be offered PFAS blood testing. There was very strong opposition to this recommendation, mainly from Fire Services management, with the argument being it would only increase firefighter's anxiety if they knew what their blood levels were. The other common argument was there was nothing that can be done about PFAS blood levels, so there is no point in offering the blood tests.

As a firefighter, I can assure you that we already have high levels of anxiety relating to our exposure to PFAS. We know that we have been repeatedly exposed to PFAS for decades. Firefighters are aware of being continually exposed to cocktails of various toxins and carcinogens in the course of their operational duties, which are mainly unavoidable, and are also aware of being similarly exposed during training.

The reasoning behind wanting to know about our current PFAS blood levels is about early identification, early intervention and early treatment. We know that PFAS has been linked to various illnesses and cancers. If we can monitor blood PFAS levels, then intervention to eliminate, reduce or control the risk, as well as early medical treatment where appropriate in the event of a diagnosis, will ensure a successful outcome with a greatly reduced risk of long-term consequences.

Routine PFAS blood testing has been offered to MFB firefighters since June 2016 and the results show significant elevated PFAS levels in firefighter's blood as compared to the average population in Australia. However, it is essential to ensure that PFAS levels determined in an occupationally exposed cohort such as firefighters are not included in any population average as this will artificially inflate the average. In assessing the reliability of any test results, quality control data and especially percentage recoveries should be factored in to the choice of suitable laboratories used for testing.

The South Australian Metropolitan Fire Services (SAMFS) have followed MFB's lead and also provide PFAS blood testing to their firefighters and once again the results show significant elevated PFAS blood levels, some as high as 1600 ng/ml. Additionally, the SAMFS have also offered PFAS blood testing to their recruit firefighters. These are basically civilians from the general population who have not been previously occupationally exposed to PFAS, who are being trained to be professional firefighters, so therefore have had minimal PFAS exposure. The results indicate that on average PFOS levels for this group are below 5 ng/ml and PFOA levels are below 3 ng/ml, representing a snapshot of average levels in the community.

Thankfully, after the release of the Fiskville Parliamentary Inquiry Final Report, and several senior management changes in MFB, the focus has now been directed to solutions. The MFB at behest of the UFU has adopted a 'Precautionary Principle approach' in relation to PFAS and its firefighters. I was requested by the MFB Chief Officer to lead a PFAS Project Team to finally deal with PFAS management and mitigation issues.

MFB transitioned to non-persistent, fluorine-free firefighting (F3) foam in 2014, after extensive testing on live fire scenarios. Since then, every B Class fire that MFB have responded to has been extinguished with fluorine-free foam. Recently there has been misleading information circulated by various people with vested interests, regarding the effectiveness of fluorine-free foam (F3) on flammable liquid fires. Based on MFB's experience, Solberg RF3x6 foam concentrate has performed just as well as our previous fluorinated AFFF concentrate.

In 2016, as a result of a positive PFAS test in the water supply used for training at our new Firefighting Training College, MFB embarked on testing every fire appliance (107) in the MFB fleet, to establish how this contamination could have occurred.

The results of the PFAS testing showed that every MFB fire appliance, apart from four recently commissioned vehicles, had high levels of PFAS contamination in both water and foam tanks, as well as in most delivery systems. Further investigation established significant residual PFAS legacy contamination, including solidified AFFF residues inside the pumps, pipework and breather caps of the foam and water tanks.

The MFB decided to lead the way in Australia rather than wait for various governmental and regulatory bodies to act. With the assistance of subject matter experts such as Dr. Roger Klein as well as Supt. Nigel Holmes from the Queensland Department of Environment and Science, MFB has now developed an operational firefighting foam policy. This Policy was developed after completion of a rigorous human health risk assessment that examined both exposure pathways and the average number of times that firefighters would be exposed to PFAS for both operational firefighting and firefighting training or maintenance procedures. This Policy has also been endorsed by CFA, EPA and WorkSafe Victoria.

Acceptable ('safe') PFAS threshold limits were established for both operational applications (413,000ppt) and training (70ppt) in the water used and well as for foam concentrate (9ppm). The difference between the two water threshold limits is due to the fact that during operations, breathing apparatus and personal protective clothing (PPC) is always worn and generally for relatively short durations. During firefighter training, exposure is generally for longer and is more frequent, with the wearing of breathing apparatus for eight hours, five days a week, not being a feasible option.

After the establishing the PFAS threshold limits and the PFAS legacy issues with our fire appliances, work then commenced on finding a solution and process for decontaminating the fire trucks. After much trial and error, we have now developed a 36-stage process in order to decontaminate fire trucks to well below the PFAS threshold limits. Every fire appliance, after completing the process is now below 1000ppt (1 ppb) and all appliances required to be used for firefighting training are below 70ppt (0.07 ppb).

The approximate cost of decontaminating each appliance, including hose and equipment, is A$15000-A$20,000. This cost pales into insignificance when one considers the cost of a new fire appliance, the costs to human health and the costs to the environment, by not addressing these concerns. Several legal class actions are now under way in Australia relating to PFAS contamination in properties surrounding airports and defence force bases.

MFB and UFU are now sharing this process with various national and international Fire Services and firefighting unions, in order to reduce potential PFAS exposure for firefighters, the community and the environment, worldwide.

PFAS-containing foam concentrate that requires destruction as part of the MFB appliance decontamination process is destroyed via high temperature incineration using an industrial process subject to strict licensing conditions set by the regulatory authorities.

Further to this work that the newly established MFB PFAS Project Team, for which I am the Project Leader, has been the commissioning for a Firefighter PFAS Blood Reduction Study. Macquarie University has been tasked with establishing whether regular blood and or plasma donations, are able to reduce serum PFAS levels in the blood of firefighters.

The study involves the voluntary participation of 350 MFB Firefighters broken into three groups; a non-intervention group, a blood donation group and a plasma donation group.

The importance of this study is to assess methods of reducing firefighter PFAS levels. There are numerous self interest groups attempting to deflect concern about PFAS chemicals and any risks associated with exposure. From a firefighter's perspective, we know we have significantly raised PFAS levels in our blood.

> *We feel we have a ticking time-bomb in our bodies; we do not know when it will explode or even if it will explode - we just want the bomb removed!*

From personal experience, this not only has an effect on my own well-being but also has an effect on my wife and three children. Every time I cough or feel a bit unwell, my kids in particular are concerned that something more sinister is occurring. It is accepted and backed up by scientific research that firefighting as an occupation is a risky one and reduces both the quality and length of life, due to occupational illnesses and diseases.

Firefighters cannot avoid exposure to toxins and carcinogens during the course of their job. We cannot change what we have been exposed to in the past but we can certainly change what we will be exposed to in the future. Additionally, we can attempt to remove these PFAS chemicals that have accumulated in our bodies before any more damage is done.

FOOTNOTES

(1) PFAS contamination issues and exposure of firefighters at the CFA Fiskville Training Centre have been examined extensively during the Parliament of Victoria Inquiry by the Environment, Natural Resources and Regional Development Committee (ENRRDC) chaired by Bronwyn Halfpenny MP – final report May 2016 https://www.parliament.vic.gov.au/images/stories/committees/enrc/Fiskville_training_college/Final_report/ENRRDC_58-03_Text_WEB.pdf

APPENDIX IX

REMEDIATION OF PFAS IN THE ENVIRONMENT

Statement from Dr. Richard Stewart, Managing Director, Ziltek Pty, Adelaide SA, Australia

1. PFAS CHEMISTRY

Per- and Polyfluoroalkyl Substances (PFASs) are a group of thousands of synthetic chemicals characterised by the presence of a highly stable carbon-fluorine (C-F) backbone “the strongest bond in organic chemistry”. The hydrophobic (water repelling) C-F backbone is of varying length (typically C2 – C16) with a polar terminal group. The backbone is partially or fully fluorinated (Buck *et al.*, 2011).

The chemical and physical stability of these chemicals makes them ideal for a range of commercial products including non-stick cookware, waterproofing agents and firefighting foams.

2. PFAS IN THE ENVIRONMENT

As an unwanted consequence of their stability, PFASs are very resistant to degradation in the environment. It is well accepted that PFASs show persistency, bioaccumulation and biomagnification properties in the environment and are potentially toxic. Most are highly soluble in water and can readily leach from contaminated soil into ground water and drinking water sources, where they pose a potential risk to health and ecological receptors.

To date, regulators have focussed on the simple longer-chain PFAS compounds (>C6) such as PFOS and PFOA, primarily because these have been the major constituents of commercial legacy products containing PFAS and are therefore the most dominant species identified during site assessment.

However, the more complex PFAS fluorotelomers, including short-chain compounds (RC6), may be as problematic as their longer-chain counterparts in terms of adverse effects on health and the environment. Short-chain PFASs generally have a higher mobility in soil and water and there is evidence to suggest that they preferentially accumulate in sensitive receptors such as grasses, earthworms and edible fruits with the potential to enter the food chain (Brendel et al., 2018; Bräunig et al., 2017; Bräunig et al., 2019).

> **Industry sources estimate that the global need for the remediation of PFAS contamination is between 30 Billion and 300 Billion USD. Some leading academics have warned that the total clean-up bill could exceed 1 Trillion USD spread across a wide range of affected social, economic, health and environmental resources.**
>
> *(personal communication)*

Site Contamination

Because of their widespread and frequent use in firefighting training and the highly dispersive and uncontained nature of this use, efforts to characterise PFAS in the environment have focussed on sites that historically used Aqueous Film Forming Foams (AFFF) and the related FP (Fluoroprotein) and FFFP (film forming fluoroprotein) foams. The AFFF and related foams were regularly used for emergency response and firefighting training events from the 1960’s onwards at the majority of commercial and defence airports in Australia, USA and parts of Western Europe.

According to industry market data, there are more than 2,500 airport sites in the USA alone that have been required to use AFFF foams – only a handful of these have been sampled to date. There are an estimated 664 Department of Defence sites across the USA where PFAS contamination is likely to exist (Lerner, 2015). The map in Figure 1 shows 664 Department of Defence sites across the USA where PFAS contamination is likely to exist.

In Australia, PFAS contamination has been found at numerous commercial and Defence airport sites including in ground water and drinking water sources. This is causing a significant socio-economic impact on surrounding communities by impacting livelihoods (e.g. fishing, farming and cropping restrictions) and property values, and has the potential to affect health. Several legal class actions are pending.

PFAS contamination is not limited to airport sites. Refineries, pipelines, ports, bulk fuel storage and refuelling sites are set to represent the next wave of PFAS site remediation challenges, due to their extensive historical and ongoing uncontained use of firefighting foams containing PFAS (Pancras et al., 2016). Then of course there are the PFAS

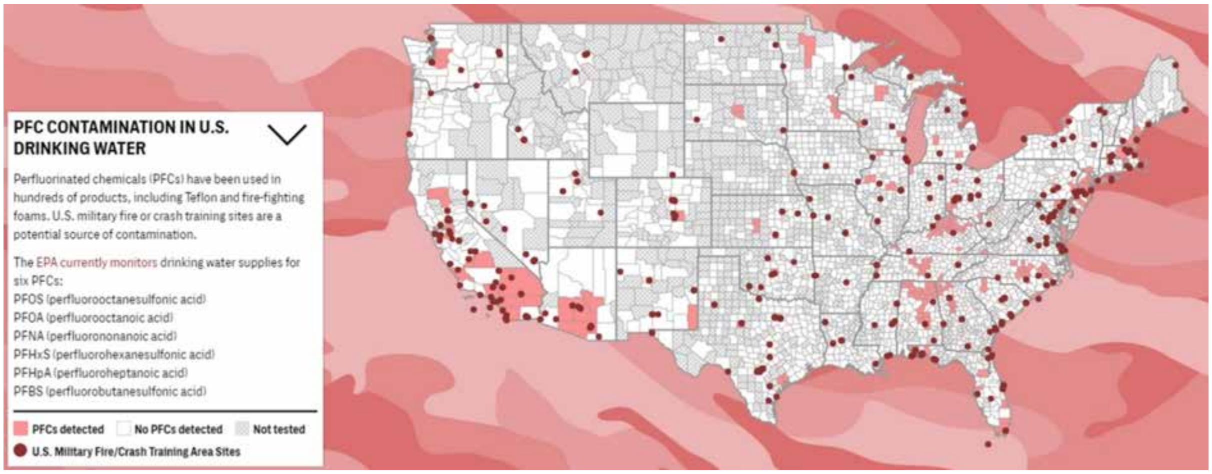


Figure 1. PFC Contamination in U.S. Drinking Water` (from "Poisoning the Well" by Sharon Lerner, December 2015, The Intercept). https://theintercept.com/2015/12/16/toxic-firefighting-foam-has-contaminated-u-s-drinking-water-with-pfcs/

Figure 2. At least 90 sites across Australia are under investigation for elevated levels of per- and poly-fluoroalkyl (PFAS) chemicals.). © Carrie Fellner and the Sydney Morning Herald

chemical manufacturing sites themselves, many of which have contributed to extensive soil, ground water and surface water contamination over decades of production.

3. PFAS REMEDIATION

A unique challenge

Because PFAS chemicals are inherently very stable and heat resistant, they pose a unique challenge for remediation practitioners. Many of the traditional remediation methods that have been used for decades to treat a wide range of environmental contaminants are not viable for PFAS. Relatively high energy inputs are required to break down these contaminants, which makes the remediation of PFAS much higher cost than for many other environmental contaminants (Ross et al., 2018; Kucharzyk *et al.*, 2017; Yao *et al.*, 2015).

Another challenge is that there are literally 1,000's of different PFAS molecules in AFFF foams as well as in other products such as PFAS treated textiles and food packaging with many yet to be characterised. Commercial laboratories routinely assess only about 28 of these compounds; this makes it difficult for industry to set and measure meaningful remediation objectives, and adds to cost and uncertainty.

There is a direct correlation between the C-F chain length of PFAS molecules and their ability to adsorb to hydrophobic/carbonaceous surfaces; this means that short-chain molecules tend to leach more readily from contaminated soil (Sörengård et al., 2019) and are difficult to remove from water using conventional carbon-based filtration media (Appleman *et al.*, 2014). The potential for transformation of some PFASs to more problematic end-products in the environment adds further complexity to the remediation design process.

Water treatment methods

Current standard industry practice for treating PFAS-contaminated water is via filtration through granular activated carbon (GAC). While GAC is effective at removing long-chain PFAS compounds, the short-chain compounds are not removed as efficiently (Appleman *et al.*, 2014; Inyang and Dickenson, 2017; Eschauzier *et al.*, 2012). This can lead to early breakthrough and costly GAC replacement, and results in an unsatisfactory remediation outcomes for short-chain PFASs.

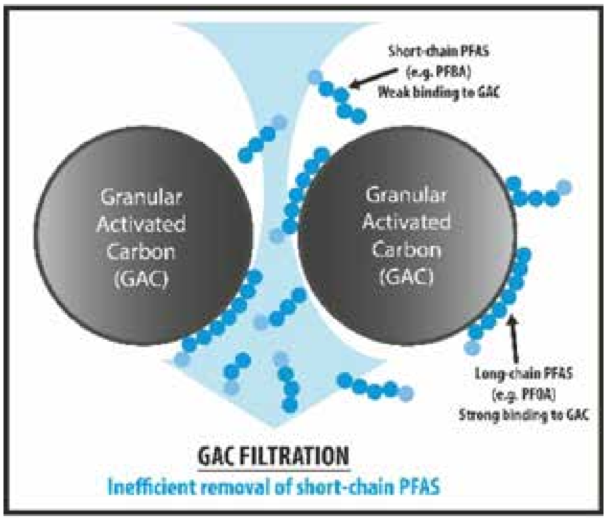


Figure 3. GAC filtration removes long-chain PFAS but does not remove short-chain PFAS efficiently

A new wave of synthetic resins show promise as viable alternatives to GAC because they claim to bind long- and short-chain compounds with higher affinity (Zaggia *et al.*, 2016). Another potential advantage offered by resins is that they can be washed and reused on site many times by actively 'desorbing' the contaminants with proprietary processes. The downside is that these resins are very expensive relative to GAC and their long-term cost efficiency and performance is yet to be verified, at least in the public domain.

For any filtration system, the spent media and/or the wash liquid concentrate still needs to be safely disposed. The main options here are currently high temperature incineration and landfill disposal.

More traditional processes used at fixed water treatment plants such as reverse osmosis and ozone fractionation have been successfully used to remove PFAS from water but these processes require significant capital outlay and operating costs and still generate a PFAS residue that requires disposal.

Other water treatment methods showing some promise include electrochemical oxidation (destructive) and flocculation/coagulation (separation) but more testing is required.

Soil treatment methods

Oxidation of the PFAS carbon-fluorine backbone under environmental conditions is not viable. This eliminates bioremediation and chemical oxidation as remediation options for degrading PFAS contaminants in soil.

Stabilisation is a remediation method that has been used for decades to immobilise heavy metal and hydrocarbon contaminants in soil. It is currently considered the most viable and mature treatment technology available for PFAS contaminated soil (Ross *et al.*, 2018). This method involves adding sorbents to the soil to chemically stabilise or 'lock up' the PFAS to prevent leaching into ground water.

GAC has been used as a stabilisation reagent to bind PFASs in soil (Hale *et al.*, 2017). However, it is well documented that GAC does not bind strongly to shorter chain compounds, which could have negative implications on the sustainability of soil stabilisation with GAC, where these compounds could be eventually released by desorption.

New aluminium hydroxide/carbon blends designed to bind long- and short-chain PFASs in soil have been demonstrated at full-scale in Australia (Stewart, 2017) and Europe (Helena Hinrichsen, Envytech, *pers. comm.*) at a cost of around €40 to €80 per tonne of soil. Long-term sustainability studies are underway.

Soil stabilisation can be followed by solidification with cementitious agents to create an extra physical barrier to leaching and/or to ensure the soil has sufficient compressive strength for certain reuse applications (e.g. placement under infrastructure). A recent study showed that PFASs were successfully immobilised using a combination of stabilisation with carbon and carbon/mineral blends followed by solidification with Portland cement (Sörengård *et al.*, 2019).

Thermal desorption is a common remediation method for destroying organic contaminants in soil. It firstly removes the contaminants by heating the soil in a kiln at up to about 600 degrees Celsius and then degrades them in the gaseous phase in an oxidiser. However, for PFAS contaminants, oxidiser temperatures of >1,100 degrees Celsius are required for destruction which makes the modified process very expensive (around €300 to €1,300+ per tonne of soil). Also, the fluorine forms hydrofluoric acid which needs to be captured and neutralised and can compromise equipment and worker safety. Fully proven thermal desorption systems for PFAS in soil are not yet available commercially.

Soil washing is potentially viable for removing PFAS from contaminated soil. The process involves washing the soil with water or other solvents to remove the PFAS into the aqueous phase. Soil washing is viable for sandy soils but washing becomes more technically challenging and expensive for clays/silts because there are numerous fines organic fractions to manage. Based on industry sources in Europe, the cost of soil washing PFAS contaminated soil is expected to be in the vicinity of €90 to €250 per tonne of soil depending on soil type and volume. Pilot scale testing is underway.

Other emerging technologies for treating PFAS-impacted soil include ultra-sonication and ball milling which both create a high temperature micro-environment for potential destruction of PFAS. These technologies are still in the R&D phase and are not commercially available.

Remediation of alternative C6 foams

Foams based on pure short-chain ≤C6 fluorotelomers have been developed and marketed as 'environmentally friendly' alternatives to fluorinated AFFF foam, based on them being less toxic and less bio accumulative than their longer-chain counterparts. However, this does not take into account the potential for increased exposure due to their greater mobility in soils and water plus uptake in plants including edible crops.

There is limited evidence based around single compounds tested in isolation to support the claims that short-chain PFASs are more environmentally acceptable. There is growing evidence of the potential for adverse effects by the increasing diversity of different PFASs being identified in a range of commercial products and in the environment. The short-chain PFASs create the potential for increased exposure due to their greater mobility in soils and water plus uptake in plants including edible crops (Brendel *et al.*, 2018).

From a remediation perspective, short-chain ≤C6 contaminants pose no lesser problem than longer-chain PFAS contaminants, as both groups are highly resistant to oxidation and require relatively high temperatures for destruction.

In fact, short-chain compounds are generally more challenging to remediate because they are more difficult to remove using conventional filtration media.

Remediation of non-persistent (fluorine-free) foams

More recently, 'fluorine-free' biodegradable foams have been developed as alternatives to persistent fluorinated AFFF related foams and C6 fluorotelomer foams. Manufacturers claim that these foams are more sustainable and environmentally acceptable as they are formulated from degradable components such as organic hydrocarbon surfactants, solvent, saccharides and carbohydrates that are less harmful and persistent than PFASs in the environment. Although theoretically the chemistry makes sense, the claims that these foams are partially or fully biodegradable are not yet substantiated in the published literature.

Caution should be exercised over the badging of 'fluorine-free' products, because this does not guarantee that they are free of Persistent Organic Pollutants (POPs). For example, other emerging alternatives to PFAS include siloxanes that may or may not be environmentally acceptable. Current opinion on siloxanes suggests that both linear and cyclic siloxanes are bio-accumulative and toxic to aquatic organisms with short-chain siloxanes exhibiting greater toxicity in a reverse of the trend in PFAS that are more toxic for longer chains (Jensen, 2011).

From a remediation perspective, if fluorine-free foams and other products can be shown to be fully biodegradable then this would reduce the cost and complexity of the remediation process by allowing more traditional treatment techniques to be used. Biodegradable constituents would also be expected to be less bio accumulative and persistent in the environment because they would be potentially vulnerable to breakdown via natural attenuation processes.

4. SUMMARY

It is now widely accepted that PFASs are persistent and bio accumulative in the environment and at least some of these chemicals are likely to be toxic to ecological receptors and/or to human health, causing significant socio-economic problems.

Due to their inherent stability, PFAS contaminants are not amenable to many of the traditional remediation methods. The economic consequences of this are unprecedented, with industry and academic experts putting the potential PFAS contamination clean-up bill at between 30 Billion and 1 Trillion USD.

There is an urgent need to implement viable PFAS alternatives that show comparable performance across all product applications but with the proviso that they are proven to be more environmentally acceptable.

There are now significant doubts that shorter-chain ≤C6 compounds and other fluorotelomers that were thought to be 'environmentally friendly' are suitable alternatives to AFFF foams, and caution should be exercised in their application.

From a remediation perspective, these short-chain constituents are just as difficult and costly to treat as their longer-chain counterparts due to the inherent stability of the C F bond chemistry. They are also more difficult to remove via filtration.

More recently, 'fluorine-free' foams have been developed using organic components which may be partially or fully biodegradable and less persistent in the environment. If these claims can be validated, it would allow more traditional remediation methods such as bioremediation to be utilised, significantly reducing the clean-up cost burden.

At this stage, it seems unlikely that the replacement of AFFF foams with other shorter-chain fluorine-based foams is viable or advisable without further assessment of the potential socio-economic, human health and environmental effects. Fluorine-free foams promise to offer an environmentally acceptable alternative which is biodegradable and less persistent, but more work is needed.

Finally, we need to be very careful that alternative foam formulations do not contain other POPs that become the 'new PFAS', adding further uncertainty to the already unprecedented PFAS remediation challenge that lies ahead.

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APPENDIX X

PROBLEMS REMOVING SHORT CHAIN PFAS FROM WASTE STREAMS

Statement by Martin Cornelsen, Manging Director, Cornelsen Umwelttechnologie GmbH, Essen, Germany

The use of granulated activated charcoal has a long history in chemistry and water treatment as a means of removing impurities. The following diagrams show the breakthrough behaviour of individual PFAS substances on GAC, with and without prior treatment with a commercially available pre-treatment (PerfluorAd™) which enhances absorption and removal of PFAS by granulated activated charcoal and resins using targeted micro-flocculation.

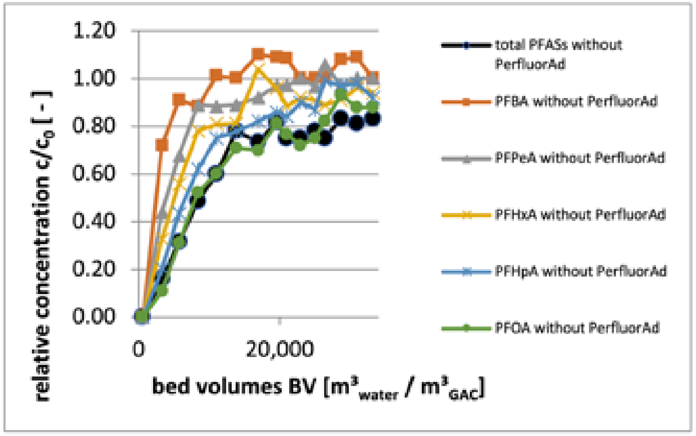
The different breakthrough behaviour of the perfluoroalkyl sulfonates (PFSA) and the perfluorocarboxylic acids (PFCA) is clearly demonstrated, as well as the behaviour of the short chain PFAS compared to their longer chain homologues with early breakthrough. The data from pre-cleaning with microflocculant also show clearly that PFBA (C3F-7COOH) is only poorly absorbed.

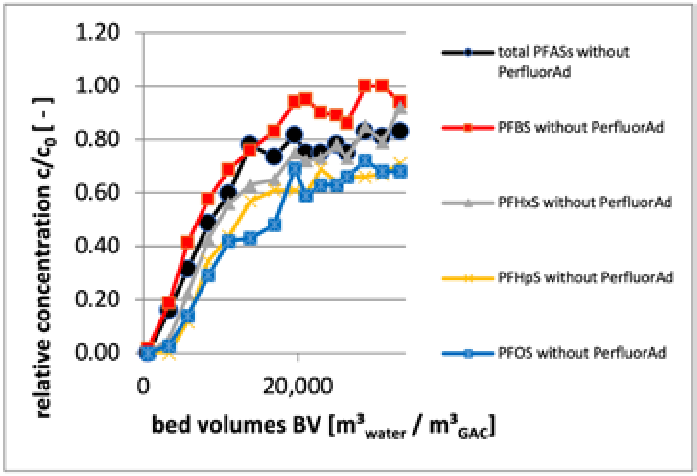
The data shown are based on groundwater contaminated by a fire event.

The boundary conditions encountered can be described as almost optimal when granulated activated carbon (GAC) is used, namely this groundwater sample was characterised with virtually no increased dissolved organic carbon (DOC), or at most a very low dissolved organic carbon content (~ 3 mg/l).

The PFAS concentrations in this raw water were: PFBA: 0.80 µg/l; PFPeA: 3.0 µg/l; PFHxA: 4.7 µg/l; PFHpA: 0.72 µg/l; PFOA: 1.3 µg/L; PFBS: 1.9 µg/l; PFHxS: 11.0 µg/l; PFHpS: 0.77 µg/l; PFOS: 9.7 µg/l; 6:2 FTS: 0.70 µg/l; total PFASs: 30.1 µg/l.

As can be clearly seen from the graphs in figures 1 and 2 the perfluorocarboxylic acids (PFCAs) break through earlier than the perfluoroalkyl sulphonates (PFSAs) of equivalent chain length.

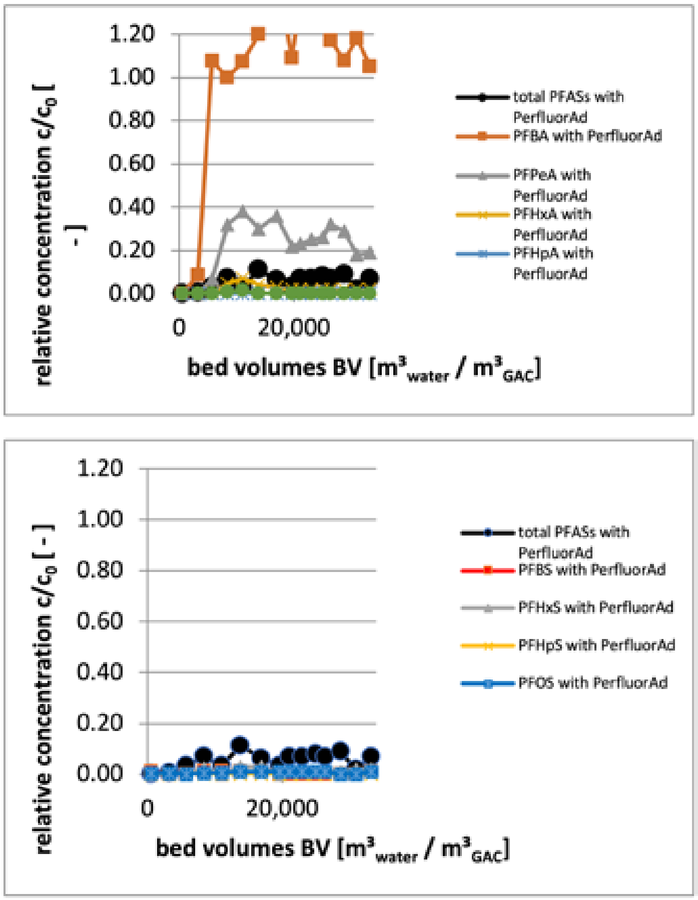




Figures 1 and 2 showing breakthrough for PFCAs and PFSAs without PerfluoAd™ treatment.

Treatment of the PFAS raw water sample in the presence of a micro-flocculation aid, on the other hand makes very little difference to the rapid breakthrough for perfluoro-butanoic acid (PFBA)a at low bed volumes, has a moderate effect for perfluoropentanoic acid (PFPeA) and a dramatic effect on longer chain length PFCAs dramatically reducing breakthrough on the longer chain homolgous perfluoro-carboxylic acids studied with 6 carbons or more, PFHxA, PFHpA and PFOA, to the extent that virtually no breakthrough occurs for either PFHpA or PFOA under the experimental conditions used.

In stark contrast are the results for the perfluoroalkyl sulphonates (PFSAs) in combination with micro-flocculant treatment. Negligible breakthrough for any of the PFSAs is observed as shown in the second graph of the pair. This suggests that the sulphonate groups which are substantially more acidic with much lower pKa values than carboxylate groups, makes GAC absorption together with flocculation treatment extremely effective. (See Figures 3 and 4.)

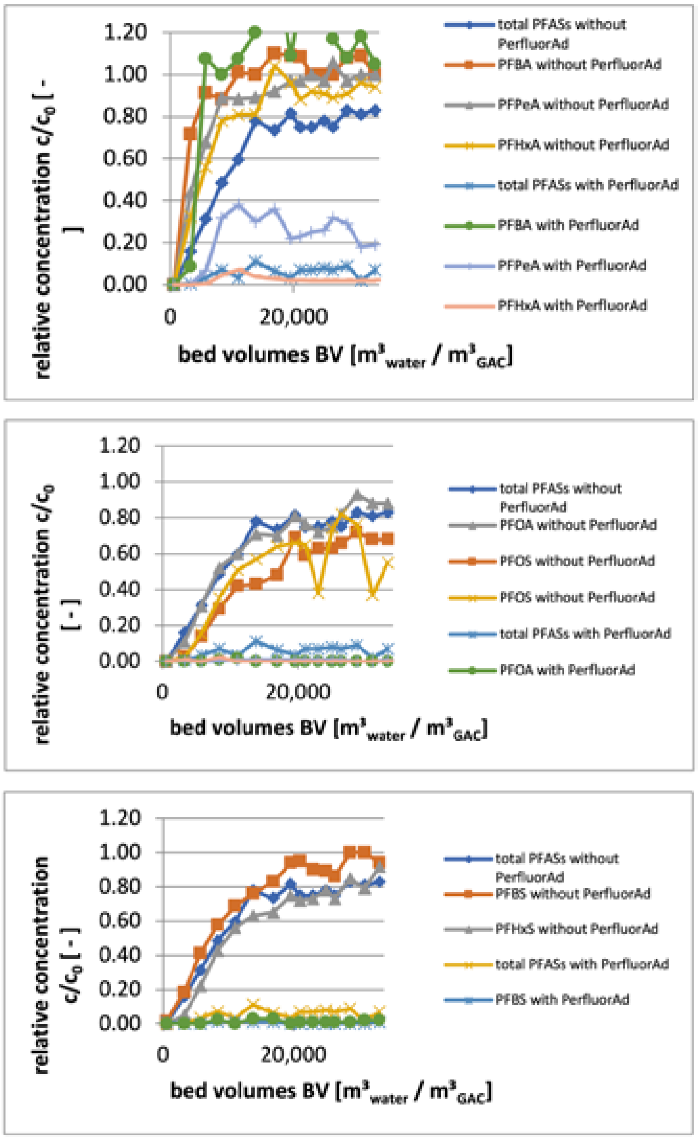


Figures 3 and 4 showing breakthrough for PFCAs and PFSAs with PerfluoAd™ treatment.

In November 2018 comparable experiments were carried out with the treatment of 1% AFFF extinguishing water. The DOC raw water concentration of this extinguishing water was 1800 mg/l and thus corresponds to realistic practical conditions. The same granulated activated carbon was used as in the groundwater experiments (Chemviron C301). In numerous comparative tests, the GAC was found to be a very suitable product for removing both perfluoro-alkyl substances (PFAS) and dissolved organic carbon (DOC). Parallel to the use of GAC, an ion exchange resin was also used, which is currently often used in the USA for the treatment of PFAS-contaminated water (Purofine® PFA694E). Note that the values in Figures 5, 6 and 7 refer to the groundwater characterised above and not to the 1% premix solution. In these diagrams the breakthrough curves for the individual PFAS substances are shown with and without microflocculation pre-treatment.

A comparison of an unproblematic groundwater with an artificial but more realistic fire water is shown, because to date even in scientific publications only data from less spectacular or realistic water samples have been used. This often gives a false impression of what is technically possible. Adsorption on adsorbant materials (GAC as well as ion exchange resins) is particularly influenced by competition with any dissolved organic carbon content (DOC) and this is often not taken into account.

In a second series of experiments was conducted using a 1% premix solution in intermediate bulk containers (IBCs) was pre-treated with 2.0 g/l PerfluorAd™. The resulting PFAS microflocculant flakes were separated with a conventional bag filter. The pre-treated water was then fed to fresh granulated activated carbon (GAC) and a commercially available ion exchanger (resin IX). The 1% AFFF premix solution was mixed in several IBCs. In a first test, this premix solution was fed directly onto an activated carbon filter (GAC) and in parallel onto an ion exchanger (IX). In the attached diagrams, this first test run is referred to as 'without PerfluorAd™ pre-treatment'.



Figures 5, 6 and 7 showing breakthrough for PFCAs and PFSAs with and without PerfluorAd™ treatment

COMPOSITION OF THE 1% AFFF PRE-MIX SOLUTION

Analysis of the pre-mix solution for PFAS substances gave the following concentrations for individual substances. The stock 1% AFFF Premix solution contained 100.3 mg/l organically bound fluorine.

Organic bound fluorine as well as the sum of 21 PFAS single substances was evaluated throughout this series of experiments.

DETAILED ANALYSIS OF THE PFAS CONTENT OF THE 1% AFFF PRE-MIX SOLUTION.

Perfluorobutanoic acid C4 PFBA	µg/l	**21**
Perfluorpentanoic acid C5 PFPeA	µg/l	**3,8**
Perfluorhexanoic acid C6 PFHxA	µg/l	**41**
Perfluorheptanoic acid C7 PFHpA	µg/l	**0,3**
Perfluorooctanoic acid C8 PFOA	µg/l	**0,2**
Perfluorononanoic acid C9 PFNA	µg/l	<0,1
Perfluordecanoic acid C10 PFDeA	µg/l	<0,1
Perfluorundecanoic acid C11 PFUnA	µg/l	<0,1
Perfluordodecanoic acid C12 PFDoA	µg/l	<0,1
Perfluorooctanesulphonamide C8 PFOSA	µg/l	<0,1
Perfluorbutane sulphonic acid C4 PFBS	µg/l	<0,1
Perfluorpentane sulphonic acid C5 PFPeS	µg/l	<0,1
Perfluorhexanesulphonic acid C6 PFHxS	µg/l	**0,2**
Perfluorheptanesulphonic acid C7 PFHpS	µg/l	<0,1
Perfluorooctanesulphonic acid C8 PFOS	µg/l	<0,1
Perfluordecane suphonic acid C10 PFDS	µg/l	<0,1
Fluorotelomersulphonate 4:2 FTS	µg/l	**8,9**
Fluorotelomersulphonate 6:2 FTS	µg/l	**2400**
Fluorotelomersulphonate 8:2 FTS	µg/l	**0,1**
DPOSA (Capstone A)	µg/l	**17**
CDPOS (Capstone B)	µg/l	**1100**
Total PFAS without Capstone	µg/l	2475,5
Total PFASs including Capstone	µg/l	3592,5

The behaviour of the 1% AFFF pre-mix on GAC and IX columns show an extremely fast breakthrough already after approximately 50 bed volumes (BV) of more than 50%.

The previous studies conducted with only slightly polluted groundwaters (low DOC values) had shown that for some individual PFAS components breakthrough occurred at a few 1000 bed volumes (BV) in stark contrast to a more realistic foam contaminated sample with higher dissolved organic content.

The breakthrough curves show conclusively that more complex contaminated firewater runoff cannot be treated effectively using either granulated activated carbon GAC or ion-exchanger IX.

The diagrams also show the breakthrough behaviour of the identical GAC and IX materials after the raw water has been pre-treated with microflocculant. Using 2.0 g/l microflocculant, the concentration of organic bound fluorine was reduced from 100.3 mg/l to 9.3 mg/l, i.e. an efficiency of more than 90% was achieved solely through the use of pre-treatment with commercially available micro-flocculant, a precipitating agent developed specifically for the absorption of PFAS contaminants.

After the pre-treatment, the break-through curves of both GAC and IX adsorbants show an almost identical course parallel to the X-axis. It can, therefore, be concluded that PFAS material that cannot be treated with PerfluorAd™ cannot be removed from water using GAC and IX either.

The breakthrough curves, plotted using individual PFASs that are currently analytically measurable, show a similar picture compared to the breakthrough measured as organically bound fluorine. However, the fact that the 1% AFFF Premix contains ~100 mg/l organically bound fluorine but

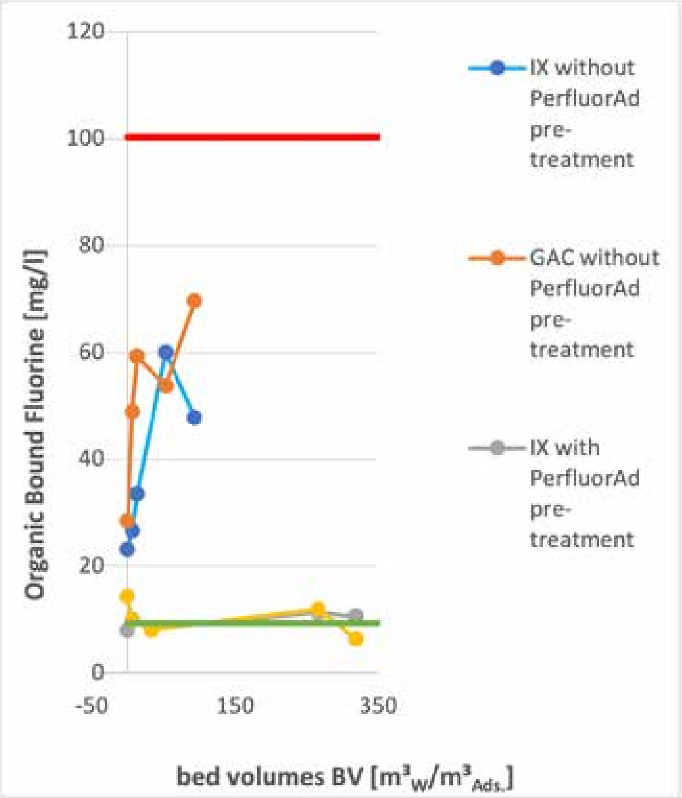


Figure 8 Breakthrough behaviour of GAC and IX based on organic bound fluorine [mg/l]).

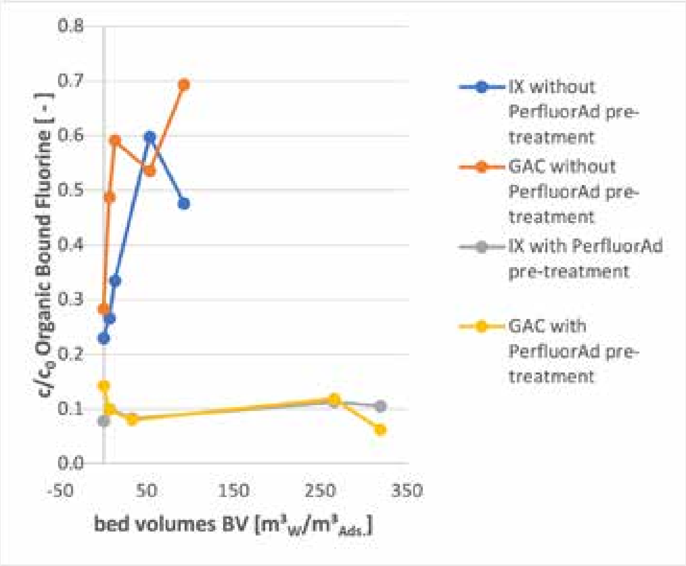


Figure 9. Breakthrough behaviour of GAC and IX based on organic bound fluorine [c/c_0].

only 3592 µg/l ∑PFAS as single substances could be detected is to be particularly emphasized. (See Figure 8.)

These values clearly show that current firefighting foams may contain an extremely high content of normally undetectable precursor sub-stances which cannot be removed by conventional cleaning techniques such as by absorption using activated carbon, GAC, or an ion exchange resin, IX.

In relation to the ∑PFAS for individual substances, both GAC & IX show significantly longer breakthrough (increased bed volume before breakthrough) after pre-treatment of the contaminated water with PerfluorAd™. (See Figure 9.)

The ratios of the concentration after cleaning to the concentration before treatment (c/c0) shows that significantly longer running times for both adsorbents are achieved using flocculation treatment. (See Figures 10 and 11.)

In particular the current data with a comparison of breakthrough behaviour for both granulated activated carbon GAC and the ion-exchanger resin IX for the treatment of weakly polluted groundwaters and more highly polluted water with higher dissolved organic carbon containing AFFF fluorochemical species, with and without pre-cleaning, are significant in terms of assessing the feasibility of removing PFAS contaminants from foam-contaminated runoff.

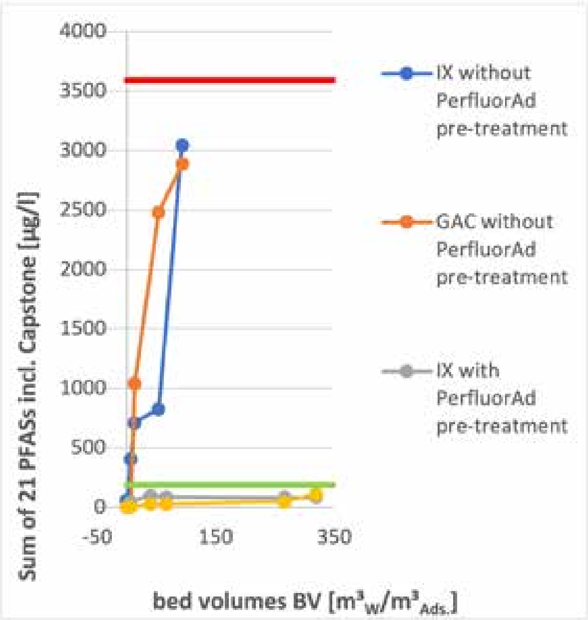


Figure 10 Breakthrough behaviour of GAC and IX based on Sum of 21 PFASs substances incl. Capstone [µg/l].

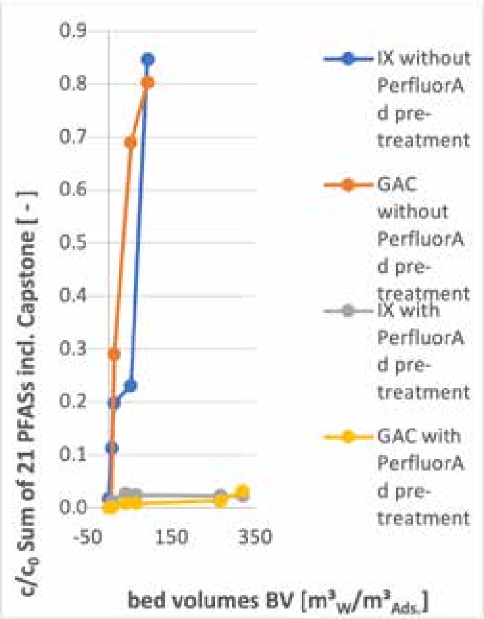


Figure 11 Breakthrough behaviour of GAC and IX based on Sum of 21 PFASs substances incl. Capstone [c/c_0].

APPENDIX XI

LIFETIME COST OF FIREFIGHTING FOAM

THE COST – AND STILL COUNTING!

FIRE FIGHTING FOAM – DISPOSAL, REMEDIATION AND LIFETIME COSTS, BY ROGER A. KLEIN

All fire fighting foams have to some degree or other an unacceptable impact on the environment when released in an uncontrolled or regulated manner. Class A or Class B formulations all have BOD/COD values that are high enough to be of considerable concern to environmental regulators if discharged into waterways or other bodies of water either as finished foam or as concentrate. One is caught, however, between an environmental Scylla and Charybdis, between a rock and a hard place: on the one hand rapid degradation is desirable with a BOD28 greater than 90% but this implies a relatively short half-life and a high BOD5 which increases acute oxygen stress; on the other hand a low BOD5 means extended >90% degradation times well in excess of 28 days. Moreover, some components may also be acutely toxic to biological systems. Fluorosurfactant foams (AFFF, FP, FFFP and their AR variants) give rise to extremely stable, environmentally persistent fluorinated degradation products. Fluorine-free (F3) foams, however, by their very nature, do not. This distinguishing difference has important practical environmental advantages.

Large-scale operational incidents can produce huge quantities of firewater runoff, running to tens of millions of litres. This runoff will be contaminated not only with foam used to fight the fire but also with a mixture of chemicals depending on the incident site. At the Allied Colloids fire near Bradford (UK) in 1992, millions of litres of runoff containing a toxic cocktail of some 400 chemicals had to be diverted through the storm water bypass at the local sewage works serving a very large urban population, in order to protect the treatment beds. The result was a significant river-kill in the Aire and Calder rivers for some 50 km downstream. In December 2005 the fire at Buncefield contaminated the drinking water aquifer for North London with fuel mixed with fire fighting foam, mainly because the tank bunds failed as a result of the fuel dissolving the seals between the bund walls and around service pipes (see below left – copyright HSE). With the fire at the Kosan refinery in Hokkaido, Japan, in 2003, the advantages of using fluorine-free (F3) foam compared to an AFFF were clearly illustrated in the ability to discharge firewater runoff sooner without expensive remediation. After recovering any oil, fire fighting water containing fluorine-free foam was held bunded for 30 days, before being given the OK by regulators for release into the ocean. However, AFFF-contaminated runoff in tanks and bunded areas was held for about three years before being treated at considerable expense.

Training sites can give rise to significant environmental contamination. Probably the two best-documented examples available are the former US Military fire training grounds investigated by Jennifer Field and her colleagues at Oregon State University (Schultz et al. (2004) Environ. Sci. Technol.38, 1828-1835), and the groundwater contamination resulting from ARFF training at Jersey Airport in the Channel Islands.

Schultz et al. (2004) clearly showed that continued use of training areas over many years had resulted in significant contamination of groundwater with breakdown products of both PFOS-based and fluorotelomer-based formulations, essentially fingerprinting foam usage. Additionally these results showed the extremely environmentally persistent nature of these fluorinated materials. Some groundwater samples still foamed 10-15 years after the sites were last used and the highest concentration of pollutant found was 14,600 microgram per litre 6:2 fluorotelomer sulphonate (6:2 FtS) (14.6 mg/l), an astonishingly high level for an environmental contaminant.

Information published by the States of Jersey in 2004 about the Jersey Airport Fire Service foam training ground contamination of the island's drinking water aquifer with PFOS provides an unusual insight into remediation costs even for a relatively small incident ('Jersey Airport: Fireground Remediation – Deed of Settlement', lodged 'au Greffe' on 19th October 2004 by the Harbours and Airport Committee: <http://www.statesassembly.gov.je/documents/propositions/30624-...>). It is unusual to have financial estimates for remediation costs released into the public domain as this is normally considered commercially or

Top: An image of the coral reef near Lady Elliot Island, Great Barrier Reef, taken using the Seaview SVII camera. © Underwater Earth /Catlin Seaview Survey – www.catlinseaviewsurvey.com. Below: Figure 1 – failure of bund wall and pipework seals, Buncefield. Crown Copyright HSE Buncefield Report.

In Decatur, Alabama, PFC-contaminated biosolids from a local municipal wastewater treatment facility that had received waste from local fluorochemical facilities were used as a soil additive in local agricultural fields for as many as 12 years. Picture by AlabamaGuy2007 on en.wikipedia.

politically sensitive, as was clear from a Channel News TV report at the time.

Section §4.7 of the Deed of Settlement listed four possible remediation strategies. whilst estimated budgeting needs at 1999-2000 prices. The options included:

(i) Removal of the entire Fire Training Ground to a depth of 30 metres and construction of a replacement Fire Training Ground – total estimated cost £30 million at 1999 prices;

(ii) Alternatively removal of contaminated stone to a depth of 10 metres rather than 30 metres, then as in (i) – total estimated cost £22 million at 1999 prices;

(iii) A four part scheme consisting of (a) lifting approximately 2 metres of contaminated soil, shale and rock and placing this on an impermeable base with a covering of soil and grass, leaving it as a bund on the outside edge of the training ground; (b) insertion of a deep concrete wall to prevent groundwater running through the site; (c) placing a concrete cap on an impermeable base so that fire appliances could train using a new rig installed with containment of all burnt and unburnt fuel, as well as firewater runoff contaminated with foam and other residues; (d) installation of a new LPG or oil training rig. Estimated cost between £3.7 and £4.9 million (at 2000 prices).

(iv) Doing nothing at all – recognised as completely unacceptable for environmental, health and political reasons.

Apart from the long term remediation costs incurred by this incident, likely to ongoing and increasing, other costs included legal and analytical fees, the provision of bottled drinking water to members of the public affected, as well as political costs which are much more difficult to quantify.

Accidental discharges from fixed systems have also caused detectable environmental contamination. Examples include the discharge of 22,000 litres of 3M LightWater AFFF (containing FC-206 fluorosurfactant) plus 450,000 litres of water on June 8, 2000, at Toronto Pearson Airport, Canada, from an aircraft hanger sprinkler system; approximately 330-1650 kg of total PFOS-related PFCs were released. The runoff entered Spring Creek and then Etobicoke Creek ultimately polluting Lake Ontario. Subsequently in August 2005, a further 48,000 litres of AFFF entered Etobicoke Creek as a result of extinguishing the fire caused by Air France AF358 over-running the runway; however, on this occasion the AFFF used did not contain PFOS as it was a fluorotelomer-based AFFF. Ten years after the 2000 incident PFOS levels downstream were still elevated especially in sediments and in fish liver (Awad et al. (2011) Env. Sci. Technol. 45, 8081-8089), indicating that release of PFCs to the environment can have long-term impact.

More recently, in January 2013, a similar incident occurred in Cairns, Queensland. A fixed loading bay deluge system was triggered by ants in a switch box, resulting in 31,000 litres of foam being discharged into Trinity Inlet, Cairns, leading to potential environmental pollution by PFCs of one of the most ecologically sensitive habitats in the world, the Great Barrier Reef Marine Reserve. The release, which happened outside normal working hours, went unchecked because the automatic discharge warning system relied on communications systems that had been compromised by severe flooding in North Queensland (Murphy's Law for worst case scenarios – what can go wrong, will go wrong!). The direct and indirect costs of this incident are not yet clear as investigations are still be carried out, but will certainly be considerable involving amongst others analytical, consultancy and legal costs.

Two other situations exist in which there is a need for the disposal of substantial volumes of AFFF: fire extinguisher maintenance and replacement of old legacy foam stocks with new material.

Extinguisher maintenance requires the regular discharge and refilling of the extinguisher. Although this appears, at least on the surface, to involve only limited quantities of foam, it is the sheer number of Class B extinguishers in use and requiring maintenance on a recurrent regular basis that makes the problem significant. The old practice by maintenance engineers of regularly discharging AFFF-containing extinguishers either to open ground, for example in a car park, or into the drains, is no longer considered acceptable as the foam must be collected and treated as hazardous waste preferably by incineration. This adds significantly to extinguisher maintenance costs.

Decisions to change the foam used in order to minimise environmental issues may require disposal of old stock as a hazardous trade waste. This may contain PFOS now classified as a POP (Persistent Organic Pollutant) under the Stockholm Convention. Disposal costs, especially high temperature incineration, add considerably to the lifetime cost of the foam. A major aviation industry operator recently switched to fluorine-free foam (FFF) at all their national airports, budgeted $17 million for assessing legacy contamination, not including remediation. This $17 million compares to ~$1

Möhnetal (Sauerland) in Germany has been identified as a site where PFCs have been spread across the whole of the Ruhr valley through the use of PFC-contaminated sludge for agricultural purposes. © Garver (Essen), Wikimedia Commons.

million for replacement foam plus $0.5 million for incineration of old stock in cement kilns -technically preferred plasma-arc incineration would have cost $4 million.

What are the options for disposing of foam-contaminated firewater runoff or legacy stock?

Current options for disposing of fluorochemical-contaminated waste are limited and expensive. Discharge of liquid waste to the sewage system is not recommended although many water undertakings, without regulatory consent or trigger levels for PFCs in wastewater, will permit limited volumes to enter treatment plant. However, large volumes produce foaming and may destroy the bacterial treatment beds. In the Allied Colloids fire near Bradford in 1992, millions of litres of contaminated firewater runoff had to be diverted to the Calder and Aire Rivers to protect the treatment beds, causing a 50km river-kill. Additionally, PFCs end up in WWTP sediment or sludge which is often used for agricultural top dressing, a certain way to ensure environmental pollution as happened in both the Möhnetal (Sauerland) in Germany affecting the whole of the Ruhr valley water catchment area, and in Decatur, Alabama (Lindstrom et al. (2011)). Deposition of solid waste to landfill may appear superficially attractive; however, under flood conditions contaminated leachate will spread in an uncontrolled manner. Additionally both WWTP and landfill produce volatile short chain PFC degradation products with global warming potential (GWP) that can then diffuse to the upper atmosphere (Ahrens et al. (2011)). The general lack of consent or trigger levels for fluorochemical-containing waste at both national and international level is currently being addressed in detail by Australian state environmental regulators.

High temperature incineration is currently the recommended method for both liquid and solid waste. Disadvantages are that it is expensive, adding to total lifetime cost for a foam, of limited availability in many countries, with exportation of hazardous waste being illegal. Incineration must be carried out at >1,100°C in special furnaces with scrubbing of the flue gases using calcium carbonate (limestone) or quicklime to remove the hydrogen fluoride (HF) produced since there are regulatory limits on the HF that can be released to atmosphere. Incineration with fixation of the HF as calcium fluoride (CaF_2) is a classic example of an environmentally neutral life cycle, with CaF_2 the source from which the fluorochemical industry derives fluorine!

A problem with firewater runoff at a large incident is its sheer volume – typically tens of millions of litres. Methods have been developed to reduce the volume of fluorochemical-contaminated material to be subsequently incinerated thus reducing a major component of treatment costs. Methods include absorption onto granular activated charcoal (GAC) followed by incineration – a technique used successfully after a major refinery incident in Missouri – or the development by DuPont, as described at the recent 5th International Reebok Foam Conference in Bolton March 2013, of combined electrocoagulation (EC) and reverse osmosis (RO) capable of removing fluorochemicals from 4 m^3/hr contaminated water. Both these methods can reduce disposal costs significantly. The DuPont EC/RO method achieved a ~1400-fold concentration of pollutant, thus greatly reducing the quantity of fluorochemical contaminated material needing further treatment, with a ~20-30-fold reduction in cost per litre of effluent treated.

Incineration costs are substantial. In Australia current estimates range from $17-$20 per litre using a plasma-arc, with trials under way using cement kilns with a 10-15-fold reduction to approximately $1-1.5 per litre, compared to around €0.77 per litre in Europe. Reduction in fluorochemical concentration using either granular activated charcoal (GAC) or electro-coagulation and reverse osmosis (EC/RO) minimises incineration costs by greatly reducing the volume requiring treatment, although both methods incur high initial capital expenditure: around €92,000 for GAC and €230,000 for EC/RO.

A number of other promising methods are being developed, including:

- Ion Exchange: to reduce the volume of polluted water before treatment of the solid resin by high temperature incineration.
- Catalytic Mineralization: perfluorochemicals cannot be oxidised by biological systems or standard chemical oxidants such as nitric acid or acid potassium dichromate (the COD standard analytical method), requiring catalytic methods, eg, such as persulphate together with high-pressure Hg short-wave UV-light or hyperbaric oxygen, or zero valent iron. Diphenylsodium may be used analytically to mineralize efficiently the fluorine in perfluorochemicals but is far too expensive for use on an industrial scale.
- Groundwater and Soil Remediation: CRC CARE, Adelaide Australia, with the University of South Australia, is perfecting techniques to clean up surface or groundwater contaminated with PFOS and PFOA. A new product (MatCARE – Australian Provisional Patent No. 2009905953) developed by CRC CARE and based on bio-organic clays, has undergone field trials and shows promising results in the removal of PFOS and PFOA in contaminated water and soil. However, as with the use of all absorbents to remove fluorinated material, one is left with solid waste requiring high temperature incineration.

Finally, do not forget that there are hidden costs of permitting significant environmental pollution however caused. These may actually be more significant for an organisation or business in the long term than expenditure at the time of the incident or financial penalties such as fines. The most important and long lasting include loss of reputation, damage to the organisation's brand image, class actions, and potential loss of operating licenses. For senior management involved – mens rea, the controlling mind concept – custodial sentences may apply in the most extreme cases.

APPENDIX XII

FEDERAL COURT OF JUSTICE FINDS FIRE SERVICE LIABLE FOR AFFF FOAM USED

Editorial that appeared in the Industrial Fire Journal News 29 June 2018

Industrial Fire Journal - Fire & Rescue - Hemming Group Ltd: Poisoned chalice

Poisoned chalice

Published: 29 June, 2018

Germany's highest court of law finds German fire service liable for AFFF used at incident and dismisses claim of public-office immunity.

On 14 June the German Federal Court of Justice in Karlsruhe, southwest Germany ruled that the fire service of the city of Baden-Baden could not claim immunity from liability after using PFOS-containing foam during an emergency.

The judgement is the result of an eight-year-long legal battle between the owner of an industrial premises and the city of Baden-Baden. It is widely regarded as an important test case that will affect the fire service's operations and its use of firefighting foam.

Sometime prior to 2010 the local fire service had been donated old foam stocks by a chemical company on the Baden-Airpark industrial site. Without realising that it contained PFOS, the fire service used around 8,000 litres of this AFFF foam concentrate at an incident on 8 February 2010 involving a major fire that destroyed commercial warehousing and administrative buildings. As a result, the site in the district of Sandweier became heavily contaminated with fluorochemicals.

Baden-Baden took landowner Claus Reformwaren to court for the remediation and clean-up costs in 2010, with court judgements in 2014 and 2017 finding against the landowner. However, the latest judgement from the highest court in Germany has unanimously reversed the previous ruling on the grounds that the earlier judgement was clearly faulty and incorrect.

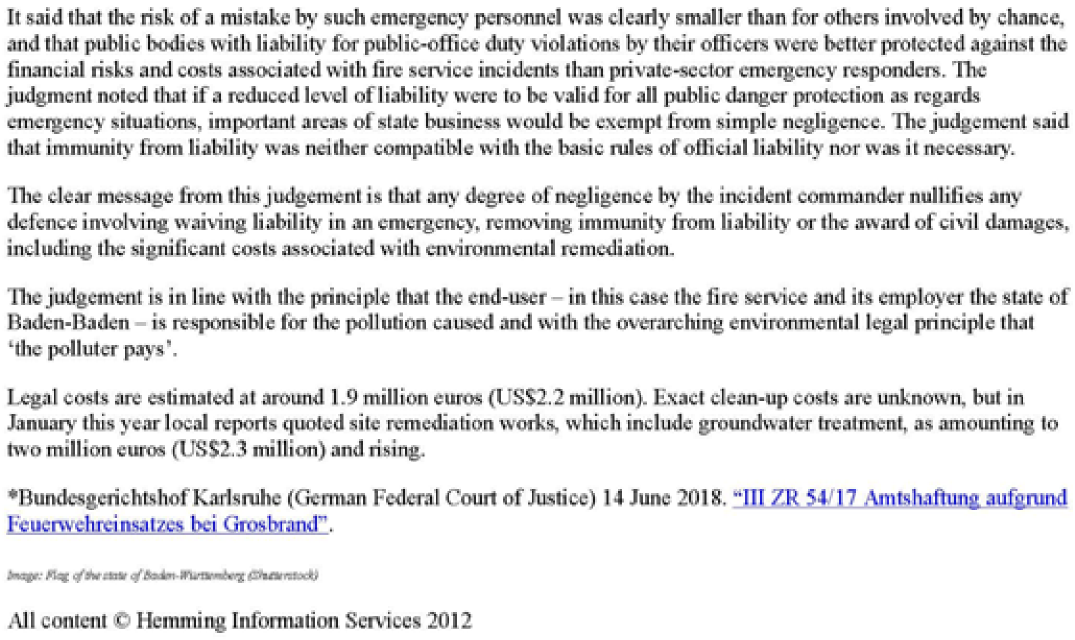
The German Federal Court of Justice judgement dismissed the claim that the actions of the fire service incident commander were covered by immunity to liability (haftungsprivileg) because it was an emergency, but rather that their actions counted as contrary to the obligations of public office (amtspflichtwidrig).

The full court judgement* was clear in its denial of the appeal of the defendant, the city of Baden-Baden. It said that the lower court had correctly recognised that the decision of the incident commander to use a PFOS-containing foam in order to prevent spread of the fire to an adjoining warehouse, represented a failure of judgement and was therefore a dereliction of duty in a public office, and that the incident commander had behaved negligently.

However, the judgement ruled that neither the incident commander nor the defendant could claim immunity from liability in accordance with German Civil Code regulation §680 BGB (*Security management*).

Based on the requirements of the obligations of public office under §839 BGB (*Liability in the case of official breach of duty*), every degree of negligence establishes liability when public-office obligations are violated. This also applies in the case of an emergency incident and when ensuring protection against danger under public law. It also said that a reduction in the level of liability did not apply in such cases.

The judgment noted that office holders are obliged to respond professionally to an urgent danger and are typically prepared for the associated emergency situation; they are specifically trained for this and can fall back on established procedures.



It said that the risk of a mistake by such emergency personnel was clearly smaller than for others involved by chance, and that public bodies with liability for public-office duty violations by their officers were better protected against the financial risks and costs associated with fire service incidents than private-sector emergency responders. The judgment noted that if a reduced level of liability were to be valid for all public danger protection as regards emergency situations, important areas of state business would be exempt from simple negligence. The judgement said that immunity from liability was neither compatible with the basic rules of official liability nor was it necessary.

The clear message from this judgement is that any degree of negligence by the incident commander nullifies any defence involving waiving liability in an emergency, removing immunity from liability or the award of civil damages, including the significant costs associated with environmental remediation.

The judgement is in line with the principle that the end-user – in this case the fire service and its employer the state of Baden-Baden – is responsible for the pollution caused and with the overarching environmental legal principle that 'the polluter pays'.

Legal costs are estimated at around 1.9 million euros (US$2.2 million). Exact clean-up costs are unknown, but in January this year local reports quoted site remediation works, which include groundwater treatment, as amounting to two million euros (US$2.3 million) and rising.

*Bundesgerichtshof Karlsruhe (German Federal Court of Justice) 14 June 2018. "III ZR 54/17 Amtshaftung aufgrund Feuerwehreinsatzes bei Grosbrand".

Image: Flag of the state of Baden-Wurttemberg (Shutterstock)

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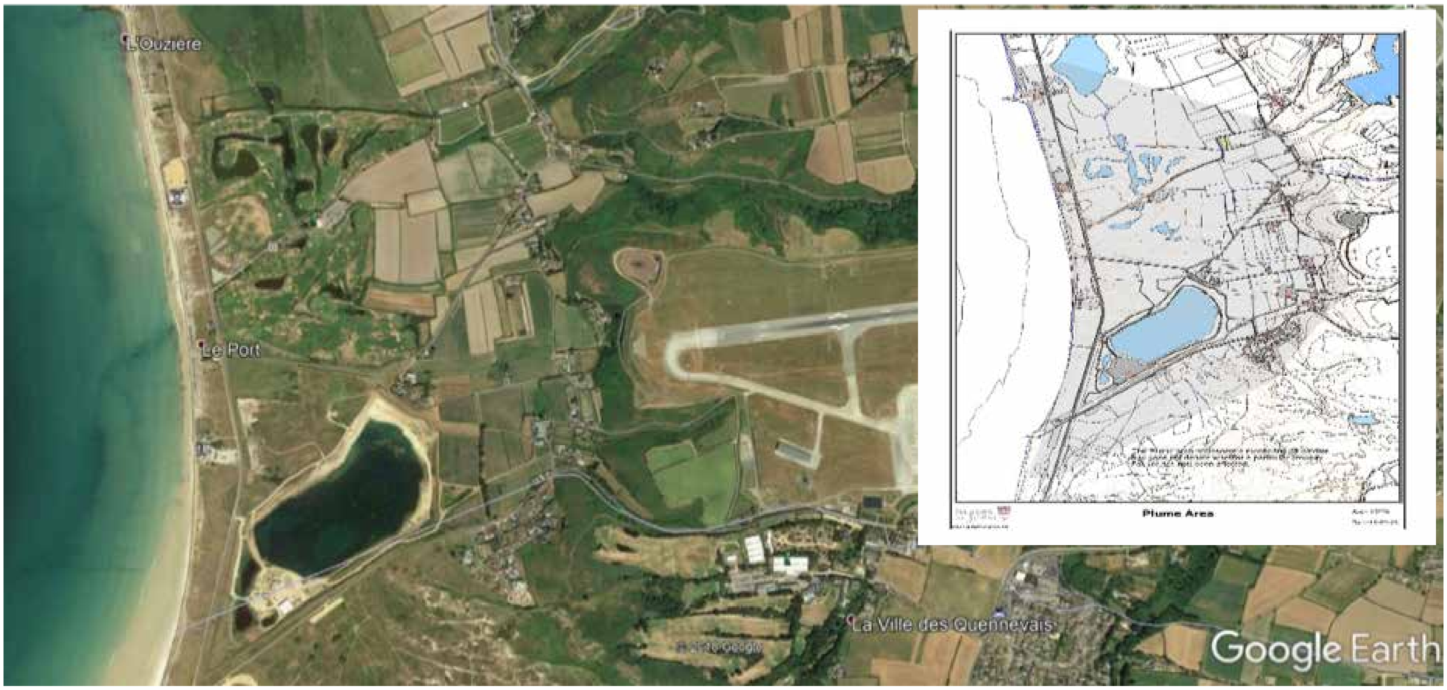
2. Legal Tribune Online (LTO) 2018 14 June. 2BGH zur Amtshaftung bei Brand bekämpfung: Aush im Notfall kein Haftungsprivileg". < https://www.lto.de/persisent/a_id/29167/ > (abgerufen am: 18 June 2018.
3. Stefan Jehle (2018) Stuttgarter Nachrichten. 14 June BGH-Urteil Karlsruhe https://www.stuttgarter-nachrichten.de/inhalt.giftiger-loeschschaum-baden-baden-muss-fuer-feuerwehr-einsatz-zahlen.2ba96997-51d4-4d6d-98c7-f73e926cead7.html

APPENDIX XIII

CASE STUDY - JERSEY AIRPORT, ST. PETER, JERSEY, CHANNEL ISLANDS



PFOS CONTAMINATION OF THE JERSEY AIRPORT FIRE TRAINING GROUND

First identified in the 1990s the contamination of groundwater supplies as the result of fire service training with fluorochemical containing firefighting foams (AFFF) achieved public and political prominence in the early 2000s because of a Channel News television report. Fire Service training with LightWater™ and Petroseal™ AFFF-type foams on open ground had, over many years, led to significant pollution with fluorochemicals of the underlying groundwater in the Jersey Shale aquifer. The island of Jersey represents an example of a hydrologically sensitive area with essentially an isolated groundwater resource with many properties using boreholes or wells for drinking water.

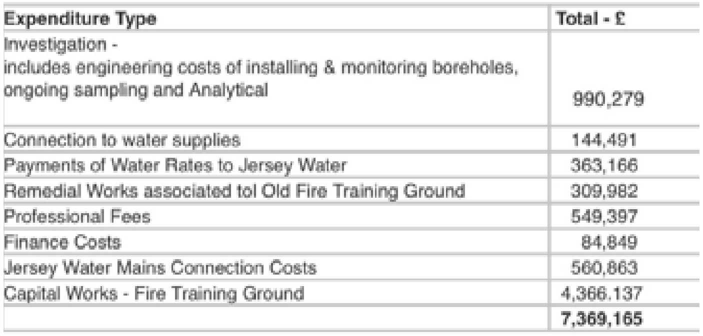
The contamination plume has continued to spread down the hydrological gradient over the last twenty years in spite of considerable remediation work involving sealing the fire training ground with an impermeable concrete apron.

Given the relatively small size of this example of pollution by fluorochemicals from firefighting foam the costs to the States of Jersey are considerable including not only on-site remediation costs and immediate bottled water for human consumption but also the provision of mains water supplies to affected properties and the waiving of water charges.

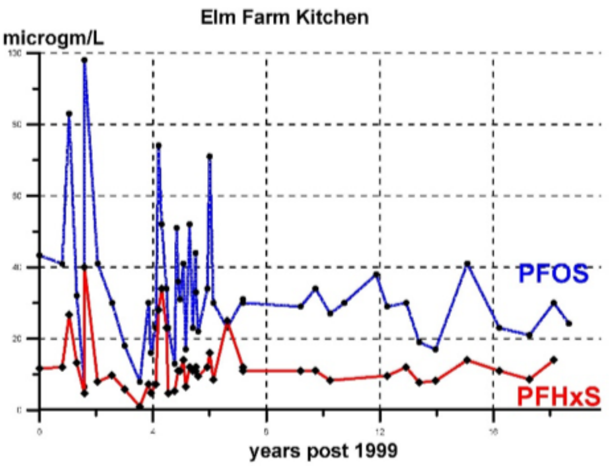
A Deed of Settlement published in P176/2004 by the States of Jersey gave a breakdown of possible options with the financial implications for the States of Jersey associated with each option. Some fifteen years later the true cost is now becoming clear.

Of the options considered, which included removal of large amounts of contaminated soil from the fire training ground or sealing the area with concrete to prevent further contamination of the aquifer, isolating the fire training area with an impermeable concrete barrier was considered to be the most cost effective.

Costs associated with the PFOS contamination have totalled circa £7.4m to date (information on the States of



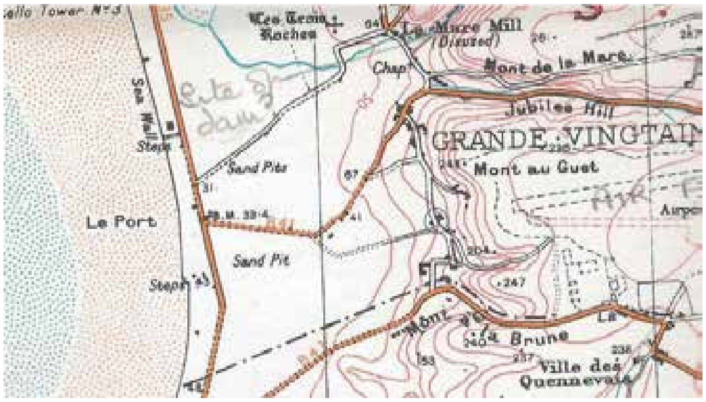
Expenditure Type	Total - £
Investigation - includes engineering costs of installing & monitoring boreholes, ongoing sampling and Analytical	990,279
Connection to water supplies	144,491
Payments of Water Rates to Jersey Water	363,166
Remedial Works associated tol Old Fire Training Ground	309,982
Professional Fees	549,397
Finance Costs	84,849
Jersey Water Mains Connection Costs	560,863
Capital Works - Fire Training Ground	4,366.137
	7,369,165



Jersey website February 2019) which can be broken down as shown in the table above. Of particular note are the substantial ongoing costs of close on one million pounds involved in monitoring boreholes and consultancy analytical costs.

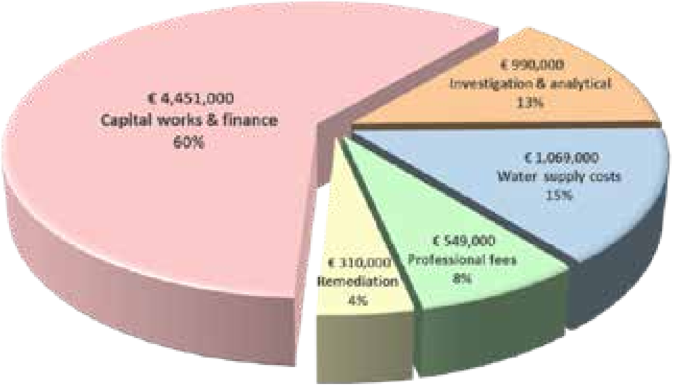
Monitoring for PFAS contamination as continued over a period of nearly twenty years in the St.Ouen's Bay area to the west of St. Peters. Although many locations have shown a decrease in levels of contamination over the intervening two decades, some remain high and above the acceptable levels of 1 µg/l for drinking water. As an example of contamination of water supplies persisting for decades published values for a sampling point at Elm Farm are shown for PFOS and PFHxS in µg/l. Elm Farm is located directly downstream from the former fire training ground within the contamination plume and down the hydrological gradient.

The topography of the area as shown in the attached section from an Ordnance Survey map from the 1960s makes it clear that Elm Farm lies at the bottom of steep slope at the end of the airfield's runway.



Other locations with continuing levels of contamination above the acceptable threshold for drinking water wholesomeness (UK Drinking Water Inspectorate (DW)) include, for example, Les Cotils, Chateau du Port, Les Tris Vents borehole, and particularly the former Fire Training Ground (FTG) which still (2017) has exceptionally high levels of contamination in the region of 200-300 µg/l for PFOS and 100-200 µg/l for PFHxS.

The costs of remediating and managing fluorochemical contamination of the environment and especially groundwater resources used for drinking water should not be underestimated. Although in this current example the cost of capital works appears as the major component it represents a one-off payment. There are the ongoing and continued financial liabilities associated with (i) consultancy and professional fees together with monitoring and analytical costs, and (ii) costs associated with the installation, connection and payment of water rates for properties affected by the pollution. In addition, in many instances of widespread pollution affecting property prices or livelihoods there would also be legal liabilities and financial compensation which can be very substantial.



The message is clear – contamination of soil and groundwater with persistent fluorochemicals such as PFOS and PFHxS lasts decades and the plume continues to spread!

APPENDIX XIV

SHORT-CHAIN PFAS REPLACEMENTS BIND TO LIVER FATTY ACID BINDING PROTEIN (HUMAN AND RAT FABP).

EU Commission News Alert 22 November 2018 #517, © EU Commission 2018)

European Commission

Science for Environment Policy

New research suggests that alternatives to legacy PFASs may be no safer

PFASs — per- and polyfluoroalkyl substances — are a family of chemicals used in a wide range of industrial and consumer applications. Due to concerns about their persistence, bioaccumulation and toxicity, long-chain PFASs are increasingly being phased out, creating a growing market for alternatives. Researchers have developed a novel method, based on molecular simulation techniques, to estimate the rate at which novel PFASs interact and bind with particular proteins ('binding affinity') — an important factor in determining a substance's bioaccumulation potential in organisms. The method indicates that replacement PFASs may be just as bioaccumulative as original (legacy) PFASs and are, therefore, not necessarily safer. If correct, this finding has significant policy implications.

22 November 2018
Issue 517

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Source: Cheng, W. and Ng, C. A. (2018). Predicting Relative Protein Affinity of Novel Per- and Polyfluoroalkyl Substances (PFASs) by An Efficient Molecular Dynamics Approach. *Environmental Science & Technology*, 52: 7972-7980. DOI: 10.1021/acs.est.8b01268.

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It is estimated that there are more than 4 000 PFASs on the global market; these chemicals are often used in products such as fire-fighting foams, food contact materials, and clothing. Concerns have been raised about the persistence, bioaccumulation and toxicity of long-chain PFASs. This has led to the phasing out of their production for the majority of uses and the increasing use of replacement PFASs, such as perfluoroether carboxylic acids (PFECAs) and perfluoroether sulfonic acids (PFESAs). However, information on the identity, frequency of use, and potential impacts of these alternative PFASs remains scarce.

A rapid and reliable method to predict how these chemicals behave in the environment and within organisms would be of significant benefit in hazard and risk assessment. A novel *in-silico* (computer simulated) method based on molecular dynamics has been proposed to predict PFAS-protein interactions — the method is suitable for large-scale screening. The researchers intend this method to give insight into how PFASs accumulate within organisms, and to provide information and parameters for use in physiologically-based pharmacokinetic (PBPK) models, which are used to predict how drugs and other chemical substances are absorbed, distributed, and excreted in the body.

As a test, the method was used to estimate the relative binding affinity of a total of 15 legacy and replacement PFASs for human and rat liver-type fatty acid binding proteins (hLFABP and rLFABP). The results were compared to experimental data extracted from three pre-existing studies. Overall, there was good correlation between the simulated and measured binding affinities, with correlation coefficients of 0.97, 0.79, and 0.96.

In total, five replacement PFASs were assessed: three PFECAs (ADONA, GenX, and EEA) and two PFESAs (F-53 and F-53B). The results suggest that EEA and ADONA are at least as strongly bound to rLFABP as the legacy PFAS perfluoroheptanoic acid (PFHpA) and as strongly bound to hLFABP as the legacy PFAS perfluorooctanoic acid (PFOA). Both F-53 and F-53B had similar or stronger binding affinities than the legacy PFAS perfluorooctanesulfonate (PFOS). Since protein-PFAS interactions are important determinants of bioaccumulation potential in organisms, these findings indicate that these alternatives are not necessarily safer than long-chain legacy PFASs.

From a policy perspective, these findings are likely to influence new substance groups considered by the European Human Biomonitoring Initiative (HBM4EU). Moreover, this research has implications for hazard and risk assessment of non-tested PFASs, as it provides a novel method for the large-scale screening of protein-PFAS interactions. Such screening is economically and logistically desirable, especially given the potentially vast number of PFASs on the market and the limited resources available for their evaluation.

Environment

APPENDIX XV

GLOBAL PFAS IMPACTS AND THE NEED FOR ACTION

Contribution from Nigel Holmes, Principal Incident Response Advisor, Department of Environment and Science, Queensland Government, Australia

1. GLOBAL PFAS IMPACTS AND THE NEED FOR ACTION

There is no longer any doubt that contamination by highly persistent, toxic and bio-accumulative fluorinated organic compounds (PFAS) is having very widespread and costly impacts on a broad range of social, economic, health and environmental values and resources globally. Unlike most POPs where contamination tends to concentrate in particular localities the extreme persistence and dispersion of PFAS means that they spread widely and their adverse effects are now not only being felt close to the sources but also globally in air, water, soils, plants, wildlife, food sources and humans at great distances from their release points.

The scale of legacy and ongoing PFAS impacts has resulted in very high and growing social and economic costs to industries, governments and communities impacting across:

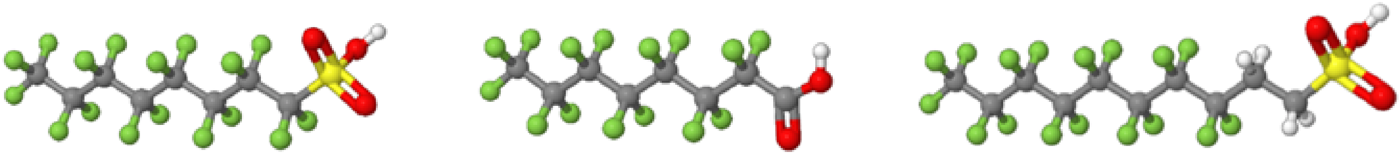
- Economic values (fisheries, crops, land values, etc.)
- Resource degradation (soils, industrial and drinking water sources, etc.)
- Social values (amenity, recreational fishing, tourism, etc.)
- Costs to business & community (cleanup, land use limitations, etc.)
- Public infrastructure (taxpayer burden-cost recovery from PFAS manufacturer unlikely)
- Legacy sites (collateral impacts, orphan sites, clean-up costs, wastes, etc.)
- Reputation (corporate, industry, political, location, etc.)
- Environmental values (waterways, wildlife, habitats, etc.)
- Human health (persistent, toxic, bio-accumulative chemicals, etc.)

There are very few environmental compartments, locations or resources that have not been impacted by PFAS to some degree. With the realisation that PFAS are effectively permanent pollutants, highly mobile and extremely costly and difficult to manage has come the need for urgent restrictions on their use, management of contamination and detailed research into their behaviour and effects.

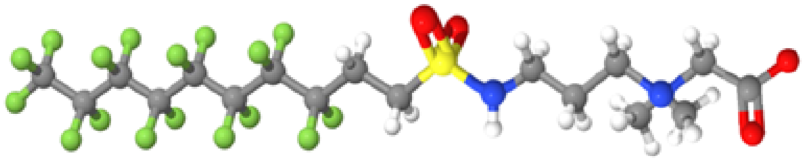
2. PFAS THE GROWING AWARENESS - FROM TWO TO A FAMILY OF THOUSANDS

One of the persistent and dangerous myths that has compounded the PFAS problem and delayed action has been the simplistic and outdated view that PFOS and PFOA are the only substances of concern. This has now been soundly debunked by the realisation from research that PFOS and PFOA are only two of thousands of even more common,

Perfluoroalkyl and fluorotelomer PFAS illustrating the fluorinated tails that are common to all.
Carbon (grey); Fluorine (green); Sulfur (yellow); Oxygen (red); Hydrogen (white); Nitrogen (blue).



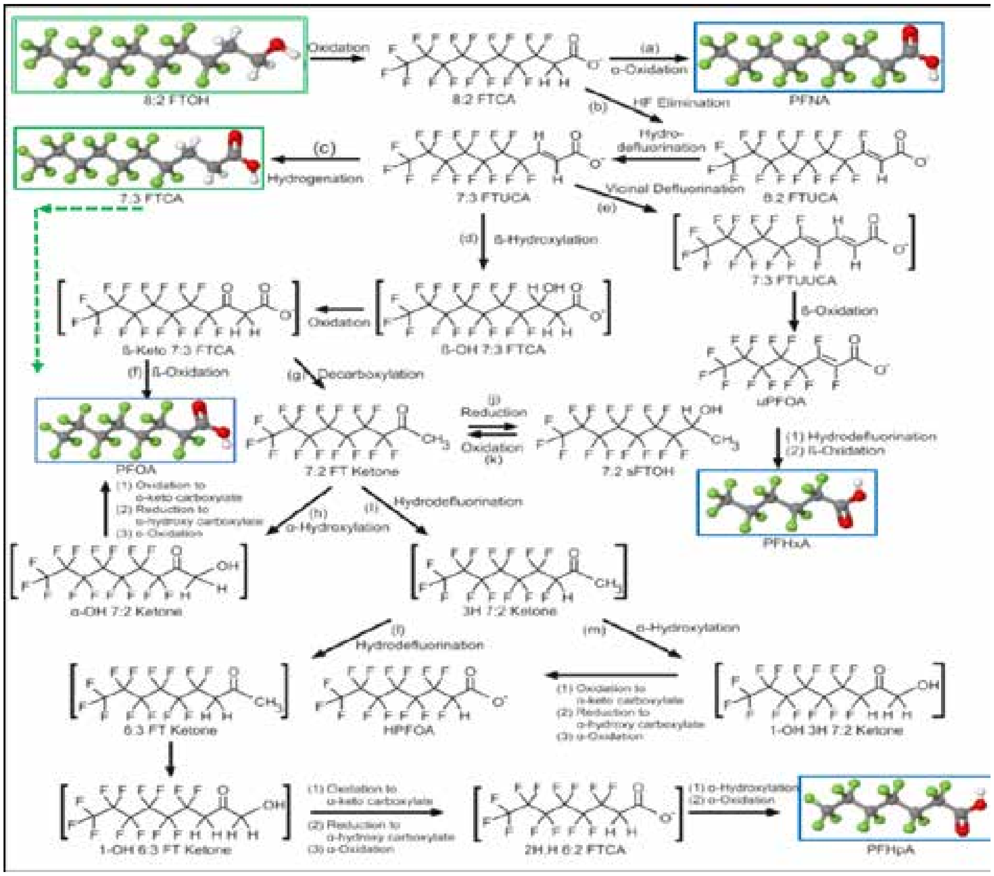
PFOS (perfluoroalkyl sulfonic acid) **PFOA** (perfluoroalkyl carboxylic acid) **8:2 FtS** (8:2 fluorotelomer sulfonic acid)



8:2 FTAB (8:2 fluorotelomer sulfonamido propyl betaine) used in firefighting foam.

closely-related compounds in the PFAS family. These newly recognised PFAS being of the same or greater concern and effects as PFOS and PFOA in their own right or via the characteristics of their biotransformation products.

The focus on PFOS and PFOA has been misleading as they have not been widely used in products for more than at least a decade (with some exceptions) so the occurrence of PFOS and PFOA contamination primarily relates to legacy releases or products with little relevance to contamination by current generation products, except from PFOA (C8) precursors, that have long been based on more complex fluorotelomer compounds from C4 to C20 carbon-chain lengths. With this shift to complex fluorotelomers PFOS and PFOA are very old news and we now need to consider exposure and contamination by the whole PFAS family of perfluorinateds, polyfluorinateds, fluoropolymers and fluoro--composites.



The hidden PFAS of biotransformation (from Washington et al. 2015)

Some limited progress has been made in recognising the impacts of these compounds apart from PFOS and PFOA, such as C6 PFHxS and longer chain relatives of C8 PFOA (C9 PFNA, C10 PFDA, C11 PFUnDA, etc.), but the wholesale shift that has occurred to fluorotelomers and short chain PFAS without appropriate risk assessment is only now becoming evident.

For example, assurances that a product "does not contain PFOA" have neglected to mention that where any of the diversity of replacement 8:2 fluorotelomer compounds that are used will transform to PFOA in the environment and in body tissues and that there may also be other longer and shorter-chain compounds with similar characteristics present.

3. CHARACTERISING THE PFAS RISK

The scope of the substantial risk component of the broader PFAS family has effectively gone unrecognised until recently; in part this has been because the analytical methods commonly available have not been able to reveal their presence. Despite the broader PFAS risk having now being exposed by researchers and new analytical methods, the blinkered and out-of-date focus on PFOS and PFOA still persists in some quarters resulting in very serious underestimation and underreporting of the current and emerging extent of PFAS risk for the community, the economy, human health and the environment from the diversity of PFAS occurring in products and in the environment. Similarly, there is very limited value in basing risk assessment on what fluorotelomer PFAS were originally present in products or on their likely end-point compounds as:

- Original PFAS are altered and transformed under environmental conditions into a series of further PFAS species that are only now being identified, so knowing about or testing for the original compounds will always underestimate the overall PFAS presence.
- PFAS transformation pathways are variable and complex according to the environmental conditions and therefore the combination(s) of intermediate transformation PFAS are not predictable even if the original PFAS are known.
- Toxic ketone, aldehyde, carboxylates and odd-chain PFAS are now known to occur commonly as transformation intermediates and are of greater toxicity and concern than the initial or end-point compounds. e.g., 6:2 and 8:2 fluorotelomers potentially have ~16 intermediate PFAS and up to 5 end-point PFAS including PFOA via environmental transformations (Washington et al. 2015, Shaw et al. 2019, Butt et al, 2014).

- Intermediate PFAS are persistent in their own right including ketones and aldehydes and so risk assessment based only on the initial or end-point compounds will further under-estimate the overall risk contribution by more toxic compounds.
- Current generation fluorotelomer PFAS are mostly undetectable by the PFAS standard analysis method that is limited to 20-40 particular compounds.

Biotransformation of a single PFAS yields many intermediates of similar or greater concern.

4. EMERGING INFORMATION ON PFAS

Fortunately, in recent years there has been an exponential growth in published independent research into PFAS behaviour and its various effects that is helping to inform the management of PFAS sources, uses, releases, restrictions and remediation. This growth of information on PFAS has triggered the realisation that we now face costly large-scale adverse effects from numerous legacy and ongoing long-chain and short-chain PFAS uses. There are now more than sufficient grounds to review and impose restrictions on dispersive PFAS uses especially since there are now viable non-persistent sustainable alternatives readily available for almost all applications.

The growth in research and peer-reviewed publications about PFAS has expanded well beyond the initial blinkered focus on PFOS and PFOA, showing that all compounds have the potential to cause adverse effects, especially in current applications that ultimately result in releases to the environment. The promotion of short-chain PFAS (≤C6) as less toxic and less bio-accumulative has faltered with the emerging evidence that short-chain PFAS are far more mobile, more likely to pollute drinking water, more readily taken up in edible plants and far more difficult to remediate from soils and water while still having the same extreme persistence of all PFAS.

5. THE OBLIGATION TO APPLY THE PRECAUTIONARY PRINCIPLE

A significant failure by the fluorochemicals industry and those using their chemicals in products has been to neglect to meet their international obligations under the *Precautionary Principle* (*United Nations Rio Declaration of Environment and Development 1992, Principle 15; Preston 2017*). The Precautionary Principle is also one of the tenets at the heart of the Stockholm Convention and a major test of the need for concern and action on persistent organic pollutants. Under the Precautionary Principle the proponent (manufacturer) has the legal obligation, *prior to* releasing products, to investigate the potential long-term adverse effects and must provide *solid proof* that their products will not cause serious or irreversible adverse effects. This is now the expectation of all communities and is no different to the requirement for drugs to be proven safe.

The Precautionary Principle is triggered for a product or activity when there is:

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

For PFAS it is clear that these conditions are satisfied, the damage is both serious and irreversible in many cases and more than ample evidence that the scope of the threat is considerable, long term and affecting a wide range of values even if the full extent has not been scientifically determined as yet.

Many legal precedents have now been set regarding the interpretation and application of the Precautionary Principle since the Rio Declaration (Preston 2017) emphasising that:

- *A lack of proof of direct causation is not an excuse to fail to apply controls to the threat; and*
- *The proponent must provide solid proof that there will not be serious or irreversible adverse effects of exposure.*

The excuse of *direct causation* not having been explicitly proved is the most common excuse used by industries to postpone or fail to act on their potential to cause serious or irreversible harm.

The Precautionary Principle obligations also apply in turn to the regulator when making decisions to approve or set conditions for activities, such as operating licenses; this has been legally applied to the extent of even regulatory development approval decisions being overturned on the basis that the regulatory authority did not consider the Precautionary Principle appropriately. Regulatory authorities can therefore not be complacent and rely on the manufacturers or end users for the application of the Precautionary Principle.

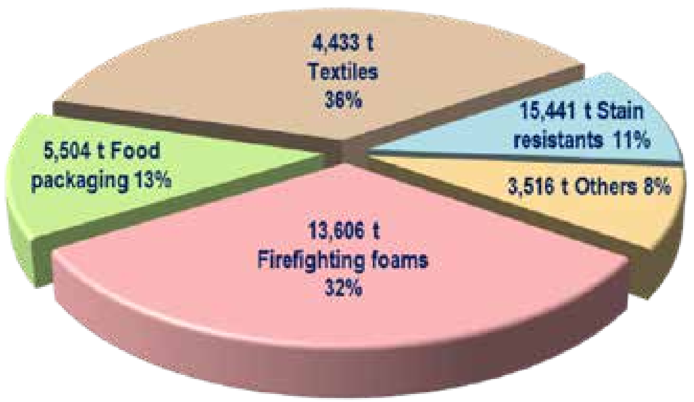
Ultimately it is the end user who must apply the Precautionary Principle as the proponent of an activity that could result in harm. In order to do this they need to be very sure that they have sufficient information to make an informed decision (as does the regulator). For most PFAS products the accompanying information is usually aimed at sales promotion and basic handling with very limited information about environmental risk management. The end user also has the *Polluter Pays* obligations under the Rio Declaration and in most environmental legislation, this provides a very strong monetary incentive to prevent permanent pollution by PFAS. In effect the manufacturer, regulator and end user can all be held liable if they do not act promptly and responsibly in making assessments and decisions in their particular spheres of influence.

For the part of the fluorochemical industry that is becoming aware of the potential adverse effects of PFAS, at the very least sufficient information and cautions for use of the chemicals should have been provided to end users and regulators so that the appropriate management measures could have been put in place.

In the face of this lack of assessment and/or failure to inform it has therefore fallen to the end-users and government regulators belatedly to apply the appropriate controls reactively in the face of considerable actual and potential damage to resources, values and reputation caused by legacy and ongoing PFAS contamination.

6. THE GROWING SCOPE OF THE PFAS PROBLEM

Given the indefinite persistence of end-point PFAS substances (e.g. sulfonates and carboxylates), continued release of PFAS will result in continued and increasing exposure. There is more than sufficient evidence of possible widespread and long-term adverse effects to trigger the Precautionary Principle and restrict the release of these substances until the industry provides “solid proof” that there will not cause serious or irreversible effects *in the long term*.



Projected fluorotelomer production in 2019 of 42,500 tonnes. After Global Market Insights, 2016. Projected compound annual growth rate of 12.5% from 26,500 tonnes in 2015.

Estimated annual fluorotelomer production for 2019 is 42,500 tonnes, up from 26,500 tonnes in 2015, note that this is conservative and does not include some large developing world sources with fluorotelomer or ongoing PFOS/ PFHxS production.

Management of PFAS wastes requires secure containment/ immobilisation or destruction and conversion to inert minerals. For many chemicals, management by containment and proper final disposal is possible but for the large

ASSESSMENT OF PFAS AGAINST THE PRECAUTIONARY PRINCIPLE ELEMENTS VERSUS NON-PERSISTENT ALTERNATIVES. After Queensland Environmental Management of Firefighting Foam Policy Explanatory Notes (2016)

Assessment element	Persistent toxic compounds	Non-persistent 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 socio-economic, environment & human health impacts through high-level or enduring low-level exposure & increasing build-up over time including 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, socio-economic values & long-term human health.	High perceived value for local natural environment. No significant lasting socio-economic or health implications.
Temporal scale of possible impacts	Long-term exposure – Effects lasting decades to intergenerational.	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 and scientific evidence	Worldwide established concerns & mounting scientific evidence of adverse social, economic, human health and environmental effects for PFAS. 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 very high cost for remediation where possible.	Reversible with basic remediation or rapid natural recovery.

amounts involved and diversity of structural forms of fluorochemicals this is not practical and many can or will inevitably be released to the environment. The current application of PFAS fluorotelomers across the main uses potentially results in point-source and diffuse releases to the environment such as:

- **Direct releases of PFAS** in firefighting foams during incidents or illegal or poor waste disposal.
- **Indirect releases of PFAS** via sewers and waste-water treatment plant (WWTP) from washing of textiles and fabrics (in effluent and biosolids).
- **Litter and unconfined dumping of PFAS** treated materials at their end-of-life.
- **Eventual leaching of PFAS** from landfilled end-of-life food packaging, textiles and other products.
- **Atmospheric releases of volatile PFAS** from landfills, WWTPs and other contaminated sites.
- **Effluent and volatiles releases** from fluorochemical manufacturing sites.

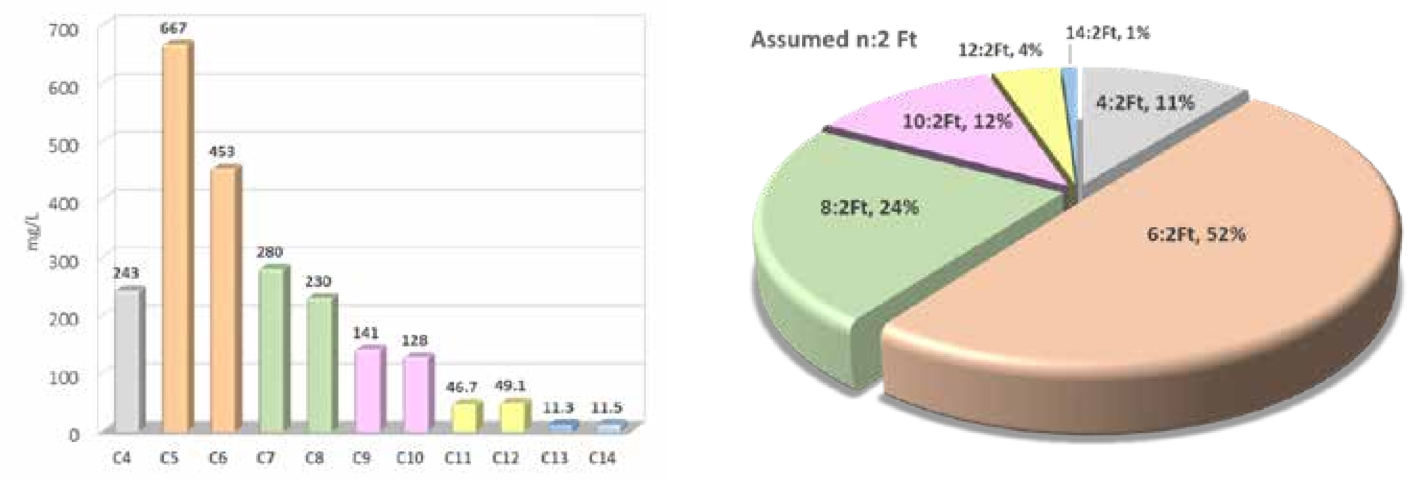
Landfilling is thought of as secure disposal but for PFAS it is not a suitable method of containment of PFAS-related wastes as the PFAS will outlast the containment life of the landfill. Post-closure management of landfills is only of the order of 30 years to allow organic material to decay fully and to allow soil conditions to become aerobic and suitable for unrestricted vegetation growth. The structural integrity of the landfill will be longer (say 100-200 years so long as it was properly constructed) but ultimately this will fail and PFAS will leachate out to the environment. Bulk PFAS contaminated wastes such as soils can be treated to fix the PFAS in the matrix in some existing and emerging methods for disposal in landfills but diffuse PFAS sources leaching from wastes such as textiles and food wrappers cannot be managed in the same way.

The best option for disposal of PFAS is by thermal destruction at high temperatures (in excess of ~1,100°C) and the sequestering of the fluorine as an inert mineral. High temperature incinerators can capture the fluorine (as HF) in wet scrubbers or in high temperature industrial processes that capture it chemically.

7. NO EXEMPTIONS FOR FIREFIGHTING FOAM WITH PFOA OR PFOA PRECURSORS

It is recommended that there should be no exemptions allowed for firefighting foams which may contain PFOA, its salts of PFOA-related substances, i.e., precursors, including foam concentrates or end-use dilutions contained as part of installed systems or held on-site in storage systems such as pressure tanks, bladder tanks or in bulk containers. Modern foam concentrates have very long shelf lives, often 10-15 years at least, and material in installed systems may represent a very significant source of PFOA and PFOA-precursors as well as more toxic and bioaccumulative perfluorocarboxylic acids (PFCAs) such as PFNA, PFDA, PFUnDA, PFDoA, PFTriDA, PFTetrDA, as shown in the data below from a sample of commercial foam concentrate at a port installation.

The TOP assay shows all the PFCA breakdown products including chain shortening resulting from partial dehydrofluorination reactions of the fluorotelomer CnF2n+1CH2CH2-moiety, e.g., 8:2 → PFOA, PFHpA, PFHxA; 6:2 → PFHxA, PFPeA, PFBA; etc.



TOP Assay and assumed n:2 fluorotelomer precursor content for a recent AFFF.

APPENDIX XVI

SHORT CHAIN PFAS

A critique of recent claims by fluorochemical industry consultants concerning the alleged favourable environmental profile of short-chain replacements for longer chain technology.

1. SHORT CHAIN PFASs

In May 2016, the United States Environmental Protection Agency (USEPA) announced a long-term health advisory of 70 nanograms per liter (ng/L) for a combination of PFOS and/or PFOA in drinking water. However, more recent toxicological assessments, by the Agency for Toxic Substances Disease Registry are suggesting lower levels are more appropriate (7 ng/L for PFOS and 11 ng/L for PFOA). This corresponds with Maximum Contaminant Levels (MCL) being establised in the State of New Jersey in drinking water (14 ng/L for PFOA and 13 ng/L for PFOS), with the same levels proposed in California.

There is significant ongoing uncertainty regarding the environmental risk the flurotelomers and short chain PFAAs pose. Fluorotelomers transform in the environmnet to ultimately create the ultra-persistent PFAAs, via intermediates such as 6:2 fluorotelomer suphonate (6:2 FTS), 6:2 fluorotelomer alcohol (6:2 FTOH) and the lesser characterised intermediates, such as the 5:3 fluorotelomer carboxylic acd (5:3 FTCA or “5:3-acid”), which has been highlighted as potentially biopersistent (i.e., showing slow clearance from organizms, having potential for bioaccumulation) [1]. The short chain PFAAs have been identified to concentrate in the edible portion of crops [2-4], they bind to proteins, have non-negligible half-lives in organisms, are potential endocrine disruptors with human toxicity still to be assessed [5]. Examples of crops, such as asparagus, being removed from the food chain as a resut of their capacity to concentrate PFASs, are already being seen in Germany.

The short-chain PFAAs have increased mobility in the environment as a result of greater solubility, so form long groundwater plumes, such as the 250 square kilometer mega plume described in Minnesota [6]. The increased solubility of the short-chain PFAAs, makes their removal from potable water supplies costly and challenging [7]. Regulators are concerned that they are subject to long range transport, with the potential for widespread contamination of drinking water [5]. The results of four studies in Europe reported widespread detections of short chain PFASs in tapwater, with between 18% - 86% of samples assessed containing short chan PFAAs [8-10] [11]. The global distribution and long-range transport of PFASs was studied in 2012 with the five most frequently detected compounds reported as perfluorooctanoic acid (PFOA), perfluorohexanesulfonate (PFHxS), perfluorohexanoic acid (PFHxA), perfluorooctane sulfonate (PFOS) and perfluorobutane sulfonate (PFBS) [12], demonstrating the widespread distribution of both long and short chain PFASs, however short chain PFASs are still being widely manufactured, so their concentration sin the biosphere will rise, with unknown future consequences, which has been described as a global boundary threat [12].

To summarize, the general regulatory trend appears to be enforcement of lower standards and inclusion of additional PFASs beyond PFOS and PFOA. Environmental regulators globally are rapidly increasing focus on PFASs as priority environmental contaminants. It apears that the short chain PFASs may be termed “regretable replacements”, in terms of the perceived hazards they pose to the environment and subsequent future potential laibilities, as a result of forthcoming reglatory attention.

The rapid extinguishment of hydrocarbon-based fuel fires is crucial to maximize incident survivability and firefighter safety in aviation related incidents. The widespread use of Class B firefighting foams such as historic C8 PFOS based or C6 AFFFs, containing 6:2 fluorotelomer compounds at incidents and during firefighter training and system testing has led to the contamination of both groundwater aquifers and surface waters; and consequently, the impact on numerous public and private drinking water supplies.

The increasingly used short-chain PFASs are assumed to have a lower bioaccumulation potential. Nonetheless, they have other properties of concern and are already widely distributed in the environment, also in remote regions. The 2016 International workshop for authorities on the assessment of risks of short-chain per- and polyfluoroalkyl substances (PFASs) in Berlin described many of these concerns, some of which are detailed below.

Short-chain PFASs have a high mobility in soil and water, and final degradation products are extremely persistent. This results in a fast distribution to water resources, and consequently, also to a contamination of drinking water resources. Once emitted, short-chain PFASs remain in the environment. A lack of appropriate water treatment technologies results in everlasting background concentrations in the environment, and thus, organisms are permanently and poorly reversibly exposed. Considering such permanent exposure, it is very difficult to estimate long-term adverse effects in organisms. Short-chain PFASs enrich in edible parts of plants and the accumulation in food chains is unknown. Regarding these concerns and uncertainties, especially with respect to the precautionary principle, short-chain PFASs are of equivalent concern to PBT substances [13].

The "long chain" PFASs, including PFOS, PFOA (perfluorooctanoic acid) and PFHxS (perfluorohexanesulfonic acid) accumulate in humans through consumption of impacted drinking water. Replacement PFASs are "short chain" (termed C6 or C4) and while the understanding of their toxicology and bioaccumulation potential is evolving, there is some evidence that short-chained PFASs accumulate in the edible portion of crops are more mobile in the environment than the long-chained variety, making them a potentially larger threat.

For long-chain PFASs, concerns have been identified due to their persistent, bioaccumulative and toxic properties. They are ubiquitously found both in samples from humans and the environment. This has led to risk reduction measures initiated by authorities and certain companies. As a reaction, a shift in the production and use towards PFASs with shorter perfluorinated alkyl chains can be observed. Short-chain PFASs are thus used as alternatives to long-chain PFASs, although they also have some properties of concern. Similar to long-chain PFASs, short-chain PFASs are used in a wide dispersive way, and are equally persistent. Thus, these chemicals are distributed in the environment ubiquitously due to their mobility. Already today, short-chain PFASs are increasingly detected in different environmental media, in remote places far from any obvious sources and in drinking water resources including ground water. Therefore, it is of importance to illustrate possible concerns of the not naturally occurring substances and adverse effects related to their presence in different environmental compartments in order to initiate regulatory measures, where needed.

The combination of this extreme persistency with high mobility lead to further concerns:

- Short-chain PFASs can occur in raw water and can therefore be found in drinking water.
- Short-chain PFASs cannot be eliminated from water with the commonly applied measures. Furthermore, modern technologies are ineffective in removing short-chain PFASs from water.
- Ubiquitous presence of short-chain PFASs in aquatic systems might lead to continuous background exposure to short-chain PFASs.
- Short-chain PFASs can be taken up by plants and have already been found in edible crops.
- Exposure via food might lead to increased exposure, due to the consumption of water rich edible plant (parts) contaminated with short-chain PFASs.
- Short-chain PFASs show a relevance in organisms:
- toxicokinetic experiments illustrate bioavailability of short-chain PFASs.
- protein interactions are similar to that of long-chain PFASs.
- the half-lives of short-chain PFASs enable sufficient exposure durations for provoking adverse effects in organism.
- Exposure via background concentrations of short-chain PFASs may affect sensible population groups or development stages.
- Due to the prognosticated increasing use of short-chain PFASs (based on substitution of long-chain PFASs), background concentrations might reach toxic levels.
- Effects cannot be sufficiently predicted, and experimental data are not suited to describe potential long-term effects with adequate clarity.

2. ASSESSING PFHxA IN ISOLATION

To set the scene concerning the environmental hazards associated with short chain PFASs, their origin from manufactured man-made chemicals (fluorotelomers) and biotransformation pathways via multiple semi-stable intermediates, to form the extremely persistent perfluoroalkyl acids (PFAAs) needs to be understood. Consideration of all the intermediates and persistent daughter products allows a more complete picture of their environmental hazards, as opposed to a narrow and inappropriate focus on one compound –namely (PFHxA).

Fluorotelomers with a 6 carbon perfluoroalkyl group, adjacent to an ethyl group are typically components of many replacement PFASs for the long chain PFAAs. The remainder of the molecule can comprise multiple functional groups, such as carboxyl groups, sulphate and amino groups. These parent compounds are often considered proprietary, so their structures can be unknown, but they will all be transformed in the environment to eventually form the persistent PFAAs, via various pathways and intermediates.

The regrettable replacement "short chain" PFASs are generally proprietary fluorotelomers, which dominate the composition of modern Class B firefighting foams, such as AFFF. The fluorotelomers are termed polyfluoroalkyl substances and they transform in the environment or can be metabolized in higher organisms to create short chain PFAAs which are also ultra-persistent [16]. Some fluorotelomers have been described to be more toxic than the PFAAs they form [4, 6], with exposure to fluorotelomers being more complex as the parent molecule, the various reactive transformation intermediates and the dead-end daughter PFAAs can all pose a concerted toxicological burden [17].

Following release to the environment, the spectrum of compounds emanating from 6:2 fluorotelomer compounds, commonly applied as replacements for long chain PFASs, such as perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) includes those presented in Table 1, [14, 15] where ultra-persistent compounds are shown in bold red, semi stable compounds are in bold and more reactive hence toxic intermediates shown in orange.

Alcohols	Aldehydes / Ketones	Organic Acids	Others	Persistent Perfluoroalkyl acids
4:2 sFTOH	**5:2 ketone**	**5:3 acid**	**6:2 FTS**	**PFEA**
5:2 sFTOH	**5:3 ketone aldehyde**	**4:3 acid**	5:3 U amide	**PFBA**
6:2 FTOH	**6:2 FTAL**	3:3 acid		**PFPeA**
	5:2 Aldehyde	5:3 U acid		**PFHxA**
	4:2 Aldehyde	4:3 U acid		
		a-OH 5:3 acid		
		5:2 U acid		
		5:2 acid		
		6:2 FTCA		
		6:2 FTUCA		
		4:3 U acid		
		3:3 U acid		
		4:2 acid		
		4:2 U acid		

The recent focus on determining environmental risks posed by short chain PFAAs as being represented by one molecule (PFHxA) is clearly inappropriate given the spectrum of compounds tabulated above, which will all exhibit a toxicological burden. The fluorotelomers as bioactive precursors to the persistent PFAAs have been described to exhibit additional toxicological effects [16, 17]. Some fluorotelomers have been described to be 10,000 fold more toxic than the PFAAs they transform to [18], so the concept of assessing the environmental risks posed by 6:2 fluorotelomer compounds by considering PFHxA in isolation is not credible.

The presence of a range of PFASs in drinking water as a reported of recent surveys [19, 20], is of concern, with 6:2 fluorotelomer compounds (such as 6:2 FTS) detections in drinking water highlighted in 2017 [21]. The recent surveys identified that 6:FTS and the 5:3 acid are detected both tap and bottled water [19]. The US focussed study found PFHxA detections in all treated drinking water samples tested [20], whilst precursors such as 6:2 FTS were not measured.

Whilst consultants have recently proposed a drinking water lifetime health advisory of 1,400 µg/L for PFHxA [22], their work clearly biased, as a result it being funded by the fluorochemical industry (Fluorocouncil) [23]. Independent environmental regulators in Italy, Canada, Belgium, Denmark, Sweden and Germany have assessed the toxicity of PFHxA and set screening levels between 500 and 90 ng/L, which is some 2,800 to 15,500 fold lower than the Fluorocouncil consultants have proposed.

In January 2018, an article by US Food and Drug Administration (FDA) scientists published an stating a 6:2 fluorotelomer alcohol (FTOH) and its metabolites are likely to persist in the human body [1]. This challenges the prior assumption that short-chain PFASs, as a class, do not bioaccumulate and was highlighted in a Chemical Watch article [24], which described that it is not yet known exactly how C6 fluorotelomer alcohols such as 6:2 FTOH are absorbed, distributed, metabolised and excreted by the body, as their 'pharmacokinetic' processes are unknown as no-one has fully evaluated their potential to persist in mammalian tissues. It was recently pointed out that two Fluorocouncil-funded reviews of short chain toxicity [22, 25] perpetuate flawed assumptions, concluding that perfluorohexanoic acid (PFHxA) is a suitable marker for the "safety of fluorotelomer replacement chemistry" and related short-chain PFAS "present negligible human health risk" [26].

These C6 compounds that replace the long chain PFASs, comprise a series of proprietary parent 6:2 fluorotelomers which can transform to create 6:2 FTS and 6:2 FTOH before potentially forming PFHxA, via a series of reactive intermediates such as aldehydes and the potentially biopersistent 5:3 acid. It was proposed that the C6 chemistries would 1) be less toxic than long-chain PFAS such as 8:2 FTOH, PFOA and PFOS; and 2) not accumulate in the body. However the FDA study in 2015 concluded that significant data gaps remain about the toxicity of 6:2FTOH [27] and the 2018 study highlights the potential for biopersistence [1].

The FDA study identified three metabolites, PFHxA, 5:3 acid and perfluoroheptanoic acid (PFHpA) that could be used as markers of 6:2 FTOH exposure. As a result of their analysis hey identified 5:3 acid as an important biomarker for the potential biopersistence of 6:2 FTOH because it had the highest internal exposure and the slowest elimination by the body and its elimination was reduced when exposure to 6:2 FTOH increased.

The Fluorocouncil-funded studies conclude that:

- PFHxA "is less hazardous to human health than PFOA";

- “PFHxA and related fluorotelomer precursors currently appear to present negligible human health risk to the general population”; and
- PFHxA is not expected to bioaccumulate due to its “rapid and nearly complete elimination” from the body.

These reviews evaluated the toxicology, exposure and biomonitoring data available for PFHxA in isolation, as an inert terminal biotransformation product [22, 25].

The overall conclusion of the Fluorocouncil-funded study was that PFHxA levels currently present in the environment are well below levels that may present a concern for human health. However, there will be exposure to multiple bioactive transformation products from 6:2 fluorotelomers, as exemplified by the widespread detection of 6:2FTS in drinking water [19]. The goal of the Fluorocouncil-funded research was to review the literature relevant to risk assessment to answer questions regarding “potential human health risks associated with exposure to fluorotelomer-based products” using PFHxA as a reference chemical for the entire short-chain PFAS class. The use of PFHxA for this purpose is inappropriate and seemingly a deliberate attempt at scientific misdirection, potentially similar to what was described in the “Weinberg Proposal” where control of the science was described to be a commercial service [28].

3. INCREASING GLOBAL REGULATORY FOCUS ON SHORT CHAINS

Short-chain PFASs are now subject to environmental regulations in a rapidly increasing number of locations including: Sweden, Denmark, Germany, Italy, Belgium, Switzerland, Canada, Alaska, Minnesota, Texas, North Carolina, Indiana, Nevada, Oregon, Vermont, Delaware, Maine, Connecticut and Massachusetts.

There are many more proprietary PFASs present in commercial products than are regulated, such as in C6 fluorotelomer based AFFFs. These polyfluorinated varieties have evaded detection by common analytical methods but in the environment will all eventualy transform to create the extremley persistet perfluorinated PFASs commonly subject to regulation, so are termed ‘precursors’. Some of these fluorotelomer precursors are now themselves regulated, such as in Sweden, Germany, Denmark and Switzerland. Firefighting foams, for example, comprise hundreds of individual PFASs which have not been accounted for until recent analytical advances have enabled the polyfluorinated PFASs to be measured indirectly, using a novel technology termed the total oxidizable precursor (TOP) assay [29-31]. Regulators in Australia have recently adopted this advanced analytical tool for sampling multiple environmental matrices and compliance, with the TOP assay now being used regularly in North America and Europe as a result of it’s commercial availability.

Given growing evidence of human health risks and potential ecological harm, more and more countries are now regulating an increasing number of PFASs including precursors and both long and short chain varieties, while the latter are still commonly used as commercial replacements (e.g. C6 in firefighting foams). Restrictions have been imposed on the use of all PFAS containing firefighting foams (C6 and C8 etc.) in South Australia and Washington State, then in 2019 the European Union are also considering similar regulations.

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APPENDIX XVII

THE PRECAUTIONARY PRINCIPLE AND SUSTAINABLE DEVELOPMENT

Presentation by HH Justice Brian J Preston, Chief Judge, Land and Environment Court of New South Wales

"The Judicial Development of the Precautionary Principle"

to the Queensland Government
Environmental Management of Firefighting Foam Policy
Implementation Seminar

21 February 2017, Brisbane

I. SETTING THE CONTEXT: THE CONCEPT OF ECOLOGICALLY SUSTAINABLE DEVELOPMENT

(A) Introduction

The concept of ecologically sustainable development (ESD) or sustainable development has been around for at least three decades. In the international arena, the concept has appeared, under various names, in multilateral environmental agreements, soft law instruments, and international policies, plans and programs. Nation states have incorporated the concept into domestic legislation and articulated some of its constituent principles. Executive governments have applied the concept and its principles in decision-making concerning the environment. Notwithstanding this recognition, the concept of ESD still remains elusive. Many questions remain unanswered by the actions of nation states, and of their legislatures and executives.

The judiciaries of the world have, through their decisions, cast some light on the concept and have answered to varying degrees some of the questions about the concept of ESD and the principles of ESD and how and when they should be applied. These judicial decisions have explicated the spare skeleton of ESD, filled the interstices, and put flesh on the skeleton. In these ways, judicial decisions are developing a body of jurisprudence on ESD.

The development of a body of ESD jurisprudence is the product of judicial decision-making. It was not its purpose. Courts have neither a policy agenda nor a legislative rule making function. Courts are reactive not proactive institutions. Courts ordinarily do not seek out disputes to resolve. They await and resolve only disputes that parties elect to bring to the court. Their function is adjudication.

This paper's primary purpose is to explicate the judicial development of the precautionary principle, one of the key principles of ESD. It is important to recognise that the precautionary principle is only one of the principles and that ESD can be achieved through the implementation of the precautionary principle as well as the other principles of ESD. It is, therefore, instructive to first consider the meaning of ESD as a whole before turning to consider the meaning and application of one of its constituent principles, the precautionary principle.

(B) The importance of the language of ESD

(1) The variety of terminology

The meaning of ESD depends on the specific legislation that incorporates it. Judicial interpretation of ESD is, therefore, very dependent on the statutory language in both the provisions defining ESD and in the provisions establishing the strategic rules and liability rules that utilise ESD. It is difficult, therefore, to generalise about the meaning given to ESD by the courts.

Legislation that incorporates ESD typically describes ESD in general terms. Sometimes, the actual concept of ESD is not defined at all, although the principles of ESD may be defined.[2] Some legislation simply refers to the object of "the need to maintain ecologically sustainable development"[3] or to "promote ecologically sustainable development" [4] but leaves unspecified what is it that is to be maintained or promoted.

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[2] For example, *Environment Protection and Biodiversity Conservation Act 1999* (Cth) s 3A.

[3] *Protection of the Environment Administration Act 1991* (NSW) s 6(1)(a).

[4] *Threatened Species Conservation Act 1995* (NSW) s 3(a).

Alternatively, there may be a definition of ESD but the definition speaks in general terms of what ESD requires or how ESD is to be achieved without actually defining what ESD is. Consider three examples. First, there are legislative and policy instruments that define ESD in the terms used by the World Commission on Environment and Development (WCED) in its report *Our Common Future* as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".[5] Second, there is legislation that says that ESD requires the effective integration of economic and environmental considerations in decision-making processes.[6] Third, there is legislation that says that ESD can be achieved through the implementation of specified principles which may be defined to be principles of ESD. These include the principle of sustainable use; the principle of integration of economic, environmental and social considerations; the precautionary principle; the principle of intergenerational equity; the principle of conservation of biological diversity and ecological integrity; and the promotion of improved valuation, pricing and incentive mechanisms, including the polluter pays principle and the user pays principle.[7]

(2) The language of process and outcome

It is suggested that these legislative and policy approaches point to a degree of means-ends fluidity. Legislation is traditionally more concerned with means than ends. Hence, environmental legislation characteristically leaves unspecified what the end or outcome of decision-making under the legislation should be. It will, however, prescribe the process and the methodology that decision-making should follow. The end or outcome becomes clear only as a result of going through the prescribed process.[8]

Notwithstanding this means-ends fluidity, there would appear to be a common thread that the concept of ESD does embody an outcome and this is to be achieved through implementation of the various principles of ESD.[9] ESD operates in legislation as "a standard of conduct or behaviour, as a standard of methodology of decision-making or as a standard of outcome or result".[10] ESD, therefore, involves both a substantive outcome as well as a process to achieve that outcome. Indeed, ESD has been described as being "all about integrating process and substance with a view to achieving a single, unified objective".[11]

But what is the substantive outcome that ESD requires? The WCED definition in Our Common Future calls for development that meets the needs of the present without compromising the ability of future generations to meet their own needs. These needs of present and future generations are economic, environmental and social. However, economic and social needs cannot be met continuously in a deteriorating environment. Any further degradation of the earth's natural capital must be prevented for the sake of future generations. Hence, at the core of ESD is ecological sustainability. This is the outcome that ESD demands. ESD requires living within the planet's ecological limits.[12] ESD involves development that improves the total quality of life both now and in the future, in a way that maintains the ecological processes upon which life depends.[13]

(C) Judicial analysis of the language of ESD as requiring an outcome

The Constitutional Court of South Africa recognised the need to protect the environment in order to achieve economic and social development:

> *Economic and social development is essential to the well-being of human beings. This Court has recognised that socio-economic rights that are set out in the Constitution are indeed vital to the enjoyment of other human rights guaranteed in the Constitution. But development cannot subsist upon a deteriorating environmental base. Unlimited development is detrimental to the environment and the destruction of the environment is detrimental to development. Promotion of development requires the protection of the environment, yet the environment cannot be protected if development does not pay attention to the costs of environmental destruction. The environment and development are thus inexorably linked.*[14]

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[5] World Commission on Environment and Development, *Our Common Future* (OUP 1987) 44, ch 2 [1]; adopted by the United Nations General Assembly, *Report of the World Commission on Environment and Development* GA Res 42/187, UN GAOR, 2nd Comm, Agenda Item 82e (11 December 1987) A/Res/42/87; included by the UK Department for Communities and Local Government in the National Planning Policy Framework (March 2012) 2; cited in *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 265 [108]; MC Mehta v. Union of India [2004] INSC 179; AIR 2004 SC 4016, 4044 [46].

[6] *Protection of the Environment Administration Act 1991* (NSW) s 6(2); adopted by *Environmental Planning and Assessment Act 1979* (NSW) s 4(1); *Threatened Species Conservation Act 1995* (NSW) s 4(1).

[7] For example, *Environment Protection and Biodiversity Conservation Act 1999* (Cth) s 3A; *Protection of the Environment Administration Act 1991* (NSW) s 6(2); *Environmental Planning and Assessment Act 1979* (NSW) s 4(1); *Threatened Species Conservation Act 1995* (NSW) s 4(1).

[8] DE Fisher, *Australian Environmental Law: Norms, Principles and Rules* (3rd edn, Lawbook Co 2014) 47.

[9] Fisher (n 26) 173, 174, 219, 331-332.

[10] ibid 219.

[11] Douglas Fisher, *Legal Reasoning in Environmental Law: A Study of Structure, Form and Language* (Edward Elgar 2013) 64.

[12] The UK Government's Sustainable Development Strategy, *Securing the Future* (The Stationary Office 2005) 17.

[13] *National Strategy for Ecologically Sustainable Development* (Australian Government Publishing Service 1992) 8.

[14] *Fuel Retailers Association of Southern Africa v. Director-General Environmen-*

Bosselmann has argued that ESD involves "the obligation to promote long-term economic prosperity and social justice within the limits of ecological sustainability". The principle of sustainability is defined as "the duty to protect and restore the integrity of the Earth's ecological systems".[15] Echoing the land ethic of Aldo Leopold, Bosselmann suggests "development is sustainable if it tends to preserve the integrity and continued existence of ecological systems; it is unsustainable if it tends to do otherwise".[16]

This need for maintenance of "ecological balance" led the High Court of Calcutta to issue an injunction restraining reclamation of wetlands in East Kolkata for development activities. The court recognised that sustainable development requires there to be "a proper balance between the development and the environment so that both can co-exist without affecting the other".[17] The goal is "maintenance of ecological balance". If development leads to ecological imbalance, the function of the court is to intervene.[18]

Similarly, the Supreme Court of India held that sustainable development ensures that "mitigative steps are and can be taken to preserve the ecological balance. Sustainable development means what type or extent of development can take place which can be sustained by nature/ecology with or without mitigation".[19] This ecological core of ESD places a first claim on the earth's natural resources. Only when ecological needs are met should the remaining natural resources be available to supply and meet economic and social needs.[20]

The ecological core of ESD also sets an environmental bottom line that needs to be met. The Supreme Court of New Zealand held that the *Resource Management Act 1991* (NZ) (RMA) and the New Zealand Coastal Policy Statement (NZCPS) made under the Act established an environmental bottom line of preservation and protection of the coastal environment as part of the concept of sustainable management.[21] The core purpose of the RMA is to promote sustainable management of natural and physical resources.[22] "Sustainable management" is defined to mean:

> *managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic and cultural well-being and for their health and safety while –*
>
> *(a) sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and*
>
> *(b) safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and*
>
> *(c) avoiding, remedying, or mitigating any adverse effects of activities on the environment.*[23]

Section 5 is "a carefully formulated statement of principle intended to guide those who make decisions under the RMA".[24] It is given further elaboration by section 6 of the RMA.

The RMA envisages the formulation and promulgation of planning documents to give effect to the core purpose. One of the documents made to achieve the purpose of the RMA in relation to the coastal environment of New Zealand is the NZCPS.[25] One of the principal objectives of the NZCPS is "to preserve the natural character of the coastal environment and protect natural features and landscape values" through specified means, including identifying those areas where various forms of development would be inappropriate and protecting them from such activities.[26]

This objective and these policies of the NZCPS set an environmental bottom line.[27] The NZCPS gives primacy to protecting areas of the coastal environment with outstanding natural features from the adverse effects of development, in order to promote sustainable management.[28] Any regional plan is required to "give effect to" the NZCPS[29] and any decision to change a regional plan must also give effect to the NZCPS. Hence, it was an error, in considering a plan change, to adopt an "overall judgment" approach - balancing conflicting environmental, economic and social considerations - rather than the "environmental bottom line" approach which

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tal Management, Department of Agriculture, Conservation and Environment, Mpumalanga Province [2007] ZACC 13; 2007 (6) SA 4 (CC), 21 [44].

[15] Klauss Bosselmann, *The Principle of Sustainability: Transforming Law and Governance* (Ashgate 2008) 53, 57.

[16] ibid 53.

[17] *People United for Better Living in Calcutta v. State of West Bengal* AIR 1993 Cal 215, 217 [2].

[18] ibid 227–228 [29]–[30], 231 [40].

[19] *Narmada Bachao Andolan v. Union of India* [2000] INSC 518; AIR 2000 SC 3751, 3804 [150]; *MC Mehta v. Union of India* [2004] INSC 179; AIR 2004 SC 4016, 4044 [46].

[20] Volker Mauerhofer, Klaus Hubacek and Alastor Coleby, 'From Polluter Pays to Provider Gets: Distribution of Rights and Costs under Payments for Ecosystem Services (2013) 18(4) *Ecology and Society* 41, 43.

[21] *Environmental Defence Society Inc v. The New Zealand King Salmon Company Ltd* [2014] NZSC 38; [2014] 1 NZLR 593.

[22] *Resource Management Act 1991* (NZ) s 5(1).

[23] *Resource Management Act 1991* (NZ) s 5(2).

[24] *Environmental Defence Society Inc v. The New Zealand King Salmon Company Ltd* [2014] NZSC 38; [2014] 1 NZLR 593, 618 [25].

[25] See *Resource Management Act 1991* (NZ) ss 56, 57.

[26] New Zealand Coastal Policy Statement 2010, objective 2, policies 13, 15.

[27] *Environmental Defence Society Inc v. The New Zealand King Salmon Company Ltd* [2014] NZSC 38; [2014] 1 NZLR 593, 651 [132].

[28] ibid 656 [149].

[29] *Resource Management Act 1991* (NZ) s 67(3).

means giving effect to the NZCPS policy of preserving the coastal environment and protecting it from inappropriate development.[30]

(D) Conclusion on ESD

It was suggested earlier in this paper that the concept of ESD involves a substantive outcome that is to be achieved through the implementation of the principles of ESD. The implementation of these principles achieves different aspects of the substantive outcome. Each of the principles should not be viewed in isolation but rather as part of a package. Sometimes the principles reinforce each other and strengthen the case for taking some particular action. At other times they tug in different directions and may need to be weighed against one another to determine the appropriate action to be taken. Courts have emphasised the need to consider all of the principles of ESD that are relevant to the decision to be made.[31]

II. INTERPRETING THE PRECAUTIONARY PRINCIPLE

(A) The history of precaution

One of the best known principles of ESD is the precautionary principle. This principle has deep historical roots. As Resnik has observed, the precautionary principle has its origins in the "common folk wisdom that 'it is better to be safe than sorry' and 'an ounce of prevention is worth a pound of cure'".[32] However, this primitive concept of precaution only began to crystallise as a normative principle to guide decision-making during the 1970s in West Germany.[33] The social democratic government of West Germany during this period expressed its intention to conserve and protect the environment by ensuring that foreseeable environmental harm was anticipated and prevented.[34] Boehmer-Christiansen has suggested that the first application of the concept of precaution to West German environmental policy was when the objective of *dem Enstehen schadlicher Umwelteinwirkungen vorzubeugen* ('to prevent the development of harmful environmental effects') was included in clean air legislation enacted in the early 1970s.[35] By 1976, the *Vorsorgeprinzip* had been expressly introduced into West German environmental law and "had become a cornerstone of German environmental policy".[36] The *Vorsorgeprinzip* was defined to require the "early detection of dangers to health and [the] environment" and, where appropriate, the taking of actions to protect the environment despite scientific uncertainty concerning such dangers.[37]

Throughout the 1980s, the *Vorsorgeprinzip* became increasingly influential internationally.[38] In particular, the precautionary principle started to gain traction throughout Europe and the English-speaking world.[39] The first international treaty to be explicitly influenced by the precautionary principle was the 1985 *Vienna Convention of the Protection of the Ozone Layer*,[40] "in which the Parties acknowledged the "precautionary measures" which had already been undertaken at both the national and international levels in relation to the protection of the ozone layer".[41] Within a decade of this convention, the precautionary principle had become internationally recognised as a legitimate normative principle capable of guiding environmental law and policy both on the domestic and international planes. Internationally, this was confirmed by the inclusion of the precautionary principle in a range of significant environmental declarations and conventions including, amongst many others,[42] the 1987 *Second North Sea Conference Ministerial Declaration*,[43] the 1990 *Bergen Ministerial Declaration on Sustainable Development in the Economic Commission for Europe Region*,[44] the 1991 *Convention on the Ban of Import into Africa and the Control of Transboundary Movement and Management of Hazardous Wastes within Africa*,[45] the 1992 *Convention on the Protection of the Marine Environment*

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[30] *Environmental Defence Society Inc v. The New Zealand King Salmon Company Ltd* [2014] NZSC 38; [2014] 1 NZLR 593, 657–658 [152]–[154].

[31] *Northcompass Inc v. Hornsby Shire Council* (1996) 130 LGERA 248, 264–265; *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 280 [182]–[183]; *Blue Wedges Inc v. Minister for Environment, Heritage and the Arts* [2008] FCA 399; (2008) 167 FCR 463, 480–481 [76]–[78].

[32] David Resnik, 'Is the precautionary principle unscientific?' (2003) 34 *Studies in History and Philosophy of Biological and Biomedical Sciences* 329, 329.

[33] Sonja Boehmer-Christiansen, 'The Precautionary Principle in Germany – enabling Government' in Timothy O'Riordan and James Cameron (eds), *Interpreting the Precautionary Principle* (Earthscan, 2009) 35-36.

[34] Sonja Boehmer-Christiansen, 'The Precautionary Principle in Germany – enabling Government' in Timothy O'Riordan and James Cameron (eds), *Interpreting the Precautionary Principle* (Earthscan, 2009) 36-37.

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[36] Sonja Boehmer-Christiansen, 'The Precautionary Principle in Germany – enabling Government' in Timothy O'Riordan and James Cameron (eds), *Interpreting the Precautionary Principle* (Earthscan, 2009) 36.

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[38] Brian J Preston, 'The Role of the Judiciary in Promoting Sustainable Development: The Experience of Asia and the Pacific' (2005) 9(2-3) *Asia Pacific Journal of Environmental Law* 134.

[39] David Resnik, 'Is the precautionary principle unscientific?' (2003) 34 *Studies in History and Philosophy of Biological and Biomedical Sciences* 329, 329-330.

[40] 26 ILM 1516 (1987) *Preamble.*

[41] Brian J Preston, 'The Role of the Judiciary in Promoting Sustainable Development: The Experience of Asia and the Pacific' (2005) 9(2-3) *Asia Pacific Journal of Environmental Law* 134.

[42] See Brian J Preston, 'The Role of the Judiciary in Promoting Sustainable Development: The Experience of Asia and the Pacific' (2005) 9(2-3) *Asia Pacific Journal of Environmental Law* 135-138; Philippe Sands, *Principles of International Environmental Law* (2nd ed, CUP 2003) 271; Nicolas de Sadeleer, *Environmental Principles, From Political Slogans to Legal Rules* (OUP 2002) 98.

[43] 27 ILM 835 (1988) Arts VII, XV(i) and XVI(i),

[44] UN Doc. A/CONF.151/PC/10 (Bergen, 16 May 1990) par 7.

[45] 30 ILM 773 (1991).

of the North-East Atlantic,[46] the 1992 *Helsinki Convention on the Protection and Use of Transboundary Watercourses and International Lakes,*[47] the 1992 *Convention on Biological Diversity*[48] and the 1992 *United Nations Framework Convention on Climate Change.*[49], [50]

Domestically, the precautionary principle also became well-established in the body of environmental legislation of many nation states. For example, by the end of the twentieth century, the precautionary principle was expressly included in many Australian statutes,[51] often as "objectives of the respective enactments, but there are instances where there is an obligation to take them into account".[52]

(B) The concept of precaution

The precautionary principle should be understood as a "culturally framed,"[53] "normative principle for making practical decisions under conditions of scientific uncertainty".[54] Its purpose is the removal of scientific uncertainty as a reason for postponing or not taking measures to prevent environmental damage.

There are numerous formulations of the precautionary principle but the most widely employed formulation is based on Principle 15 of the Rio Declaration on Environment and Development which states:

In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.[55]

An example of a domestic statutory incorporation of the precautionary principle is section 6(2)(a) of the *Protection of the Environment Administration Act 1991* (NSW):

> *the precautionary principle—namely, that if there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.*
>
> *In the application of the precautionary principle, public and private decisions should be guided by:*
>
> *(i) careful evaluation to avoid, wherever practicable, serious or irreversible damage to the environment, and*
>
> *(ii) an assessment of the risk-weighted consequences of various options ...*[56]

Another example is s 5 of the *Sustainable Planning Act 2009* (Qld) which provides:

> *the precautionary principle is the principle that lack of full scientific certainty should not be used as a reason for postponing a measure to prevent degradation of the environment if there are threats of serious or irreversible environmental damage.*

The precautionary principle is the principle of ESD that has been the subject of the most judicial consideration by courts throughout the world.[57] Difficulties in its application flow from the "the indifference of the precautionary approach, both in terms of *when* and *what* action is required".[58] The courts, by their decisions, have assisted in elucidating the meaning and scope of the precautionary principle in three ways.

First, courts have recognised the precautionary principle to be part of the law of the land. The precautionary principle might not have been expressly incorporated in legislation. Courts have nevertheless found that the precautionary principle is to be implied in the legislation or the common law. The Supreme Court of India has held that "the precautionary principle and the polluter pays principle are part of the environmental law of the country", notwithstanding that neither was expressly incorporated in constitutional or statutory law.[59] Similarly, the Land and

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[46] 32 ILM 1069 (1993) Art 2(2)(a).

[47] 31 ILM 1312 (1992) Art 2(5)(a).

[48] 31 ILM 822 (1992).

[49] 31 ILM 849 (1992) Art 3(3).

[50] Brian J Preston, 'The Role of the Judiciary in Promoting Sustainable Development: The Experience of Asia and the Pacific' (2005) 9(2-3) *Asia Pacific Journal of Environmental Law* 135-138.

[51] Paul Stein and Susan Mahoney, 'Incorporating Sustainability Principles in Legislation" in Paul Leadbetter, Neil Gunningham and Ben Boer (eds), *Environmental Outlook No 3: Law and Policy* (Federation Press 1999) 73-77.

[52] Brian J Preston, 'The Role of the Judiciary in Promoting Sustainable Development: The Experience of Asia and the Pacific' (2005) 9(2-3) *Asia Pacific Journal of Environmental Law* 139.

[53] Timothy O'Riordan and James Cameron, 'The History and Contemporary Significance of the Precautionary Principle' in Timothy O'Riordan and James Cameron (eds), *Interpreting the Precautionary Principle* (Earthscan, 2009) 11.

[54] David Resnik, 'Is the precautionary principle unscientific?' (2003) 34 *Studies in History and Philosophy of Biological and Biomedical Sciences* 329, 330.

[55] *Rio Declaration on Environment and Development* 31 ILM 874 (1992) Principle 15.

[56] See also *Environment Protection and Biodiversity Conservation Act 1999* (Cth) s 3A(b).

[57] Lee Godden and Jacqueline Peel, *Environmental Law: Scientific, Policy and Regulatory Dimensions* (OUP 2010) 137; Brian J Preston, 'The Role of the Judiciary in Promoting Sustainable Development: The Experience of Asia and the Pacific' (2005) 9 *Asia Pacific Journal of Environmental Law* 109, 133-174; Preston, (n 1) 115-121; Stephen Estcourt, 'The Precautionary Principle, the Coast and Temwood Holdings' (2014) 31 *Environmental and Planning Law Journal* 288, 288.

[58] Klauss Bosselmann, *The Principle of Sustainability: Transforming Law and Governance* (Ashgate 2008) 60.

[59] *Vellore Citizens Welfare Forum v. Union of India* AIR 1996 SC 2715, 2721 [13]; *MC Mehta v. Kamal Nath* (1997) 1 SCC 388 [37], [38]; *AP Pollution Control Board v. Prof MV Nayudu* AIR 1999 SC 812, 818–821; *MC Mehta v. Union of India* [2004] INSC 179; AIR 2004 SC 4016, 4045 [48].

Environment Court of NSW has held that decision-makers who are required to have regard to the public interest in development decision-making are obliged to have regard to the principles of ESD, including the precautionary principle, where issues relevant to those principles arise.[60] The State Administrative Tribunal of Western Australia and Supreme Court of Western Australia have held that "the precautionary principle is a consideration of relevance to the assessment of sustainable use and development of land."[61]

Second, courts have explained when the precautionary principle will apply. Formulations of the precautionary principle based on Principle 15 of the Rio Declaration refer to two matters for the application of the precautionary principle. The first is in the opening phrase "if there are threats of serious or irreversible environmental damage". The second is in the statement as to what should not be done: namely "lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation". The Land and Environment Court of NSW has held that satisfaction of these two matters is necessary to trigger the application of the precautionary principle:

> *The application of the precautionary principle and the concomitant need to take precautionary measures is triggered by the satisfaction of two conditions precedent or thresholds: a threat of serious or irreversible environmental damage and scientific uncertainty as to the environmental damage. These conditions or thresholds are cumulative. Once both of these conditions or thresholds are satisfied, a precautionary measure may be taken to avert the anticipated threat of environmental damage, but it should be proportionate.*[62]

Third, it is clear that the two conditions interrelate. This is because the degree of scientific uncertainty that needs to be established varies depending upon the magnitude of the environmental damage. Nevertheless, it assists explanation of the application of the precautionary principle to address the two conditions separately.[63] The following paragraphs address the two conditions separately before considering the application of the principle.

(C) A threat of serious or irreversible environmental damage

The existence of a threat is critical. It is not necessary that serious or irreversible environmental damage has actually occurred. It is the *threat* of such damage that is required.[64] The concept of a "threat" has been taken by the Environment, Resources and Development Court of SA to mean "likelihood" or "probability".[65] However, the Supreme Court of Victoria has held that, in speaking of a threat of environmental damage, the precautionary principle is not making any statement as to the likelihood or probability of its occurrence, except for asserting that the risk is not one that is far-fetched or fanciful. Instead, a threat of environmental damage refers to the foreseeability of the risk of environmental damage. A risk of environmental damage which is remote, in the sense that it is extremely unlikely to occur, may nevertheless constitute a foreseeable risk. "A risk which is not far-fetched or fanciful is real and therefore foreseeable".[66]

The threats to the environment that should be considered have been held to include "direct and indirect threats, secondary and long-term threats and the incremental or cumulative impacts of multiple or repeated actions or decisions. Where threats may interact or be interrelated (for example where action against one threat may exacerbate another threat) they should not be addressed in isolation".[67]

The environmental damage threatened must attain the threshold of being *serious or irreversible*. Assessing the seriousness or irreversibility of environmental damage involves consideration of many factors. These include:

(a) the spatial scale of the threat - for example, local, regional, statewide, national, international;

(b) the magnitude of possible impacts on both natural and human systems;

(c) the perceived value of the threatened environment;

(d) the temporal scale of possible impacts in terms of both the timing and the longevity - or persistence - of the impacts;

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[60] *BGP Properties v. Lake Macquarie City Council* [2004] NSWLEC 399; (2004) 138 LGERA 237, 262 [113]; *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 268 [124]; *Minister for Planning v. Walker* [2008] NSWCA 224; (2008) 161 LGERA 423, 451 [42]–[43].

[61] *Wattleup Road Development Co Pty Ltd v. State Administrative Tribunal* (No 2) [2016] WASC 279 [53].

[62] *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 269 [128]; applied in *Environment East Gippsland Inc v. VicForests* [2010] VSC 335 [188]; *MyEnvironment Inc v. VicForests* [2012] VSC 91 [272].

[63] Peel criticises the separation of the threat and uncertainty assessments: Jacqueline Peel, 'When (Scientific) Rationality Rules: (Mis)Application of the Precautionary Principle in Australian Mobile Phone Tower Cases' (2007) 19 *Journal of Environmental Law* 103, 103.

[64] *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 269 [129].

[65] *Conservation Council of South Australia v. Development Assessment Committee and Tuna Boat Owners Association* (No 2) [1999] SAERDC 86 (16 December 1999) [24].

[66] *Environment East Gippsland Inc v. VicForests* [2010] VSC 335; (2010) 30 VR 1, 47 [191]; citing *Wyong Shire Council v. Shirt* (1980) 146 CLR 40, 47–48.

[67] *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 269 [130].

(e) the complexity and connectivity of the possible impacts;

(f) the manageability of possible impacts, having regard to the availability of means and the acceptability of means;

(g) the level of public concern, and the rationality of and scientific or other evidentiary basis for the public concern; and

(h) the reversibility of the possible impacts and, if reversible, the time frame for reversing the impacts, and the difficulty and expense of reversing the impacts.[68]

If there is not a threat of serious or irreversible environmental damage, there is no basis upon which the precautionary principle can operate. The precautionary principle does not apply.[69] This was the conclusion reached by a number of courts in relation to proposed telecommunications developments that, by reason of compliance by a significant margin with relevant standards for the protection of public health and safety, there was no threat of serious or irreversible damage to public health and safety from the developments.[70] Similarly, courts have held that, by reason of the measures taken to protect threatened species of fauna in native forests, logging would not constitute a real threat of serious or irreversible damage.[71]

(D) The lack of scientific certainty

The second condition necessary to trigger the application of the precautionary principle and the necessity to take precautionary measures is that there be "a lack of full scientific certainty." Three points arise about this formulation of the precautionary principle.

First, the subject matter about which there is to be a lack of full scientific certainty is the nature and scope of the threat of environmental damage.[72] Assessing the degree of scientific uncertainty about the threat of environmental damage involves a process of analysis of many factors, including:

(a) the sufficiency of the evidence that there might be serious or irreversible environmental harm caused by the development plan, programme or project;

(b) the level of uncertainty, including the kind of uncertainty - such as technical, methodological or epistemological uncertainty; and

(c) the potential to reduce uncertainty having regard to what is possible in principle, economically and within a reasonable time frame.[73]

Second, the formulation of the precautionary principle raises the issue of how much scientific uncertainty must exist. On a literal reading, the threshold is crossed whenever there is a lack of "full" scientific certainty. Yet, such a literal interpretation of the precautionary principle would render this condition meaningless. "Full" scientific certainty as to the threat of environmental damage would be an unattainable goal. It is impossible to be completely certain about the threats of environmental damage.[74] Hence, there would always be "a lack of full scientific certainty" about the threats of environmental damage. This second condition would be satisfied in every situation. This makes a literal interpretation unworkable.

Once it is accepted that the second condition must be interpreted to means something less than "full" scientific certainty, the question becomes how much less? Or turning the question around, how much scientific uncertainty need there be as to the threat of environmental damage before the second condition to trigger application of the precautionary principle is fulfilled?

It has been suggested that the degree of scientific uncertainty required for the second condition is inversely proportional to the degree of potential environmental damage required for the first condition of the precautionary principle. Where the degree of potential environmental damage required for the first condition is greater, the degree of scientific uncertainty about that potential environmental damage that will be necessary to activate the precautionary principle will be lower. For the formulation of "serious or irreversible environmental damage", the correlative degree of uncertainty about the threat of environmental damage has been held to be "highly uncertain of threat" or "considerable scientific uncertainty"[75] or "substantial uncertainty".[76] This would

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[68] *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 269–270 [131]; cited in *Environment East Gippsland Inc v. VicForests* [2010] VSC 335; (2010) 30 VR 1, 47 [190]; *MyEnvironment Inc v. VicForests* [2012] VSC 91, [274].

[69] *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 271 [138].

[70] For example, *Hutchinson Telecommunications (Australia) Pty Ltd v. Baulkham Hills Shire Council* [2004] NSWLEC 104 [27]; *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 280 [184]–[185].

[71] *MyEnvironment Inc v. VicForests* [2012] VSC 91, [277], [341]; upheld on appeal *MyEnvironment Inc v. VicForests* [2013] VSCA 356; (2013) 198 LGERA 396.

[72] *Leatch v. National Parks and Wildlife Service* (1993) 81 LGERA 270, 282; *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 271 [140].

[73] *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 271 [141]; cited in *Environment East Gippsland Inc v. VicForests* [2010] VSC 335; (2010) 30 VR 1, 48 [195].

[74] *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 271-272 [142]-[144] and *Nicholls v. Director-General of National Parks and Wildlife* (1994) 84 LGERA 397, 419.

[75] *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 272 [146]–[147].

[76] *Environment East Gippsland Inc v. VicForests* [2010] VSC 335; (2010) 30 VR 1, 48 [197].

contrast with a formulation of the precautionary principle that sets a lower degree of potential environmental damage in the first condition, such as "potential adverse effects", where the correlative degree of certainty about the threat would be higher, such as "highly certain of threat".[77]

The rationale for the inverse relationship between environmental damage and uncertainty about that damage is that if the potential environmental damage or consequence is greater there should be a lower or more easily crossed threshold for the uncertainty about that potential environmental damage so as to trigger the need to take precautionary measures to prevent that environmental damage. Conversely, if the potential environmental damage or consequence is less serious, there can be a higher threshold for the uncertainty about that potential environmental damage before precautionary measures need to be taken.

Third, the formulation speaks of lack of "scientific" certainty. The adjective "scientific" implies a grounding in the methods and procedures of science.[78] There needs to be "reasonable scientific plausibility" about the assessment of the uncertainty of the threat of environmental damage. The Land and Environment Court of NSW explained:

> *N de Sadeleer posits a threshold test of "reasonable scientific plausibility," or where a threat or risk of environmental damage is considered scientifically likely. N de Sadeleer explains his test of reasonable scientific plausibility as follows (Environmental Principles: From Political Slogans to Legal Rules, at 160:*
>
>> *"...That condition would be fulfilled when empirical scientific data (as opposed to simple hypothesis, speculation, or intuition) make it reasonable to envisage a scenario, even it if does not enjoy unanimous scientific support.*
>>
>> *When is there 'reasonable scientific plausibility'? When risk begins to represent a minimum degree of certainty, supported by repeated experience. But a purely theoretical risk may also satisfy this condition, as soon as it becomes scientifically credible: that is, it arises from a hypothesis formulated with methodological rigour and wins the support of part of the scientific community, albeit a minority.*
>>
>> *The principle may consequently apply to all post-industrial risks for which a cause-and-effect relationship is not clearly established but where there is a 'reasonable scientific plausibility' that this relationship exists. This would be particularly appropriate for delayed pollution, which does not become apparent for some time and for which full scientific proof is difficult to assemble" (footnotes omitted).*
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> *See also Applying the Precautionary Principle at 33.*[79]

These three interpretative points may result in the second condition not being satisfied. The second condition might not be satisfied where there is not the required degree of uncertainty or the required scientific plausibility of uncertainty.

In relation to the former, there may not be considerable or substantial uncertainty about the threat of serious or irreversible damage. Instead, it may be relatively certain that serious or irreversible environmental damage will occur because it is possible to establish a causal link between the action or event and any environmental damage, to calculate the probability of the occurrence and to insure against them. In those circumstances, the precautionary principle does not need to be applied. Measures will still need to be taken but these will need to be preventative measures to control the relatively certain threat of serious or irreversible damage rather than precautionary measures which are appropriate in relation to uncertain threats of environmental damage.[80]

In relation to the latter, there will not be reasonable scientific plausibility about the uncertainty if it is pure speculation or unsupported opinion not grounded in the methods and procedures of science. Whatever the uncertainty about the threat of serious or irreversible environmental damage, it is not "scientific" uncertainty. The second condition would not be satisfied and the precautionary principle would not apply. Although precautionary measures would not be taken, the reason for not taking them would not be any lack of full "scientific" certainty.

(E) A shift of the burden of proof

If each of the conditions is satisfied – there is a threat of serious or irreversible damage and there is the requisite degree of scientific uncertainty about that environmental damage – the precautionary principle will be activated. Courts have held that, at this point of activation of the precautionary principle, there is a shifting of the burden

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[77] *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 272 [146].

[78] *Daubert v. Merrell Dow Pharmaceuticals Inc* 509 US 579, 589-590 (1993); *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 272 [135].

[79] *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 272 [148].

[80] *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 273 [149].

of proof. A decision-maker must assume that the threat of serious or irreversible environmental damage is no longer uncertain but is instead certain and real. The burden of showing that the threat does not in fact exist or is negligible effectively reverts to the proponent of the development plan, program or project.[81] The Land and Environment Court of NSW explained:

> The rationale for requiring this shift of the burden of proof is to ensure preventative anticipation; to act before scientific certainty of cause and effect is established. It may be too late, or too difficult and costly, to change a course of action once it is proven to be harmful. The preference is to prevent environmental damage, rather than remediate it. The benefit of the doubt is given to environmental protection when there is scientific uncertainty. To avoid environmental harm, it is better to err on the side of caution.
>
> The function of the precautionary principle is, therefore, to require the decision-maker to assume that there is, or will be, a serious or irreversible threat of environmental damage and to take this into account, notwithstanding that there is a degree of scientific uncertainty about whether the threat really exists …[82]

Similarly, the ERD Court of South Australia has held that "[o]nce an appellant has established a likelihood or possibility that serious or irreversible environmental harm might occur, then '… the proponent would have to satisfy the burden of proof by evidence as to the likely consequences of the proposal, including scientific evidence (with its limitations), evidence as to the proposed management regime and measures, and evidence to assist the Court in the assessment of the risk-weighted consequences of the proposal'".[83]

Importantly, however, the significance of this reversal of the burden of proof must be viewed in the context that "the precautionary principle is but one factor to which a decision-maker must have regard. Legislation does not require the principle to be the determinative factor in decision-making."[84] As the Land and Environment Court of NSW has said:

> *It should be recognised that the shifting of the evidentiary burden of proof operates in relation to only one input of the decision-making process – the question of environmental damage. If a proponent of a plan, programme or project fails to discharge the burden to prove that there is no threat of serious or irreversible environmental damage, this does not necessarily mean that the plan, programme or project must be refused. It simply means that, in making the final decision, the decision-maker must assume that there will be serious or irreversible environmental damage. This assumed factor must be taken into account in the calculus which decision-makers are instructed to apply under environmental legislation (such as s 79C(1) of the Environmental Planning and Assessment Act). There is nothing in the formulation of the precautionary principle which requires decision-makers to give the assumed factor (the serious or irreversible environmental damage) overriding weight compared to the other factors required to be considered, such as social and economic factors, when deciding how to proceed: D Farrier, "Factoring biodiversity conservation into decision-making processes: The role of the precautionary principle" at 108.*[85]

III. CRITICISM OF THE INTERPRETATION OF THE PRECAUTIONARY PRINCIPLE BY THE COURTS

The precautionary principle has been the cause of much public policy consternation and academic debate over the past four decades. As Resnik observes:

> Proponents of the precautionary principle argue that it should play a role in public policy because we often need to make important decisions even though we lack scientific certainty. Failing to take precautionary measures in a timely manner could result in devastating and irreversible consequences.
>
> Opponents argue, on the other hand, that the precautionary principle is a highly conservative, risk aversive rule that can stifle progress, change and growth. Taking precautionary measures when we have no good reason to do so can waste time and resources and deprive us of important benefits. The principle is not only anti-science but it is unscientific.[86]

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[81] *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 273 [150].

[82] *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 273 [151]–[152]; *Conservation Council of South Australia v. Development Assessment Committee and Tuna Boat Owners Association* (No 2) [1999] SAERDC 86 (16 December 1999) [24]-[25]; *Tuna Boat Owners Association of SA Inc v. Development Assessment Commission* [2000] SASC 238; (2000) 77 SASR 369, 373–374 [27]–[30]; *Vellore Citizens Welfare Forum v. Union of India* AIR 1996 SC 2715, 2720–2721 [11]; *AP Pollution Control Board v. Prof MV Nayudu* AIR 1999 SC 812, 821 [37]–[39]; *Narmada Bachao Andolan v. Union of India* [2000] INSC 518; AIR 2000 SC 3751, 3803–3804 [150].

[83] Gerry Bates, *Environmental Law in Australia* (9th ed, LexisNexis 2016) 312 quoting *Conservation Council of South Australia v. Development Assessment Committee and Tuna Boat Owners Association* (No 2) [1999] SAERDC 86 (16 December 1999) [24]-[25].

[84] Gerry Bates, *Environmental Law in Australia* (9th ed, LexisNexis 2016) 313.

[85] *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 274 [154] and see *Wattleup Road Development Co Pty Ltd v. State Administrative Tribunal* (No 2) [2016] WASC 279 [57]-[59].

[86] David Resnik, 'Is the precautionary principle unscientific?' (2003) 34 *Studies in History and Philosophy of Biological and Biomedical Sciences* 329, 330.

As this extract indicates, much of the debate concerning the precautionary principle has focussed on the merits and effectiveness of the precautionary principle as "a normative principle for making practical decisions under conditions of scientific uncertainty".[87] In contrast, there has been less debate and critical examination of the interpretation and application of the precautionary principle by the courts. Nevertheless, whilst the statutory interpretation of the precautionary principle by the courts - as requiring the triggering of two conditions precedent - is well-established, this so-called "two-step, threshold analysis"[88] has been challenged for inappropriately limiting the scope of the precautionary principle:

> *"Rather than facilitating 'rational' application of the precautionary principle in appropriate cases, the approach would appear to leave little room to respond in situations of scientific uncertainty and serious threats, thus potentially replicating many of the shortfalls of conventional, science-based decision-making on risks that have failed to anticipate 'unexpected' effects and so prompted the emergence of the precautionary principle in first place" (sic).*[89]

In particular, three criticisms have been levelled at the interpretation of the precautionary principle by the courts.

First, it has been argued that the conceptualisation of each of the two conditions precedent to the operation of the precautionary principle "as a threshold, which if not met, invalidates the application of the precautionary principle" artificially separates out the assessment of the threat and the uncertainty of the threat and "assumes that both factors are measurable and quantifiable".[90] This is challenged because the assessment of the threat and the uncertainty relating to the threat should be "intimately connected" and because those aspects of the threat and uncertainty of the threat that are not scientifically quantifiable are marginalised.[91]

Second, it has been contended that the courts should not require a threat of damage to be reasonably scientifically plausible to activate the precautionary principle. This limitation has the consequence of potentially "severely restrict[ing] the scope of possible application of the precautionary principle".[92] Furthermore, the inability of such risks to activate the precautionary principle means that "the possibility of these harms must be borne 'regardless of the nature of the risk-generating activity and the social worth attaching to it'".[93] Instead, it has been suggested that the judgment of a community that precautionary action is warranted, for risks that have not been shown to be scientifically plausible, may "have an equal claim to rationality".[94]

Third, the consequence of the successful activation of the precautionary principle – the reversal of the burden of proof – has been criticised. It has been claimed that the reversal of proof is divisive because it suggests that the affected proponent must prove the absence of risk.[95] Moreover, it is argued that the assumption that the particular threat is real, "represents an overly stark understanding of the effect of the precautionary principle".[96] Instead of assuming harm, the decision-maker should only be required to assess "the risk-weighted consequences of various, alternative options".[97]

IV. REBUTTAL TO CRITICISM OF THE INTERPRETATION OF THE PRECAUTIONARY PRINCIPLE BY THE COURTS

In response to the first criticism, the claim that the assessment of the threat and the uncertainty of the threat are "intimately connected" is indisputable. As has been stated above, the two conditions interrelate because the degree of uncertainty that needs to be

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[87] David Resnik, 'Is the precautionary principle unscientific?' (2003) 34 *Studies in History and Philosophy of Biological and Biomedical Sciences* 329, 330.

[88] Jacqueline Peel, 'When (Scientific) Rationality Rules: (Mis)Application of the Precautionary Principle in Australian Mobile Phone Tower Cases: Telstra Corporation Limited v. Hornsby Shire Council" (2007) 19(1) *Journal of Environmental Law* 103, 113.

[89] Jacqueline Peel, 'When (Scientific) Rationality Rules: (Mis)Application of the Precautionary Principle in Australian Mobile Phone Tower Cases: Telstra Corporation Limited v. Hornsby Shire Council" (2007) 19(1) *Journal of Environmental Law* 103, 113.

[90] Jacqueline Peel, 'When (Scientific) Rationality Rules: (Mis)Application of the Precautionary Principle in Australian Mobile Phone Tower Cases: Telstra Corporation Limited v. Hornsby Shire Council" (2007) 19(1) *Journal of Environmental Law* 103, 113-114.

[91] Jacqueline Peel, 'When (Scientific) Rationality Rules: (Mis)Application of the Precautionary Principle in Australian Mobile Phone Tower Cases: Telstra Corporation Limited v. Hornsby Shire Council" (2007) 19(1) *Journal of Environmental Law* 103, 114-115.

[92] Jacqueline Peel, 'When (Scientific) Rationality Rules: (Mis)Application of the Precautionary Principle in Australian Mobile Phone Tower Cases: Telstra Corporation Limited v. Hornsby Shire Council" (2007) 19(1) *Journal of Environmental Law* 103, 116.

[93] Jacqueline Peel, 'When (Scientific) Rationality Rules: (Mis)Application of the Precautionary Principle in Australian Mobile Phone Tower Cases: Telstra Corporation Limited v. Hornsby Shire Council" (2007) 19(1) *Journal of Environmental Law* 103, 115.

[94] Jacqueline Peel, 'When (Scientific) Rationality Rules: (Mis)Application of the Precautionary Principle in Australian Mobile Phone Tower Cases: Telstra Corporation Limited v. Hornsby Shire Council" (2007) 19(1) *Journal of Environmental Law* 103, 117.

[95] Jacqueline Peel, 'When (Scientific) Rationality Rules: (Mis)Application of the Precautionary Principle in Australian Mobile Phone Tower Cases: Telstra Corporation Limited v. Hornsby Shire Council" (2007) 19(1) *Journal of Environmental Law* 103, 117.

[96] Jacqueline Peel, 'When (Scientific) Rationality Rules: (Mis)Application of the Precautionary Principle in Australian Mobile Phone Tower Cases: Telstra Corporation Limited v. Hornsby Shire Council" (2007) 19(1) *Journal of Environmental Law* 103, 118.

[97] Jacqueline Peel, 'When (Scientific) Rationality Rules: (Mis)Application of the Precautionary Principle in Australian Mobile Phone Tower Cases: Telstra Corporation Limited v. Hornsby Shire Council" (2007) 19(1) *Journal of Environmental Law* 103, 118.

established varies depending upon the magnitude of the environmental damage.[98] Yet, the criticism of interpreting the precautionary principle to have two separate (albeit interrelated) conditions precedent is difficult to reconcile with the statutory language of the precautionary principle. The necessary implication of such criticism is that the precautionary principle can operate if a threat of serious or irreversible environmental damage has not been demonstrated or if there is no, or not considerable, scientific uncertainty as to that threat. Yet, the precautionary principle is phrased so that "if there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not …". For the precautionary principle not to have the two identified conditions precedent, it would have to be drafted differently.

First, the principle operates "*if* there are threats of serious or irreversible damage". Therefore, it is contrary to the explicit terms of the legislation to claim that a threat of serious or irreversible environmental damage is not a condition precedent. Second, the principle is not phrased such that "*if* there are threats of serious or irreversible environmental damage *or there is a* lack of full scientific certainty". Again, a lack of full scientific certainty must be a condition precedent. This form of drafting is unlikely to be accidental. As the World Commission on the Ethics of Scientific Knowledge and Technology noted some time ago, "[c]onsiderable scientific uncertainty *must* exist" for the precautionary principle to operate.[99] The only question is "how much scientific uncertainty need there be *as to the threat of environmental damage* before the second condition precedent of the precautionary principle is fulfilled?"

Accepting that the precautionary principle has these two conditions precedent means that an assessment must be made that a serious threat exists and that there is considerable scientific uncertainty about that threat for the principle to operate. Hence, if a development does not pose threats of serious or irreversible environmental damage, or if there is not a lack of scientific uncertainty concerning the threats of serious or irreversible environmental damage, there is no necessity to impose precautionary measures. Such threats are not dealt with by the precautionary principle. Why should precautionary measures be imposed on a development where a threat cannot be shown to pose any serious risk of environmental damage? Why should precautionary measures (as opposed to preventative measures) be imposed when the science is relatively settled as to a threat of serious environmental damage?

These same questions apply to the second ground of criticism outlined above, namely, that the courts should not restrict the operation of the precautionary principle to threats of environmental damage that are scientifically plausible. This may well restrict the application of the precautionary principle, however that is justifiable. First, the terms of the precautionary principle explicitly state the lack of "scientific" uncertainty should not be used as a reason for postponing cost effective measures to prevent environmental damage. As noted earlier, the scientific uncertainty relates to the nature and scope of the threat of environmental damage. It is not any uncertainty to the threat; it is "scientific uncertainty". This leads to the conclusion that the principle applies to threats of environmental damage that are scientifically plausible.

Second, adopting the position that scientifically implausible (or scientifically unknown) threats of environmental damage should be able to activate the precautionary principle would be unworkable and produce unintended results. What does it mean to say that lack of full scientific certainty should not be used to postpone measure to prevent scientifically implausible or scientifically unknown threats of environmental damage? What precautions could ever be taken to deal with scientifically implausible threats of environmental damage aside from a blanket prohibition of development whenever a threat of serious environmental damage is alleged?

Third, widening the scope of the precautionary principle to operate in circumstances where there is no reliable evidence to support an alleged threat of environmental damage might have adverse consequences. As Cross has written, "[t]he truly fatal flaw of the precautionary principle, ignored by almost all the commentators, is the unsupported presumption that an action aimed at public health protection cannot possibly have negative effects on public health. Yet these unanticipated adverse effects are demonstrably common … ."[100] For this reason, de Sadeleeer observes that the precautionary principle's "field of application must exclude those risks characterised as residual, that is, hypothetical risks resting on purely speculative considerations without any scientific foundation".[101] If not, the precautionary principle risks becoming "the application of junk science to phantom risks to make them seem plausible".[102]

In relation to the third ground of criticism, the challenge to the reversal of the burden of proof, it is incorrect that such

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[98] See, *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 272 [146]-[148].

[99] World Commission on the Ethics of Scientific Knowledge and Technology, *The Precautionary Principle* (UNESCO 2005) 31 (emphasis added).

[100] Frank Cross, 'Paradoxical Perils of the Precautionary Principle' (1996) 53 *Washington and Lee Law Review* 851, 859-860.

[101] N de Sadeleer, *Environmental Principles: From Political Slogans to Legal Rules* (2005 OUP) 158 quoted in Telstra Corp Ltd v. Hornsby Shire Council [2006] NSWLEC 133; (2006) 67 NSWLR 256, 272 [160].

[102] US EPA's Office of Water scientist P Wise quoted in B Cohen, 'The safety Nazis' (2001) 34(6) The American Spectator 16.

a reversal of the burden of proof suggests that the affected proponent must prove the absence of risk. The proponent only needs to show that the risk is negligible to escape the operation of the precautionary principle. More importantly, as will be demonstrated below, the reversal of the burden of proof is not "overly stark" for three reasons.

First, if the conditions precedent are satisfied, there will be a justifiable basis for the taking of precautionary measures. The precautionary principle operates to assume that there will be serious or irreversible environmental damage, so that precautionary measures should be taken to prevent that damage, unless the proponent can show otherwise. Of course, the imposition of precautionary measures would certainly be stark if the precautionary approach could be applied regardless of the triggering of the conditions precedent. This only emphasises why the first and second criticisms are misguided.

Second, precautionary measures need not have stark consequences for the proponent. The proponent may be able to successfully adopt proportionate precautionary measures that allow the development to occur whilst minimising the risk of serious environmental damage. Certainly a "zero risk precautionary standard is inappropriate".[103] Measures based on the precautionary principle should be proportionate to the threat of environmental damage. A reasonable balance must be struck between the stringency of the precautionary measures, which may have associated costs such as financial, livelihood and opportunity costs, and the seriousness and irreversibility of the threat.[104] Considerations of practicality, including cost, need to be taken into account in the selection of the precautionary measures. The cost consequences of increasing levels of precaution must be evaluated.[105]

Third, "[t]here is nothing in the formulation of the precautionary principle which requires decision-makers to give the assumed factor (the serious or irreversible environmental damage) overriding weight compared to the other factors required to be considered ...".[106] The assumed factor (which might support pursuing one option, including not allowing the development) may be overridden by other factors (which support pursuing other options, including allowing the development). However, in contrast, if damage is not assumed, why would (and how does) a decision-maker seriously or credibly consider and weigh "the risk-weighted consequences of various, alternative options"? As the legislation mandates, risk-weighted consequences of various options are to guide "the application of the precautionary principle". What is the effect and purpose of the precautionary principle if, once activated, nothing flows from its operation? For the precautionary principle to be more than an aspirational goal, it must have weight in the decision-making calculus once activated.

V. THE APPLICATION OF THE PRECAUTIONARY PRINCIPLE BY THE COURTS

(A) Types of precautionary measures

Courts have explained what actions are required when the precautionary principle does apply. The Land and Environment Court of NSW has said:

> *The type and level of precautionary measures that will be appropriate will depend on the combined effect of the degree of seriousness and irreversibility of the threat and the degree of uncertainty. This involves assessment of risk in its usual formulation, namely the probability of the event occurring and the seriousness of the consequences should it occur. The more significant and the more uncertain the threat, the greater the degree of precaution required.*[107]

For example, it has been said that for substances that are persistent and have a tendency to build-up in the environment, "it is necessary to adopt a more precautionary approach and constrain the amounts permitted to be discharged by means of emissions standards".[108] Similarly, greater precautionary measures need to be taken for firefighting foams that are persistent in the environment than those that are non-persistent. All firefighting foams can have adverse impacts on the environment, but fluorinated foams that are persistent in the environment have far greater impacts than fluorine-free foams that are non-persistent. This tiered approach is adopted in the Queensland Department of Environment and Heritage Protection's Operational Policy: Environmental Management of Firefighting Foam (2016). The Policy recommends a far stricter approach to the use of persistent (fluorinated) foams than non-persistent (fluorine-free) foams. For example, for persistent firefighting foams, the Policy recommends the non-use and the replacement of foams containing fluorinated organic compounds,[109] the use of foams containing short-chain fluorotelomers only if there are not other viable options and then only if certain strict

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[103] *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 272 [158].

[104] *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 277 [166]-[168].

[105] *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 277 [169]-[171].

[106] *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 272 [154].

[107] *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 276 [161].

[108] Lord Crickhowell, 'Foreword' in Timothy O'Riordan and James Cameron (eds), *Interpreting the Precautionary Principle* (Earthscan, 2009) 6.

[109] Such as PFOS (perfluoro octane sulphonic acid) and PFOA (perfluoro-octanoic acid).

procedures are followed, including no releases directly to the environment.[110] For non-persistent firefighting foams, the Policy recommends the taking of all reasonable and practical measures to proactively manage, contain, treat and properly dispose of the foam, firewater, wastewater and runoff and regulates the conditions for direct releases to land and to waterways.[111]

In considering how to implement and operate the precautionary principle, once the conditions precedent are present, "a number of general principles or measures of risk management must not be deviated from. These principles of risk management include:

(i) **Proportionality:** the action must be proportionate to the desired level of protection. It is unrealistic to have a goal of zero risk, and in some cases, a total ban of development may not be a proportional response to a potential risk.

(ii) **Non-discrimination:** the action taken should not be discriminatory in its application such that comparable situations should not be treated differently.

(iii) **Consistency:** the action taken should be consistent with the measures already adopted in similar circumstances or using similar approaches.

(iv) **Examination of benefits and costs of action and lack of action:** a comparison of the likely short-term and long-term consequences of the action and inaction should be made, and the proposed action must produce an overall advantage in terms of reducing risks to an acceptable level. While an economic cost/benefit analysis is one way to undertake this comparison, other analysis methods, such as an examination of the socio-economic impacts, may also be relevant.

(v) **Examination of scientific developments:** action taken and measures based on the precautionary principle should be subject to review in the light of new scientific data and if necessary modified depending on results of subsequent scientific research.

(vi) **The burden of proof:** measures based on the precautionary principle may assign responsibility for producing the scientific evidence necessary for a comprehensive risk assessment."[112]

(B) Obtaining further information to reduce uncertainty

Where there is still considerable scientific uncertainty, prudence may require that the development plan, program or project not proceed until further information is obtained in order to reduce the uncertainty. For example, in the pioneering case of *Leatch v. National Parks and Wildlife Service*, the Land and Environment Court of NSW applied the precautionary principle to refuse to grant a statutory licence to take or kill endangered fauna, the Giant Burrowing Frog, which was necessary for a proposed link road development.[113] However, the Court emphasised that "refusal of this licence application should not necessarily be assumed to be an end of the proposal. Further information on endangered fauna and advances in scientific knowledge may mean that a licence could be granted in the future".[114] The State Administrative Tribunal of Western Australia refused proposed residential subdivisions exposed to fugitive dust from bauxite stockpiles at an aluminium smelter and from a sand quarry until adequate air quality monitoring of the site was undertaken demonstrating that the proposed subdivisions would be acceptable in relation to dust health and amenity impacts.[115] Subsequently, further site quality monitoring did not satisfactorily demonstrate that the proposed subdivisions were acceptable in relation to the health and amenity impacts of dust. One of the reasons was that climatic conditions relevant to dust generation affecting the site were likely to be different because of climate change and result in increased dust levels during future dust seasons in comparison with the monitoring year.[116]

Courts have also proactively sought further information to reduce scientific uncertainty. Thus, the Supreme Court of Pakistan appointed an expert commissioner to examine and study the scheme and the planning used by a government agency for an electricity grid station and to report whether there was any likelihood that the electromagnetic fields that radiated from the grid station might cause a hazard to the health of residents in the locality.[117]

(C) Allowing margin for error

Prudence would also suggest that some margin for error should be retained until all the consequences of the decision to proceed with the development plan, program or project are known. This allows for potential errors in risk assessment and cost benefit analysis. Potential errors are weighted in favour of environmental protection. Weighting

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[110] Operational Policy – Environmental Management of Firefighting Foam, s 6.2.

[111] Operational Policy – Environmental Management of Firefighting Foam, s 6.1.

[112] Brian J Preston, 'The Role of the Judiciary in Promoting Sustainable Development: The Experience of Asia and the Pacific' (2005) 9(2-3) *Asia Pacific Journal of Environmental Law* 134, 141-142 citing *Commission of the European Communities, Communication from the Commission on the Precautionary Principle*, 2 February 2000 <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52000DC0001> (accessed 22 December 2016).

[113] (1993) 81 LGERA 270.

[114] (1993) 81 LGERA 270 at 286-287.

[115] *Wattleup Road Development Company Pty Ltd and Western Australian Planning Commission* [2011] WASAT 160 [66], [71].

[116] *Wattleup Road Development Company Pty Ltd and Western Australian Planning Commission* [2014] WASAT 159 [59].

[117] *Zia v. WAPDA* PLD 1994 SC 693 [10], [16].

the risk of error in favour of the environment safeguards ecological space or environmental room for manoeuvre.[118]

Illustrations of weighting the risk of error in favour of the environment can be found in decisions of the Land and Environment Court of NSW directed at the avoidance of a risk of serious or irreversible environmental damage to endangered species and ecological communities. This is achieved, first, by resolving scientific uncertainty as to whether an endangered ecological community was widely distributed over a development site by assuming the existence of the wide distribution of the endangered ecological community[119] and, second, by determining that proposed developments were likely to significantly affect endangered species and ecological communities so as to trigger the statutory requirement to prepare a detailed environmental assessment in the form of a species impact statement.[120]

(D) An adaptive management approach

One means of retaining a margin for error is to implement a step-wise or adaptive management approach, whereby uncertainties are acknowledged and the area affected by the development plan, program or project is expanded as the extent of uncertainty is reduced.[121] The Land and Environment Court of NSW has held that an adaptive management approach might involve the following core elements:

- monitoring of impacts of management or decisions based on agreed indicators;
- promoting research, to reduce key uncertainties;
- ensuring periodic evaluation of the outcomes of implementation, drawing of lessons, and review and adjustment, as necessary of the measures or decisions adopted; and
- establishing an efficient and effective compliance system.[122]

The court found that the appropriate and proportionate response to the threat of environmental damage to stygofauna within a limestone formation proposed to be quarried was to implement a step-wise or adaptive management approach. This involved the imposition of conditions of development consent requiring monitoring linked to adaptive management.[123] The court stated:

Adaptive management is a concept which is frequently invoked but less often implemented in practice. Adaptive management is not a "suck it and see", trial and error approach to management, but it is an iterative approach involving explicit testing of the achievement of defined goals. Through feedback to the management process, the management procedures are changed in steps until monitoring shows that the desired outcome is obtained. The monitoring program has to be designed so that there is statistical confidence in the outcome. In adaptive management the goal to be achieved is set, so there is no uncertainty as to the outcome and conditions requiring adaptive management do not lack certainty, but rather they establish a regime which would permit changes, within defined parameters, to the way the outcome is achieved ...

The conditions of consent requiring monitoring and adaptive management would operate over the life of a project (and, in the case of rehabilitation, beyond it). Over this period there are likely to be changes in technology, understanding of issues and the environment (for example in 30 years time climatic conditions might be different from those currently prevailing). An adaptive management regime provides the potential for addressing changes without creating a requirement to seek formal amendment of conditions.[124]

The Supreme Court of New Zealand has held that such an adaptive management approach was available and consistent with a proper precautionary approach for managing salmon farms in coastal marine areas.[125] Three adaptive management approaches had been proposed: staged development, tiered approach to monitoring and ongoing adaptive management.[126] The court considered the threshold question of what must be present before an adaptive management approach can even be considered and responded:

> *there must be an adequate evidential foundation to have reasonable assurance that the adaptive management approach will achieve its goals of sufficiently reducing uncertainty and adequately managing any remaining risk. The threshold question is an important step and must always*

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[118] *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 276 [162].

[119] Providence Projects Pty Ltd v. Gosford City Council [2006] NSWLEC 52; (2006) 147 LGERA 274, 289 [76]–[81].

[120] *BT Goldsmith Planning Services Pty Ltd v. Blacktown City Council* [2005] NSWLEC 210 [73], [88]; *Gales Holdings Pty Ltd v. Tweed Shire Council* [2006] NSWLEC 85; (2006) 146 LGERA 236, 246–248 [56], [60], [66]–[69]; *Gales Holdings Pty Ltd v. Tweed Shire Council* [2006] NSWLEC 212 [44]–[47].

[121] *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 726 [163]; *Environment East Gippsland Inc v. VicForests* [2010] VSC 335; (2010) 30 VR 1, 49 [205].

[122] *Telstra Corp Ltd v. Hornsby Shire Council* [2006] NSWLEC 133; (2006) 67 NSWLR 256, 276 [164]; see also *Sustain Our Sounds Inc v. The New Zealand King Salmon Company Ltd* [2014] NZSC 40; [2014] 1 NZLR 673, 703 [109].

[123] *Newcastle and Hunter Valley Speleological Society Inc v. Upper Hunter Shire Council and Stoneco Pty Ltd* [2010] NSWLEC 48 [183].

[124] *Newcastle and Hunter Valley Speleological Society Inc v. Upper Hunter Shire Council and Stoneco Pty Ltd* [2010] NSWLEC 48 [184], [187].

[125] *Sustain Our Sounds Inc v. The New Zealand King Salmon Company Ltd* [2014] NZSC 40; [2014] 1 NZLR 673, 716 [158].

[126] *Sustain Our Sounds Inc v. The New Zealand King Salmon Company Ltd* [2014] NZSC 40; [2014] 1 NZLR 673, 702 [104].

> *be considered. As Preston CJ said in Newcastle, adaptive management is not a "suck it and see" approach.*[127]

The court considered the secondary question of what an adaptive management regime must contain in any particular case before it is legitimate to use such an approach rather than prohibiting the development until further information becomes available. The court stated that this will depend on an assessment of a combination of factors:

(a) the extent of the environmental risk (including the gravity of the consequences if the risk is realised);

(b) the importance of the activity (which could in some circumstances be an activity it is hoped will protect the environment);

(c) the degree of uncertainty; and

(d) the extent to which an adaptive management approach will sufficiently diminish the risk and the uncertainty.[128]

The Land and Environment Court of NSW has found on a number of occasions that, consistent with the precautionary principle, an adaptive management approach could be implemented for proposed developments. These included a pearl farm in the waters of Port Stephens;[129] open cut and underground coal mines that might have insufficient water supply for operations;[130] longwall coal mining that might affect hydrological regimes and dependent ecosystems;[131] and a limestone quarry that might affect stygofauna.[132]

(E) Prohibiting the development or action

Where precautionary measures cannot reduce the threat of serious or irreversible environmental damage to acceptable levels, the appropriate action may be to prohibit the carrying out of the environmentally damaging activity. The Supreme Court of New Zealand has noted that this may be the case "where urgent measures are needed to avert imminent potential threats, where the potential damage is likely to be irreversible and where particularly vulnerable species or ecosystems are concerned".[133]

The Environment, Resources and Development Court of SA has found that a proposed tuna farm would be ecologically sustainable only if an adaptive management regime could be implemented but, because a regime could not be implemented, consent for the development should be refused.[134]

The Land and Environment Court of NSW has held that the scarcity of scientific knowledge about the population, habitat and behavioural patterns of two threatened fauna species and about the impacts of a proposed road on the species justified the refusal of a licence to take or kill the species.[135] Similarly, the Land and Environment Court has refused development consent to an open cut coal mine, finding that the precautionary measures proposed, including compensatory biodiversity offsets, were unlikely to prevent serious and irreversible harm to an endangered ecological community.[136]

The Victorian Civil and Administrative Tribunal has held, applying the precautionary principle, that because of, first, the uncertainties associated with the potential effects on aquifers from changes in rainfall and associated recharge by reason of climate change, second, the potential seriousness of permanently depleting the groundwater storage and, third, the risk of irreversible damage to the environment, it was inappropriate to grant water extraction licences.[137]

The Queensland Planning and Environment Court adopted a precautionary approach in refusing approval to a seaside resort development. The court found that changes in sea levels and storm surges due to climate change would subject a greater proportion of the future development site to inundation to what was modelled, making approval of the development unacceptable.[138]

VI. CONCLUSION

ESD and its principles have been criticised as vague and for being framed appropriately for the purpose of political aspirations but not for implementation as legal standards.[139] This impedes the achievement of ESD. As courts have recognised, in order to achieve sustainability 'hortatory statements of principle and aspirational goals

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[127] *Sustain Our Sounds Inc v. The New Zealand King Salmon Company Ltd* [2014] NZSC 40; [2014] 1 NZLR 673, 708 [125].

[128] *Sustain Our Sounds Inc v. The New Zealand King Salmon Company Ltd* [2014] NZSC 40; [2014] 1 NZLR 673, 709 [129].

[129] *Port Stephens Pearls Pty Ltd v. Minister for Infrastructure and Planning* [2005] NSWLEC 426 [56]–[58].

[130] *Ulan Coal Mines Ltd v. Minister for Planning* [2008] NSWLEC 185; (2008) 160 LGERA 20, 40 [98], [99].

[131] *Rivers SOS Inc v. Minister for Planning* [2009] NSWLEC 213; (2009) 178 LGERA 347, 379 [131].

[132] *Newcastle and Hunter Valley Speleological Society Inc v. Upper Hunter Shire Council and Stoneco Pty Ltd* [2010] NSWLEC 48 [187]–[189].

[133] *Sustain Our Sounds v. The New Zealand King Salmon Company* [2014] NZSC 40; [2014] 1 NZLR 673, 704 [111].

[134] *Conservation Council of South Australia v. Development Assessment Committee and Tuna Boat Owners Association* (No 2) [1999] SAERDC 86 (16 December 1999); affirmed on appeal *Tuna Boat Owners Association of SA Inc v. Development Assessment Commission* [2000] SASC 238; (2000) 77 SASR 369.

[135] *Leatch v. National Parks and Wildlife Service* (1993) 81 LGERA 270, 284, 286–287.

[136] *Bulga Milbrodale Progress Association Inc v. Minister for Planning and Infrastructure and Warkworth Mining Ltd* [2013] NSWLEC 48; (2013) 194 LGERA 347.

[137] *Alanvale Pty Ltd v. Southern Rural Water* [2010] VCAT 480 [154]–[159], [200].

[138] *Rainbow Shores Pty Ltd v. Gympie Regional Council* [2013] QPEC 26.

[139] *Nicholls v. Director-General of National Parks and Wildlife* (1994) 84 LGERA 397, 419.

are insufficient; the grand strategy must be translated into action'. This involves institutionalising ESD and its principles in policies and laws as well as ensuring that functions under those policies and laws are performed in a way that promotes and implements ESD and its principles.[140] It also involves articulating clearly when, how and what action needs to be taken to achieve ESD.

The Operational Policy: Environmental Management of Firefighting Foam is an illustration of institutionalising the precautionary principle into regulatory policy and articulates when, how and what action needs to be taken to allow for the use of firefighting foams whilst safeguarding the environment.

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[140] *Hub Action Group Inc v. Minister for Planning* [2008] NSWLEC 116; (2008) 161 LGERA 136, 141 [2].

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