Reducing Environmental Impacts of Class B Firefighting Foams

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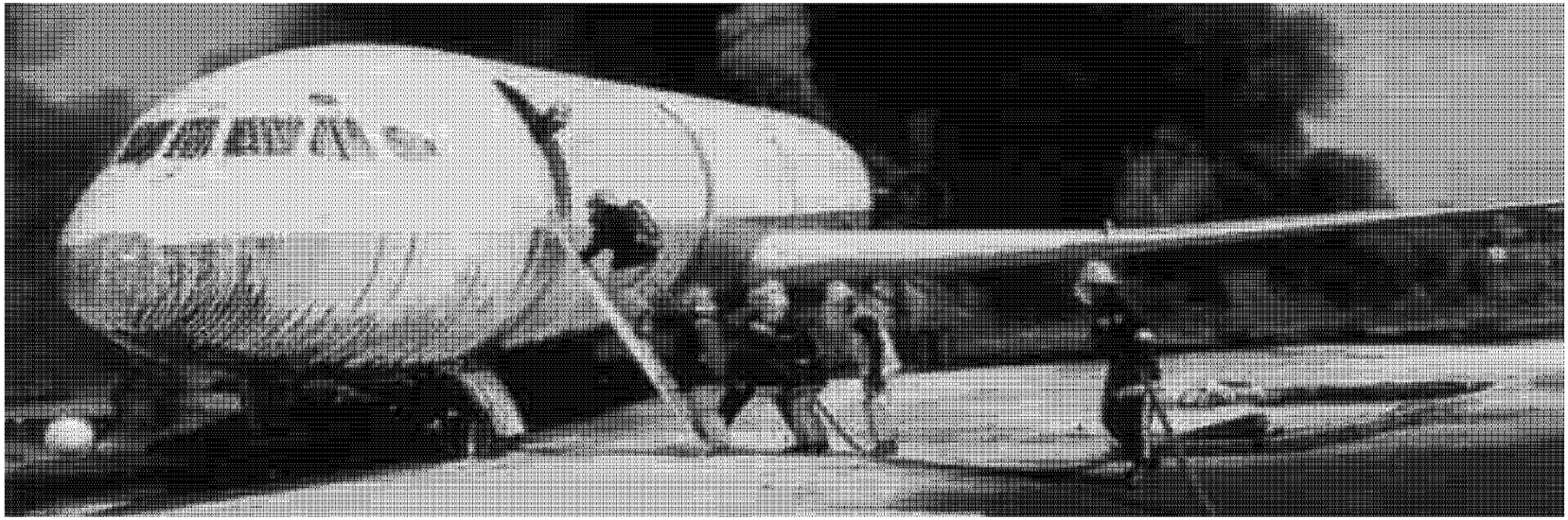

by Mike Willson,
SAA-IAFPA Firefighting Foam Seminar, Singapore, 21st July 2016

Overview

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- Public concerns over PFOS & PFOA - Need for Change
- Q's over alternatives: short chain C6 v F3
  - Concerns and considerations : choices bring consequences
  - Leaching, impacts fire breakdown products, health risks
  - Remediation options
- Navigating this minefield…risks, liabilities and exposures
- Conclusions – potential way forward

Public Concerns

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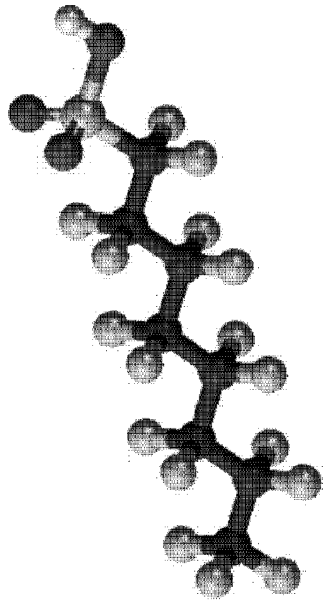
- PFOS
  - Electro Chemical Fluorination (ECF) process - ceased 2002, except China
  - Long chain ≥C8 perfluorosulfonate chemicals degrade to PFOS/PFHxS
  - PBT, mobile - UN Stockholm Convention **POP listed PFOS 2009**
  - PFOS likely carcinogenic, transfers to unborn foetus and found in mothers milk, polar bears & penguins!
  - Banned in EU 2011 & Canada 2013, import prohibited Singapore and NZ, now little manufactured… except China
- PFOA
  - Breakdown product and impurity from the ECF – PFOS process
  - Also unintended manufacturing by-product in Fluorotelomer process (ppm levels)
  - Chemical of high concern: PBT, mobile, and potentially harmful human effects
  - Allows transition to more benign C6 agent usage with minute traces PFOA (ppb levels)



PFOS - stock and LEGACY issue; PFOA - under review

US EPA Stewardship Program

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- 2006 major manufacturers and US EPA recognised Need for Change
- Voluntary PFOA stewardship program – 2 key objectives:
- by *2010 - removal 95% PFOA from products & facilities*
- *by 2015 - work towards elimination of PFOA from those facilities & products*
- Latest 2014 report shows major progress towards virtual elimination of PFOA
- Increasing development of short chain ≤ C6 FT surfactants resulted, allowing transition away from PFOA
- ECHA increasing PFOA restriction level to 1,000ppb for foams to allow C6 usage
- C6 has no PFOA ingredients, cannot degrade to PFOA, just few ppb as unavoidable trace from manufacturing process; + Not B, Not T; + Fast & Effective

Context:
1ppm = 32sec in 1 year
1ppb = 3sec in 100 yrs!
1ppt = 3sec in 100,000 yrs! (Wikipedia)

US EPA & ECHA support transition to C6 fluorinated foams

Need for Change

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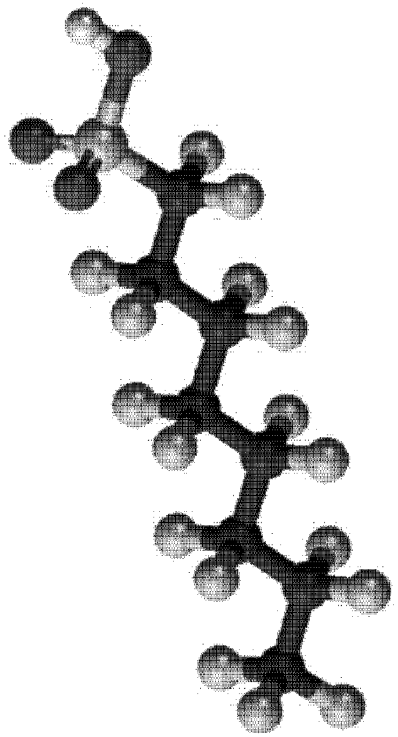
- Transition from long chain fluorochemicals because:
  - Very resistant to degradation, PBT
  - PFOS, PFHxS & PFOA found widely in human blood and environment
  - University QLD study showed average PFC levels of 15ppm in US population, 30ppm in Australians, 60ppm in Australian firefighters, some factory workers showed 800ppm+!
  - **Mostly derived from house dust, fish, seafood, food packaging etc.**
  - Builds up, slow to decline as long half-lives in humans – averages: PFOS 5.4yrs, PFHxS 8.5 yrs, PFOA 3.5 yrs (Olsen 2007)
  - **We need a more sustainable solution** … transitioning to short chain ≤C6 fluorotelomer foams or F3 alternatives…



Need to transition away from PFOS and PFOA

Questions Over Alternatives?

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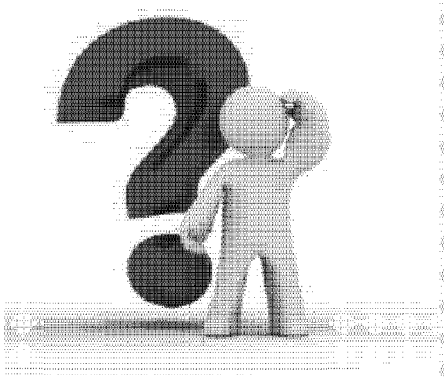

- ***Users Qs***
  - Which alternatives are most effective and responsible to use?
  - What foam should we transition to for the next 10+ years? …C6 FluoroTelomer (FT) based or Fluorine Free?
  - Will other fluorinated agents follow PFOS and PFOA into restriction, prevention of use, or POP listing?
  - Which foam provides the most responsible environmental and usage profiles?
  - Which can combine delivery of the best environmental outcomes, most effective firefighting capabilities plus safety for firefighters, across diverse fuels and incidents? ….*Does this even exist?*

Answering them lies in scientific research, critical fire testing and incident experiences…

Choices bring Consequences in Risks, Liabilities and Exposures

Research Confirms C6 is Different

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- Research highlights major differences between PFOS/PFOA and short chain ≤C6 FT surfactants
- C6 FT increasingly used at ≥ 95% purity level in firefighting foams, embracing US EPA PFOA stewardship criteria.
- C6 FT NOT Bioaccumulative, nor Toxic, nor Carcinogenic, nor Mutagenic, nor Reproductive Toxicant (Chengalis 2009, Loveless 2009, Iwai 2011, Serex 2008, Hoke 2015).
- Although C6 FT persistent, no evidence to show harm to humans or environment.
- Potential POP listing assessment of C6 FT shows cannot be listed POP as only meets 1 of 4 essential criteria, although some questions about mobility
- C6 FT delivers more benign transition away from PFOS and PFOA - retains unique fire performance benefits NOT adequately provided by F3.

C6 FT already approved by NICNAS for use in Australia

Short Chain ≤C6 Agents

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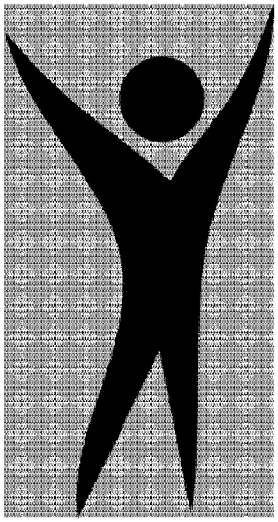

- C6 FTs main breakdown product is PFHxA
- PFHxA extensively tested and confirmed:
- Equivalent% C6 to C8 achieves same MilF Spec fire performance (FFFC, 2016)
- Short chain PFHxA fully excreted through human kidneys/urinary system with half-life in humans averaging 28-32days (Russell 2013)
- Also reviewed and approved by several global regulatory bodies including US EPA, UK EA, Danish EPA, ECHA, NICNAS Australia
- Avoids fundamental drawbacks of PFOS/PFOA and alternative F3 agents.

C6 already approved by NICNAS for use in Australia

All Foams Pollute

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- Long chain, short chain and Fluorine Free Foams (F3) ALL pollute **+ firewater runoff** (UK Environment Agency, 2014)

- **Main choice:** short chain C6 v F3
- C6 persistent, F3 10x more aquatically toxic
- C6 fuel shedding, fast, resists flashbacks, less usage
- F3 not fuel shedding, slower, picks up fuel –vulnerable to flashbacks, fires burn longer = more noxious runoff
- 3x more F3 often required, especially on Gasoline

Fire performance benefits are critical

Aquatic Toxicity

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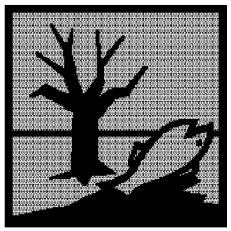
- High detergent levels mean F3s typically 10x more aquatically toxic than AFFF
- If 3x more used, then **30x greater toxicity** from specific incident



Agent	96hr LC50 Rainbow Trout mg/L (ppm) (4 day static water -aerated)	96hr LC50 Fathead Minnow mg/L (ppm) (4 day flow, 6 changes/24hr)
Wetting Agent 0.1-1% (F3)	1.06	0.887
Class B 3% F3 – Foam A	65	171
Class B 3% F3 – Foam B	71	171
Milspec 3% AFFF	2,176	884
AR-AFFF 3x3%	3,536	1,487
UL 3% AFFF	5,657	1,726

Source: FFFC AFFF update – Aquatic Toxicity of Firefighting Foams, 2006

Why is Foam So Be

- **Can we use Water?** Water sinks through fuel, lifting/spreading flammable liquid to other areas
- Makes worse -escalates fires fast, generating more smoke and breakdown products = ***unsuitable***

BEST FOAMS like ≤C6 DELIVER:

- fast control & reduced spread of fire
- reliability with minimal re-ignition risks
- improved life safety for casualties & firefighters
- protection of investments & property
- reduced business interruption
- reduced financial & job losses
- reduced smoke, breakdown products, runoff
- reduced environmental impacts

neficial?

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Fluorine Free Foam (F3) Struggles

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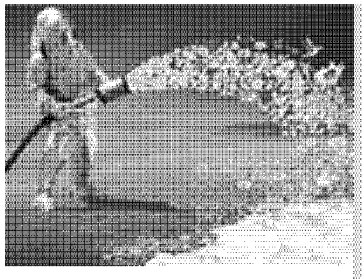

- **F3 agents suit some applications** eg. Brigades, Training , **but probably NOT Major Hazard Facilities (MHFs) including Airports**
- Major F3 Concerns:
  - Slower control and extinguishment than AFFF/FFFP because **NO critical shedding** (Jho 2012)
  - Removing fluorine = **extra detergent** (hydrocarbon surfactant) attracts more fuel into bubble
  - Fuel released as **unreliable bubbles** collapse
  - Incandescent materials ignite vapour = sudden **unpredictable flashbacks** and flare ups
  - **Exposes casualties and firefighters to potential danger & unexpected escalation**
  - F3 effectively **limited to gentle aspirated application on volatile fuels (gasoline)** (Jho 2012)
  - Often **3x shorter vapour seal** with F3 blanket **than AFFFs** (Schaefer 2008)
  - **So 3x more F3 and water resources** needed than AFFF/FFFP on same incident! (Caltex 2013)
  - Larger quantities, longer applications = **3x more run-off, potentially 30x more toxicity**

= Potentially bigger incidents and larger environmental impacts

Does this seem environmentally responsible?

Variability on ICAO Level B test

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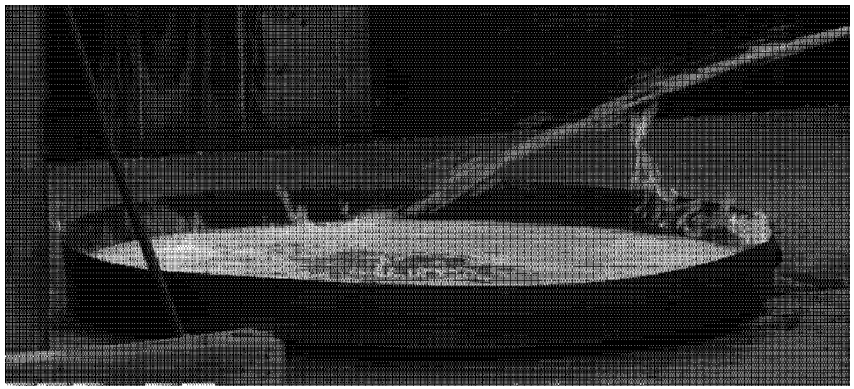
Independently witnessed ICAO Level B testing, Denmark, 2012 (60 sec extinguishment)

- Tested with Jet A1, UNI86 nozzle - fixed improved reproducibility
- All 5 x F3s failed ICAO Level B, incl. 3 certified to pass -best 1min24s (AR-F3), popular 6% F3 failed to extinguish
- Reasonable fire control, but delays from persistent edge flickers
- Contrary to expectations, when tested with Modified Military Spec Nozzle to mirror more fluid foam commonly used, control times extended for 2 of 3 foams, failing to extinguish (popular 6% extinguished 1min 58s)
- This heavier foam picks up more fuel than lighter foam from UNI86!
- Concern - Substantial drop off in performance when more realistic aspirated nozzle used
- Since 2013 ICAO changes, extinction in 120s not 60s
- Allows several previously inferior AFFF foams to pass – is that right?



Typical ICAO Level B fire performance of tested F3 at 1 minute (from Danish testing –Hubert, Jho,Kleiner,2012)

"Dumbed down" ICAO fire test seems to increase life safety risk?

Factor of 3x repea

Incident Caltex Banksmeadow Sydney, 2013

- Unleaded gasoline tank 901 - valve leaked into bund
- 3-4m high fountain, 130,000L unignited fuel in bund
- F3 blanket suppressed vapours for only 15-20 mins between "top-ups"
- Considered failing as unacceptably short
- Kurnell Refinery FP foam used, controlled vapours for 90 mins between "top-ups" = 4.5x longer
- FP allowed incident to be controlled reliably and effectively with minimal resources used

- Confirms Newcastle University research ***"…best F3 provides only 30% durability of AFFF on gasoline"*** (Schaefer, 2008)

15 years of F3 use … where is the

ting

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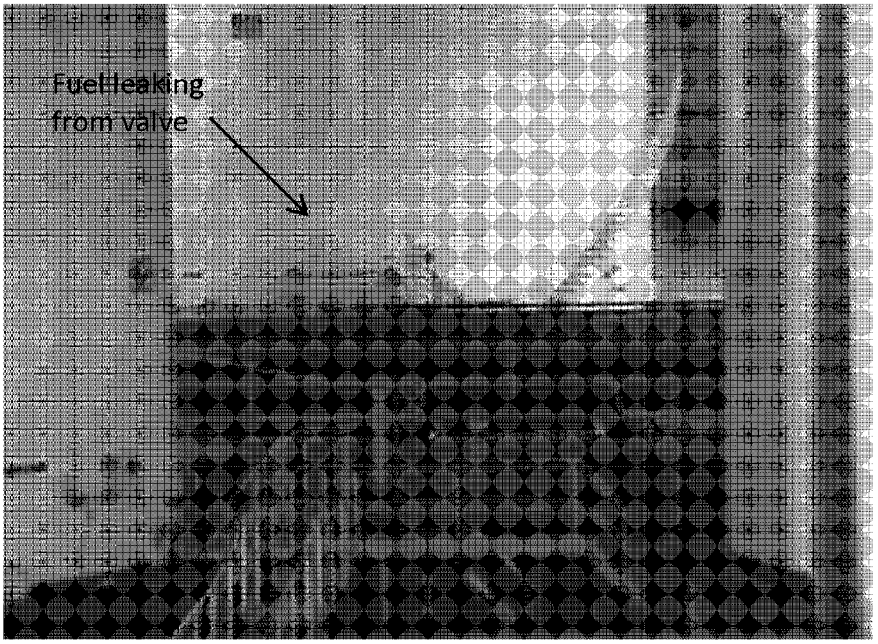
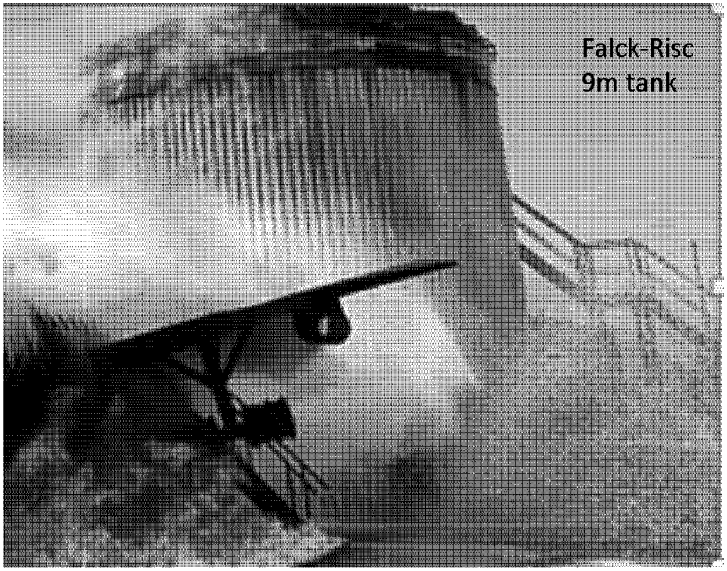


successful F3 track record?

Factor of 3x



Likely reason: Forceful pl

repeating

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Falck-Risc storage tank test - 2010

- Small 9m dia. (64m^2) test storage tank fire
- 40cm layer light gasoline
- NO preburn
- 7L/min/m^2 for 15 minutes but NO control
- Increased 18.2 L/min/m^2 for further 15mins little effect, until fuel burnt away and fire out! (virtually 3x NFPA 11 recommendation of 6.5L/min/m^2)

- *2 weeks earlier, same fire extinguished in approx. 2 mins with AR-AFFF at 10.4L/min/m^2*

unging and no fuel shedding capability of F3

Factor of 3x repeating

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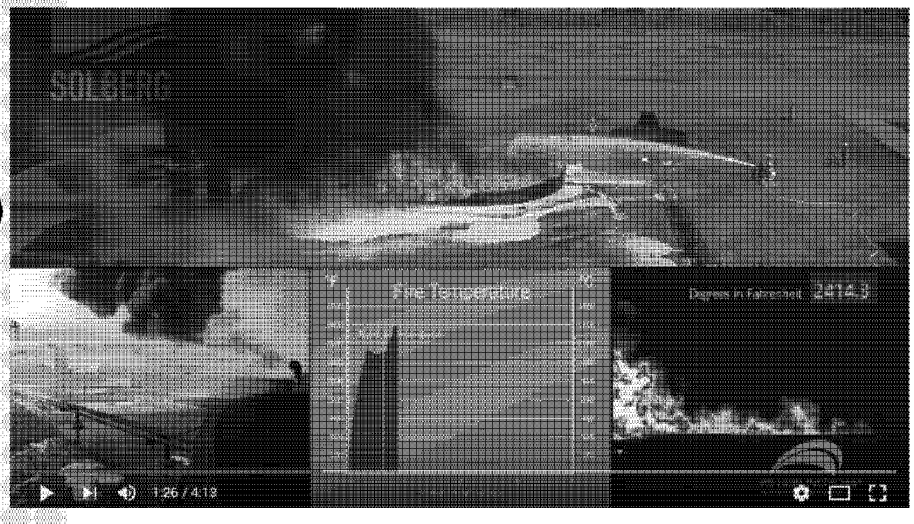
"Simulated Storage tank fire" test, Beaumont Texas 2013

- 12.8m dia storage tank (128.7m^2) "fuel in depth"
- 1,703L EIII training fluid (assume jet version FP 40°C)
- 10.3L/min/m^2 application rate (1,325L/min monitor)
- Extinguishes at 3min 5sec video, claimed extinction in 2min 5sec, but only 40sec preburn = 2min 25sec
- Looks impressive BUT…
- **actual fuel depth only 1.33cm = spill only**…
- High application rate for a jetfuel spill fire!! (*almost 3x normal 4.1L/min/m^2 rate*)… Surprising results??



https://www.youtube.com/watch?v=0H1v9DVOoaE.
Also www.youtube.com/watch?v=3MG2fogNfdQ
and www.youtube.com/watch?v=IuKRU-HudSU

15 years on … where is the successful F3 tank fire track record?

Similar Findings by Others

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•Swedish Chemicals Agency (KEMI) confirms

"Compared with fluorine-based fire-fighting foams (AFFF foams) around twice as much water and foam concentrate are required when extinguishing liquid fires. According to some analyses fluorine-free fire-fighting foams may give less protection against re-ignition which means that the fire may flare up without warning.

There are operations whose ***standards are such that current fluorine-free fire-fighting foams are not acceptable alternatives.*** *One example is the Swedish Armed Forces which, in the event of a fire, allows 90 seconds to reach the location and a maximum of 90 seconds to cool down the cockpit (Borgh 2014)."*

•The Danish EPA concludes ***"The technologically best alternatives to hazardous fluorinated chemicals are short-chain and less hazardous fluorinated chemicals with a fluorochain length of ≤C6*** *or fluoropolymers."*

Also ***"The short-chain homologues and their precursors (e.g. fluorotelomers based on short-chain fluorochemistry) generally seems to have a better human health and environmental profile than the substances based on long-chain fluorochemistry,*** *but it is difficult on the current knowledge to assess to what extent non-fluorinated substances could be alternatives of less concern to the long-chain PFASs for some applications."*

15 years on … F3 still not up to the mark

Similar Findings by Others

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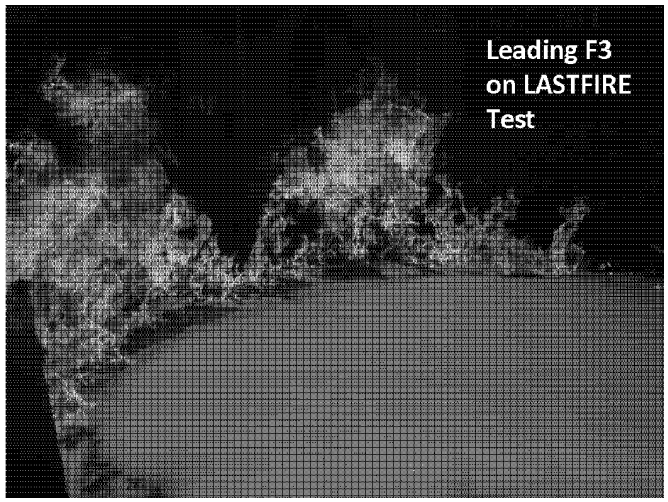
- The LASTFIRE Group's 2015 position paper acknowledges *"Regarding experience with **Fluorine Free (FF) foams, LASTFIRE testing has undoubtedly shown that improvements in formulations have occurred** since their introduction although, **as yet, no fluorine free foam has shown the same level of consistency or high performance that had become the norm with good quality Multi-purpose AFFFs or Fluoroprotein foams.** One typical issue that has been noted with **some FF foams is the tendency for small flickers of flame to occur for extended periods of time** some distance (50-150mm) from the test tank wall."*

*"These flickers reduce the overall scoring in the test and in some cases cause a "FAIL" classification because **they continue to burn even when the total test period is completed.**"*



15 years on … F3 still not up to the mark

PFOS Still Leaching After 5

- Recent study found concrete fire training areas at some Airports saturated to 12cm with PFOS
- Despite thorough clean out PFOS in 2010, change-out to F3
- PFOS still leaching when F3 used, or just water - even when it rains!
- Predicted to continue for 25 years
- So why accept inherent fire performance and toxicity drawbacks of F3?

Source: Baduel et al 2015-Perfluoroalkyl substances in a firefighting training ground, distribution and potential future release

C6 delivers superior fire performance - lega

5 Yrs F3 Use

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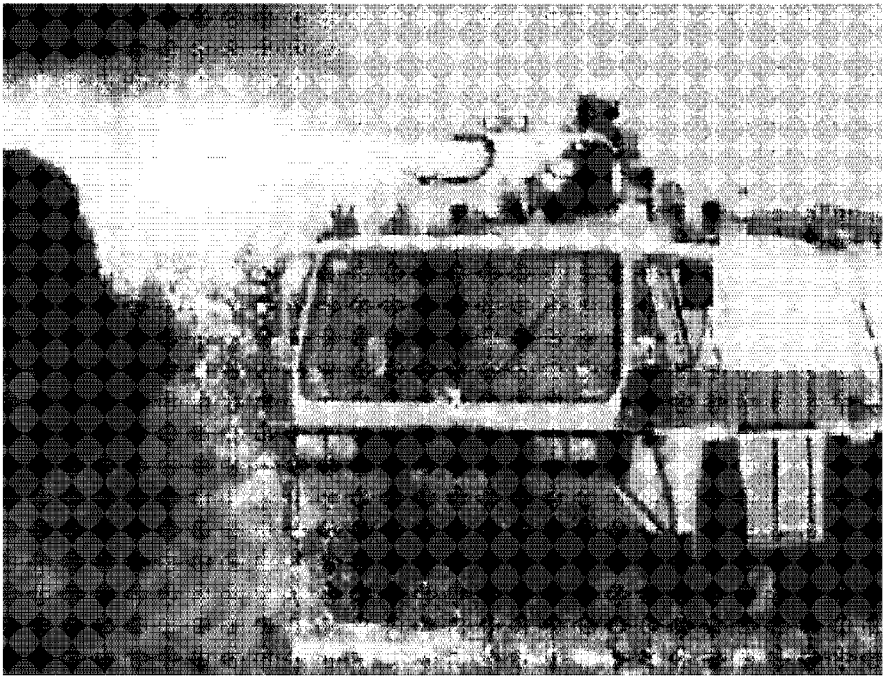

cy POPs must be collected for disposal.

Detergent Toxicity Issues

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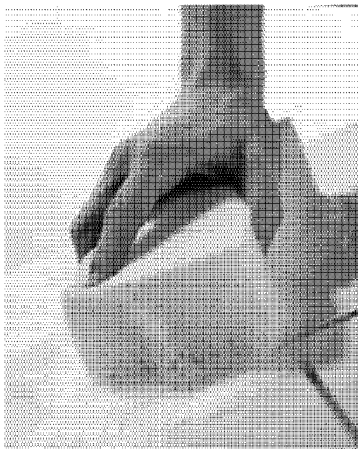

- Detergent is most toxic of all foam ingredients, increased in F3
- More poisonous to bacteria and food of fish, than fish
- Can disrupt WWTP by killing critical bacteria (Source: British Water 2009 -Code of Practice - A Guide for Users of Sewage Treatment Systems)
- Can emulsify with fuel carrying past fuel separators = potential pollution (Source: UK-EA-PPG3)
- Destroys mucous layers protecting fish from bacteria
- Can cause damage to fish gills
- Most fish will die at ≥15ppm, 5ppm kills fish eggs (Source: Lenntech)
- Reduced surface tension allows 2x organic chemicals to be absorbed by fish at just 2ppm
- F3 is 10x more toxic to fish (Source: FFFC 2006 – Aquatic toxicity update)
- F3 typically uses 3x more on volatile hydrocarbons = **30x more toxic than AFFFs!**
- F3 associated risks of sudden flashbacks as **missing critical fuel shedding capability**

Where will replacement organisms come from to re-populate isolated waterways?

Health Risks of Fire

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- Wide-range of inhalation and skin contact hazards likely cause of increased cancer risks
- Smoke, breakdown products and firewater run-off produce VOCs and PAHs - some hazardous to humans, potentially carcinogenic
- Benzo(a)pyrene (PAH) is known carcinogen
- Increased risks with more attendance at vehicle fires

Source: Australian Firefighter Study, 2015

- Fast extinction helps reduce risks and exposures to firefighters, casualties and local communities

Likely Cancer risk from fire breakdown products - average 79% fires attended were S,V,B!

Dominant Fire Types Attended

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Agency (Career, Part-time paid & Volunteers)	All fires count	All structural fires count	All landscape (bush) fires count	All vehicle fires count	*All Structural, landscape and vehicle fires count*
Total Fires, All Agencies	1,228,200	348,676	445,047	176,959	*970,682*
% of total fire count	**100%**	**28.4%**	**36.2%**	**14.4%**	***79%***

- Monash University study of 224,000 Australian firefighters showed 79% of fires attended were Structural (S), Vehicle (V) or Bush (B) fires
- All firefighter groups studied showed increased risk of prostate cancer
- Class B Foams - whether fluorinated or fluorine free - ***NOT*** mentioned, as not normally required for these hazards

Source: 2015 Australian Firefighter Study, Monash University.

Likely Cancer risk clearly from fire breakdown products – NOT Foams used!

Toxins Penetrate PPE

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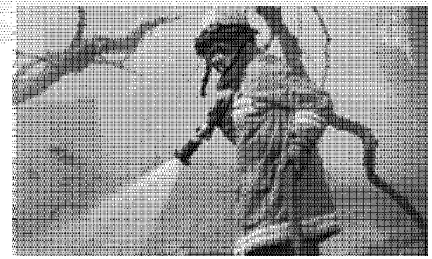
- Research shows fire breakdown products can enter skin under/through PPE during incident, overhaul and transfer back to station
- Off-gassing also inhaled during BA changes, overhaul and transport
- Exposures contributing to increased cancer risk
- Recommends shower and change on fire-ground with PPE sealed in containers and laundered regularly.

Source: Kirk &Logan, 2015 - Structural firefighting ensembles - accumulation and off-gassing of combustion products



Harmful fire exposures through PPE

Remediation Options

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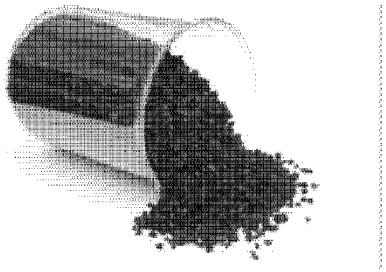
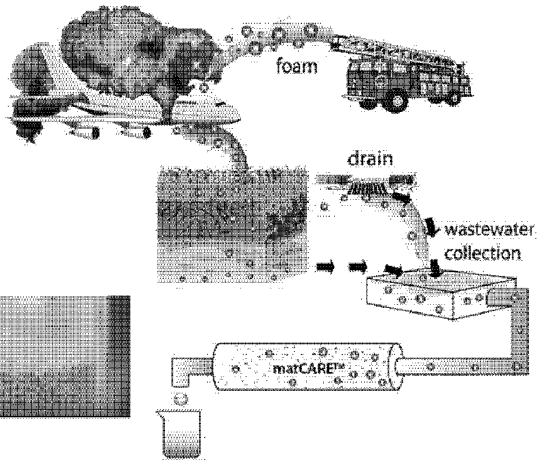
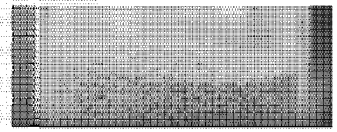
- Diverse options - varying degrees of effectiveness and complexity:
- Granular Activated Carbon(GAC) filtration
- Reverse Osmosis , electrocoagulation
- Catalytic advanced oxidation
- Reed bed technology - proven at UK airports for fire training areas.
- Adsorbing modified clays
- Specially modified clays -successfully treated > 1 million litres PFC contamination at 3 Australian airbases (QLD, SA, WA)
  - removed PFCs to below the reporting level of 5ppb
  - adsorbs PFOS and PFOA by binding them irreversibly into its structure
  - field trials shown more effective than GAC and biochar







Sources: Environment Institute of Australia, 2016 – PerFluorinated Compounds Forum, CRC Care - Firefighting foam case study, 2014

Navigating this Minefield…

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- Requires more holistic approach to whole incident
- Assess risks, exposures and liabilities
- Identify key critical factors and life safety issues
- Seek strengths and weaknesses of alternatives
- Avoid misleading assumptions/interpretations
- Select solution based on:
  - delivering strongest fire performance
  - protecting people and communities
  - delivering environmental responsibility
  - protecting valuable assets
  - minimising risks, liabilities, exposures
  - providing containment and waste treatment options

Identifies necessary components for future success

Risk Review

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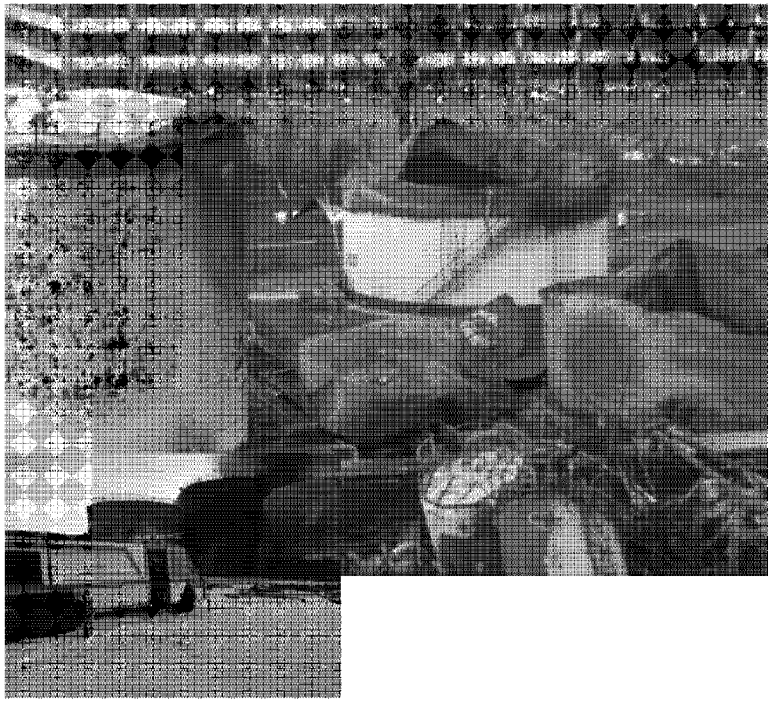

Consider fire impacts:

- Risk of more noxious smoke and breakdown products
- Risk to life, communities, businesses, associated processes/equipment /value
- Incident escalation risk = more damage
- Slower control = more fire = more run-off = ***more harm?***
- Larger Insurer pay-outs for more damage, more business interruption, more community disruption, more potential injuries
- UK Environment Agency leading field with more holistic views : ***All foams pollute***; ***extinguish fires fast!***

Foam Choice Makes BIG Difference: Reduces or Increases Risks

Legitimate Liabilities

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- Consider liabilities as part of risk assessment process
- Employers duty of care –staff health/injury liabilities
- Business/property owners - increased damage/costs
- Longer disruption: lost jobs and revenue
- Insurer liability: extensive/larger pay-outs
- Potential insurance premium increases
- Penalties/prosecution for control failures – particularly escape offsite or surface/groundwater contamination
- Controlled burn also an option, if minimising impacts!

Foam Choices Make Difference: Quick Control v Failure to Extinguish?

Exemplary Exposures

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- Impacts neighbouring facilities
- Heat damages people, buildings, processes, communities
- Escalation potential: slow control containment overflows, catastrophic failures
- Life safety, evacuation & rescue
- Reduce smoke & health exposure
- Extended environmental impacts - more smoke, more runoff, more toxicity, more community damage

Foam Choice Makes Difference: Reduces or Increases Exposures

Is F3 Relevant for MHFs?

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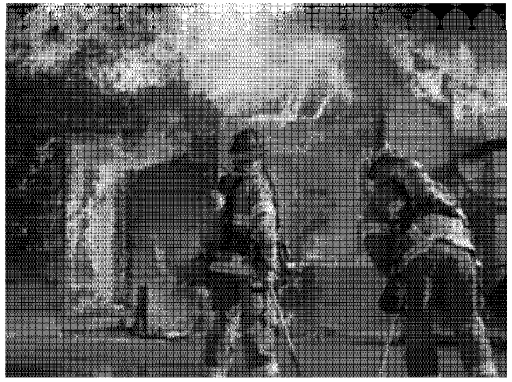

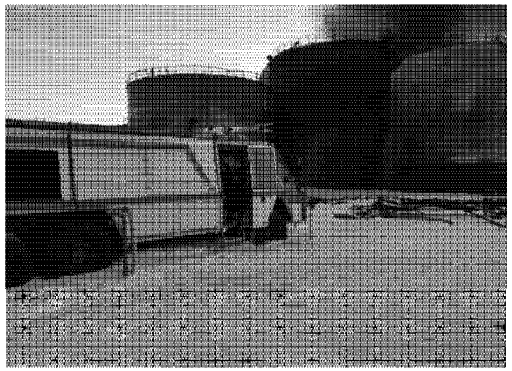

- Many Fire Services believe F3 is "Right Answer" …for smaller hazards
- *Does it translate to Major Hazard Facilities & surrounding Communities?*
- Fire breakdown products often toxic, persistent, maybe carcinogenic like PAHs – Benzo[a]pyrene, Fluorochemicals are widely used in buildings & vehicles –most now transitioning to short chain ≤C6 FTs. …Concrete leaching PFOS? ALL potentially contaminate firewater run-off and receiving environment!
- C6 FT fast acting to extinguish quickly with minimal resources and run-off.
- F3 may slow extinction, encourage escalation = ***MORE*** fire; delays; smoke; life safety risk; breakdown products; runoff; ill-health concerns; disruption; damage; repair time; community upset; cost! ***Is that right?***
- F3 also potentially 30x ***MORE*** toxic to aquatic organisms!
- Even leading F3 makers moving to C6 AFFFs & MilF spec!

Minimal use of C6 FT agents = more effective and environmentally responsible

Conclusions

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- Most agree PFOS, PFOA and PFHxS undesirable legacy issues
- All foam types can pollute: F, F3, + firewater runoff alone
- F3 brings problems – flashbacks, escalation, life safety risks, high toxicity, more fuel emulsification, high detergency
- Fuel shedding is critical C6 FT advantage + environmentally more benign as behaves differently (not B not T)
- Careful risk assessment of whole incident and how it evolves, is critical to protecting life safety
- Minimising risks, liabilities and exposures usually keeps incident manageable, and facilitates best choices
- Fast extinction with C6 FT based fuel shedding agents = way forward

C6 FT agents = fast, efficient, effective, reliable, environmentally responsible incident control

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