IC2 Webinar: Firefighting Foams: Practical Considerations to Going Fluorine-free

November 19, 2019

Presenters

- Ian Ross, Arcadis (UK)
- Nigel Holmes, Queensland (Australia) Department of Environment & Science
- Captain Kurt Plunkett, Seattle Fire Department
- Niall Ramsden, LASTFIRE
- Peter Storch, Arcadis (Australia)
- Jen Jackson, San Francisco Department of the Environment (Moderator)

Webinar Logistics

- This is a 90-minute webinar: approximately 55 minutes for presentations and 25 minutes for Q&A
- All attendee lines muted during presentation
- Please submit questions through the GoToWebinar Questions interface
- If you have technical questions, please let us know through the GoToWebinar Chat interface
- Slides will be posted on the IC2 website: http://theic2.org/events
- Your feedback is important to us! Please take the post-webinar survey.

The Training Workgroup continues to plan additional webinars intended to inform and engage. Let us know if you have ideas for future webinar topics or presenters.

Please give us your feedback through the post-webinar survey.

Jen Jackson
San Francisco Department of the Environment
(Moderator)

Ian Ross
Arcadis (UK)

Design & Consultancy for natural and built assets

THE EMERGING ISSUE

PER- & POLYFLUOROALKYL SUBSTANCES (PFASs)

Big Picture, Challenges and Solutions

Ian Ross, Ph.D.,
Global PFASs Lead
Arcadis

Safety Moment: Foam “Disposal”

ARCADIS Design & Consultancy for natural and built assets

Fire Fighting Foam

Free

Darwin, NT

Steve (11 listings)
MEMBER SINCE 2015

13 x 20 litre drums of fire fighting foam

all out of date

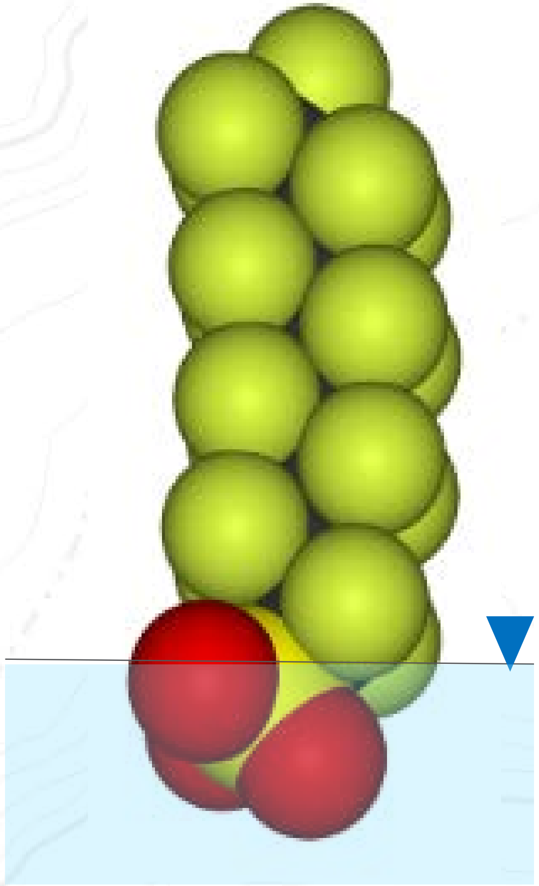
good for fire training

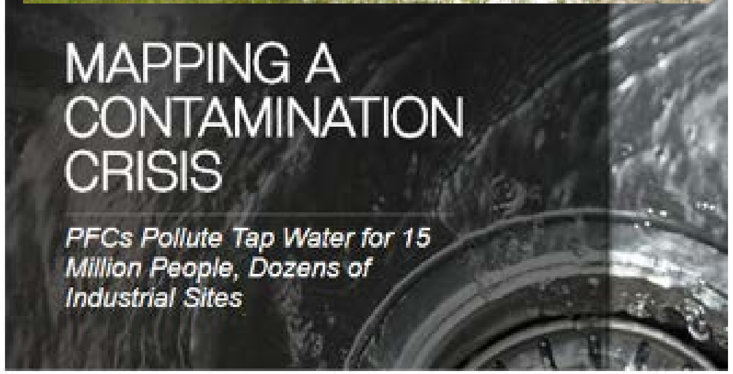
sell as one lot

Gumtree

Presentation Overview

- Whats are PFASs, why an issue?
- Foam chemistry, precursors in foams
- Which foams contain PFASs?
- Replacement chemistry fluorotelomers and C6 short chains are problematic
- Analysis using TOP Assay is essential to detect PFASs in AFFF
- Evolving PFAS Regulations
- GreenScreen Certification
- Pragmatic approach considering the environmental profile of firefighting foams
- F3 foam users
- Summary





PFASs

Specific Characteristics of PFASs

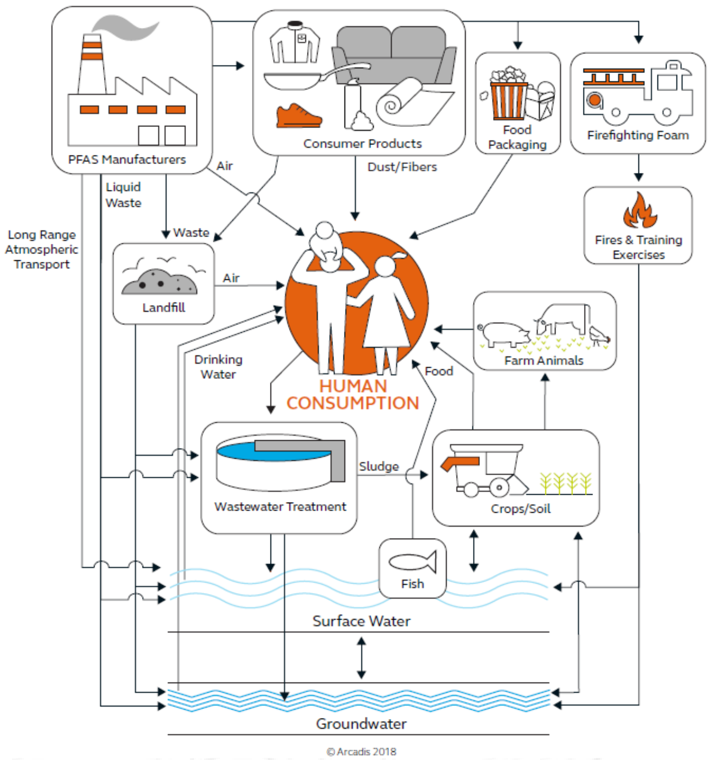
- **Mobility**
  PFASs tend to be very mobile in the environment as they are soluble in water (unlike mos other POPs) and so can travel some distance in groundwater and surface waters.

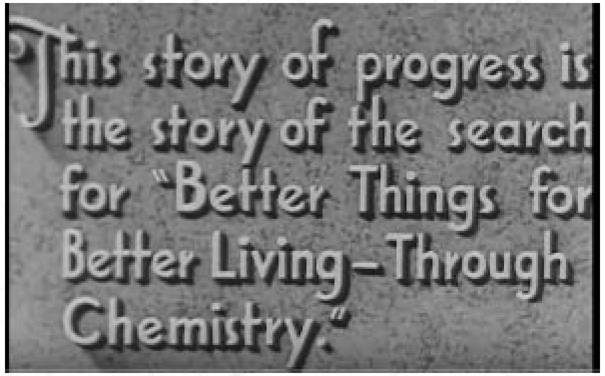
- **Extreme Persistence**
  PFASs show no sign of biodegradation, redefine the term persistence and so have been termed “forever chemicals”

- **Surfactants**
  The surfactant PFAS can coat surfaces / interfaces which become a reservoir for release

- **Bioaccumulation**
  PFASs bioaccumulate and biomagnify via interaction with proteins (not fats like other Persistent Organic Pollutants)
  Long Chain PFASs concentrate humans via renal reabsorption, so we fail to excrete them, whilst monkeys, mice and rats etc. can excrete at much faster rates

- **Toxicity**
  For certain PFASs there are very low (~70 ng/L) and diminishing regulatory acceptance criteria (drinking water standards) as a result of increasing understanding of the PFAS toxicity





https://www.youtube.com/watch?v=qdbTO-5UUFE

Poly- and Perfluoroalkyl Substances (PFASs)

More Commonly Regulated

Polyfluorinated Fluorotelomer "Precursors" -Proprietary PFASs in AFFF

100's of individual unknown parent compounds, but many more daughters e.g. 6:2 FTS, 5:3 acid

Perfluorinated Compounds(PFCs) or Perfluoroalkyl Acids (PFAAs)

~25 common individual compounds, terminal daughters i.e. "forever chemicals"
e.g. PFOS, PFOA, PFHxS, PFBA, PFHxA

Environmental / Higher Organism Biotransformation

Class B Firefighting Foams containing PFASs

- **FP** foams (fluoroprotein foams) used for hydrocarbon storage tank protection and marine applications.
- **AFFF** (aqueous film forming foams) used for aviation, marine and shallow spill fires and AR-AFFF (alcohol resistant aqueous film forming foams),
- **FFFP** foams (film forming fluoroprotein foams) used for aviation and shallow spill fires and AR-FFFP (alcohol resistant film forming fluoroprotein foams)
- High expansion foams not generally considered to contain PFASs

PFASs

Long Chain PFAS Replacements

- Fluorotelomers are not biodegradable they form persistent PFAAs
- Concerns regarding Fluorotelomer precursors and (C6) replacements
  - Multiple intermediate PFASs (~30 PFASs) evolved as fluorotelomers biotransform
  - Evidence of bioaccumulation of intermediates in rats (5:3 acid), invertebrates (6:2 FTS) and short chain PFAA bioaccumulation in edible portion of crops
  - Fluorotelomer precursors described as being 10,000 X more toxic than PFAAs they biotransform into
  - Limited information regarding toxicology of intermediates and PFAAs formed
- Short chain PFAAs, very water soluble, highly mobile, difficult to remove from wastewater, recirculate around water bodies, so more likely to be detected in drinking water
- Persistence and mobility (PMT, vPvM) criteria now being used by European regulators as bioaccumulation (PBT-based regulations) described to be marginally effective to protect drinking water supplies

Environmental Science & Technology

Feature

Mind the Gap: Persistent and Mobile Organic Compounds—Water Contaminants That Slip Through

Thorsten Reemtsma, Urs Berger, Hans Peter H. Arp, Hervé Gallard, Thomas P. Knepper, Michael Neumann, José Benito Quintana, and Pim de Voogt

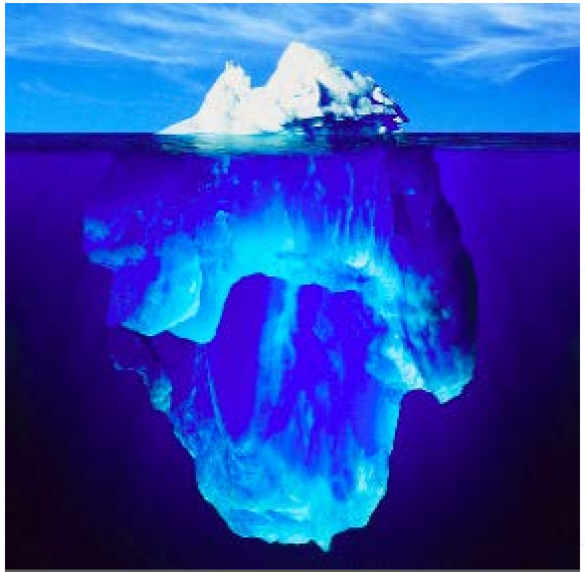
https://www.umweltbundesamt.de/sites/default/files/medien/421/dokumente/01_uba_eisentrager_pmt.pdf

PFASs

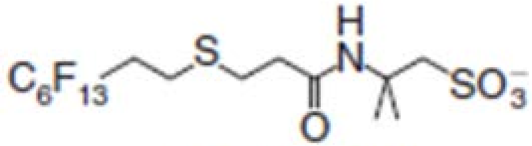
Replacement shorter chain PFASs pose potential larger environmental threat

Chemical Analysis by LC-MSMS

- **US EPA Method 537: Analysis for selected PFAS in drinking water**
  - 12 PFAAs and 2 Precursors:
    - PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUA, PFDoA, PFTrA, PFTeA
    - PFBS, PFHxS, PFOS
    - N-EtFOSAA, N-MeFOSAA
  - EPA 24
    - PFTeDA, PFTrDA, PFDoA, PFUdA, PFDA, PFNA, PFOA, PFHpA, PFHxA, PFPeA, PFBA
    - PFDS, PFNS, PFOS, PFHpS, PFHxSK, PFPeS, PFBS
    - FOSA, 8:2FTS, 6:2FTS, 4:2FTS, N-EtFOSAA, N-MeFOSAA
  - Thousands of precursors and their transient metabolites makes synthesis of a comprehensive set of standards unrealistic
  - Parent precursor PFASs in Firefighting Foams <u>are not detectable using conventional chemical analysis</u>
  - Consider more comprehensive advanced analytical tools:
    - Total Oxidizeable Precursor (TOP) Assay
    - Particle Induced Gamma Emission (PIGE)
    - Adsorbable Organic Fluorine (AOF) / Total Organic Fluorine (TOF)



Conventional analysis will not reflect total PFAS mass



6:2 FTSAS

Precursor from AFFF

Detection of PFASs in Firefighting Foams requires advanced analytical tools

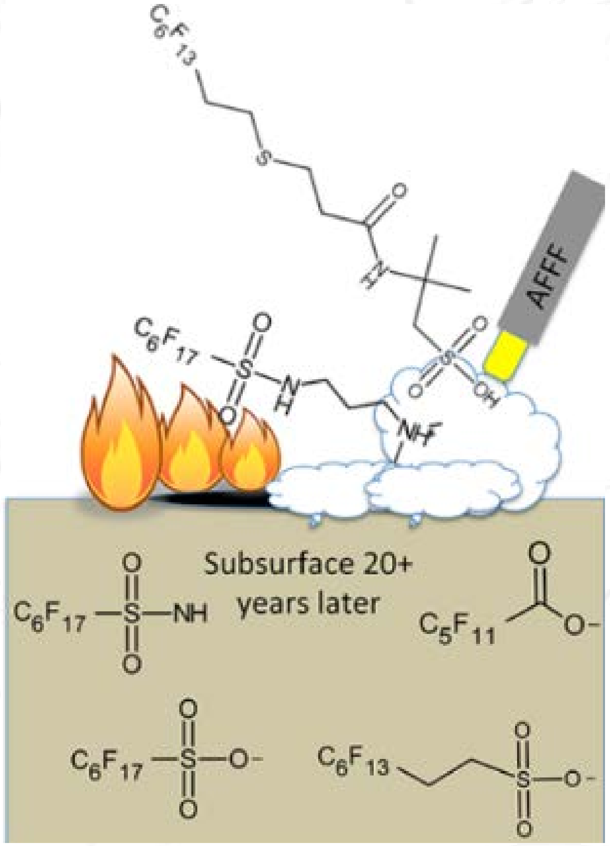
Digest AFFF precursors and measure the hidden mass: TOP Assay

Microbes slowly make simpler PFAA's (e.g. PFOS / PFOA) from PFAA precursors.

Need to determine precursor concentrations as they will form PFAAs

TOP assay is an oxidative digest that can stoichiometrically converts PFAA precursors to PFAA's

TOP assay indirectly measures total precursors as a result of increased PFAAs formed after oxidation vs before.



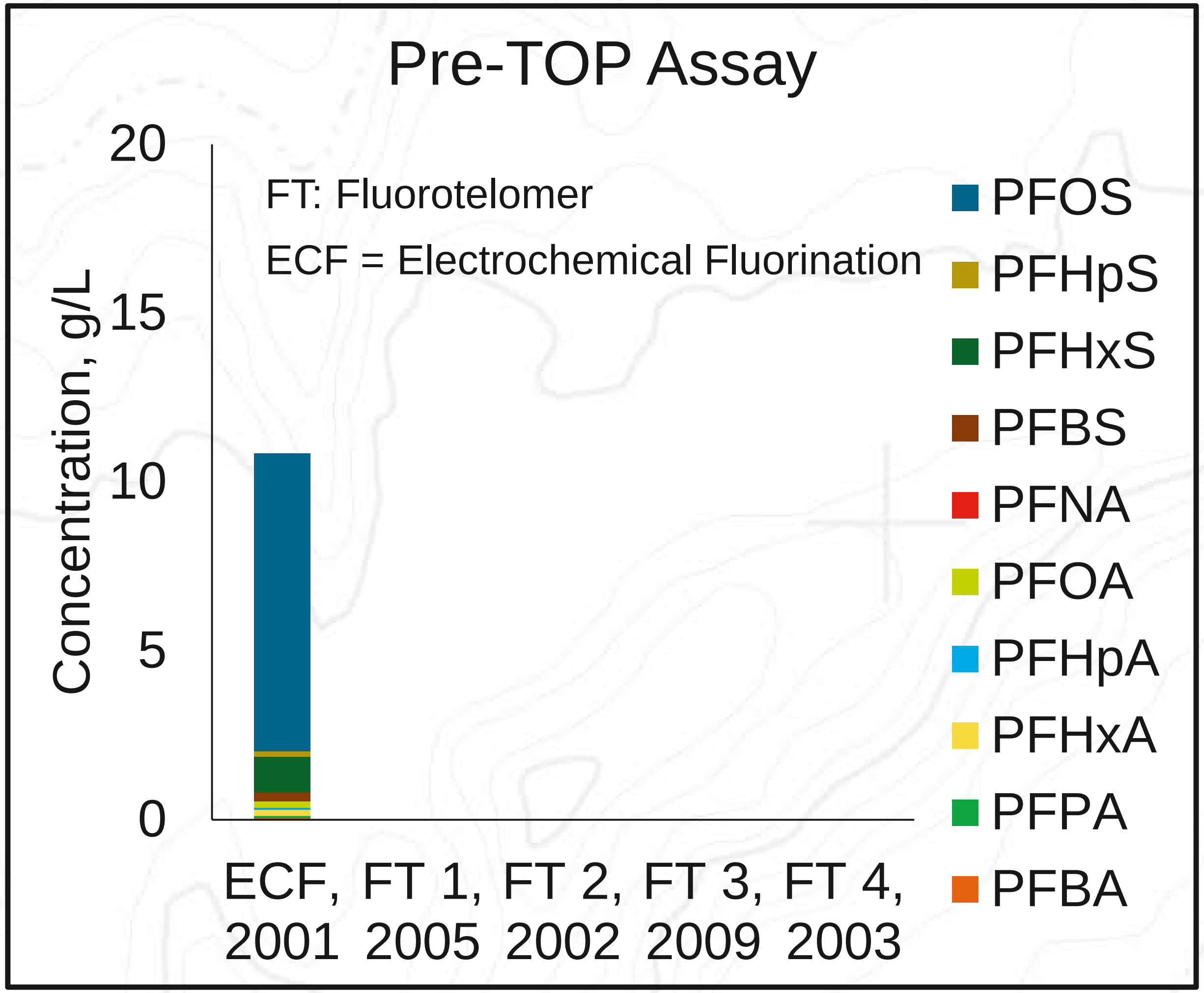
Persistence of Perfluoroalkyl Acid Precursors in AFFF-Impacted Groundwater and Soil

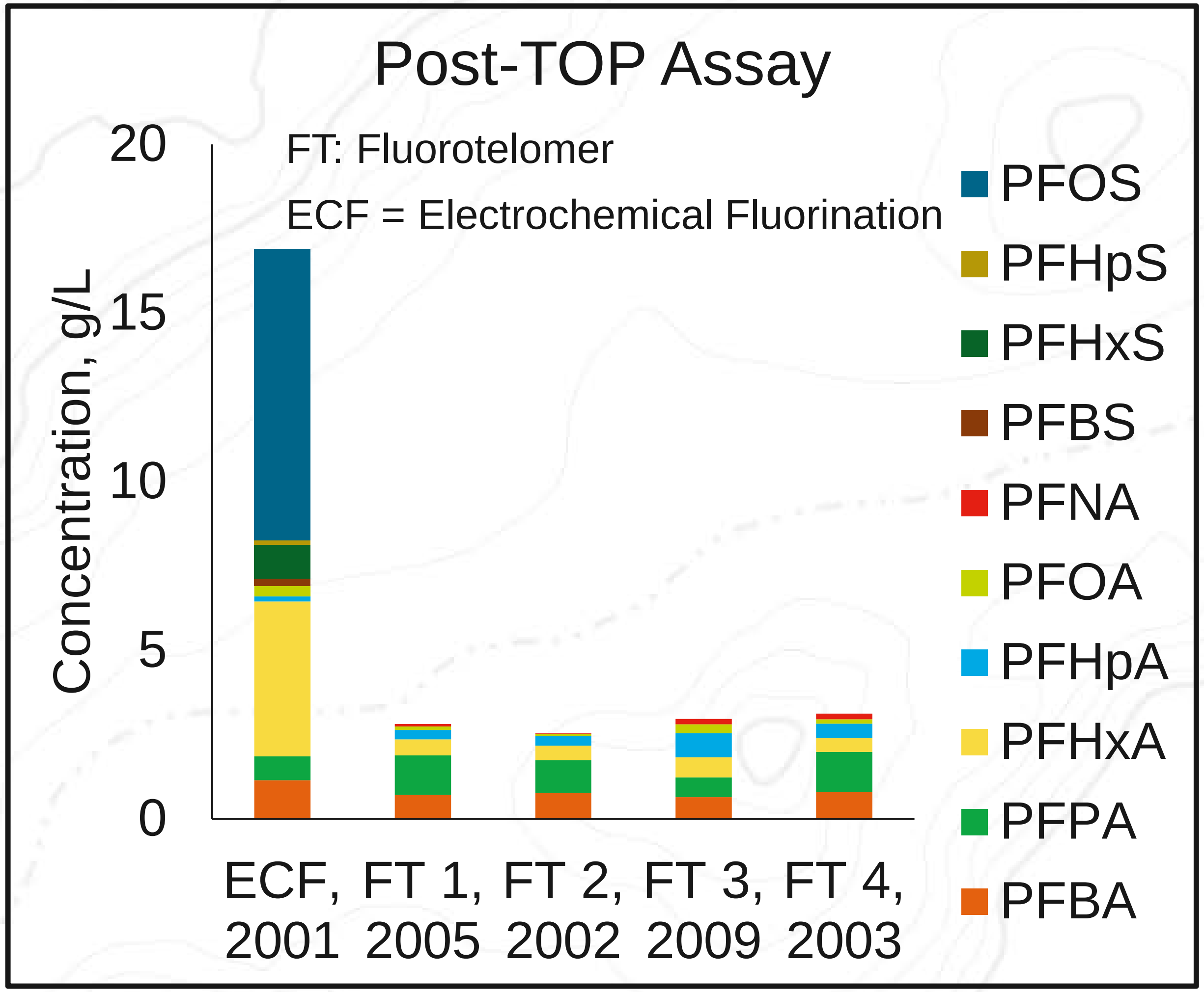
Erika F. Houtz,† Christopher P. Higgins,‡ Jennifer A. Field,§ and David L. Sedlak†,*

PFASs

Analytical tools fail to measure hidden PFAS precursor mass, TOP assay solves this

TOP Assay Applied to AFFF Formulations



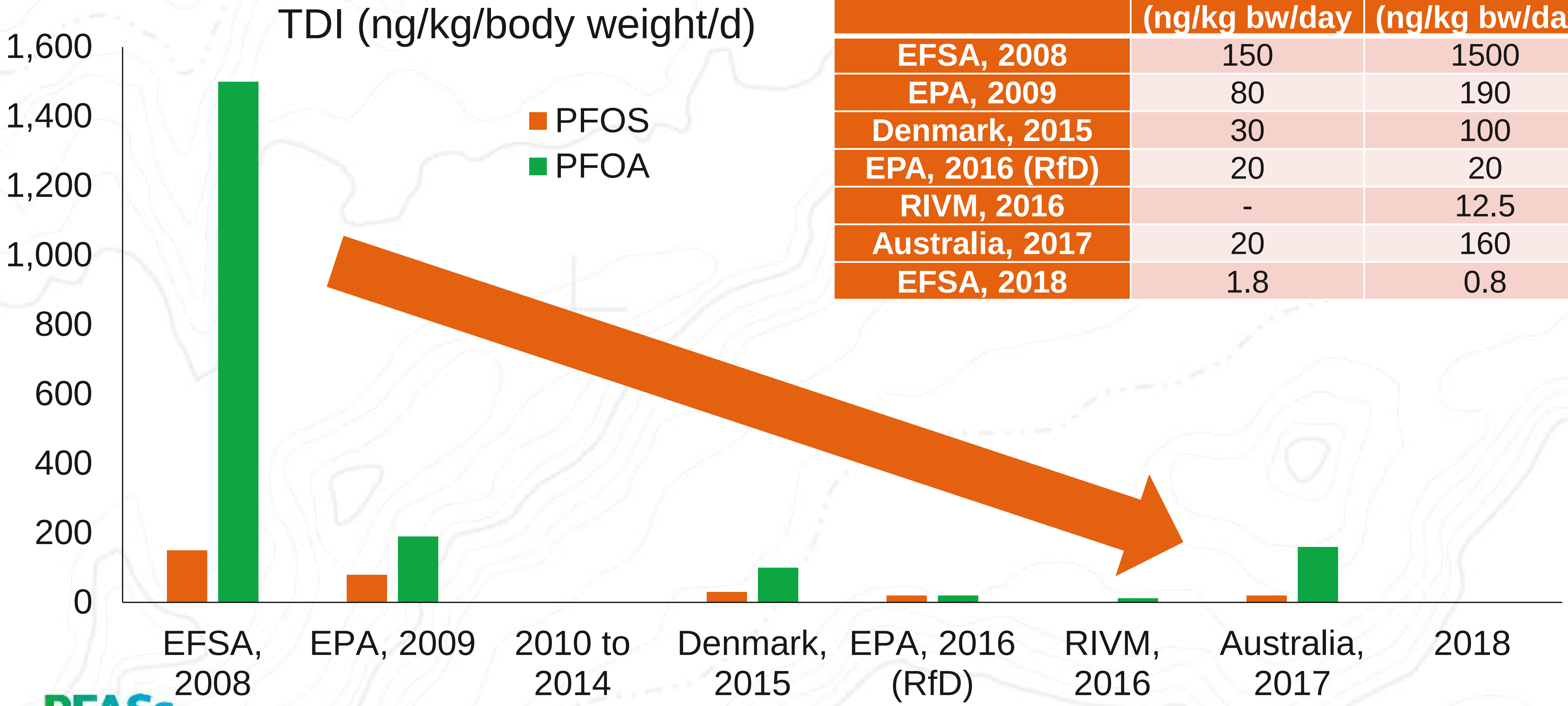


Houtz et al., 2013

Many AFFF formulations may appear PFAS-free until precursors are revealed by TOP Assay

PFASs

Tolerable Daily Intake (TDI)



Source	TDI PFOS (ng/kg bw/day	TDI PFOA (ng/kg bw/day)
EFSA, 2008	150	1500
EPA, 2009	80	190
Denmark, 2015	30	100
EPA, 2016 (RfD)	20	20
RIVM, 2016	-	12.5
Australia, 2017	20	160
EFSA, 2018	1.8	0.8

PFASs

Evolving Regulatory PFAS Values

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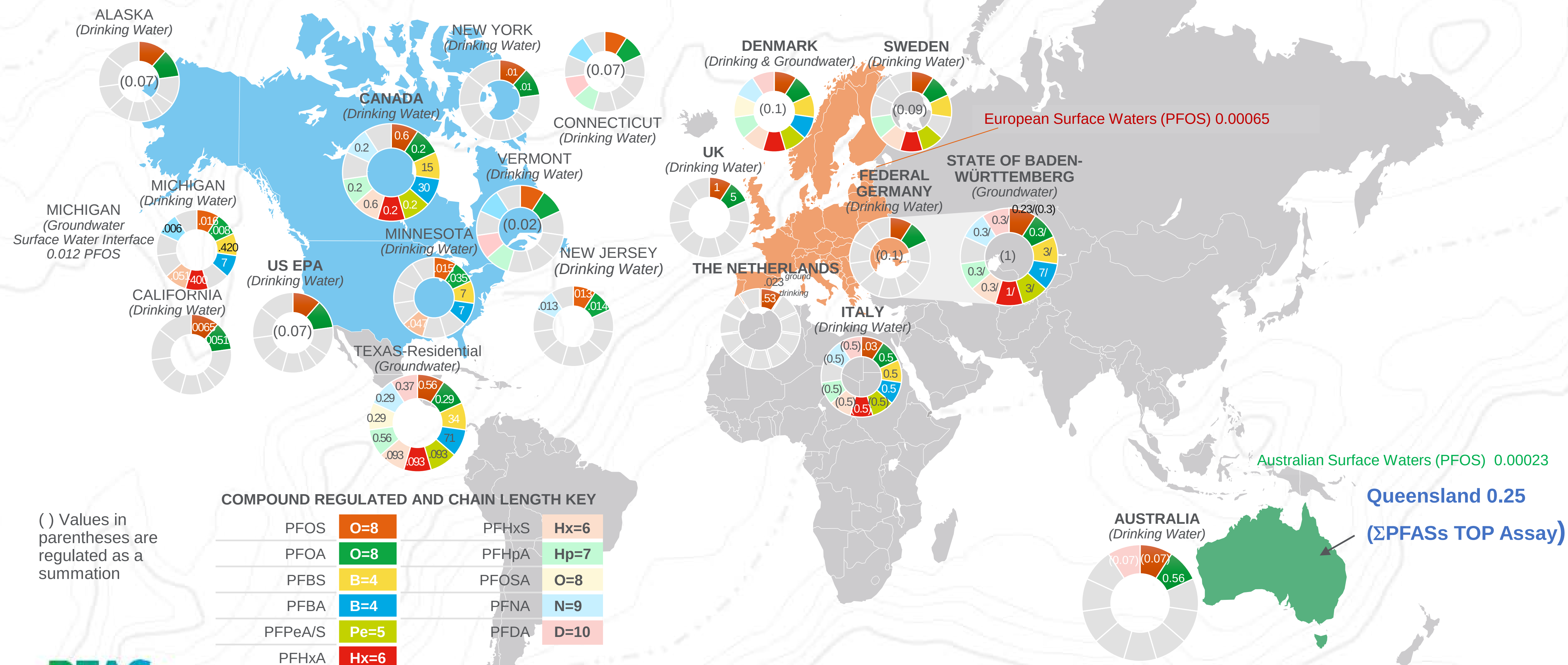
Drinking, Surface and Ground Water (µg/l)



COMPOUND REGULATED AND CHAIN LENGTH KEY

Compound	Key	Compound	Key
PFOS	O=8	PFHxS	Hx=6
PFOA	O=8	PFHpA	Hp=7
PFBS	B=4	PFOSA	O=8
PFBA	B=4	PFNA	N=9
PFPeA/S	Pe=5	PFDA	D=10
PFHxA	Hx=6		

( ) Values in parentheses are regulated as a summation

PFASs

Updated October 4, 2019

US Regulatory Heat Map

Drinking Water and Groundwater (µg/L - ppb)

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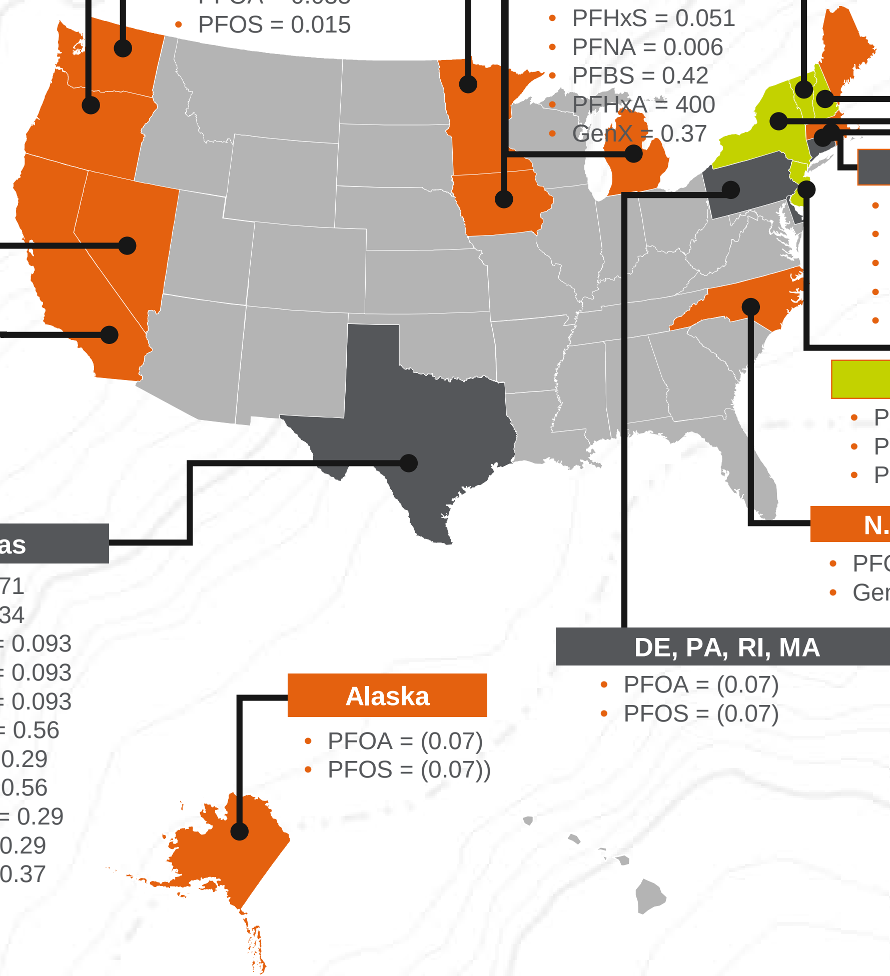
Legend:
- Drinking Water Guideline
- Drinking Water MCL
- Groundwater Guideline



Washington*
- PFOA = (0.07)
- PFOS = (0.07)

Oregon
- PFHpA = 300
- PFOA = 24
- PFOS = 300
- PFOSA = 0.2
- PFNA =1

Nevada
- PFBS = 667
- PFOA = 0.667
- PFOS = 0.667

California*
- PFOA = 0.0054
- PFOS = 0.0065

Minnesota*
- PFBA = 7
- PFBS = 2
- PFHxS = 0.047
- PFOA = 0.035
- PFOS = 0.015

Iowa
- PFOA = 0.07 (0.7)
- PFOS = 0.07 (1)

Michigan
- PFOA = 0.008
- PFOS = 0.016
- PFHxS = 0.051
- PFNA = 0.006
- PFBS = 0.42
- PFHxA = 400
- GenX = 0.37

Vermont
- PFOA = (0.02)*
- PFOS = (0.02)*
- PFHxS = (0.02)*
- PFHpA = (0.02)*
- PFNA = (0.02)*

New Hampshire
- PFOA = 0.012
- PFOS = 0.015
- PFHxS = 0.018
- PFNA = 0.011

New York*
- PFOA = 0.01
- PFOS = 0.01

( ) Values in parentheses are regulated as a summation

Connecticut
- PFOA = (0.07)
- PFOS = (0.07)
- PFHxS = (0.07)
- PFHpA = (0.07)
- PFNA = (0.07)

Massachusetts
- PFBS = 2
- PFHxS = (0.07)
- PFHpA = (0.07)
- PFOA = (0.07)
- PFOS = (0.07)
- PFNA = (0.07)

New Jersey
- PFOA = 0.014*
- PFOS = 0.013*
- PFNA = 0.013

N. Carolina
- PFOA = 2
- GenX = 0.14

Texas
- PFBA = 71
- PFBS = 34
- PFPeA = 0.093
- PFHxA = 0.093
- PFHxS = 0.093
- PFHpA = 0.56
- PFOA = 0.29
- PFOS = 0.56
- PFOSA = 0.29
- PFNA = 0.29
- PFDA = 0.37

Alaska
- PFOA = (0.07)
- PFOS = (0.07))

DE, PA, RI, MA
- PFOA = (0.07)
- PFOS = (0.07)

U.S. EPA Lifetime Health Advisory for Drinking Water

Not enforceable (not an MCL)
- PFOA = (0.07)
- PFOS = (0.07)

EPA is in the process of determining whether MCLs will be set (as of 2019)

PFASs

Updated October 4, 2019

GreenScreen Certified™

- Provision of a full product inventory from foam manufacturers to Clean Product Action under a confidentiality agreement
- Clean Product Action reviews all relevant environmental and human health data
- Data requirements vary by certification level and include :
  - GreenScreen List Translator™ scores and GreenScreen Benchmark scores
  - Product-level acute aquatic toxicity data for fish, aquatic invertebrates and algae
  - Ingredient-level aquatic toxicity and fate data meet USEPA Safer choice criteria (Master criteria or Direct Release criteria)
- Restricted ingredients:
  - Organohalogens, PFASs, Siloxanes, Alkyl Phenols & Alkylphenol Ethoxylates
- Three levels of certification: Bronze, Silver and Gold

Pragmatism Considering Environmental Impacts

- Holistic Approach to evaluating the environmental impacts of firefighting foam essential
- All foams contain glycols which can cause fish kills in static surface water features as the dissolved oxygen is rapidly consumed as the glycols biodegrade
- Milk may cause a short term fish kill by diminishing dissolved oxygen
- AFFF contains higher average glycol levels than F3 foams
- Acute aquatic toxicity associated with any ingredients of F3 will be short lived as biodegradable
- PFASs as ultra-persistent ingredients can cause permanent pollution potentially affecting future generations

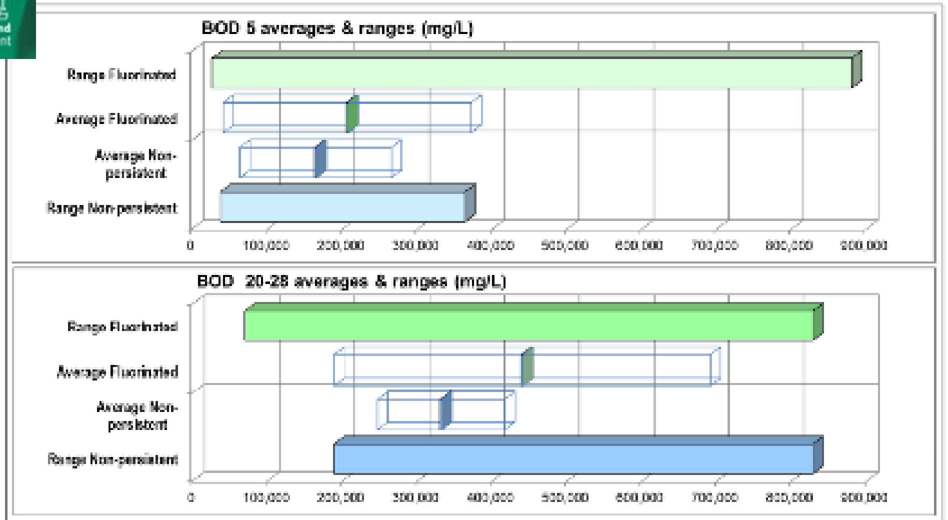


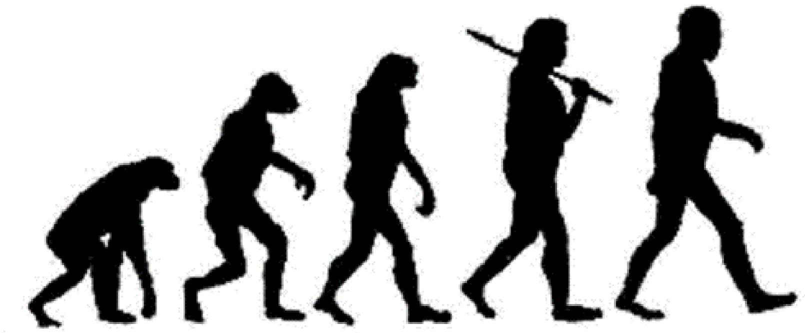
Figure 2.2.1
Comparison of BOD_5 and BOD_{20-28} for ~70 fluorinated and non-persistent foams. Standard deviations (SD_n) shown in outline relative to the average values.

https://environment.des.qld.gov.au/__data/assets/pdf_file/0022/89140/firefighting-foam-policy-notes.pdf

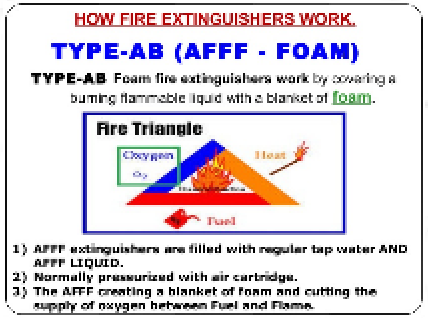
PFASs persist indefinitely whilst their toxicology is studied

PFAS Foams being Replaced

- C8 (PFOS and PFOA) generally phased-out
- C8 replaced with compounds with shorter (C6) perfluorinated chains
- C4, C6 PFAS are less bioaccumulative, but extremely persistent and more mobile in aquifer systems vs C8 - more difficult and expensive to treat in water.
- Solutions for characterizing all PFAS species important to cover current and future risks / liabilities
- Regulations addressing multiple chain length PFAS (long and short) are evolving globally
- Fluorine free (F3) foams contain no persistent pollutants
- F3 foams pass ICAO tests with highest ratings for extinguishment times and burn-back resistance and are widely available as replacements to AFFF



C8 C6 F3 Foams


HOW FIRE EXTINGUISHERS WORK.

TYPE-AB (AFFF - FOAM)

TYPE-AB Foam fire extinguishers work by covering a burning flammable liquid with a blanket of foam.

Fire Triangle

Oxygen O_2 Heat Fuel

1) AFFF extinguishers are filled with regular tap water AND AFFF LIQUID.
2) Normally pressurized with air cartridge.
3) The AFFF creating a blanket of foam and cutting the supply of oxygen between Fuel and Flame.

GREEN APPLE AWARD WINNER 2016

2014 PRESIDENTIAL GREEN CHEMISTRY CHALLENGE AWARD winner

RE-HEALING FOAM
AUTHENTIC FLUORO-FREE

PFASs

Performance of F3 Foams

Lars Andersen, Fire Chief, Royal Danish Airforce:

“Put you self in the place of a crewmember trapped in a fuselage engulfed in flames. Ask yourself a question; would I trust the fluorine free foam? I would.”

https://www.linkedin.com/pulse/high-flow-fluorine-free-foam-lars-andersen/

“My experience is that fluorine free foam works flawlessly. We have used it in two major incidents, and we are using it for training purposes”

“When it comes to the extinguishing capability of the fluorine free foam, there are, from my point of view, no difference compared to the old AFFF foam containing PFAS. It works exactly as good as the old stuff.”

https://www.linkedin.com/pulse/how-fluorine-free-foam-does-work-practice-lars-andersen/

Royal Danish Airforce in action using F3 foams

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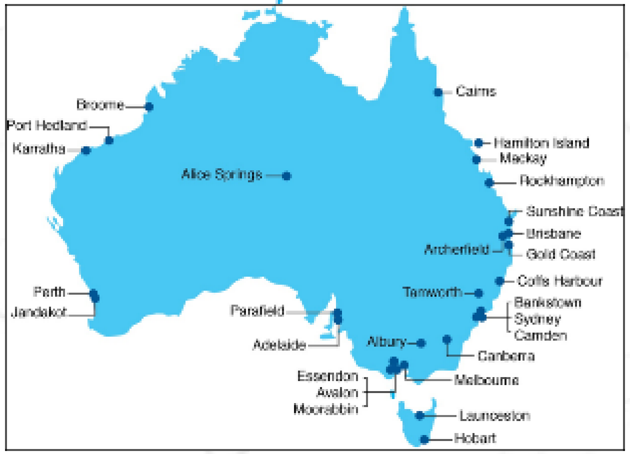
Civil Aviation: F3 Foams Users

airservices connecting australian aviation



Airservices Australia. : Re-Healing Foam is in use on all 27 airports

Dubai Airports

Dubai World Central

Dubai International

Stuttgart Airport

Köln Bonn Airport

Dortmund Airport 21

Blackpool International Airport

nqy newquay airport

Allgäu Airport Memmingen

norwegian

SAS Scandinavian Airlines

Bristol Airport Amazing journeys start here

Billund Airport - West Denmark direct

Guernsey Airport YOUR GATEWAY TO THE CHANNEL ISLANDS

Copenhagen Airports CPH

Is the burst of the AFFF bubble a precursor to long term environmental liabilities?

Ian Ross from Arcadis explains how the use of new generation Fluorine Free foams are not only playing a key part in aviation fire extinguishment, but also helping to mitigate the widespread environmental concerns surrounding PFASs.

https://www.internationalairportreview.com/article/98795/fire-fighting-foam-chemicals-water/

Summary

- PFASs are increasingly being found in drinking water
- Firefighting foams contain precursors to the PFASs that are increasing being regulated
- Replacement chemistry fluorotelomers and C6 short chains are problematic
- Analysis using TOP Assay is essential to detect PFASs in AFFF
- PFASs regulations becoming more comprehensive and conservative
- Greenscreen Certification available for foams
- Many sectors have transitioned or are transitioning to F3 foams

PFASs

Nigel Holmes
Queensland (Australia) Department of Environment & Science

The Queensland Experience
Transitioning from persistent foams

Nigel Holmes
Principal Advisor Incident Management
Incident Response Unit

Foam environmental characteristics

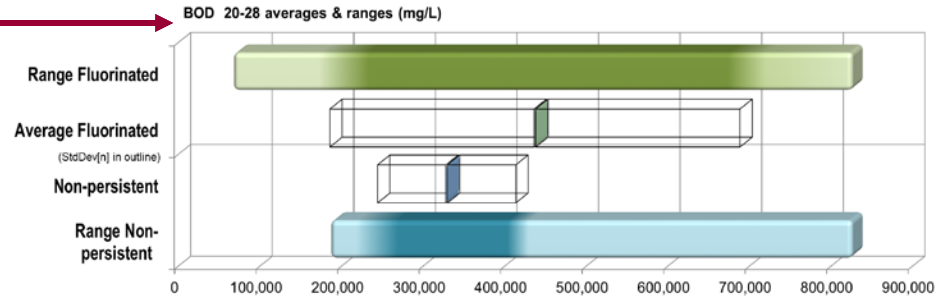
CLASS B FOAMS
Liquid fuel fires
(hydrocarbons, solvents)

Persistent
(AFFF, FFFP, FP, etc.)

Non-persistent
(fluorine-free)

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

Short-term (aquatic) toxicity – ALL very LOW
Oxygen depletion potential – ALL very HIGH



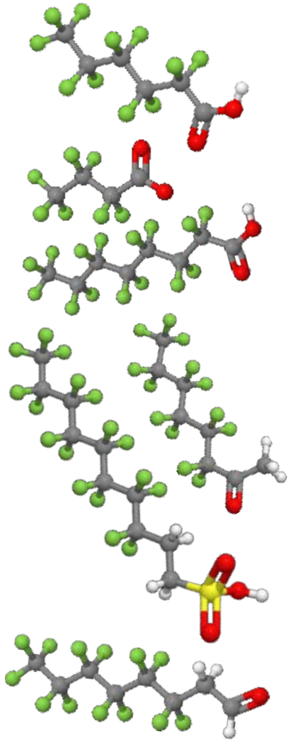
E.g., BOD versus raw sewage at 300-400 mg/L

Long term – PFAS
Indefinitely persistent
Long-term toxicity
Bioaccumulative

(Non-persistent)
(Short-term effects)
(Biodegradable)
(Natural remediation)

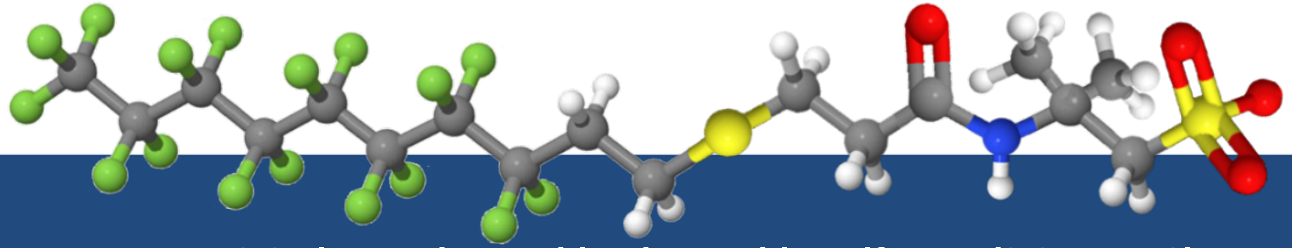
ALL FOAMS MUST BE MANAGED – NO FOAM IS “*ENVIRONMENTALY FRIENDLY*”

PFAS – Queensland’s Realisation of Liability



>5,000 PFAS

- Emerging PFAS awareness and concerns globally (2000→).
- Not a new risk, just a recent wake-up from emerging science.
- Firefighting PFAS foam identified as high-risk, dispersive use.
- Information vacuum and steep learning curve 2011-2016.
- Complex information of variable reliability and bias (↑↓).
- High socio-economic, health and environmental costs.
- Obligation to act under the *Precautionary Principle.*
- Phase-out of PFAS and transition to alternatives needed.
- Risks and pathways to transition initially unclear.

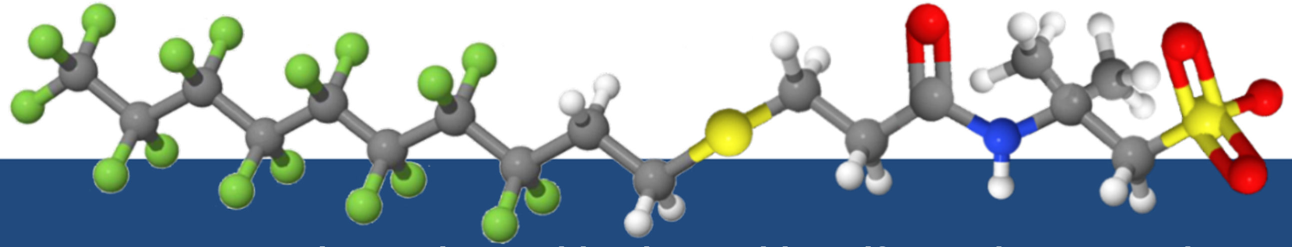


AFFF - 8:2 Fluorotelomer thioether amido sulfonate (8:2 FtTAoS)

PFAS – Drivers for change and the scale of effects

VERY HIGH SOCIAL & ECONOMIC COSTS

- Resource degradation (soils, **drinking water sources**,...)
- Social values (amenity, recreation, tourism,...)
- Economic values (**fisheries, crops, livestock**, land values,...)
- Costs to business & community (cleanup, land use limitations,...)
- Legacy sites (collateral impacts, **cleanup costs**, wastes,...)
- **Reputation** (corporate, industry, **political**, location,...)
- **Health impacts** (persistent, toxic, bioaccumulative chemicals,…)
- Environmental values (waterways, wildlife,...)
- **Legal actions** & claims growing (against manufacturers & end users)



AFFF - 8:2 Fluorotelomer thioether amido sulfonate (8:2 FtTAoS)

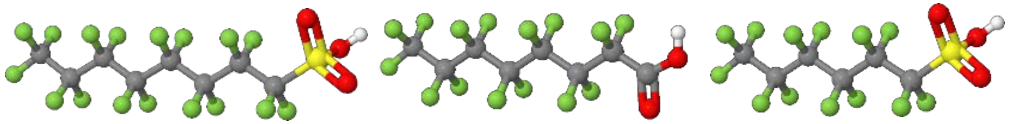
What are “PFAS” anyway

“Per and poly-Fluoro Alkyl Substances”

ALL have fluorinated carbon chains (CF_3-CF_2-…)

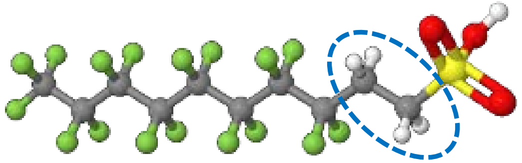
PER-fluorinated = fully fluorinated C-chain

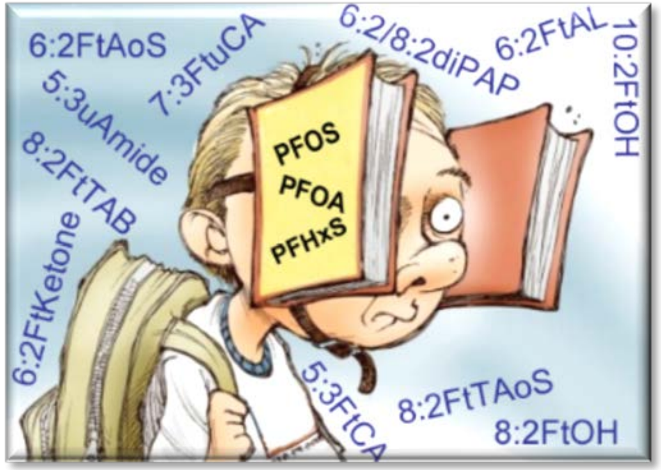
- E.g. PFOS, PFOA & PFHxS
  (legacy foams)



POLY-fluorinated = not fully fluorinated C-chain

- Fluorotelomers (Ft)
  (current foams)





ALL are, or transform to indefinitely persistent Perfluorinated-PFAS

Measuring PFAS in foam

Analyses Problems:

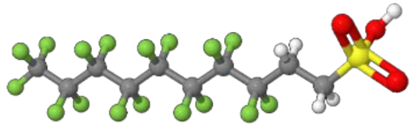
- About 200-600 PFAS associated with foam.
- Standard analysis only measures 20-40.
- 60% to 90%+ hidden to standard analyses.

PFOS, PFOA & PFHxS occur in legacy foams.

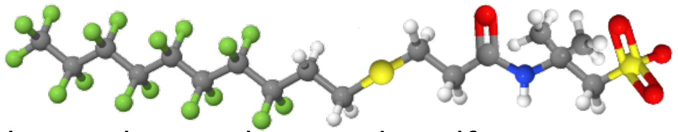
FLUOROTELOMERS (Ft) in current foams.

- More inclusive analysis method was needed.
- **TOP-A** (total oxidisable precursor assay)
  - Converts hidden Ft to measurable PFCAs.
  - C-chain length used as surrogate for risk.

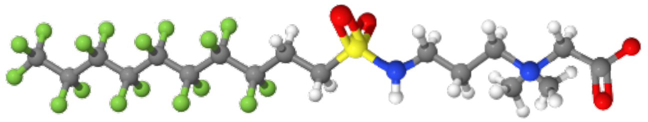
Foam Fluorotelomers



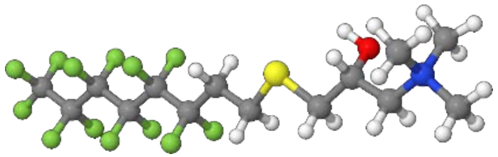
Fluorotelomer Sulfonates C4-C8



Fluorotelomer Thio Amido Sulfonates C4-C14



Fluorotelomer Sulfonamido Alkyl Betaines C4-C12



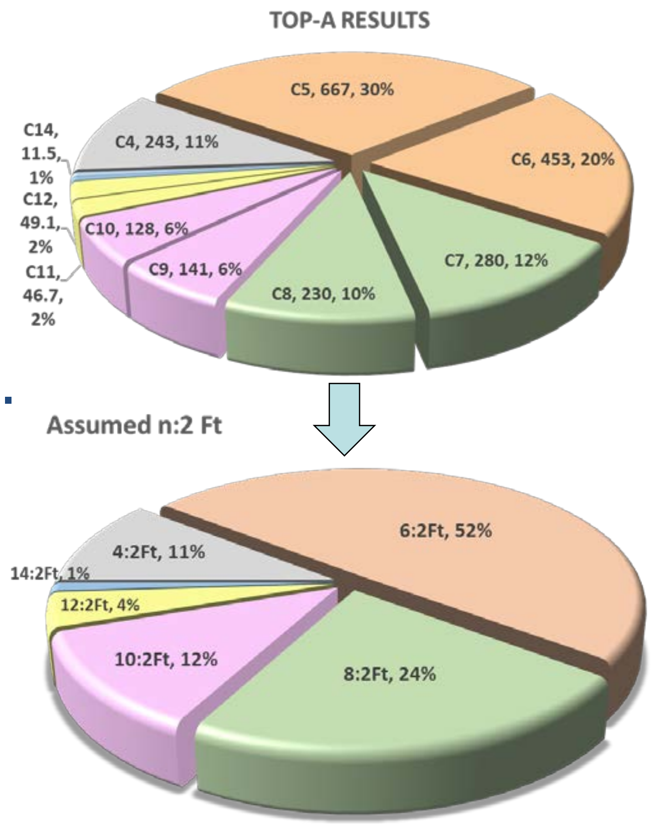
Fluorotelomer Thio Hydroxy Ammonium C4-C14

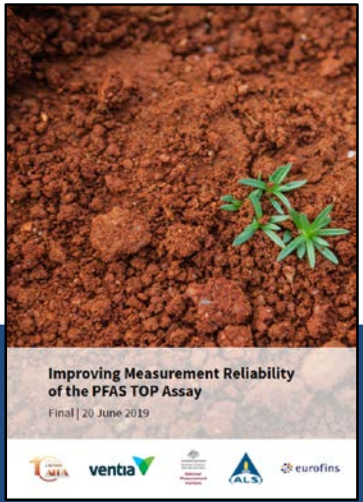
TOP-A Carbon chain length ≈ toxicity & bioaccumulation

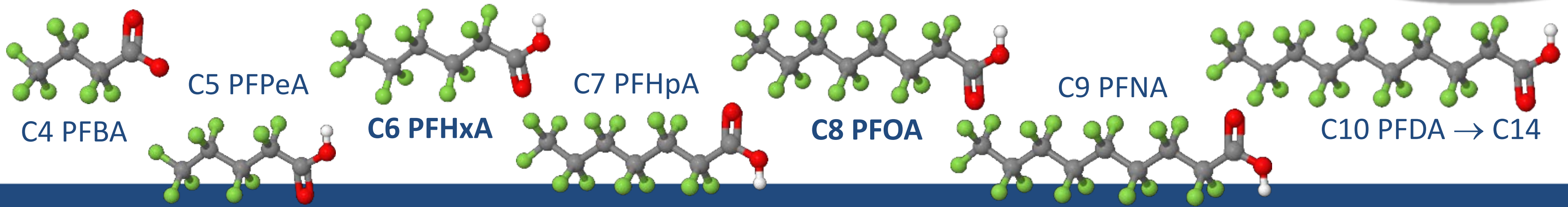
Measuring PFAS in foam

TOP-A (total oxidisable precursor assay)

- Original method by Houtz & Sedlak 2012.
- High organic content interferes with oxidation.
- Method now refined to take into account the organics.
- More aggressive than biotransformation, <u>but</u>
- Indicative of foam Ft chain-length distribution (≈risk).
- C4-C14 limits cover the expected foam Ft content.
- TOF-CIC as check on total organic F content/losses.







(TOF-CIC = Total organic fluorine by combustion ion chromatography analysis)

Queensland Government

The Queensland Foam Policy

PRACTICALITIES & CONCESSIONS

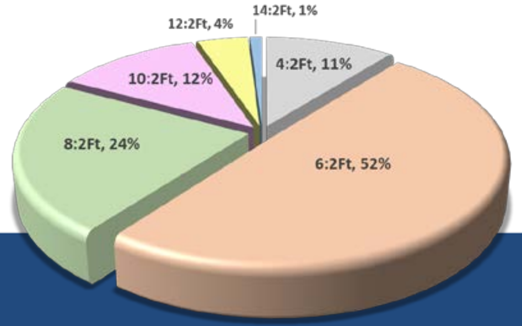
- Balancing Safety-Performance-Cost-Environment issues.
- Assessing risks to values as inputs to setting priorities.
- Setting achievable stages and timelines for transition.
- Interim physical or procedural measures to reduce risk.
- Setting achievable standards for cleanout of systems.
- Accepting contamination from residues in new foam.
- Accepting interim limited (conditional) use of C6 products until particular alternatives are fully developed and proved viable.
- Facilitating new waste disposal technologies.

The Queensland Foam Policy

Persistent
AFFF, FFFP, FP, etc.

Phase-out of PFAS foams

- Phase out over 3 years (2016 to 2019).
- Regulatory mechanisms to allow justifiable extensions of time.
- During transition - full containment of all PFAS foam wastes.
- C6 pure foams permitted if they are the only viable alternative.
- C6 pure foams must be certified pure and fully contained.
- Allowable levels set for C7+ contamination in new foams.
- PFAS waste contained and disposed of in approved manner.



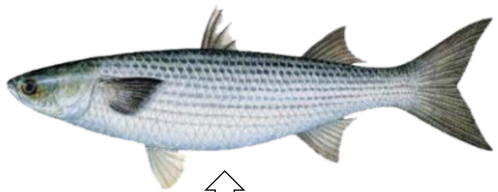
*C6-based foam is NOT C6 PURE

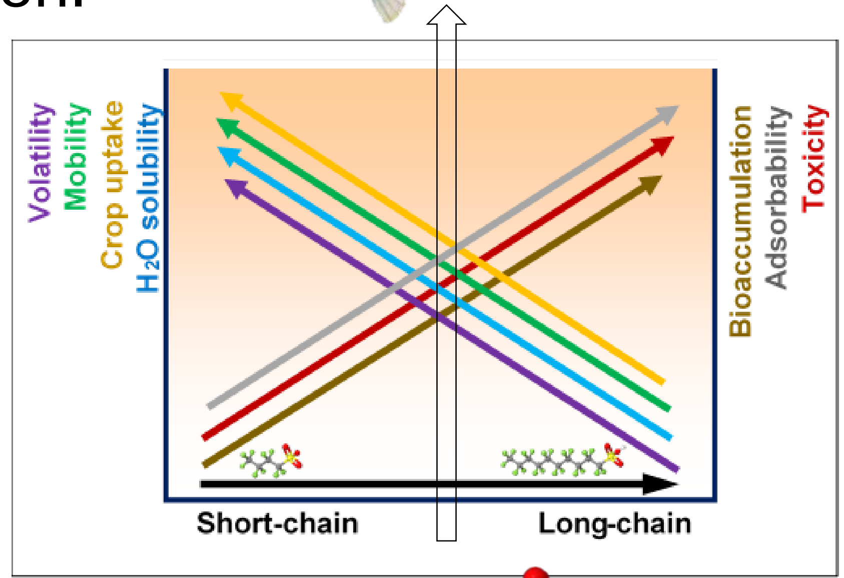
Short-chain PFAS (“C6”) - *Regrettable Substitution*

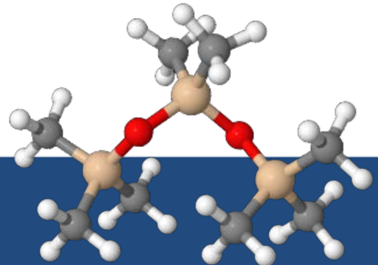
Short-chain PFAS particularly problematic:

Less toxic but countered by…

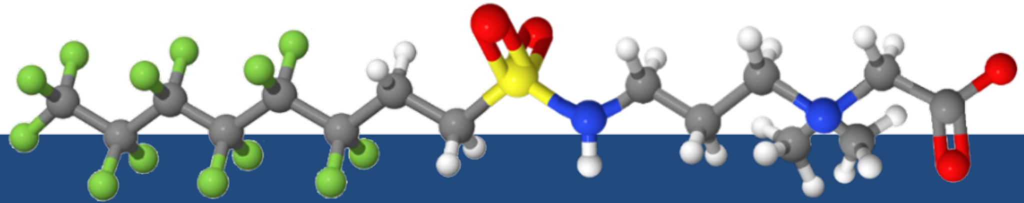
- Increasing exposure from increasing accumulation.
- High mobility in soils and groundwater.
- Displaced to groundwater by larger PFAS.
- Readily taken up in food crops.
- Recirculates in the environment & food chain.
- Bioconcentration up the food chain.
- Very difficult/expensive to remediate.



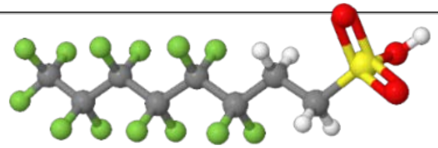




Siloxanes?



AFFF - 6:2 Fluorotelomer sulfonamide propyl betaine



6:2 Fluorotelomer sulfonate bioaccumulation

Global Directions on PFAS – The future for "C6"

Stockholm Convention

*"Recognizing the importance of developing and using environmentally sound **alternative processes and chemicals.**"*

Recent Stockholm Convention decisions and recommendations

- PFOS, PFOA and related substances flagged for phase out.
- PFHxS and related substances to be listed for elimination.
- Appropriate disposal of wastes in a sustainably sound manner.

Short-chain PFAS longer-term prospects

The Stockholm Convention decisions and recommendations (2018-19) included:

> **"*… a transition to the use of short-chain per- and polyfluoroalkyl substances (PFASs) for dispersive applications, such as fire-fighting foams, is not a suitable option from an environmental and human health point of view*".**

Foam types under the Policy

Non-Persistent	C6 Pure PFAS	Long chain PFAS	PFOS & PFHxS
Class A Hi-expansion Class B Fluorine-free	Must be certified <50 ppm ≥C7 <10 ppm PFOS+PFHxS	Most current foams. "*C6-based*" contain ≥C7 PFAS ≤10 ppm PFOS+PFHxS	3M Lightwater. Other PFOS contaminated stocks.
Must be contained from release as far as practicable.	Must be fully contained in impervious bunding or sumps.	Must be phased out by 07 July 2019. Interim containment measures put in place. Or TEL for extended transition.	Must be withdrawn from use immediately.
Regulated waste (surfactants). May be disposed of to sewer, composting or by on-site treatment.	Regulated waste (organohalogens & surfactants). Dispose of by high-temperature incineration. E.g. plasma-arc furnace or cement kiln.		

Cradle-to-Grave considerations

Foam disposal and destruction options

CLASS B FOAMS
Liquid fuel fires
(hydrocarbons, solvents)

Non-persistent
(fluorine-free)

Standard biodegradation methods
(e.g. WWTP)
$

Persistent
(AFFF, FFFP, FP, etc.)

PFAS - High temperature destruction
(~1100C)
$$$

PHASE OUT MEANS WASTE

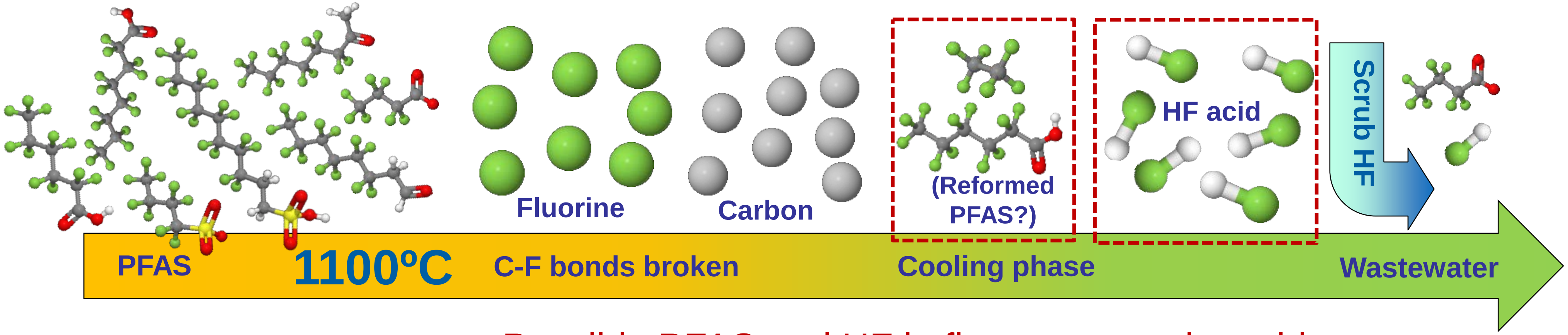
The PFAS destruction problem

- Limited facilities to handle PFAS
- Limited throughput (25L/hr)
- Fine liquids only, no solids
- High cost, energy intensive
- Flexible alternative needed.

PFAS waste destruction

Standard High Temperature Incineration problems

- High temperature to break carbon-fluorine bonds (~1100°C)
- Potential release of hydrofluoric acid in flue gasses
- Potential for residual PFAS or for C+F to reform PFAS
- Strict process control required, slow throughput, $$$

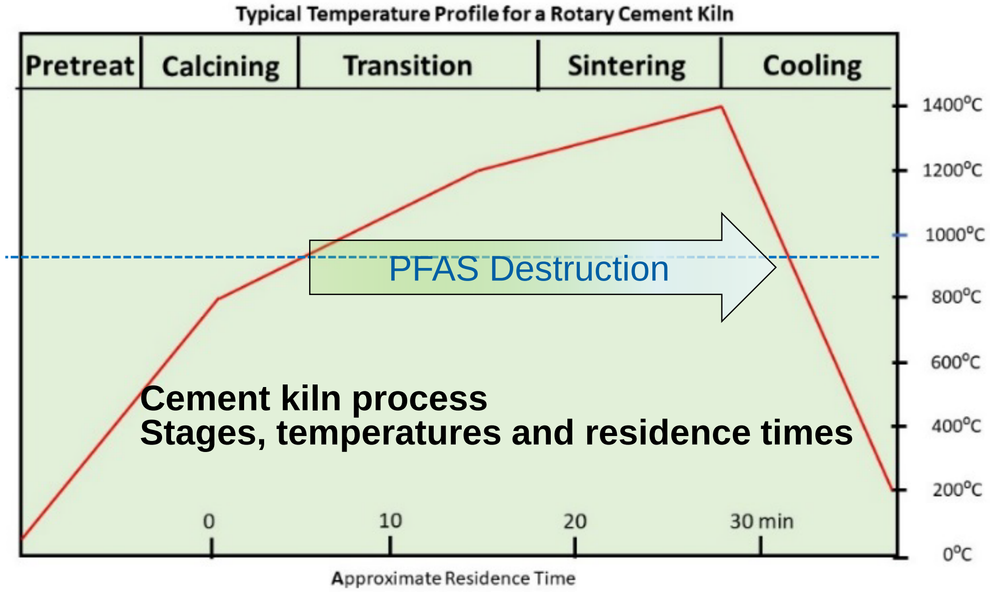


Possible PFAS and HF in flue gases and scrubber wastes

PFAS waste destruction

Cement kiln alternative

- High temperatures
- Long residence times
- **Very high calcium content**
- PFAS input with fuel



Cement kiln process
Stages, temperatures and residence times

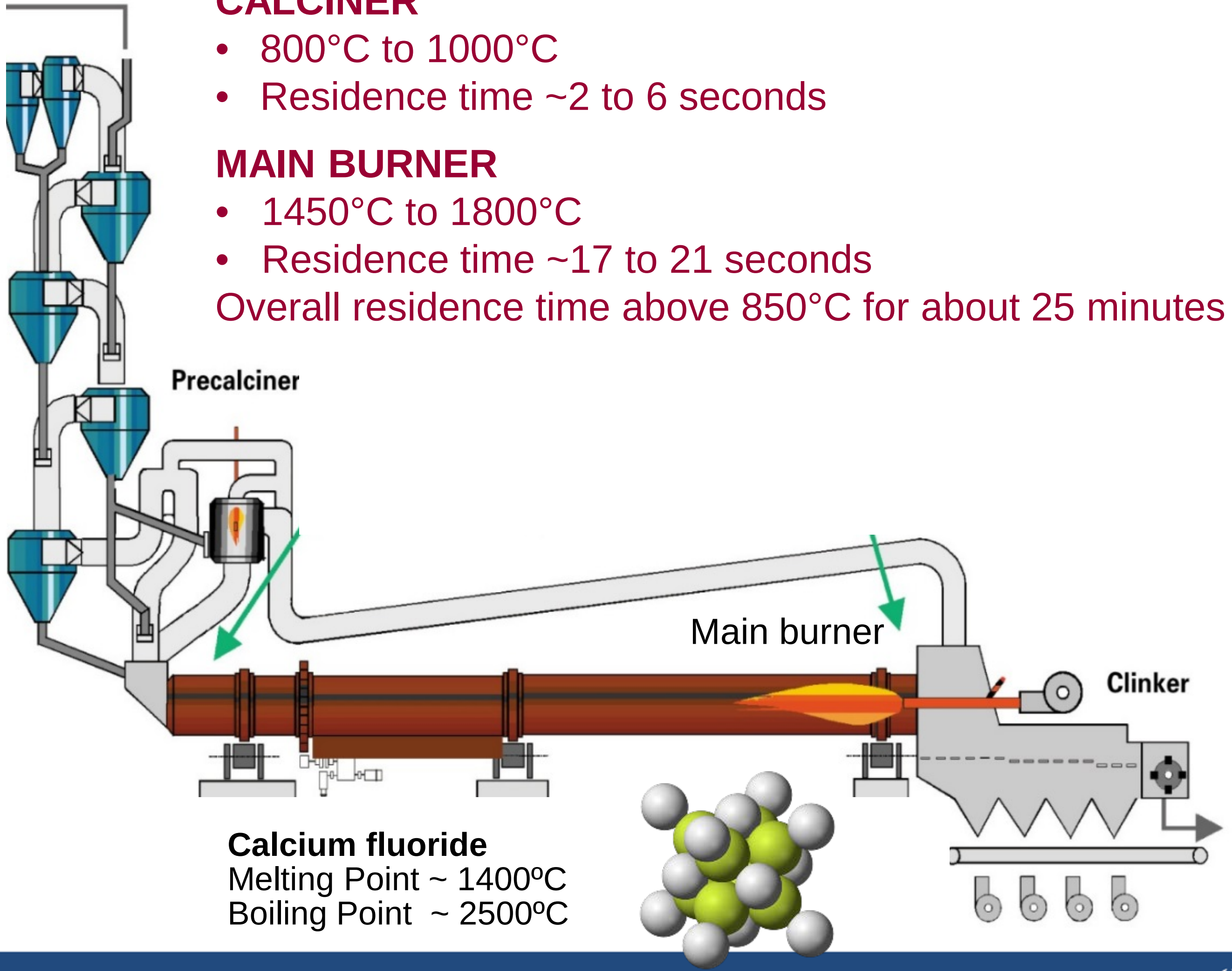
CALCINER

- 800°C to 1000°C
- Residence time ~2 to 6 seconds

MAIN BURNER

- 1450°C to 1800°C
- Residence time ~17 to 21 seconds

Overall residence time above 850°C for about 25 minutes



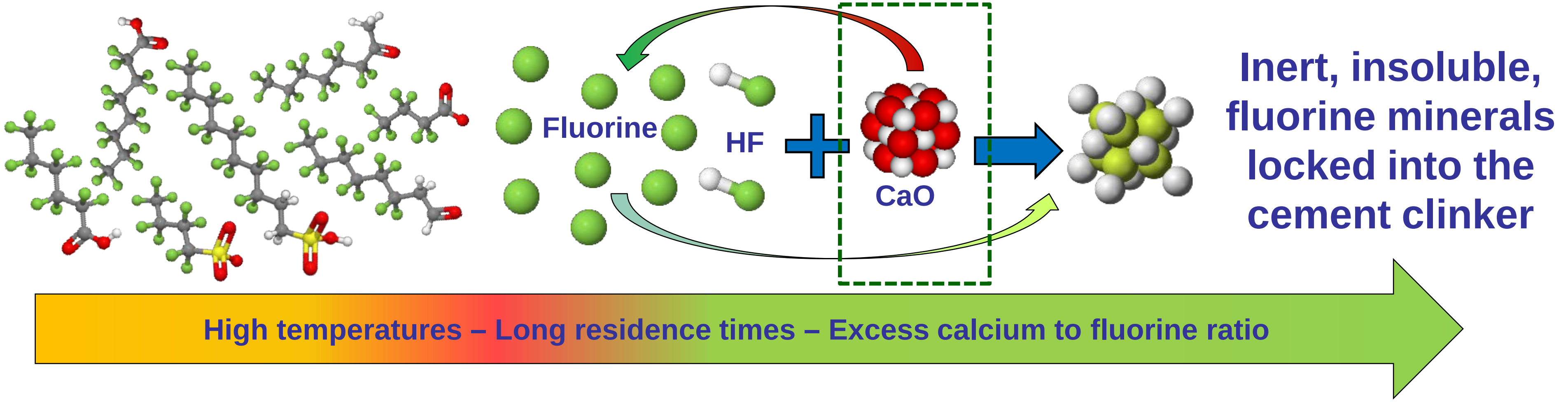
Calcium fluoride
Melting Point ~ 1400ºC
Boiling Point ~ 2500ºC

Geocycle/Cement Australia at Gladstone (Australia) now licensed for PFAS destruction

PFAS waste destruction

Cement kiln process controls and safety factors

- High temperatures and long residence times to break C-F bond.
- Calcium progressively strips out any free fluorine or HF.
- Stable cement clinker production conditions exceed requirements.
- Insoluble, inert CaF_2 - no end-point wastes for disposal.

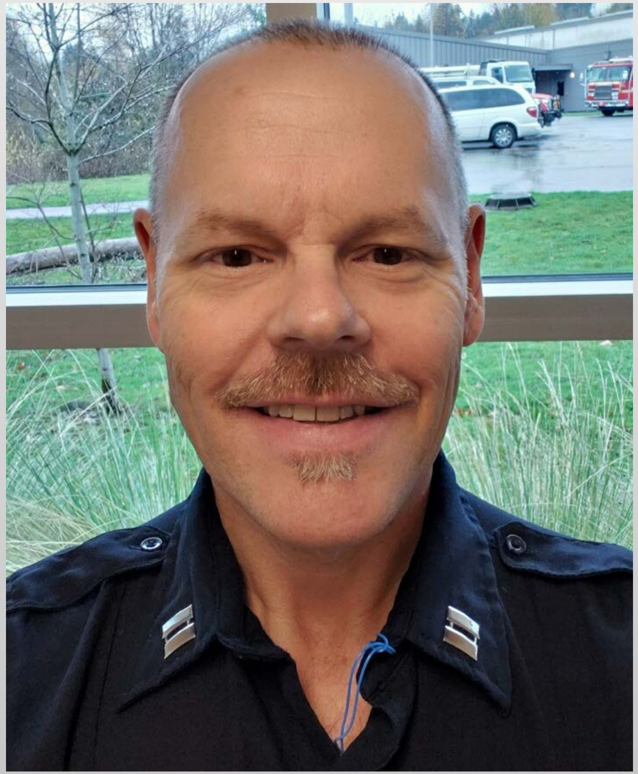


Energy neutral (no extra fuel) as fluorine catalyses cement clinker production
Calcium catalyst / Fstripping could be applied in standard high temperature incineration.

Thank you

Nigel Holmes
Principal Advisor Incident Management
Incident Response Unit
Queensland Department of Environment and Science

Captain Kurt Plunkett
Seattle Fire Department



Seattle Fire Department
Firefighting Foam Operations

Seattle Fire Department
Firefighting Foam Operations

Seattle began researching changes to foam operations in 2003

- **New Fireboats**
  - **FoamPro equipped Engines (pumpers)**
    - **Desire for a multi-fire class foam: A/B/D/K**

Universal Extinguishing Foam

- Non toxic
- Non-corrosive
- Rapid cooling effect
- No reportable hazardous substances
- Compatible with other finished foams at incidents
- Rated to extinguish 3-D fires:

  cascading, boiling, pressurized

Overhaul - use at 0.1%

Class A/D/K Fire - use at 0.4%

Class B Fire - use at 0.5%
including polar solvents

Structural Firefighting with Foam

Structural Firefighting with Foam

- Use standard fire flows:
  - Volume/100 ***or***
  - Area/3

Structural Firefighting with Foam

Los Angeles County Fire Dept
2001- Structure Fire Tests

- 3 identical 1100 ft^2 homes - lath & plaster ramblers with identical furnishings
- 4 rooms in each structure set afire; windows pulled at approx 700°; fires free-burned prior to attack
- Same Engine crew fought each fire, flowing 90 gpm
  - Water **- Foam** - Compressed Air Foam
- Data was collected throughout the testing
- Foam beat water in controlling the fire

Product Testing

Seattle Fire Department performed comparative product testing at the Grant County Airport and at the Washington State Fire Training Academy

- Class B fuels
  - 2-D pooled fuel
  - 3-D spray fires
- Ethanol
- Piled auto tires
- Magnesium shavings & engine blocks
- Class A fuels

❖ Current foam product was selected for use

Structural Firefighting with Foam

ATF: proper use of foam does not impede timely fire investigation; no effect on canine operations

Firefighting Foam

Proper Overhaul

- Expose char
- Low percentage foam
- Turn debris piles

Following knockdown of the fire, lower the foam percentage

Use at 0.1% for Overhaul

Firefighting Foam

WETTING AGENT APPLICATION

Use at 0.1% for Overhaul

Class B Firefighting

Hydrocarbons

Polar Solvents

Class B Firefighting with Foam

Use proper application technique: **0.5%**

- Shallow spills - parallel to ground, sweeping attack
- Deep fuels - gentle application to surface

Class B Firefighting with Novacool

Spill fires - shallow, spreading fuels

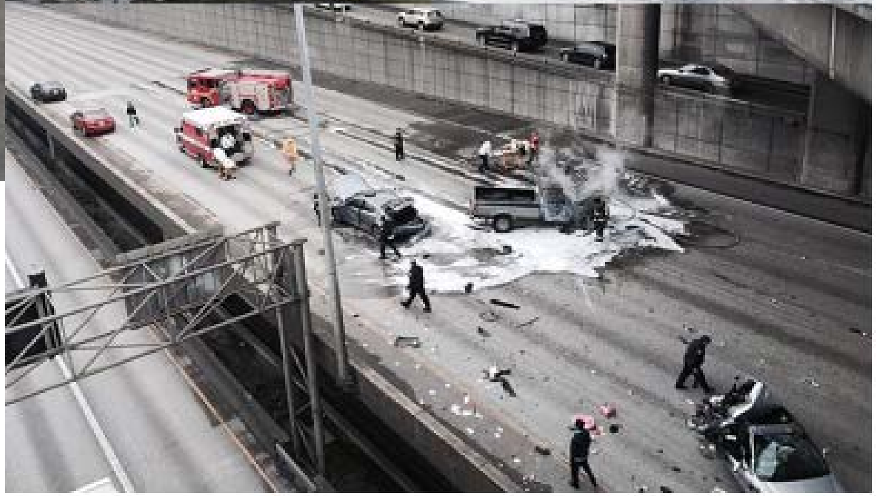
Class B Firefighting with Foam

Deep Fuels – pooled fuels or tanks

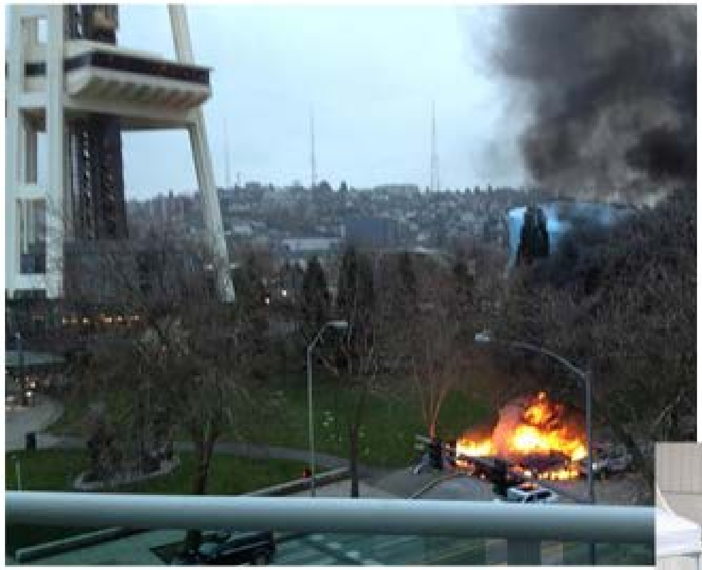

Gentle Foam Application
to the Surface of Deep Fuels

Firefighting for multi-class fires

- Fire control will be easier when the proper application techniques and application rates are used
- Continue to staff a foam line after knockdown
- For vapor control, use an air monitor & maintain a foam blanket when necessary
- Avoid moving through the fuel if possible



Using water, enhanced with firefighting foam, to extinguish a vehicle fire on the freeway



Engine 5 at the helicopter crash by the Space Needle.

Note the foam solution from the fire hose.

MARINA FIRES

Firefighting Foam

Overhaul - use at 0.1% as a wetting agent

Despite hard work, numerous access points, thousands of gallons of water, and foam application, these containers had to be dumped out onto the pavement in order to achieve extinguishment. The plastic wrapping around the products shielded the combustibles from extinguishment. Terminal 18, 10/11/08

Firefighting Foam

Rated for

Class A/D/K Fires

at 0.4%

SFD Firefighting Foam

Rated for Class B Fires, including Polar Solvents, at 0.5%

Use proper application techniques for a spill fire or for deep fuel

Firefighting Foam

1% is the MAXIMUM proportioning rate for UEF

Above this percentage, the extinguishing capabilities of the foam solution decrease:

- surface tension increases
- heat absorption decreases

Firefighting Foam

Reasons to enrich the foam percentage

Structural Coating

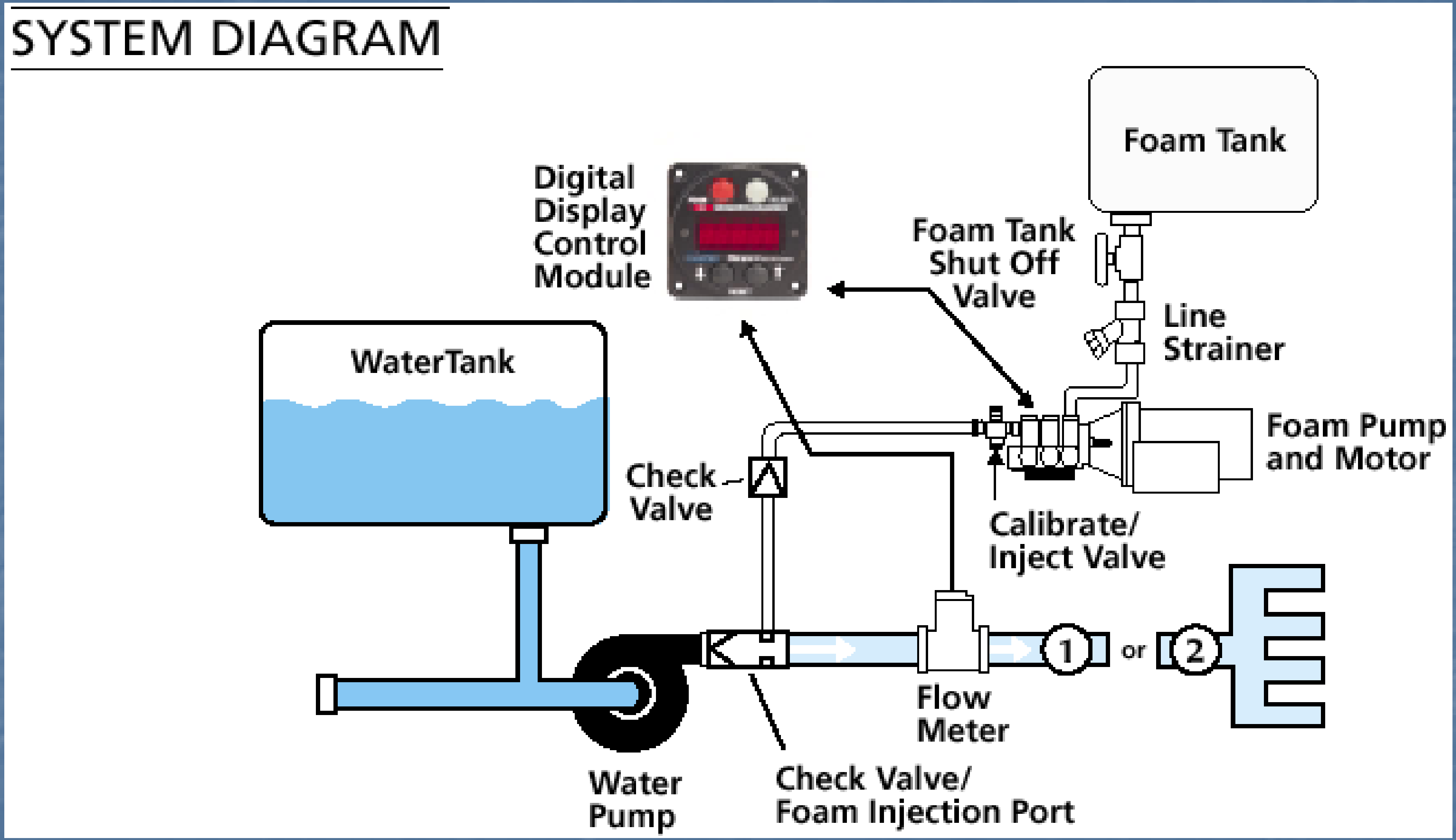
Where's his buddy?

Extreme Fire Conditions

Class B Fire Incident with Heavy Rain

Use Novacool at a MAXIMUM of 1%

FoamPro System



The rear Foam discharge port on FoamPro equipped Engines has a maximum delivery of approximately **850 gpm**

FoamPro Engines

All of the FoamPro Engines should be capable of implementing a foam attack by deploying a **1 ¾" Preconnect** as well as an additional foam hoseline.

FoamPro Engines

All of the FoamPro Engines are capable of pumping enough foam solution to support both a **2 ½" Blitz Line** as well as a **Portable Monitor** operation.

Seattle Fire Department
Firefighting Foam Operations

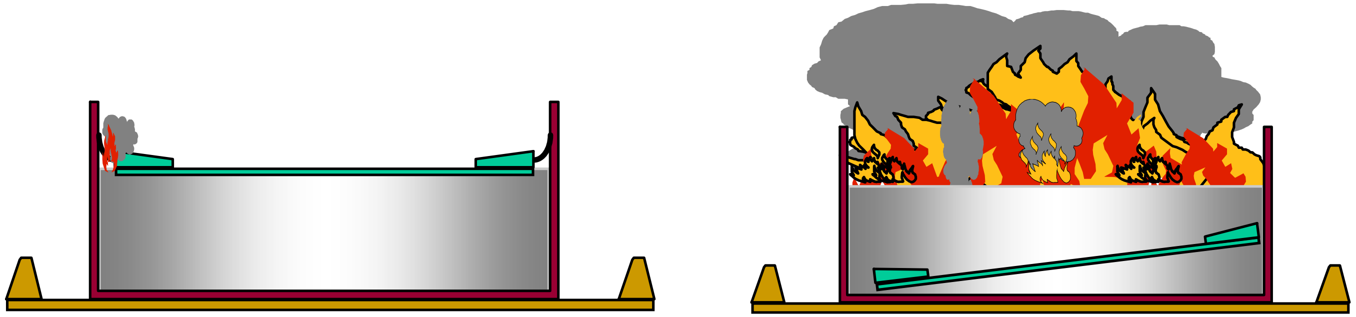
The End!

Niall Ramsden
LastFire (UK)

LASTFIRE
Large Atmospheric Storage Tank Fires

The Organisation

A consortium of international oil companies developing best industry practice in storage tank Fire Hazard Management through operational feedback, networking, incident analysis and research



Niall Ramsden

30 + years experience as independent
Previously worked with foam companies
Member NFPA 11 committee (25+ years)
LASTFIRE Project Coordinator
Major incident foam application experience

Current situation!

- A lot of information and misinformation
- Not always independent or end user led
- Make sure information is relevant to needs
- Different applications, different needs

What is the most important performance issue for a foam?


Can it put
out the
fire!

The ideal fire test!

Tends to be expensive!

Research Work

Different applications
Different foam characteristics

LASTFIRE
Large Atmospheric Storage Tank Fires

Research Work

Different applications
Different foam characteristics
Different fire pans/test protocols
Must reproduce real life and be validated in the large scale!
That is what LASTFIRE has done

LASTFIRE
Large Atmospheric Storage Tank Fires

Research Work

Overall objective:

To provide a firm basis for future cost effective, long term, sustainable policies regarding the selection and use of fire fighting foam based on rational, relevant and independent, end user driven test programmes.

Research Work – Rational Progression - more than 200 tests

Small scale
Simulated tank fire
Critical application rates

Phases have included
- Different foams
- Different nozzles
- Different application methods
- Different rates
- Different fuels (including crude)
- Different preburns
- Fresh/Salt water

Subsurface tests

Spill fire
Critical application rates

Larger scale
“Real life” Application
NFPA rates

Longer flow
“Real life” Application
NFPA rates

Self expanding foam

Vapour suppression

Hybrid Medium Expansion

Further obstructed spill fire testing

www.lastfire.org.uk

LASTFIRE
Large Atmospheric Storage Tank Fires

Overall Achievements/Conclusions

- Carried out over 200 tests
- Validated extrapolation of test data from small scale LASTFIRE testing to large scale
- Cannot be generic!

Important not to draw generic conclusions!

info@lastfire.org
www.lastfire.org.uk

LASTFIRE
Large Atmospheric Storage Tank Fires

2019→ What is Missing?

- Polar Solvent tests
  - Etank Fire – small scale but very useful!! Need larger



- Dry chemical compatibility – better evaluation
- Big monitor application – longer distances. Currently looking at building test rig – options for location. Now have possibilities in France, Russia and Hungary – 25m diameter, 50m rectangle
- Other foams/combinations of foam/application methods

Environmental data!

info@lastfire.org
www.lastfire.org.uk

Other issues

Some member companies partial transition
At least one company known to have full transition decision

LASTFIRE
Large Atmospheric Storage Tank Fires

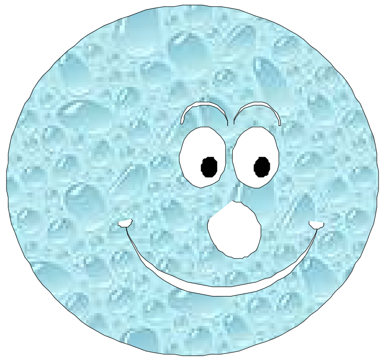
We all know fluorosurfactants give special properties
But can we do without them?
It looks as if we can
But we still need to demonstrate it for some circumstances

Anyone wanting copy of presentation or other information please ask direct

niall.ramsden@lastfire.org

LASTFIRE

Large Atmospheric Storage Tank Fires



We have achieved a lot

We are confident we can do it!

An opportunity, not a crisis!

Peter Storch, Arcadis (Australia)

PRACTICALITIES OF TRANSITIONING TO FLUORINE FREE FOAM

PFAS IMPACT AND CLEANOUT CONSIDERATIONS

Peter Storch, P.E.
Arcadis Melbourne

Rev 5

PFASs

Fire Suppression Foam Systems

PFASs

Foam Selection

Fluorine Free vs C6 AFFF

Parameter	F3	C6 AFFF
Availability	More than 24 companies, production in US, UK, and Europe	8 main companies, commercially available, well-distributed
Performance	Meeting NFPA and ICAO requirements	Meeting NFPA and ICAO requirements
Accreditation for Insurance	UL, FM, and EN Listings Exception: some polar solvent applications	UL, FM, and EN Listings
System Modifications	Likely More - Proportioners - Pump replacement - Storage tank replacement	Likely Less - Proportioners - Additional containment

Both F3 and Modern C6 are relatively new to the market

Foam Selection (con't)

Fluorine Free vs C6 AFFF

Parameter	F3	C6 AFFF
Biodegradable	Yes	No
Containment/Waste Disposal	Less restrictions/ precedence for discharge to sewer	Required containment/ offsite disposal
Environmental Liability	Low	High
Concentrate Cost	Au$ 9-15/L	Au$ 12-24/L

Is C6 AFFF "The Regret Spend"

Accreditation

- Insurance Requirements: UL and FM
- Accreditation applies to
  - Type of fuel
  - Specific fire suppression system / equipment / components
  - Foam applied
- Specific Accreditations
  - Aviation Rescue / ARFF Vehicles – ICAO
  - Aboveground Storage Tanks (ASTs) - LASTFIRE
  - Sprinkler systems - UL162, FM Global, EN1568, NFPA 409
  - Extinguishers/Vehicles - AS 1850 and AS 5062
- Fire Engineer Approval and Certification

System Modifications

- F3 Foam Compatibility with Existing System
  - Proportioner modifications
    – wide range proportioning equipment
  - Foam application rate and discharge duration i.e. is more foam concentrate required?
  - Aspirated vs. non-aspirated discharge devices
  - Appropriate pumps
  - Storage tank - bladder tank system?
  - Use UL listed equipment accredited with F3 foam

Minor suppression system modifications usually required

Foam Transition Team

Fire Engineering

- Fire Engineering Consultant
  - suppression system design
  - system certification
  - foam certification UL, FM, NFPA etc.
- Fire Service Engineer
  - detailed mechanical design
- Fire Technician
  - assist with foam replacement

Environmental Engineering

- PFAS Expertise
- Foam Selection
- Regulatory Approvals
- Foam Certification – TOP assay
- PFAS Cleanout
- Waste Characterisation and Disposal
- Containment

Do you have Fire and Environmental on your team?

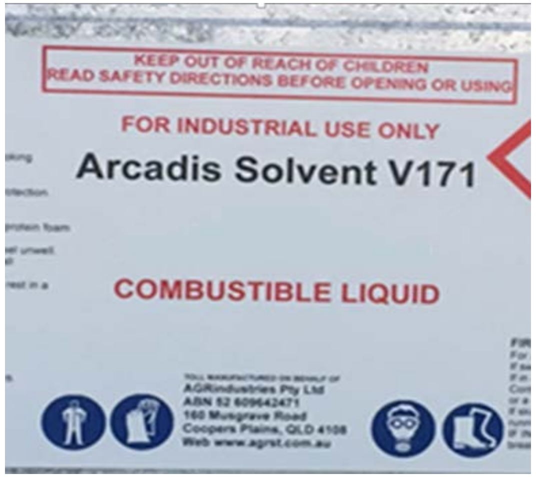
Other Transition Considerations

- Impact to Business – cost / time
- Cleanout vs Replacement
- PFAS Rebound Creates Environmental Risk
- Clean Out Strategy
  - Define strategy and objectives with environmental regulators
  - Risk Reduction Priorities – Concentrate, Fire Water Supply, Foam Mix
- Waste Disposal

Costs and practicality balanced with risks from rebound

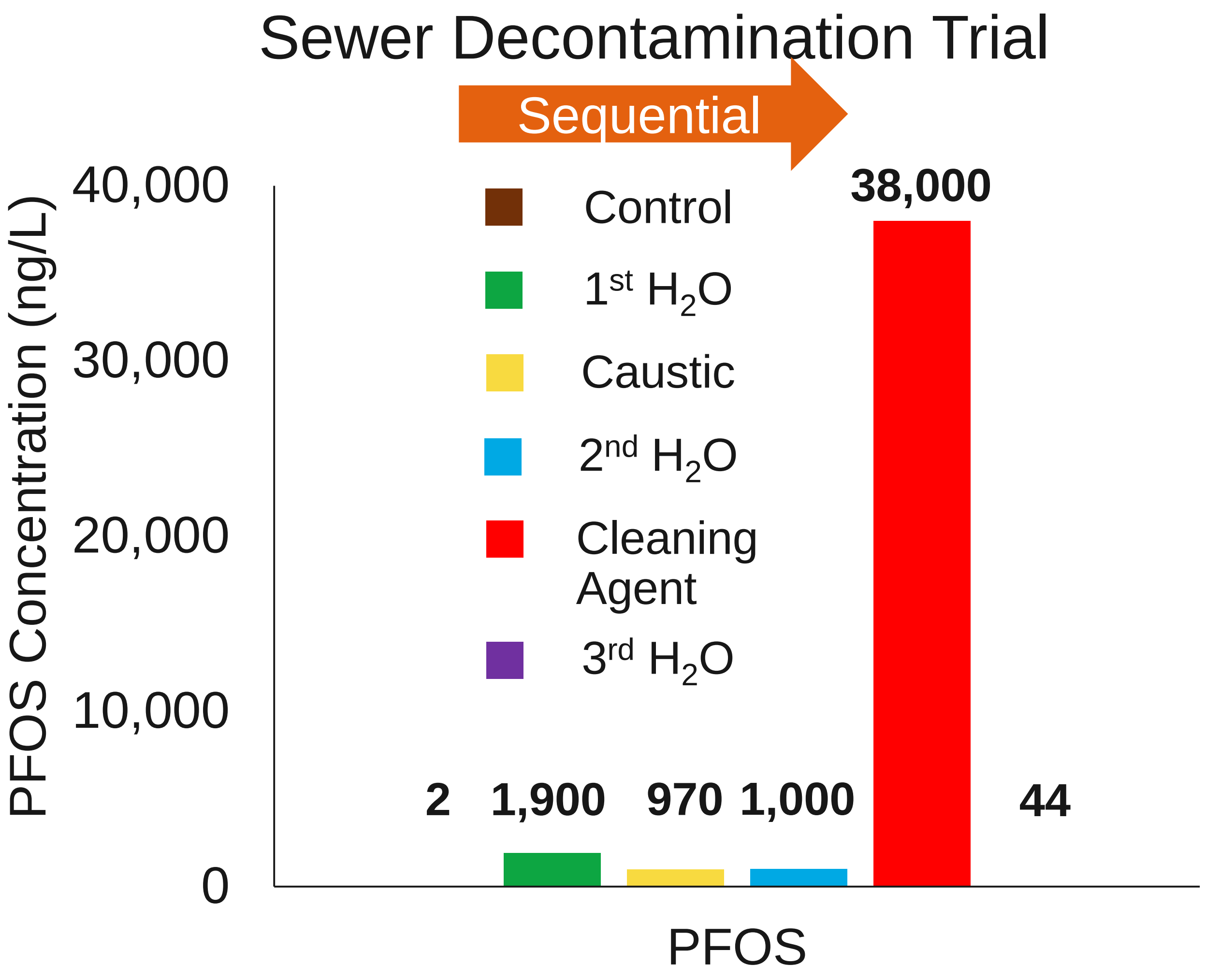
Is AFFF System Cleanout Essential?

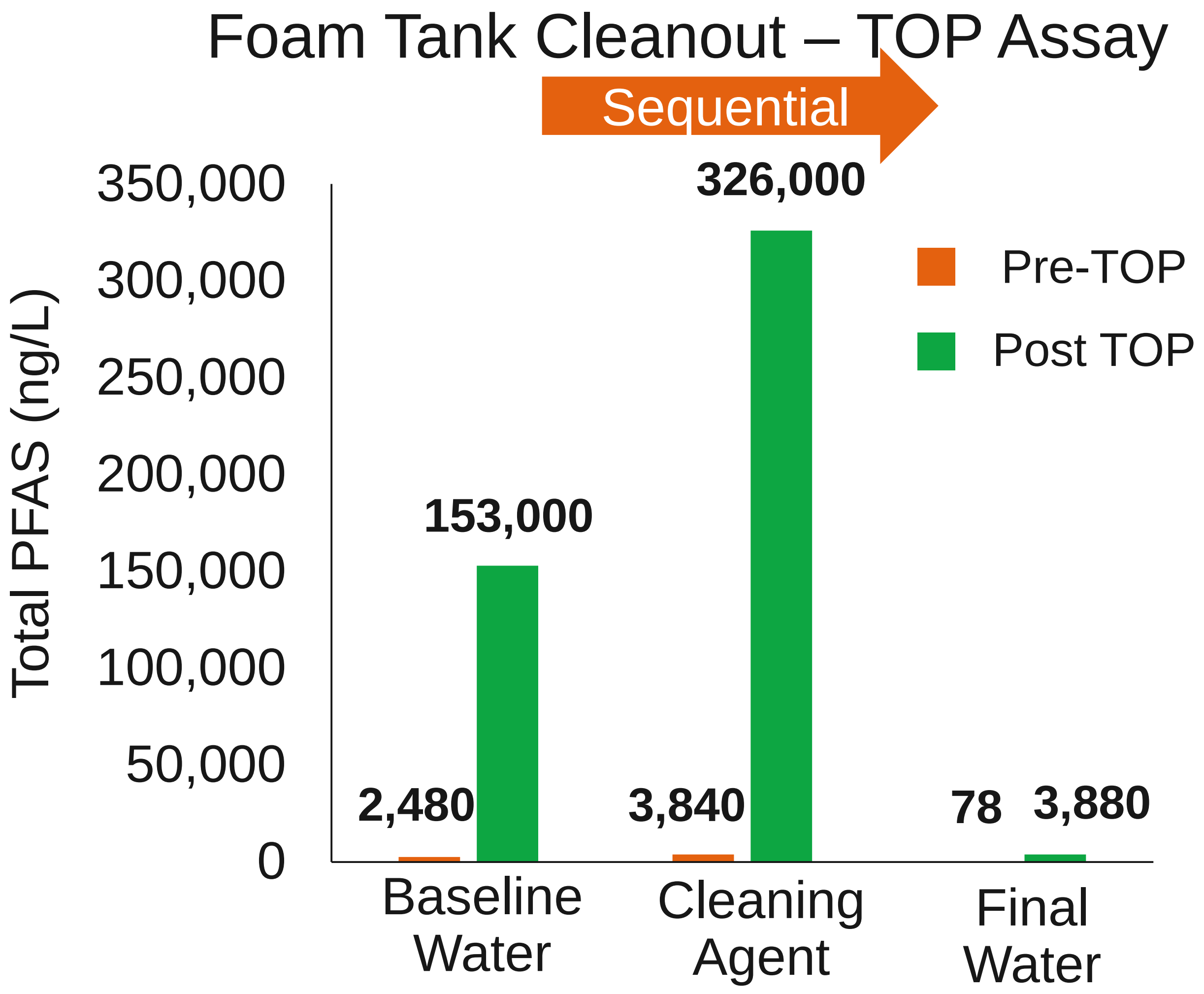
- PFASs self-assemble in layers on surfaces (e.g. Scotchguard)
- PFAS rebounds from surfaces into F3 foams
- Water ineffective for PFAS cleanout
- PFAS concentration in wash water does not reflect that system has been cleaned
- Residual PFASs remain bound to surfaces in infrastructure
- Cleanout Process Design- biodegradable cleaning agent, agitation



Potential for ongoing exposure to PFASs without effective cleanout

Case Studies
System Decontamination



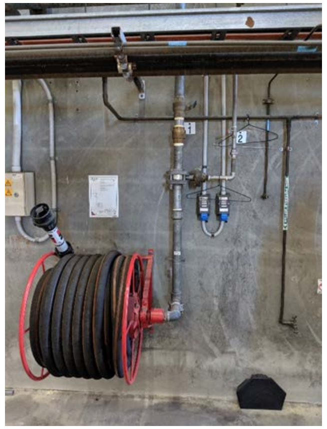


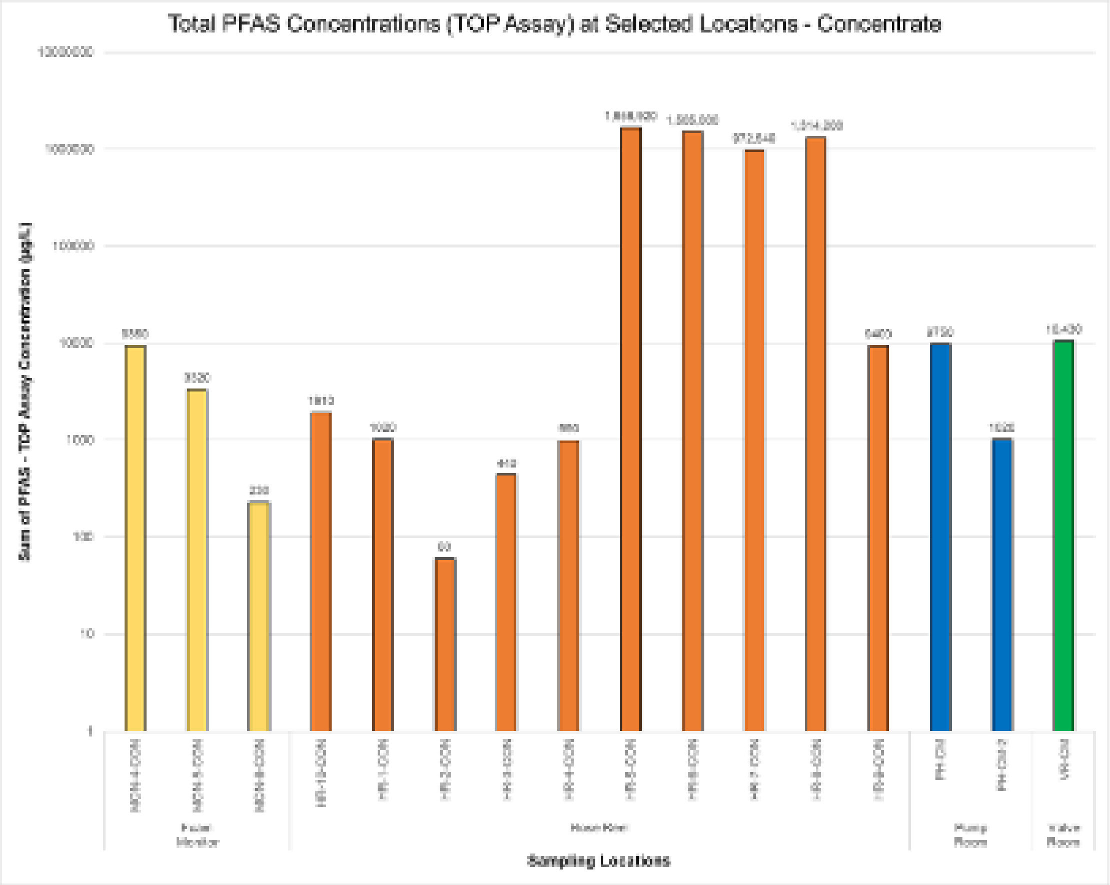
Cleaning agent and TOP assay Required for Effective Decontamination

Case Study - PFAS Rebound into F3 Foams

One year after changeout of hangar to F3 using a dual water flush:

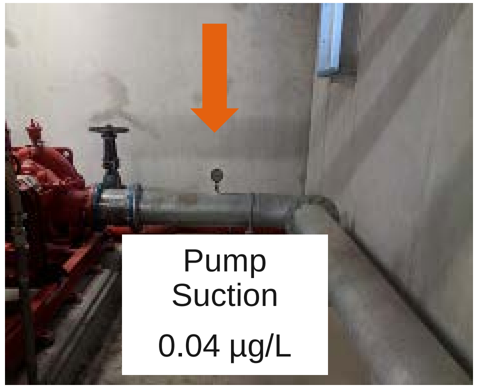
- PFAS residual up to 1.6 g/L in F3 foam;
- Fire Water Supply remains impacted

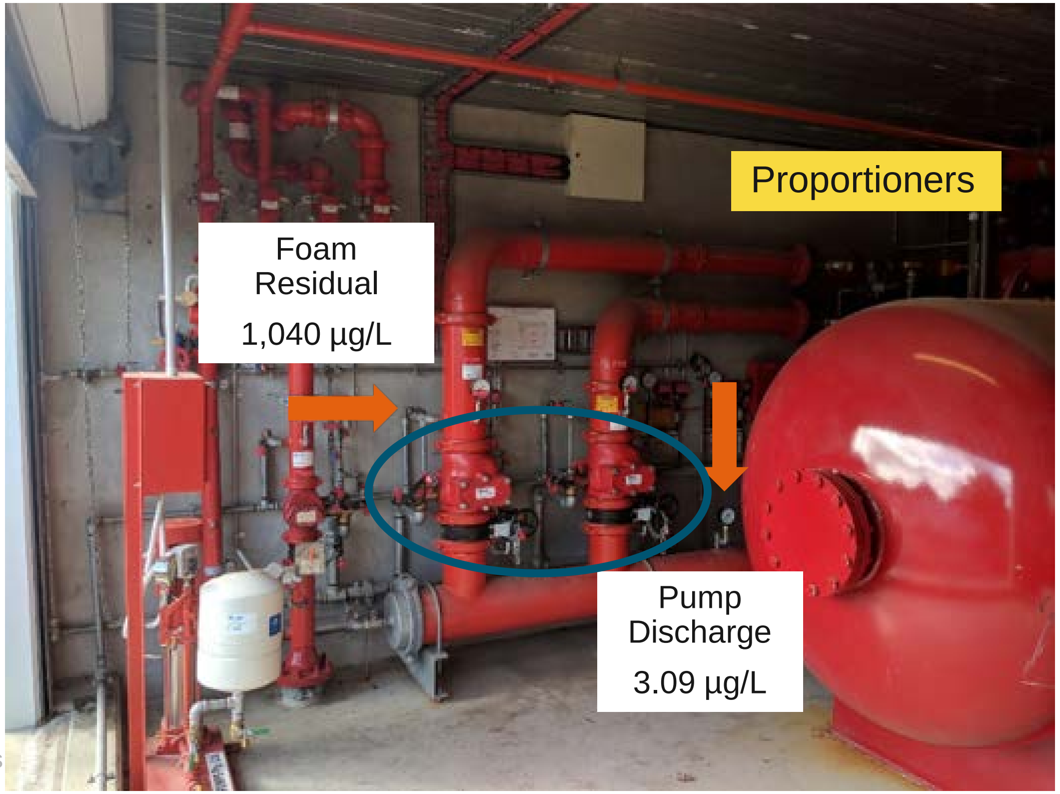




Significant rebound of PFAS into F3 Foams using dual water wash flush

Case Study Water Supply Impact





Summary

1. F3 are: Performing, Available, and Cost-Effective

2. Foam transition - rarely “plug and play,” modifications, site-specific strategy, and a qualified team

3. TOP Assay is required to assess PFAS in foams

4. Effective decontamination - preserve benefits of F3

5. Successful Transitions to F3 have been accomplished:
    - **Fire fighting services**
    - **Aviation – ARFF, aircraft hangars, helipads**
    - **Ports and terminals**
    - Bulk storage facilities
    - Chemical manufacturers

ARCADIS Design & Consultancy for natural and built assets

THE EMERGING ISSUE

PER- & POLYFLUOROALKYL SUBSTANCES (PFASs)

Big Picture, Challenges and Solutions

Foam Disposal Options

Dr. Ian Ross

Foam Disposal

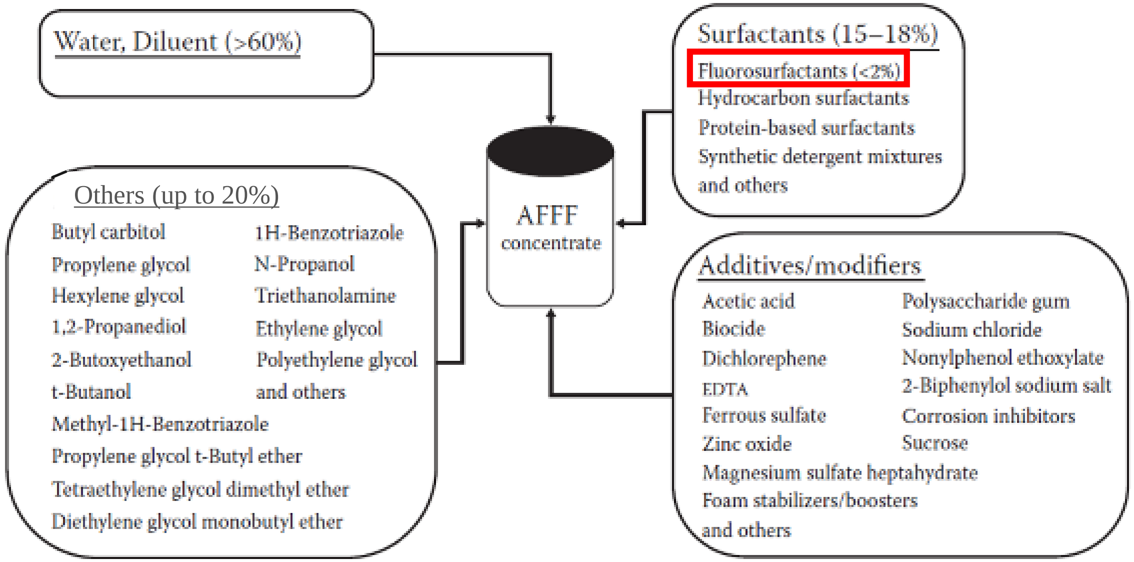
- Fluorinated fire fighting foam comprise a complex waste
- Dispensed fluorinated foam and foam concentrates cannot be treated using biological waste water treatment plants i.e.
  - ~~Municipal sewage treatment~~
  - ~~Publically operated treatment works (POTW)~~
- All fluorosurfactants / PFASs in foams are non-biodegradable, PFASs are extremely persistent
- Significant challenges and costs disposing of fluorinated fire fighting foams i.e. AFFF, FP, FFFP and their AR-variations
- Confirm that fluorine free foams100% biodegradable, so are significantly easier to dispose of via conventional biological treatment methods i.e. POTW, sewage treatment

3. COMPOSITION/INFORMATION ON INGREDIENTS

This product is a mixture.

Component	CAS Number	Concentration
Water	7732-18-5	35 - 45%
Diethylene Glycol Monobutyl Ether	112-34-5	25 - 35%
Ethylene Glycol	107-21-1	10 - 20%
Fluoroalkyl surfactants	Proprietary	5 - 15%
Ethanol	64-17-5	1 - 5%
Surfactants	Proprietary	1 - 5%

1. INGREDIENTS	CAS. #	%
Ethylene Glycol	107-21-1	20
Butyl Carbitol	112-34-5	35
Water	7732-18-5	40
Fluoroalkyl Surfactants		<5
Synthetic Detergents		<5



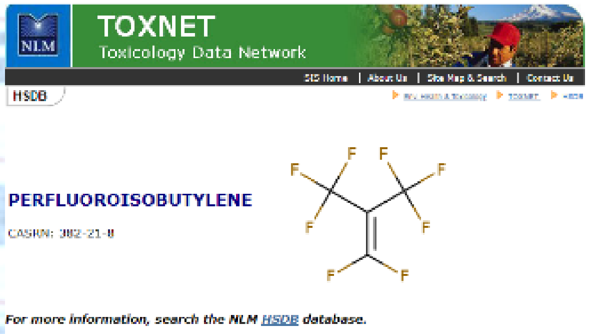
Adapted from: **Perfluoroalkyl Substances in the Environment:** Theory, Practice, and Innovation
David M. Kempisty, Yun Xing, and LeeAnn Racz

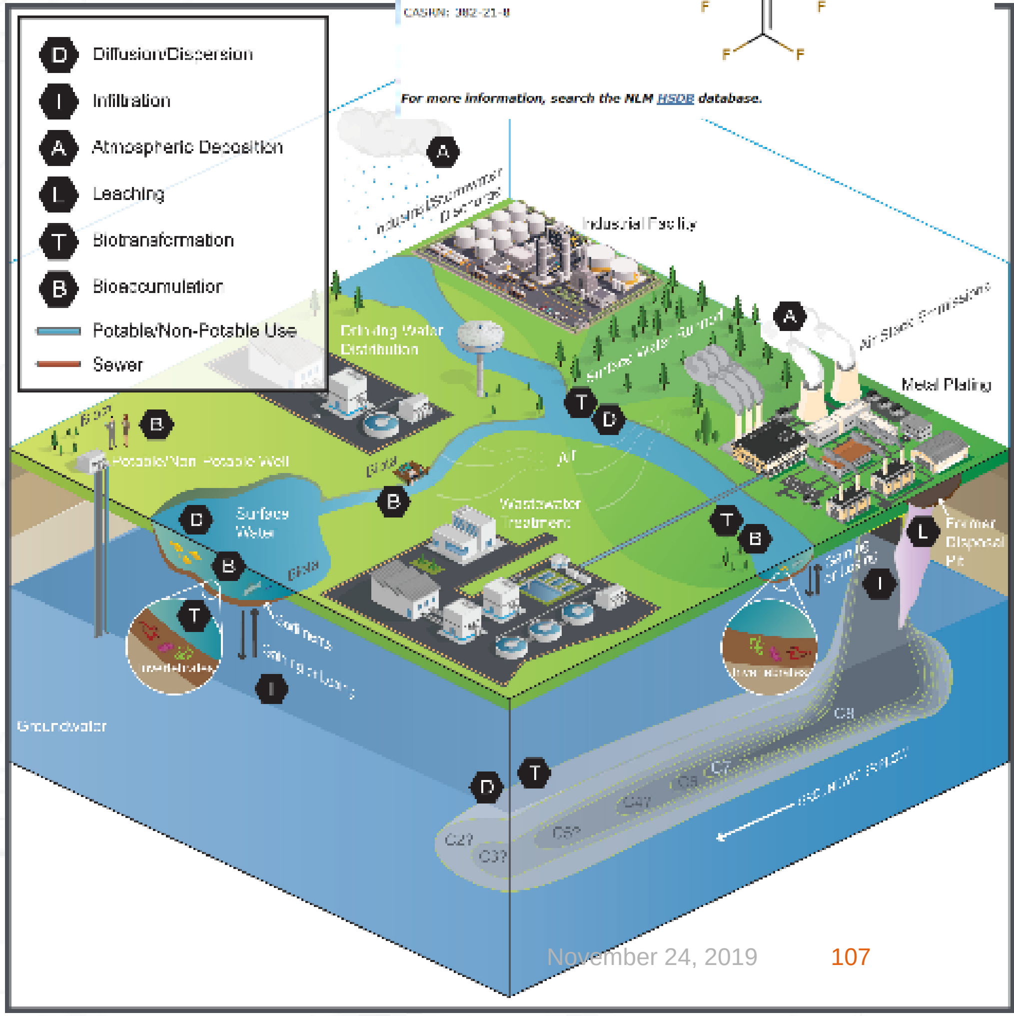
PFASs

Incineration

- 1,000 to 1,200 ºC (1,800 – 2,200 ºF) required to completely degrade PFOS
- Expensive and energy intensive options
- Hydrogen Fluoride management essential
- Lower temperature incineration of PFASs can produce toxic intermediates (e.g. perfluoroisobutylene) or potent greenhouse gases (CF_4, C_2F_6 etc.)
- Cement kilns also being employed, for effective high temperature destruction with $Ca(OH)_2$ to create CaF_2
- Comprehensive analysis of all gaseous emissions required for any thermal treatment

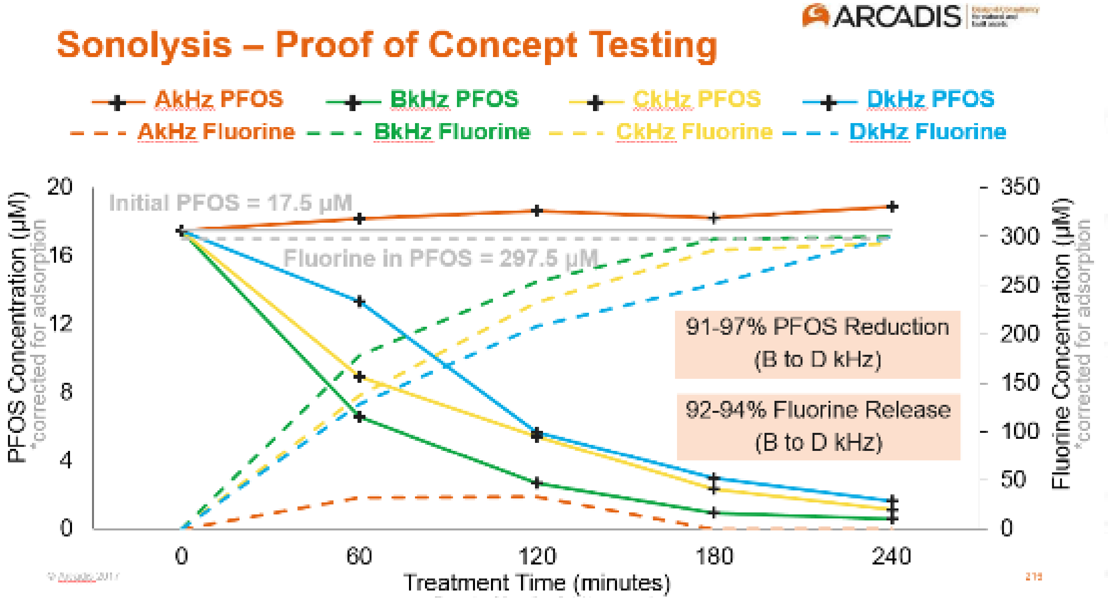
https://toxnet.nlm.nih.gov/cgi-bin/sis/search/a?dbs+hsdb:@term+@DOCNO+7708

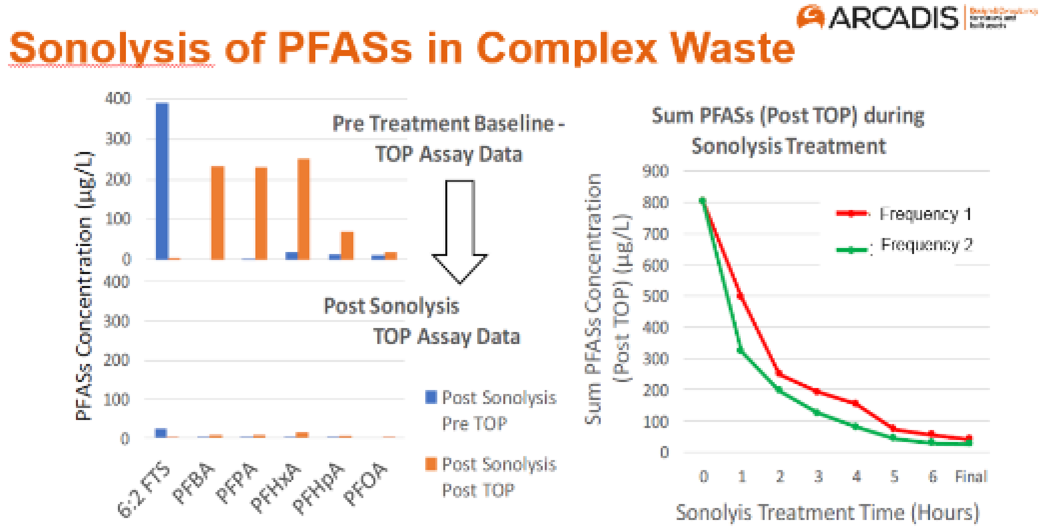




Evolving Foam Treatment Options

- Treatment trains required for complex wastes such as dispensed foam and concentrates
- Sonolysis using ultrasound proven at laboratory scale and being scaled up
- Ultrasound causes cavitation of bubbles with extremely high temperatures and plasma on the surfaces of the bubbles resulting in destruction of PFASs.
- Ultrasound trials progressing using AFFF foam concentrates
- Potential to receive samples of AFFF for testing
- Options to retain and store AFFF concentrates until more sustainable treatment technologies are commercially available





PFASs

Questions?

Presenters

- Ian Ross, Arcadis (UK)
- Nigel Holmes, Queensland (Australia) Department of Environment & Science
- Captain Kurt Plunkett, Seattle Fire Department
- Niall Ramsden, LASTFIRE
- Peter Storch, Arcadis (Australia)
- Jen Jackson, San Francisco Department of the Environment (Moderator)