Information Bulletin

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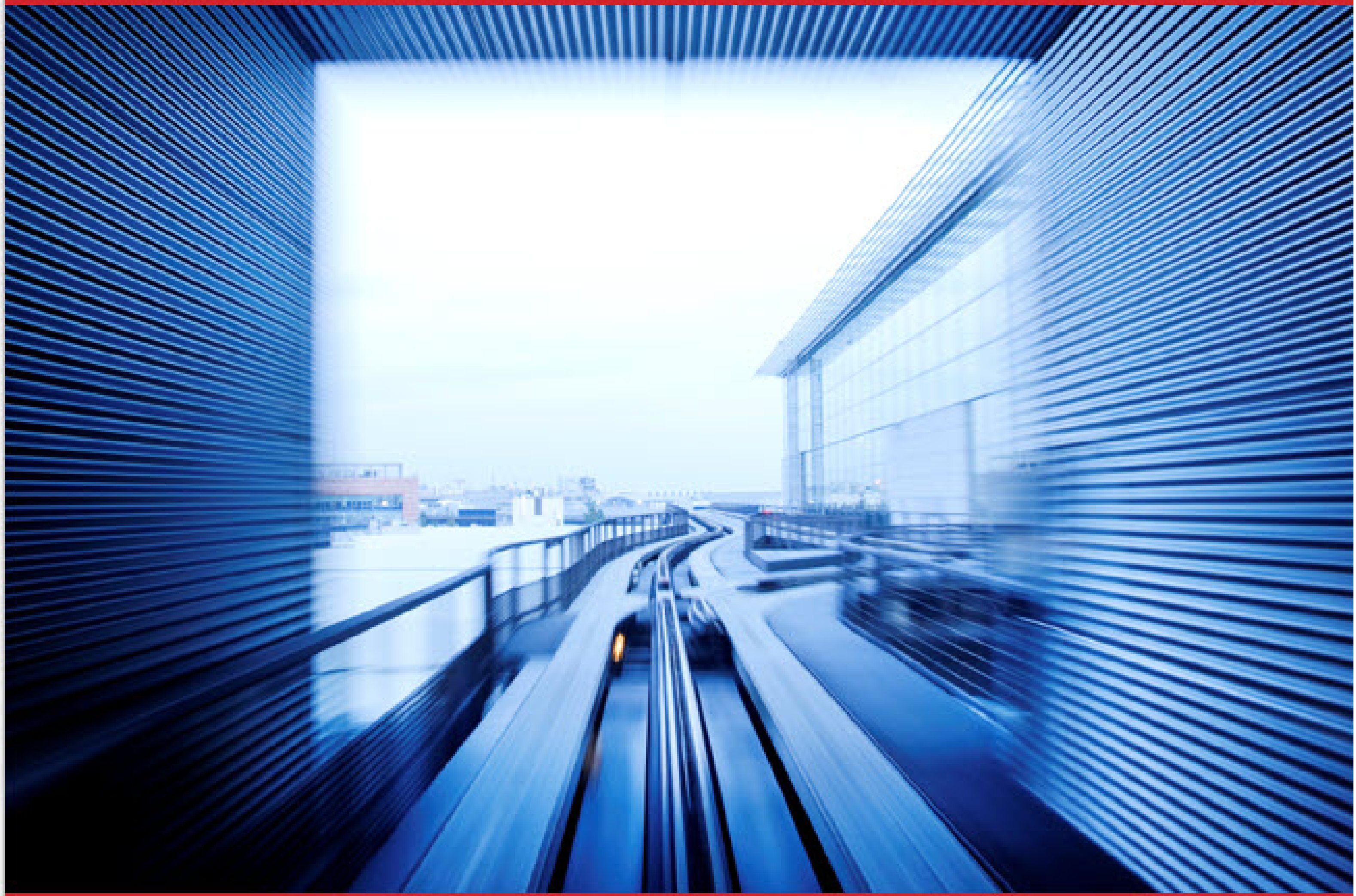
Selection and Use of Firefighting Foams



FPA AUSTRALIA

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Document history

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4.0	The following major changes have been included in this version of the document: • Updated **Environmental Regulations** section to include current Environment Regulations information • Added **A Road Map for F3 transition** section to highlight important considerations during F3 transitions • Updated **Environmental Best Practice** section to include *extra guidance on foam clean-outs and what*	September 2023

Version	Details	Date
	constitutes clean enough? information • Added Appendix A – Health concerns and phase out of C8 foams and the use of replacement C6 foams • Added Appendix B - Summary of F3 Fire Test Results.	

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1 About this Information Bulletin

The purpose of this Information Bulletin is to increase awareness of the issues surrounding the selection and use of firefighting foams based on their:

- Firefighting performance
- Environmental impact
- System and equipment compatibility.

This Information Bulletin also provides information on the different types of firefighting foams, suggestions for environmental best practice, and recommendations for the selection and use of firefighting foams.

> **Note**: The content of this Information Bulletin is based on the experiences of members, local and international research. For more information, see References.

1.1 Audience

This Information Bulletin is intended for:

- FPA Australia members
- Users of firefighting foams including owners of facilities protected by fixed foam systems
- Response agencies who use firefighting foams
- Other stakeholders involved in the selection and use of firefighting foam including manufacturers, suppliers, regulators, installers and maintainers of fire protection systems and equipment that use firefighting foam.

1.2 Acronyms

Acronyms are used throughout this Information Bulletin to make the document easier to read.

- **AFFF** – Aqueous Film Forming Foam (Fluorinated)
- **AHJ** – Authority Having Jurisdiction
- **AICIS** – Australian industrial Chemicals Introduction Scheme
- **AR-AFFF** – Alcohol Resistant Aqueous Film Forming Foam (Fluorinated)
- **AR-FFFP** – Alcohol Resistant Film Forming Fluoro-Protein Foam (Fluorinated)
- **AR-F3** – Alcohol Resistant Fluorine Free Foam (without PFAS)
- **AS** – Australian Standard
- **AS/NZS** – Australian/New Zealand Standard
- **Biodegradability** – A substance's BOD/COD as %-age.

- **BOD** – Biochemical Oxygen Demand
- **C6** – Short-chain PFAS, lower or equal to 6 carbon atoms
- **C6-foam** – Fluorinated firefighting foam containing PFAS surfactants with carbon chains shorter or equal to 6 carbon atoms
- **C8** – Long-chain PFAS, greater or equal to 7 carbon atoms widely restricted or banned from use, which may breakdown to PFOA, PFOSand PFHxS (PFHxS is defined as C8 under United Nations – OECD, 2015)
- **C8-foam** – Fluorinated firefighting foam containing PFAS surfactants with carbon chains longer or equal to 7 carbon atoms. Ceased production by 2015 to meet US EPA/EU regulations
- **CDC** – Center for Disease Control (US)
- **COD** – Chemical Oxygen Demand
- **DoD** – Department of Defense (US)
- **ECF** – Electrochemical Fluorination (process leading to C8-foams –ceased production in 2002-3)
- **ECHA** – European Chemicals Agency
- **EPA** – Environmental Protection Agency/Authority
- **EU** – European Union of 27 States
- **F3** – FAA Fluorine Free Foam (without PFAS -to agreed trace PFAS level), may also be called PFAS Free Foam or Non-Fluorinated Foam
- **FAA** – Federal Aviation Administration (US)
- **FFFC** – Fire Fighting Foam Coalition (US)
- **FFFP** – Film Forming Fluoro-Protein Foam (Fluorinated)
- **FIA** – FM Fire Industry Association (UK)
- **FM** – Factory Mutual Insurance Company
- **FP** – Fluoro-Protein Foam (Fluorinated)
- **FPA Australia** – Fire Protection Association Australia
- **GAC** – Granular Activated Carbon
- **ICAO** – International Civil Aviation Organisation
- **IMAP** – Inventory Multi-tiered Assessment and Prioritisation
- **IX** – Ion Exchange Resins
- **K_{ow}** – Octanol-water coefficient
- **LRET** – Long-Range Environmental Transport
- **mg/L** – 1 milligram per litre = 0.000,001 grams/Litre or ppm
- **µg/L** – 1 microgram per litre = 0.000,000,001 grams/litre or ppb
- **NEMP** – National Environmental Management Plan (Australia/New Zealand)

- **NF** – Nano-Filtration
- **ng/L** – 1 nanogram per litre = 0.000,000,000,001grams/litre or ppt
- **NFPA** – National Fire Protection Association (US)
- **NICNAS** – National Industrial Chemicals Notification and Assessment Scheme (Australia)
- **NRL** – Naval Research Laboratory (US)
- **OECD** – Organisation for Economic Cooperation and Development (United Nations)
- **OCRA** – Ozone fractionation Catalysed Reagent Addition
- **P** – Protein foam (without PFAS)
- **PAHs** – Polycyclic Aromatic Hydrocarbons
- **PBT** – Persistent, Bioaccumulative and Toxic
- **PFAS** – Per- and Poly-fluoroalkyl Substances
- **PFCs** – Perfluorinated and Polyfluorinated Compounds (more recently replaced by the term PFAS)
- **PFCA** – Perfluorocarboxylic Acid (PFAS sub-group)
- **PFSA** – Perfluorosulfonic Acid (PFAS sub-group)
- **PFHxA** – Perfluorohexanoic Acid
- **PFHxS** – Perfluorohexane Sulfonate
- **PFOA** – Perfluorooctanoic Acid
- **PFOS** – Perfluorooctanyl Sulfonate
- **POP** – Persistent Organic Pollutant (POPs is pleural)
- **POPRC** – Persistent Organic Pollutants Review Committee (UN Stockholm Convention)
- **ppb** – parts per billion or μg/L (1 in 1,000,000,000) equivalent to 1 sec in nearly 32 years
- **ppm** – parts per million or mg/L (1 in 1,000,000) equivalent to 1 sec in 11.5 days
- **ppt** – parts per trillion or ng/L (1 in 1,000,000,000,000) equivalent to 1 sec in nearly 32,000 years
- **QLD** – Queensland, Australia
- **RAC** – Risk Assessment Committee (EU-ECHA)
- **RO** – Reverse Osmosis
- **SA WQ Policy** – South Australia Water Quality Policy
- **SD** – Synthetic Detergent or High Expansion type foam (without PFAS)
- **SEAC** – Socio-Economic Assessment Committee (EU – ECHA)
- **UL** – Underwriters Laboratories– Insurer and Standards body (US)
- **ULC** – Underwriters Laboratories of Canada
- **UN** – United Nations

- **UNEP** – United Nations Environment Program
- **US** – United States of America
- **US EPA** – United States Environmental Protection Agency
- **VOC** – Volatile Organic Compounds
- **VHC** – Substances of Very High Concern (ECHA, UN and other regulators)

2 About Firefighting Foam

Firefighting foam is an effective suppression agent for preventing, extinguishing or controlling fires involving flammable liquids (Class B fuels). Its use can significantly reduce the risk to life, property, environment and business disruption from such fires. In addition to limiting the growth and impacts of a fire, use of these foams also reduces the amount of noxious and harmful breakdown products including known carcinogens released by the fires on which they are used.

Firefighting foam is used in fixed and portable fire extinguishing systems, and fire brigade apparatus. It is produced by mixing foam concentrate with water to produce foam solution. This solution can be applied:

- Non-aspirated (through water nozzles, sprinklers or deluge nozzles, provided the foam is suitable for application through these devices), or
- Aspirated (when the foam solution is mixed with air through dedicated foam making devices such as, a foam branch pipe, top pourer, foam induction monitor nozzle, foam sprinkler, MEX pourer or high expansion generator).

The application of firefighting foam to liquid fuel fires suppresses the release of flammable vapours, separates flames from the fuel, blocks the supply of oxygen to the fuel, and cools the fuel surface.

The environmental acceptability of different types of firefighting foam has been a topic of increasing global discussion in recent years, with particular focus on the properties of fluorinated versus fluorine free foams (F3-foams). Whilst a vast amount of environmental information is now available in the public domain, FPA Australia is concerned that much of this information focusses on environmental issues in isolation of other key factors such as firefighting performance, firefighters safety and system compatibility, which are critical for successful outcomes.

FPA Australia recognises that fire protection products and practices must be environmentally responsible. Acceptable life safety, fire protection and environmental outcomes cannot be achieved by consideration of any single performance characteristic in isolation. All the characteristics and properties of a product or system must be considered holistically to reach a well-informed view as to which product or system is best suited for a particular application. The decision to select and use a particular type of foam should only be made after careful consideration of a range of factors, including:

- Firefighting performance
- Protection of personnel (both firefighters, on-site workers and the near-by community)
- Potential adverse environmental impacts
- Compatibility with the fixed or portable fire systems in which it is to be used
- Compatibility with existing foam concentrate in storage
- Compatibility with materials (for example, potential tank/pipework corrosion and seal materials)
- Compatibility with existing proportioning equipment
- Cost.

This document is intended to provide an overview of the main issues which impact on the selection and use of firefighting foam. Only by careful consideration of all these important criteria and any regulatory restrictions, can foam users make an informed decision as to which type of foam is most suitable for their current and future needs.

3 Fighting Foam Selection and Use

The following main factors must be considered when assessing the selection and use of firefighting foam:

- Firefighting performance
- Environmental impact
- System/equipment compatibility.

3.1 Firefighting performance

Firefighting foam is used to prevent, control and extinguish fires. The foam's firefighting effectiveness, therefore must be the main consideration for its selection and use.

To be effective, a firefighting foam must:

- Rapidly spread over the fuel surface
- Cool the fuel surface
- Resist mixing with the fuel
- In the case of polar solvent (water miscible) fuels, resist attack from or breakdown by the fuel
- Suppress the release of flammable vapours
- Resist breakdown due to thermal heat
- Provide protection from re-ignition and flash-back.

A high level of firefighting performance is essential to protect life, property, and the environment.

High level firefighting performance facilitates:

- Rapid fire extinguishing
- Reduced potential for fire spread
- Reduced release of toxic products of combustion
- Reduced usage of water and foam
- Reduced risk to the life safety of responding firefighters, workers, and the community
- Reduced volumes of firewater effluent.

It is essential that the firefighting performance of any foam being considered for use, irrespective of whether it is a fluorinated or fluorine free-foam, is independently tested and certified to relevant and recognised standards that relate to the fuels, delivery devices, proportioning systems, and water type – fresh, river and sea – used on site.

Poor firefighting performance will result in fires being more difficult to extinguish and burning longer. This in turn will result in an increased release of toxic and carcinogenic products of combustion into the environment.

Contaminants in firewater runoff have a direct adverse impact on the environment, so minimising the quantity of water used to extinguish a fire is also essential to minimising environmental impacts.

Additionally, use of a foam with inferior firefighting performance can adversely affect the safety of firefighters, workers, and the wider community.

There are a range of firefighting performance test standards, which depending upon the intended application, can be used to demonstrate the suitability of a foam for a particular application. Commonly used test standards are listed in Environmental and Firefighting Performance Indicators.

Demonstrated evidence of firefighting performance—to the relevant test standard and site conditions, using representative fuels and operating devices—is essential in selecting the most suitable firefighting foam for any particular application.

3.2 Environmental impact

FPA Australia supports efforts to reduce the adverse impacts that fires and firefighting activities have on the environment. Appropriate selection and use of firefighting foams is important, as some firefighting foams do have a greater environmental impact than others by virtue of their chemical composition.

It must be clearly understood, however, that all firefighting foams and firewater runoff have the potential to pollute the environment.

Regardless of the type of firefighting foam used, it is also extremely important to consider the environmental impact from the combustion products of the fire itself. Whilst it is difficult to quantify the environmental impact of an individual fire, it is clear that extinguishing fires quickly, will reduce spreading and adverse environmental effects resulting directly from the fire. Using a foam with superior firefighting performance can minimise the amount of foam and water required, speed up extinguishment, and results in less firewater effluent whilst also reducing the quantity of combustion products released, potentially reducing adverse environmental impacts.

Failure to adequately consider the firefighting performance of a foam may result in selection of a foam that is ineffective for the intended application, increasing the adverse environmental impacts from a fire incident whilst also increasing the risk to life safety of both firefighters and the community.

For more information on environmental impacts, see Environmental and Firefighting Performance Indicators.

3.3 System and equipment compatibility

Fire testing protocols for firefighting foams evaluate performance under representative conditions for the application in question, including ambient temperatures, pressures, fuel types and suitability of the aspiration ratios available from discharge devices. Use of a firefighting foam which has not passed the fire testing protocols applicable to the fire protection system, equipment, or site conditions for which it is to be used, may increase the risk to life, property and the environment in a fire incident. Its use may also have serious implications for product/system approvals and insurance cover.

It is important to remember that firefighting foams form only one part of a system and a decision to change the type of foam used should not be made without considering the impact of that change on the complete system, its approvals, and to ensure existing levels of fire protection are not unintentionally compromised.

Before making a decision to change the type of firefighting foam used, consultation with key fire protection stakeholders, especially foam system designers, concentrate and equipment hardware manufacturers, is essential to ensure the performance of the system will not be adversely affected.

Important factors that must be considered include:

- Viscosity of the foam concentrate whether fluid (Newtonian) or thicker shear-thinning/thixotropic (non-newtonian) types.
- Suitability for use with existing proportioning hardware, or modification/replacement required.
- Homogeneous mixing and suitability of concentrate with water type being used.
- Compatibility with materials in the system (eg. metals, rubber seals, plastics etc).
- Stability of foam concentrate or pre-mix solution (separation, stratification, sedimentation) over prolonged periods of time during storage.
- Suitability for use on all flammable liquids used/processed/stored on site.
- Suitability of application method (aspirated, non-aspirated, forceful, gentle etc).
- Extremes of ambient temperature (year-round) that may be encountered in any fire incident.
- Suitability of the expansion ratios produced by existing equipment (or alternatives) for effective firefighting performance, and
- Suitability of the application rates produced by existing equipment for effective firefighting performance.

4 Environmental and Firefighting Performance Indicators

A range of methods are available to assess the environmental impact and firefighting performance of firefighting foams.

4.1 Environmental performance indicators

These are distinct from potential toxicological, human health effects, hazards and safety precautions recommended when handling various foam concentrates. All such relevant information should be available on the manufacturers Safety Data Sheets (SDS) including ecological and environmental test data.

Biodegradability (OECD 301)

This is an important environmental indicator defined by the United Nation's Organisation for Economic Cooperation and Development (OECD) as,

> *"The level of degradation achieved when the test compound is totally utilised by micro-organisms resulting in the production of CO_2, water, mineral salts and new microbial biomass."*

Scientific measures used to assess the impact of chemicals include Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and aquatic toxicity. These factors have an influence on the likely short-term impacts of the chemical.

Guidance values that can be used to quantify the biodegradation of a chemical's environmental impacts are often categorised as BOD/COD.

BOD/COD profiling identifies the biodegradability and de-oxygenating characteristics of chemicals in the environment. Chemicals that biodegrade rapidly can suffocate organisms by consuming available oxygen, as can larger quantities of high BOD chemicals in the environment.

The Organisation for Economic Cooperation and Development 301 Biodegradability testing requires readily biodegradable substances to achieve ≥ 60% in 28 days. This may not account for long-term or persistent residues in chemicals, so higher levels are increasingly required.

In Australia, Queensland's Department of Environment and Science Firefighting Foam policy has a stringent requirement for non-persistent F3-foams agents. It requires readily biodegradable foam chemicals to achieve at least 95% in 28 days. Fully biodegradable chemicals require 99% in 28 days.

To avoid oxygen depletion in waterways from damaging rapid breakdown, guidance usually suggests short-term biodegradability should be restricted to less than 40% within seven days.

Other factors are also used to establish whether a chemical has other environmental or health effects that necessitate high levels of concern and/or control.

Acute aquatic toxicity (OECD 203)

The primary organisms for such testing are fish species, but also water fleas and algae.

Fish are exposed to the test chemical for 96 hours in either static, semi-static or flow through conditions. Mortality and visible abnormalities related to appearance and behaviour are recorded. Where possible, the concentrations to kill 50% of the fish (LC50) are determined. It is important to assess whether the fish species used is relatively sensitive or tolerant to pollution (it may vary by factors of ten or more), as this will affect the results.

The Organisation for Economic Cooperation and Development uses Rainbow Trout, being amongst the most sensitive freshwater fish species. Other tests use Killifish, Guppy, Zebra Fish, or more tolerant Fathead Minnow.

Tests are often also conducted on Water Flea (Daphnia magna) which is also sensitive to pollutant chemicals. Effective concentrations (EC50) that stun half the test organisms over 48 hours is usually measured, providing useful comparative indications.

Some regulators may also require chronic and long-term aquatic toxicity tests to be performed.

UN Stockholm Convention

The Stockholm Convention on Persistent Organic Pollutants is an international treaty signed in 2001 that was effective since May 2004.

The aim of the treaty is to eliminate or restrict the production and use of Persistent Organic Pollutants. Australia is one of 179 parties that are signatories to this convention. Australia ratified the convention on 20 May 2004 and became a party to it on 18 August 2004. PerfluoroOctanyl Sulfonate (PFOS) was added as a persistent organic pollutant to the convention in 2009, then PFOA in 2019 and PFHxS in June 2022.

For more information, see Health concerns and phase out of C8-foams and the use of replacement C6-foams

The Persistent Organic Pollutants Review Committee (POPRC) established by the convention developed a procedure for the consideration of individual substances. It defines Persistent Organic Pollutants using the following criteria:

> *"POPs are organic chemical substances (carbon based). They possess a particular combination of physical and chemical properties such that, once released into the environment, they:*
>
> - *remain intact for exceptionally long periods of time (many years) ie. persistent (P);*
> - *become widely distributed throughout the environment as a result of natural processes involving soil, water and, most notably, air ie long-range environmental transport (LRET);*
> - *accumulate in the living organisms including humans, and are found at higher concentrations at higher levels in the food chain ie bioaccumulative (B);*
> - *are toxic to both humans and wildlife ie toxic (T)"*

If a substance meets each of the above criteria, risk profiling is used to evaluate whether it results in a substance being likely to lead to significant adverse human health and/or environmental effects, and therefore warrants global action. If global action is warranted, a risk management evaluation is undertaken reflecting socio-economic considerations associated with possible restriction or control measures and the substance is listed under the appropriate Annex of the convention. Annexes include:

- Annex A – Elimination
- Annex B – Restriction
- Annex C – Unintentional production.

In May 2019, the Conference of the Parties (COP-9) accepted the revision that the Stockholm Convention

> *"Encourages Parties and others to use alternatives to PFOA, its salts and PFOA-related compounds, where available, feasible and efficient, while considering that fluorine-based fire-fighting foams could have negative environmental, human health and socioeconomic impacts due to their persistency and mobility."*

The committee recognised that some time may be necessary to allow transition from long-chain C8 PFAS to more benign alternatives.

4.2 Firefighting performance standard indicators

Firefighting performance and system compatibility of foams must be considered when considering any changes.

There are a number of local and international standards that are used to rate the firefighting performance of foam. These include, but are not limited to the latest versions of:

- **Australian Standards**
  - AS/NZS 1850, *Portable fire extinguishers – Classification, rating and performance testing*
  - AS 5062, *Fire protection for mobile and transportable equipment*.
- **International Standards**
  - EN 1568, *Fire Extinguishing Media – Foam Concentrates (Parts 1, 2, 3 & 4)*
  - EN 13565, *Fixed Firefighting Systems – Foam Systems (Parts 1 & 2)*
  - *International Civil Aviation Organisation (ICAO) Fire Test Method, Doc 9137 — Airport Services Manual, Part 1 — Rescue and Fire Fighting*
  - *NFPA 11, Standard for Low-, Medium- and High-Expansion Foam*
  - *UL 162, Standard for Safety for Foam Equipment and Liquid Concentrates*
  - *Factory Mutual 5130 Foam Extinguishing Systems*
  - *FM Global Property Loss Prevention Data Sheet 4-12 Foam Extinguishing Systems*
  - *International Maritime Organisation (IMO) MSC.1/Circ.1312*
  - *US Department of Defense Mil-PRF-24385F(SH) Amendment 4 (Apr. 2020), Fire Extinguishing Agent, Aqueous Film Forming Foam (AFFF) Liquid Concentrate, for Fresh and Sea Water*
  - *US Department of Defense MIL-PRF-32725 Fire Extinguishing Agent, Fluorine Free Foam (F3) Liquid Concentrate for Land-based and Freshwater applications only (6 Jan.2023)*.

In addition to these test standards, there are several listing or product certification schemes that provide independent evaluation of fire protection products including firefighting foams.

Evidence of suitability from such listing bodies should be sought to confirm the firefighting performance of a foam on the fuels to be protected with the type of equipment to be used, and under the year-round conditions likely to be experienced on the site during fire emergencies.

When considering the use of product that has been listed or certified, it is important to check the basis for listing or certification that this includes testing to a standard relevant to the intended application and meet the specific site conditions.

The result of performance parameters identified by testing to these standards include:

- Time to achieve extinguishing of fire
- Burn-back resistance
- Speed of knockdown and vapour control (90% control time).

Recognising that some current international standards do not detail recommended application rates and operational duration for modern fluorine free F3-foams, NFPA and UL/FM in the USA have conducted testing programs to determine effective recommended application rates for F3-foams in comparison to AFFF.

For more information, see F3 Fire Test Results Summary.

While the performance of F3-foams has improved in recent years, further testing is demonstrating specific factors that need to be considered in standards relating to firefighting foams and F3-foams selection. Generally, F3-foams exhibit impaired fire performance using saltwater, but also at using expansion ratios below 6:1, particularly on flammable fuels like gasoline.

No new foam should be considered a *drop-in* replacement in existing systems without its suitability pre-confirmed.

Given the ongoing evolution of firefighting foams particularly F3-foams, consideration should also be given to any new research (see F3 Fire Test Results Summary) and the performance of specific foams from major fire incident reports, as valuable additional indicators of potential firefighting performance and environmental behaviour.

5 Environmental Regulations

Regulation and restriction of undesirable C8 PFAS chemicals is increasing around the world in response to site contamination of soils, groundwater, human blood levels, food and drinking water. Particularly where there was intensive use at specific locations for decades, for example, airports, defence sites and fire brigade training areas.

Australian Industrial Chemicals Introduction Scheme (AICIS) formerly National Industrial Chemicals Notification and Assessment Scheme (NICNAS) is a branch of the Australian Government's Department of Health, helping to protect the Australian people and the environment by assessing the risks of industrial chemicals and providing information to promote their safe use.

AICIS advice includes:

- The Inventory Multi-tiered Assessment and Prioritisation (IMAP) Environmental Tier II Risk Assessment for short-chain C6-PFAS, which sets its status as Persistent, not Bio accumulative, not Toxic.
- The IMAP Human Health Tier II Risk Assessment occupational and public health risk characterisations for C6-PFAS, which concluded:

> *"C6 chemicals are not considered to pose an unreasonable risk to worker's health" and "the public risk from direct use of these chemicals is not considered to be unreasonable".*

5.1 PFAS National Environmental Management Plan

The original PFAS National Environmental Management Plan (NEMP) was developed by the Heads of Australian State and Territory Environmental Protection Authority (EPA) and the New Zealand EPA (collectively HEPA). It was implemented in February 2018 followed by an updated v2.0 in January 2020 and a draft v3.0 for public consultation in September 2022 (closed 28 February 2023).

The latest v3.0 builds on v2.0 with new guidance proposed to focus on grouping of PFAS, environmental data and monitoring, risk-based criteria for water guidance for beneficial reuse of biosolids, soils guidance and human health guidance. It also covers resource recovery and waste with site specific principles and nationally agreed guidance and standards on investigation, assessment and management of PFAS wastes including prevention of contamination.

The NEMP is designed to help governments, industry and the community identify, monitor and respond to PFAS contamination including:

- All PFAS (C8 and C6) to be covered
- Requirements for PFAS monitoring and assessment plus site evaluation and prioritisation
- Defined measurement techniques for PFAS and acceptable environmental levels indicating need for action
- Guidance on how to deal with sites contaminated with PFAS – waste, transport and treatment with information sharing across Australia

- Requires updating of the NEMP as an evolving document to incorporate new emerging data
- Recognition of landfill leachate and Waste Water Treatment Plants (WWTP) as significant PFAS effluent sources requiring reduction and control
- Requirements for evaluation of the NEMP effectiveness with research towards future revisions
- Definition of important trigger values for soil investigation, biota guideline values, landfill acceptance and health-based drinking and recreational water values
- Requirements for collection, separation, treatment and destruction of all PFAS.

5.2 Queensland Environmental Management of Firefighting Foam Operational Policy

This policy, the first PFAS regulation in Australia, was implemented across Queensland by the Department of Environment and Heritage Protection in July 2016 (now Dept. of Environment and Science).

This policy requires:

- Immediate removal of PFOS foams from service
- Containment and control measures for all PFAS foams so none enters the environment
- Phase out of fluorinated firefighting foam where primarily the perfluorinated part of the carbon chain is longer than or equal to seven carbon atoms (C8 foams) within three years
- Preference for F3-foams use wherever possible

  Where this can be demonstrated to be impossible, special consideration may be given to use of C6-foams with a purity of >99.5% provided there is a complete collection and containment of all foam solution, firewater runoff and wastes used in impervious dikes with proper and safe disposal including accidental spills, testing and maintenance of fixed and mobile equipment.
- High temperature (>1,100^{o}C) disposal of all fluorinated organic wastes including firewater runoff and system cleaning
- Containment of non-persistent F3-foam wastes wherever possible using all reasonable and practical measures to minimise environmental harm
- A 10 parts per million (ppm or mg/L) limit of PFOS/PFHxS residual contamination in replacement foam stocks
- A 50ppm limit of PFOA precursors and higher homologues (≥ C7) contamination in replacement foam stocks
- Full compliance by all foam users to implement F3-foams by July 2019

  Extension can only by negotiation and documented progress if necessary for major industries.

5.3 South Australia Environment Protection (Water Quality) 2015 Policy

Amendment banning PFAS foam use was implemented in January 2018.

This policy covers all firefighting foam uses from portable extinguishers to fire trucks and fixed foam systems across South Australia.

This policy includes:

- A ban on the use of all fluorinated firefighting foams for all applications with a timeframe of two years for compliance for all non-handheld applications by January 2020
- A ban to hand-held applications (portable extinguishers) upon re-charge, re fill or within two years of commencement of the policy whichever is earlier
- Provisions to address PFAS contamination in existing equipment
- Certification of fluorine concentrations in replacement foam provided by suppliers

The EPA South Australia may consider an exemption application if an assessment of previous and proposed actions, and justification of why F3-foams cannot be used at the site can be demonstrated.

5.4 New South Wales Protection of Environment Operations General Amendment (PFAS Firefighting Foam) Regulation 2021

Effective April 2021, the objective of this regulation is to:

a. Prevent pollution caused by certain types of PFAS firefighting foam (prescribed as long-chain) by:
    - making it an offence to discharge PFAS firefighting foam (long and short-chain) for firefighter training or demonstration
    - (from 26 September 2022) making it an offence to discharge PFAS firefighting foam (prescribed long-chain) unless discharged by a relevant authority to prevent, extinguish, or attempt to extinguish a catastrophic fire or one with potential to be a catastrophic fire
    - by a person to prevent, extinguish or attempt to extinguish a fire on a water-craft in state waters or prescribed waters
    - (from 26 September 2022) making it an offence to sell a portable fire extinguisher containing the precursor to the PFAS firefighting foams (long and short chains), except if the extinguisher is sold to particular persons, the owner or master of watercraft or a person granted exemption by EPA.

b. Enable EPA to exempt a person or class of persons from offences in relation to prevention of pollution caused by certain types of PFAS firefighting foam

c. Declare the EPA is the appropriate regulatory authority for a matter relating to the prevention of pollution caused by certain types of PFAS firefighting foam.

5.5 Australian National PFAS Position Statement 2019

This statement outlines a unified vision for reducing further PFAS use across Australia by agreeing to the following objectives:

- Ongoing sale or use of products or articles that contain long-chain PFAS for any industrial or commercial application should be phased out in line with the Stockholm Convention
- Transitioning away from chemicals causing irreversible or long-term contamination of Australia's environment should be the ultimate goal for all users of PFAS in Australia
- Where short-chain PFAS are used in AFFF, they should only be used in emergency situations in accordance with all relevant regulations

  Any releases should be fully contained and wastes managed in accordance with the PFAS National Environmental Management Plan
- Until it is proven to be effective and economically feasible, PFAS-free alternatives are developed, the ongoing sale and use of products and articles containing short-chain PFAS may be necessary for uses for which no suitable and less hazardous alternatives are available (replacement chemicals should be less toxic, not persistent, degradable, and not bioaccumulative)
- Entities currently selling or using long or short-chain PFAS are encouraged to develop a strategy outlining current uses, and how and when they will transition away from these chemicals.

5.6 USA

An increasing number of states in the USA are passing or considering legislation to restrict the use of PFAS foams, particularly for training purposes (where most usage occurs).

Most of the US are allowing continued use of C6-PFAS based foams for major hazard facility fires including California, Connecticut, Illinois, Michigan, Minnesota, New Jersey, New York, Virginia and Washington, but restricting the use of long-chain PFAS foams.

A few states are limiting the manufacture, sale and distribution of PFAS-foams with some exemptions for C6 agents.

The National Defense Authorization Act also provides PFAS-foam restrictions from 2024 for Department of Defense (DoD) and Federal Aviation Administration (FAA).

In October 2021, the FAA issued public safety concerns with F3 foams in a Cert-Alert to airports.

January 2023 release of the new Fluorine Free Foam (F3) MilSpec fire performance Standard for land-based, freshwater applications only (MIL-PRF-32725).

In January 2023, a further Cert Alert was issued confirming that the FAA will accept airport operators use of the new F3 agents once it fully passes MIL-PRF-32725 qualification testing and is added to the Qualified Products List (QPL/QPD).

The FAA also confirmed

> *"Certified Part 139 airports will not be required by the FAA to transition to the new F3. Airport operators are authorised to continue using QPL MilSpec AFFF"*

FAA cautioned

> *"F3s lack compatibility with other F3s, so they cannot be mixed together. F3s are not available in pre-mixed solutions and operators using potassium based dry chemical should contact assigned FAA Safety Inspector to discuss options for ARFF response."*

The 2022 FAA fire performance testing found some F3 blankets were collapsed by coincident use of dry chemical, reducing burnback capabilities.

For more information, see B6 – US Federal Aviation Administration (FAA) – Fluorine Free Foam Testing Report DOT/FAA/TC-22/23 - Jul. 2022

5.7 Canada

Canada has restrictions in place for long-chain PFAS including PFOSand PFOA.

A *State of PFAS Report* is planned by end 2023 and is considering restriction activities that would address PFAS as a class.

An exemption has been made around MIL-PRF 24385F (SH) Amdmt. 4 (Apr.2020) requirements, which allows the use of fluorine free foams at Canadian airports.

5.8 Europe (EU)

The European Commission has committed to phasing out all PFAS under its *Chemicals Strategy for Sustainability*, and allowing their use only where they are proven to be irreplaceable and essential to society.

C8-PFAS including PFOS and PFOA are already prevented from use in EU since 2011.

C6-PFAS are permitted for emergency firefighting use provided they meet EU regulation 2017/1000 (residual content below 25ppb for PFOA, its salts and below 1,000ppb for all PFOA related substances, including precursors).

Five European countries – Netherlands, Germany, Denmark, Sweden and Norway (European Economic Area member) – have proposed restrictions on all PFAS in firefighting foams, and universally from all uses as a separate regulation.

Public consultations during 2023 will inform ECHA's scientific Committees for Risk Assessment (RAC) and Socio-Economic Analysis (SEAC) to assess the proposed restriction options, which are suggested in some sectors as being too short. In its draft opinion on PFAS restrictions in firefighting foams, SEAC recognises

> *"there is a concern that the transition times proposed by the Dossier Submitter might not be sufficient to ensure the development, full testing and adoption of alternatives suitable for the most challenging types of fires. Given the potential very high impacts of even a single catastrophic fire on human health and the environment, the proportionality of the proposal is uncertain if risks of such catastrophic fires are not kept as low as they are currently. SEAC recommends in this context to adopt a no-regret strategy; that is, a restriction option that remains justifiable whether catastrophic fires take place or not."*

In their final assessment, SEAC will consider the scientific evidence from consultations submitted before its May 2023 deadline. Together with the 27 EU Member States, the European Commission will finalise the decision on these restrictions and its conditions/exemptions expected early 2024 with likely implementation during 2025.

5.9 United Kingdom

The United Kingdom is considering whether further PFAS restrictions are necessary beyond compliance with the POP regulations. Currently, C8-foams are phased out under this legislation.

From January 2023, C8-foams containing PFOA or related compounds cannot be used for training or testing, and are only allowed in sites where all releases can be contained. An exemption for PFOA foams already installed in systems (mobile and fixed) is in place until July 2025 subject to certain conditions being met.

C6-foams meeting the EU regulation 2017/1000 (where minute traces of PFOA and its salts are below 25ppb, and PFOA related substances including precursors are below 1,000ppb) are permitted for installation and use during emergencies along with F3 foams where safe to do so.

6 Firefighting Foam Types

Firefighting foams are classed into the following categories:

- PFAS as fluorinated surfactants
- PFAS-free or fluorine free (F3).

Within each category are the individual foam types.

- **Fluorinated Foams**
  - AFFF– Aqueous Film Forming Foam
  - AR-AFFF – Alcohol Resistant Aqueous Film Forming Foam
  - FP – Fluoro-Protein Foam
  - FFFP – Film Forming Fluoro-Protein Foam
  - AR-FFFP – Alcohol Resistant Film Forming Fluoro-Protein Foam.
- **Fluorine Free Foams**
  - F3—Fluorine Free Foam
  - AR-F3 – Alcohol Resistant Fluorine Free Foam.

Both fluorinated and fluorine free concentrates can be either Newtonian (flow like water) or non-Newtonian (shear-thinning). Higher concentrate viscosities could lead to proportioning accuracy issues, particularly under low temperature and low flow conditions.

Note: High-expansion, protein, Class A and most training foams are, and always have been, fluorine free foams.

6.1 Fluorinated firefighting foams (C8 and C6 Foams)

Historically, fluorinated firefighting foams include small quantities of perfluorinated and/or polyfluorinated compounds (PFC) or Per- and Poly-fluoroalkyl Substances (PFAS), as they are now more commonly called.

C8-PFAS predominated before 2015, but since then all major manufacturers produce only high purity C6-foams meeting US EPA PFOA Stewardship and REACH 2107/1000 regulations.

PerfluoroOctanyl sulfonate (PFOS) and PerfluoroOctanoic acid (PFOA) are two of the most common PFAS-based products derived from a range of precursors which were contained in older C8-foams, PFHxS and other long-chain PFAS.

C8-foams had good firefighting performance, but were Persistent (P), Bioaccumulative (B), Toxic (T) with Long Range Environmental Transport (LRET) characteristics, all of which are unacceptable and have a significant negative environmental impact with a potential to harm human health. Since 2015, these C8-foams have been widely removed from service under Stockholm Convention requirements.

Note: C8-foams based on the specific formulation may contain PFOS, PFHxS, PFOA and/or PFOA pre-cursors, so should *not* be used, and should be destroyed by high temperature incineration (>1,100°C).

C6-foams may contain minute levels of PFOA, but acceptable under both the US EPA PFOA Stewardship program and REACH Regulation (EU) 2017/1000 allowing their continued use during emergencies.

C6-foams are still persistent, but are not categorised as bioaccumulative or toxic, and evidence shows they are of low concern to human health. They are also more environmentally benign than C8-foams.

For more information about health concerns and the phase out of C8-foams and replacement C6-foams, see Appendix A.

6.1.1 US EPA PFOA Stewardship Program

The United States Environmental Protection Agency (US EPA) Voluntary PFOA Stewardship Program (2006-2015) aimed to eliminate PFOA content by 2015 from the surfactants manufacturing processes, products and waste streams by transitioning from C8 surfactants to C6 surfactants. US EPA reports confirm this was achieved.

For more information on the US EPA PFOA Stewardship Program, see United States Environmental Protection Agency.

6.1.2 REACH Regulation (EU) 2017/1000

Foam manufactured or supplied in Europe must comply with the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) Regulation (EU) 2017/1000.

This regulation permits only high purity C6 foams to be used for fire emergencies, with up to:

- 25 parts per billion (ppb or µg/L) of PFOA including its salts
- 1,000 ppb for one or a combination of PFOA related substances including precursors.

For more information on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) Regulation (EU) 2017/1000, see Commission Regulation (EU) 2017/1000.

6.1.3 Summary of fluorinated firefighting foams (C8 and C6 foams)

Fluorinated firefighting foams behave differently and should not be grouped as a single class in terms of their environmental properties. C8-foams have largely been removed from service.

C6-foams compliant with the US EPA PFOA Stewardship Program and REACH Regulation (EU) 2017/1000 have distinctly different environmental and human health characteristics to C8-foams that contained PFOS, PFHxS and/or PFOA.

For more information about health concerns and the phase out of C8-foams and replacement C6-foams, see Appendix A.

6.2 Fluorine-free firefighting foams (F3-foams)

In response to the environmental concerns with C8 (PFOS and PFOA) fluorinated foams and the European and US reforms, F3-foams technology has advanced in recent years and modern F3-foams are available in both the Australian and international markets.

F3-foams do not contain persistent fluoro-surfactants (that is, fluorine free, which in EU = <1ppm PFAS, in US DoD/UL162 = <1ppb PFAS, US EPA = <70ppt) and play an important role in fire protection and training. However, as a general rule, they do not provide the same level of firefighting performance as C8-foams or C6-foams. Typically, F3-foams do not provide the same fuel shedding, film forming characteristics, vapour sealing or burnback resistance, which can be vitally important to rapid extinguishment of fires in some applications. These properties are particularly important in industrial and petrochemical applications, and where the foam is applied forcefully such as in emergency incidents.

Viscosity in F3-foams varies significantly. While a few F3-foams are Newtonian, most are more viscous shear-thinning concentrates (non-Newtonian) where viscosity reduces the faster the foam is sheared. Highly viscous foams require care to ensure accurate proportioning, particularly at low temperatures and low flow conditions.

It must be noted that increasingly F3-foams have been certified to test standards including UL 162, ULC, FM 5130, ICAO, EN1568, IMO and LASTFIRE, although many use heptane as the test fuel, which is not necessarily representative of common flammable fuels like Gasoline, E10, Jet A1 etc.

As is the case with all foams, users should verify that the foam being considered for use has been independently tested and certified to a standard relevant to the intended application and are proven effective when applied on the applicable fuels, at the extremes of ambient temperatures and at the expansion ratios and application rates expected from the discharge devices used in the system. Any change in foam type should not compromise the designed life safety and critical infrastructure protections required and provided by the existing foam-based fire protection systems.

While F3-foams are typically 95-100% biodegradable, and are therefore not persistent in the environment, it should be noted that the short-term environmental impacts of many F3-foams have been shown to be an order of magnitude higher in short-term aquatic toxicity than C6-foams. Evidence suggests when unsuited to the application, higher application rates and slower extinguishments may result, particularly on volatile fuels, so more foam is likely to be used, potentially increasing BOD issues. These factors combined could cause more short-term adverse impacts on fish and other aquatic organisms, particularly in small or isolated water bodies. It is therefore important to remember that all foams pollute regardless of the type of foam being used. As such, their use should always be minimised, and the used foam solution and firewater runoff collected and managed to reduce environmental impacts.

A huge amount of investment and resources are being directed to further improve the performance of F3-foams by organisations such as the FAA, US Naval Research Laboratory (NRL), NFPA Research Foundation, Lastfire and Sweden's Research Institute.

For more information about comparative fire test results using F3-foams, see Appendix B.

For more information about health concerns and the phase out of C8-foams and replacement C6-foams, see Appendix A.

FPA Australia supports the use of more environmentally responsible foam formulations. However, firefighting foams must only be used in applications where they provide acceptable levels of life safety and firefighting performance, demonstrated through a risk-based assessment of realistic worst case incident scenarios.

Applications that can be challenging for F3-foams include:

- Portable fire extinguishers
- Non-aspirated engineered and pre-engineered foam/water spray systems used to protect large vehicles, trains, mining machines, offshore platforms etc
- Forceful application onto flammable liquid fuels in depth (eg. storage tanks and associated bunded areas)
- Seawater and other non-potable water uses

Leading F3-foams are now used and approved for use in:

- Portable fire extinguishers
- Non-aspirated pre-engineered foam/water spray systems used to protect vehicles like trains, large mining machines
- Some non-aspirated foam sprinkler systems.

In Australia, the use of foam in *portable fire extinguishers* requires the portable fire extinguisher to pass the fire test protocols in AS/NZS 1850, *Portable fire extinguishers – Classification, rating and performance testing*.

The use of foam in *Non-aspirated pre-engineered foam/water spray systems* application requires the system to pass the fire test protocols in AS 5062:2016 *Fire protection for mobile and transportable equipment*.

6.2.1 Summary of fluorine free F3-foams

Some F3-foams are Newtonian, but most are more viscous shear-thinning concentrates. Some F3-foams have better firefighting and environmental performance than others, and just like C6-foams, evidence of suitability for adequate life safety and fire protection of the hazards/applications in question must be sought before a commitment is made to use a specific foam agent.

6.2.2 Compatibility in storage

Compatibility between any foam concentrates in storage is generally an issue and should be avoided (except some equivalently listed MilSpec AFFFs). Different foam products are rarely compatible if mixed, even from same manufacturer, so they should not be used to *top-up* bulk storage tanks.

> **Important**: Only top-up storage tanks using the existing foam concentrate in use.

When changing foam concentrate, ensure adequate clean-out is performent and the foam concentrate use from one type to another in bulk storage tanks (also with F3-foams from one brand to another) to avoid:

When changing foam concentrate from one type to another (or changing brand if F3-foams) in bulk storage tanks, ensure adequate clean-out is performed to meet local regulatory requirements and avoid:

- residues potentially contaminating the new foam
- different system requirements
- premature deterioration, unexpected separation or chemical reactions that could potentially render the new foam ineffective.

7 F3 Transition Road Map

US National Fire Protection Association Research Foundation's (NFPA-RF) *Fire Fighting Foams: Fire Service Road Map* (May 2022) provided valuable and comprehensive transition guidance to foam users that confirms:

> *"The new fluorine-free foams are similar to the legacy protein foams in that they rely solely on the foam blanket to contain the fuel vapors to extinguish the fire (i.e., fluorine-free foams do not produce a surfactant film on the fuel surface like AFFF). As a result, air-aspirating discharge devices may be required to optimize the capabilities of these products."*

Cautioning

> *"However, it is incorrect to assume that these new FFFs [F3s] are a 'drop-in' replacement for AFFF, even though they may have a specific listing or approval. At this time, there is too much difference between specific FFF's in properties and performance to suggest that the class can be a drop-in replacement for the AFFF class of foams."*

Foam quality is a critical consideration

> *"…FFFs tend to lose effectiveness when discharged through non-air-aspirating nozzles that produce lower aspirated/aerated foam with expansion ratios less that 4-5. … Specifically, reduced foam quality can be compensated for by increased application rate and vice versa."*

F3-foams are yet to be proven equally effective in major incidents, making C6-foams often necessary alternatives for emergency use on high hazard flammable liquid incidents. Where existing system application rates cannot be increased, delivery devices are unable to be changed, extra weight /space of increased storage prohibitive, or lives are exposed without easy exit options away from the incident – for example, on-board vessels, offshore platforms, remote island research stations, and so forth.

A full cost-benefit analysis is a useful tool for the entire foam system performance, including potential modifications and clean-outs, to clarify decision-making before embarking upon such major safety changes.

Consideration must be given to higher application rates, translating into larger concentrate storage, increasing delivery devices, potentially higher water pressures, flows, extra pipework. Most F3-foams approval testing uses fresh not saltwater.

Seawater can impair fire performance of many foams particularly F3-foams.

The 2022 Swedish Research Institute testing showed only two of eleven F3-foams were able to extinguish forceful applications on heptane using seawater under EN1568-3 protocol. This could be a major concern for industrial sites, airports, marine vessels, ports, jetties, offshore platforms, military applications and so forth where fire mains use seawater.

For more information, see B5 – Sweden Research institute (Ri.SE) – Fire test performance of 11x F3s, varying fuels, water and foam generation techniques - Feb. 2022.

7.1 Important considerations during F3 transitions

You can review the following questions to help avoid pitfalls and prevent unintended consequences of any F3-foams transition.

Consideration of these issues are intended to maintain existing fire protection standards of life safety and critical asset protections without being unnecessarily or unintentionally compromised.

1. **Can existing and proposed flammable liquids currently used or transported be effectively protected by F3-foams?**

   Standard approval test fuels, for example, heptane are not always representative of your hazards especially with F3-foams.

   Seek test data on the specific fuels used, transported, stored – for example, crude oil, condensate, naphtha, gasoline including blends (unleaded, E10, E15, E85), Jet A/A1 aviation fuel, polar solvent chemicals etc.

   Research confirms most F3-foams require higher application rates and longer operating times on such volatile fuels.

   This could require greater concentrate storage (and weight loadings), more space allocation, and potentially larger containment areas.

2. **If storing, handling or transporting crude oil, what F3-foams application rate reliably extinguishes before any boil-over may arise?**

   Premium AR-AFFFs typically achieve this at 9-10.25 L/min/m^2 (0.22 to 0.25 gpm/ft^2) on crude oil. Clear AR-F3-foam recommendations are necessary using meaningful scale test data.

   Expect higher AR-F3 recommendations than AR-AFFF.

3. **Could longer extinguishment times increase fire spread and incident escalation risks?**

   The main objective is getting the flames out fast, protecting firefighters, workers and infrastructure while minimising risk of fire spread or incident escalation into new areas. This could be more challenging using F3-foams.

   Check what F3-foams re-application frequency is necessary after successful extinguishments or delivery on unignited fuel spillages? Faster foam blanket deterioration where seawater and/or volatile fuels are used, may require increased and/or longer applications, likely varying with different fuels. This potentially requires extra F3-foams storage, extra delivery devices, pipework etc.

4. **Is it safe to enter F3-foams blankets during firefighting or rescue operations?**

   Guidance in this area is always challenging and F3-foams can vary with different fuels or delivery devices.

   The National Fire Protection Association Research Foundation cautions:

   > *"you are transitioning to a less forgiving agent, solely reliant on the foam blanket effectiveness from gentle application."*

   Pre-planning, training, incident command practices and decision making *all* depend on this important knowledge for firefighter safety and reducing risks.

5. **Is a total system engineering approach (for example, UL/FM protocols) provided?**

   Foam concentrates, proportioners, foam makers and the fuel being protected should all be demonstrated effective together and listed through independent 3rd party approvals.

The National Fire Protection Association Research Foundation advises F3 systems:

> *"will need to be designed and installed within the listed parameters in order to ensure a high probability of success during an actual event. …it typically took two passes to extinguish all the fires [with F3] as opposed to one for AFFF."*

Check more viscous F3-foams still meet proportioning rate accuracy requirements year-round while remaining effective with existing delivery devices, for example:

- 1% foam 1-1.3%
- 3% foam 3-3.9%
- 6% foam 6-7%

…otherwise consider alternatives.

For more information, see B2 – NFPA Research Foundation (NFPA-RF) Testing Report - Jan. 2020 – Evaluation of Fire Protection Effectiveness of F3s.

6. **Has a full cost-benefit analysis for your F3 transition been conducted?**

   Keeping control of expected costs, time-lines, out of service periods and fire performance helps ensure existing safety protections are not unintentionally compromised, and all expected benefits are delivered.

   Consider alternative solutions including optimisation of existing C6-foams containment and collection during major emergencies, which may prevent potentially increased containment requirements for F3-foams and/or likely increased risk of overflows.

7. **Is your F3 compatible with other agents used on site?**

   Dry chemical often discharged alongside or above your foam and may cause partial or instant F3 collapse.

   Limited dry chemical compatibility was found by Federal Aviation Administration in six of nine leading F3-foams tested. One F3 re-ignited immediately.

   For more information, see B6 – US Federal Aviation Administration (FAA) – Fluorine Free Foam Testing Report DOT/FAA/TC-22/23 - Jul. 2022

8. **Are current application rates and backup stock levels still appropriate?**

   F3 inventory levels may need increasing if higher application rates or durations are required. This could require extra storage and weight loadings. Ensure mutual aid partners have usable compatible stocks and quick re-stocking is available following incidents to minimise downtime exposure.

9. **What is your F3 storage life and reliability record?**

   Ensure three or five year storage samples have been tested to verify no gelling or separating, while still extinguishing volatile fuels as effectively as when new. If not, you must have an *aged* F3 sample tested by an approved independent laboratory to verify continued effectiveness to avoid unexpected performance deterioration over time. If using an AR-F3, ensure long-term stability on your specific polar-solvent fuels.

10. **Does your F3 contain toxic, persistent, or harmful ingredients?**

    National Fire Protection Association Research Foundation cautions:

    > *"It needs to be understood that the elimination of PFAS and/or fluorine from the product does not address all the potential health and environmental hazards."*

    Do Safety Data Sheets (SDS) provide aquatic toxicity, human health data and residual Fluorine/PFAS levels on the complete F3 mixture, not just key components? If not, this data is required.

11. **What level of existing system residual PFAS is *clean enough*?**

    National Fire Protection Association Research Foundation cautions:

    > *"To date, there is no clear guidance for how clean final rinsate water must be to satisfy local regulators".*

    Define residual ppm/ppb PFAS levels of system rinse-water and F3 concentrate, before installation. Federal Aviation Administration reported five of seven leading F3 concentrates contained high TOF (Total Organic Fluorine) levels of 10-87ppm (US EPA Method 537.1, 2020).

    Ensure your chosen laboratory can accurately detect levels necessary for concentrate, foam solution and rinse-water.

    For more information, see B6 – US Federal Aviation Administration (FAA) – Fluorine Free Foam Testing Report DOT/FAA/TC-22/23 - Jul. 2022

12. **Has alternative, equivalent fire cover been arranged during your F3 transition?**

    Several days or weeks may be required before system modifications, clean-out, re-commissioning and re-activation are complete and foam systems can be returned to service.

    Can discrete areas be addressed? Or is a complete site foam system re-fit envisaged? Loading/unloading turnarounds, maintenance, process shut-downs and start-ups are often considered the most dangerous times for fires with contractors and unexpected problems often arising during such operations.

13. **Has extended containment been considered?**

    Potentially necessary if higher application rates, durations and/or more frequent F3 top-ups during incidents are likely. Ensuring collection and containment of firewater run-off also prevents potentially polluting overflows into our environment.

    NFPA-RF recommends containment and collection of all foam solutions (F3 and C6) with safe disposal according to applicable local regulations.

14. **F3 system commissioning recorded?**

    Include video footage documenting your foam system's effectiveness and competency before any future major incident occurs.

15. **Do existing training programs need adjusting to ensure F3 is safely managed and operated?**

    NFPA-RF Road Map advises:

    > *"the industry trend is towards collection and disposal of F3s in the same manner as AFFF today, so unfortunately the ability to train with these foams will have the same cost burden as the legacy AFFFs requiring special facilities and waste containment/collection."*

    Proof of effectiveness and competency from F3 transitions ensures adequate protection from future fire dangers. Training with Mutual Aid partners ensures abilities and limitations of each foam being used and firefighters during a major fire emergency are understood before fire strikes.

NFPA-RF road map concludes:

> *"Ultimately, end users will need to design and install within the listed parameters in order to ensure a high probability of success during an actual event. … but a detailed evaluation must be completed prior to making that transition…"*

Adopting a *Question checklist* based on expert or NFPA-RF guidance could achieve such necessary assurances to help keep everyone safe, regulators satisfied, while retaining fire protection system objectives (that is, keeping lives and sites safe from unintended consequences, including risking life loss and/or critical facilities destruction).

8 Environmental Best Practice

This chapter outlines FPA Australia's recommended environmental best practice for use of firefighting foams.

8.1 Training, system testing and commissioning

Training of personnel in the use, testing and commissioning of fire protection systems is essential to ensure the fire preparedness of a facility. However, such activities should be undertaken in an environmentally responsible manner.

To minimise the potential for firefighting foam to enter the environment, FPA Australia recommends the following measures be implemented to facilitate training and system testing and commissioning:

- Use training foams or other surrogate liquids that do not contain fluoro-surfactants for training, system testing and commissioning purposes wherever possible
- Develop test and commissioning methods for foam proportioning systems which do not discharge foam to the environment
- Where the discharge of foam cannot be eliminated, ensure it is contained for appropriate collection, treatment and disposal in accordance with the requirements of the local regulatory authorities.

  If containment is not possible, training, testing and commissioning should only be carried out with a surrogate liquid that is not persistent, bioaccumulative, or toxic and without known potential human health or adverse environmental impacts. Comparative proportioning rates using water only against the specific foam type should be considered if sufficient reliable comparative data is available
- New system designs or system upgrades should incorporate the facilities to allow testing and commissioning of the proportioning system without the need to discharge foam. This may be achieved by comparative flow meters (assuming similar viscosities of foam to water), incorporating a test return line to the bulk foam storage tank or alternatively diverting foam or a surrogate liquid to a dedicated test tank from which it can be recovered for re-use, or disposal in accordance with the requirements of the environmental regulatory authorities.

It should be noted that the 2022 NFPA-Research Foundation *Firefighting Foams: Fire Service Road Map* advises:

> *"the industry trend is towards collection and disposal of F3s in the same manner as AFFF today so unfortunately, the ability to train with these [F3] foams will have the same cost burden as the legacy AFFFs requiring special facilities and waste containment/collection."*

8.2 Firewater effluent

Firewater effluent or runoff contains many potentially harmful breakdown chemicals from items burnt in the fire and will probably include:

- PFAS
- Unburnt hydrocarbon or polar solvent fuels;
- Products of combustion (potentially including Volatile Organic Compounds (VOC) and Polycyclic Aromatic Hydrocarbons (PAH), some of which are known carcinogens)
- Prticulates
- Surfactants
- Water-soluble polymers
- Hydrolysed proteins
- Organic matter – suspended and dissolved solids
- Co-solvents
- Anti-freezing agents
- Biocides
- Pathogens
- Other compounds.

Firewater effluent is likely to also be contaminated with PFAS from a wide range of consumer sources including pre-existing contamination of soil, water and other infrastructure even when F3-foams are being used. Pre-existing PFAS contamination is highly likely to exist on many industrial sites.

For these reasons, all firewater effluent is potentially hazardous, and it is therefore vitally important that it is contained as far as possible regardless of whether it is C6-foam, F3-foam or water only that has been used.

This contained firewater effluent or runoff should then be tested for contamination levels before remediation, treatment or disposal in accordance with the requirements of local environmental regulatory authorities. EU limit values of 1ppm PFAS (measured as Total Organic Fluorine – TOF) for F3 concentrates, rinsing water during cleanout and waste water effluent or fire water run-off is a good guide to avoid unnecessary environmental contamination, where specific requirements are not stated.

8.3 Remediating PFAS contaminated soil and water

Considerable research work has been undertaken recently into effective remediation options for soil and water contaminated with C8-foams (particularly PFOS/PFHxS and PFOA), and/or C6-PFAS. An increasing number of viable technologies are becoming commercially available.

Some of these technologies for adsorption, separation and concentration of PFAS include:

- Granular activated carbon (GAC) (more effective for C8-PFAS)
- Modified clays and bioabsorbent granules
- Ion exchange resins (IX)
- Ozone fractionation with catalysed reagent addition (OCRA)
- Membrane filtration including reverse osmosis (RO) and nano-filtration (NF)

- Electrocoagulation
- Reed bed filtration.

A number of well-documented commercially available case studies have been completed removing PFAS to non-detect levels.

Effective PFAS breakdown/destruction technologies include:

- Electrochemical oxidation
- Cement kiln destruction*
- Plasm arc incineration/thermal destruction*
- Thermal desorption
- Sonic destruction
- Heated persulphate oxidation
- Fungal degradation.

*Cement kiln destruction, plasma arc incineration and thermal desorption are available in Australia. Most other technologies are yet to be commercially available in Australia. For information on destruction options in your local region, FPA Australia recommends contacting your local environmental regulatory authority.

More recent additional technologies being explored, and which show promise at laboratory and pilot scale include the following:

- Photocatalysis — uses silicon, carbon and iron catalysts and short wavelengths (<200 nm) of UV light to degrade PFAS
- Carbon nanotubes and filters — increase the surface area for PFAS adsorption, increasing effectiveness of short-chain capture and extending life and efficiency of filters
- Advanced electrochemical oxidation — creates free radicals and has also been shown to be effective, as has advanced reduction using nano zero-valent iron
- Colloidal activated carbon — has shown effective results in case studies providing soil barriers to curtail PFAS plume movements
- Ionic Fluorogels — leverage a synergistic combination of fluorophilic sequestration and targeted ion exchange to generate high performing and selective gels for PFAS remediation.

  It has been shown to be highly effective at adsorbing PFAS substances (both long and short-chains including C4) from waste water treatment plant effluent.

  These gels can also be regenerated to provide increased operational efficiency.

These technologies could also potentially be effective methods of treating firewater runoff and fire training ground effluent if they are proven to perform and become commercially available.

8.4 Cleaning/change out of existing C8-fluorinated foams

FPA Australia recommends the following process when cleaning foam tanks, changing out or transitioning from existing C8-foams:

- Decant existing C8-foams into suitable storage containers, which are also bunded and clearly marked for safe storage, transport and incineration/destruction, according to local requirements of Authority Having Jurisdiction (AHJ).
- Thoroughly soak and flush foam system with hot water and detergent (or other suitable additives) to clean PFAS from main system components, particularly tanks, proportioners, concentrate pipework. Benefit is likely from soaking (possibly even overnight), which may require repeating two or three times before rinsate PFAS levels are sufficiently low to meet local AHJ requirements.
- Collect all effluent, *residual* concentrate (foam solutions, flushing and rinsate water) in suitable storage containers/tankers, identifying contents, and store safely in a bunded area prior to safe disposal/destruction.

Note: Changing from a long-chain C8-foams containing PFOS or PFOA to a US EPA PFOA Stewardship compliant high purity short-chain C6-foam, meeting REACH Regulation (EU) 2017/1000 or an F3-foam will require thorough washing of the tank and concentrate sections of pipework including proportioners until no frothing is visible and AHJ residual levels are met. It also requires collection, remediation and safe disposal of all effluent from this washing process to the satisfaction of AHJ.

To avoid the possibility of contamination, the tank should not be filled with the replacement foam until the results of this testing are available and confirmed sufficiently low levels meet local environmental regulatory requirements.

Also confirm the F3 concentrate's residual PFAS level is below this threshold before re-filling.

- Using suitable remediation technologies, any flushed foam solution and rinse water effluent should be treated to concentrate the PFAS into as small a volume as practical, held separately and labelled prior to disposal/destruction methods approved by AHJ.
- Analyse clean water produced (and from fire main supply) also to ensure residual PFAS levels are not exceeded, before any re-use or release to the sewer/environment to ensure local regulatory requirements are met.
- This is likely to require temporary storage in large clean tanks without any previous PFAS usage or potential pre-existing PFAS contamination in a safe and bunded area.
- Send concentrated PFAS containing waste materials for safe disposal/destruction in accordance with local regulatory requirements.
- Always seek AHJ approval for plans at each stage of transition before proceeding.

8.5 What constitutes clean enough?

This is still a confusing area without clear definition by most regulators or AHJs.

Although some EU member States are pushing ECHA (European Chemicals Agency) to require 1ppb residual PFAS (measured as Total Organic Fluorine - TOF) not ECHA's proposed 1ppm PFAS limit forF3-foams. Setting too low a level could make almost everywhere become *contaminated* requiring potentially prohibitively expensive *remediation* almost everywhere. Reliable measurement of such low levels is also problematic.

FPA Australia therefore urges AHJ acceptance of a realistic practical, achievable and consistent PFAS residual level of 1ppm, as currently accepted by ECHA.

50ppm residual PFAS levels required in Queensland have been shown to be practical and achievable, but may deliver misleading temporary performance benefits which then decay as PFAS levels drop to true *Fluorine Free* status. Lower than 1ppm is likely to be challenging and potentially impractical.

Foam users should also be aware of likely *rebound* of PFAS levels over 12-18 months upward from levels achieved after final rinsing during transition cleanouts. This may occur from PFAS still firmly bound onto system surfaces released over time into F3 concentrates and/or stationary water/foam solution residing in foam protection pipework systems (another reason to clean down to 1ppm initially). Clean out levels should be realistic and proportionate.

> **Important**: define and record residual ppm/ppb PFAS levels of system rinse-water and new F3 concentrate before installation to meet AHJ requirements, or 1ppm total PFAS, whichever is lower.

US Federal Aviation Administration (FAA) reported (Jul y 2022) five of seven leading F3 concentrates analysed contained surprisingly high TOF (Total Organic Fluorine) levels of 10-87ppm (US EPA Method 537.1, 2020) likely to impact performance (FFFC and 3M in US confirmed to ECHA that 1ppm PFAS is too low to affect fire performance of F3-foams).

For more information, see B6 – US Federal Aviation Administration (FAA) – Fluorine Free Foam Testing Report DOT/FAA/TC-22/23 - Jul. 2022.

Ensure your chosen laboratory can accurately test at detection levels necessary for F3 concentrate, foam solution and rinse-water, and record your residual levels before replacement. It could help justify reasonable *duty of care* was taken in the future and act as a baseline for future monitoring measurements.

9 Recommendations

FPA Australia recommendations on the selection and use of firefighting foam are as follows:

- Use of C8-foams containing PFOS/PFHxS/PFOA should be prevented.
- Any existing stocks of C8-foams containing PFOS/PFHxS/PFOA should be advised to AHJ, removed from service, sealed in labelled containers and sent for high temperature incineration or equivalent destruction at an approved facility.
- Foam manufacturers should only provide high purity C6-PFAS containing foams meeting US EPA PFOA Stewardship Program and/or REACH Regulation (EU) 2017/1000 (25ppb PFOA, its salts or 1,000ppb PFOA related substances (that is, precursors), or PFAS-free F3-foams.
- Replace any remaining C8-foams with US EPA PFOA Stewardship Program/REACH Regulation (EU) 2017/1000 compliant C6-foams or F3-foams using a holistic risk-based assessment approach to select the foam most appropriate for the intended application, fuels and operating conditions without compromising life safety and/or critical infrastructures.
- Training and testing of systems should be conducted at least annually with F3 agents wherever possible.

  Risk of not testing with adequate training means your system may fail during a future fire emergency.
- Evidence of fire performance suitability must be sought to demonstrate C6 or F3 ability to achieve the required firefighting performance for the specific fuel(s) stored/used at the extremes of ambient temperature that may be encountered on site year-round with the aspiration level and application rates being provided by the discharge devices and system design in place, or alternatively being modified accordingly for a suitable F3 transition.
- Evidence must also be sought to confirm that the replacement foam is compatible with the systems and equipment with which it is to be used, and that the performance of these systems is not being compromised.

  Listing of foam with components being used provides a guide to likely effectiveness.
- Whilst important, the environmental performance of a foam should not be used as the sole selection criteria, nor considered in isolation.

  Effective life safety and critical asset fire protection must also be adequately considered. Choosing the most responsible firefighting foam—the best one to protect life, property and the environment—involves selecting one that provides a combination of firefighting performance, reliability and life safety, balanced with minimal toxicological and adverse environmental impacts from the whole incident. The following key selection criteria must all be adequately considered to ensure all realistic expectations are being met:

  - Firefighting performance
  - Life safety
  - Physical properties and suitability for use on known hazards including forceful application

  - Compatibility with in-depth fuels (that is >25 mm), system design, application method, existing delivery equipment, site operating conditions and approvals
  - Environmental impacts of whole fire incident including smoke, escalation, duration, damage, firewater run-off and so on, not just the foam agent in isolation.

- Any proposal to change the type of foam used in a system requires careful consideration and must take fire safety and engineering factors into account.

  The type of foam used should not be changed without completing a detailed risk assessment review of the design, life safety, fire performance and operation of the system as a whole. Such design reviews should include consultation with fire system designers, foam and foam hardware suppliers/specialists, and the relevant authority having jurisdiction (AHJ).

- Follow the questions in Important considerations during F3 transitions to ensure unexpected consequences and/or compromised life safety protections do not eventuate.
- Having upgraded and changed any foam protection system, an important *duty of care* is to verify the system is working correctly through commissioning testing and training to verify no unintended safety compromises or consequences will result from its activation during future emergencies.
- Where possible, eliminate the discharge of foam during training, system testing and commissioning (or safely collect and contain all foam discharge to prevent escape to the environment).

  Where this is not possible, use PFAS-free surrogate liquids or training foams. Where the discharge of foams containing C6-fluorosurfactants during training, testing, or commissioning cannot be avoided, ensure all discharge is contained, collected, treated, and disposed of in accordance with the requirements of the relevant AHJ.

- All firewater run off/effluent, irrespective of foam type used, should be contained and tested for regulated contaminants (including PFAS*) prior to any discharge, as it is likely to qualify as hazardous waste. It should then be treated and disposed of according to the requirements of the relevant AHJ.

  > ***Note**: Significant PFAS levels may occur from non-foam related consumer products in fire incidents even when F3-foams or water are being used.

- For new or existing installations, consideration should be given to using emergency drainage and containment of fuel being diverted away from the hazard, which may make foam use unnecessary.

  Drainage and containment to remove flammable/combustible liquids and fire protection water to a safe location in addition to preventing burning liquids from spreading into unsafe areas, minimising pool fire size and therefore minimising the overall fire severity.

- Ensure all firefighting foam systems are appropriately maintained, checked and trained with to ensure they are *ready for use* at all times

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Appendix A: Health concerns and phase out of C8-foams and the use of replacement C6-foams

This Appendix discusses the health concerns of particular PFAS chemicals in C8-foams, the phase out of these foams and safe continued use of replacement C6-foams.

PerFluoroOctanyl Sulfonate (PFOS)

PFOS is a Perfluorosulphonic acid (PFSA, part of the PFAS family) and derives from the 3M™ developed Electrochemical Fluorination (ECF) or Simon Cell process, (no longer used outside China, and perhaps Russia).

The main global manufacturer of PFOS containing foams, 3M™, voluntarily ceased global manufacture of fluorochemicals by end 2002, but in Australia the manufacture of 3M™ Lightwater™ AFFF and ATC™ AR AFFF concentrates extended into 2003. Since then, ECF is believed to have ceased production (outside China). PFOS was added to Annex B of United Nations (UN) Stockholm Convention in 2009 as a persistent Organic Pollutant (POP) and is widely restricted or banned from use.

Australia must go through a complex domestic treaty process before PFOS, PFOA and PFHxS are ratified as Persistent Organic Pollutants, for which the Commonwealth Department of Climate Change, Energy, the Environment and Water is responsible, however they should not be used, except in certain emergency fire situations.

FPA Australia considers that these three PFAS should be ratified as Persistent Organic Pollutants in accordance with the Stockholm Convention urgently to provide clarity for foam users and improve protection of our environment. This is underway with IchEMS PFAS scheduling decisions on PFOS, PFOA and PFHxS to ratify prohibition of these Persistent Organic Pollutants in Australia under the Stockholm Convention.

The European Union (EU) has prohibited the marketing and use of PFOS since 27 June 2008. Subsequently, PFOS was banned from use in all EU countries in 2011 requiring high temperature incineration (above 1,100°C) to destroy it. New Zealand banned PFOS in 2011, followed by Canada in 2013.

PFOS listing as a Persistent Organic Pollutant under the United Nations (UN) Stockholm Convention means FPA Australia recommends that any C8 fluorinated firefighting foam containing PFOS and/or its related chemicals including PFHxS should be immediately removed from service and sent to an authorised regulated waste facility for disposal.

Perfluorooctanoic Acid (PFOA)

PFOA is a Perfluorocarboxylic acid (PFCA) (part of the PFAS family) and was listed as a POP by the UN Stockholm Convention POPRC in 2019.

Concerns about PFOA persistence, detection in human blood and effects in animal studies has led to further scientific research. This research has shown that C8 fluorochemicals have larger more complex precursor molecules, which are more likely to breakdown to C8 endpoint substances (PFOS, PFOA and PFHxS) that are persistent, toxic, bioaccumulative and remain in mammalian organisms for long periods of time. Research indicates that C8 fluorochemicals have half-lives in humans typically averaging 5.4 years for PFOS, 8.5 years for PFHxS, and 3.8 years for PFOA. In comparison, the main short-chain C6-foams breakdown product PFHxA has an average human half-life of just 32 days, being quickly excreted in urine.

PFOA was mainly used as a polymerization aid in the long-chain Fluorotelomer (FT) manufacturing process of several types of fluoropolymers. Trace amounts of PFOA (but not PFOS) can be found from long-chain FT precursors and in C8 fluorotelomer foams, but they ceased production under the US EPA PFOA Stewardship Program in 2015. Fluoropolymers were used in a wide variety of industrial and consumer products including domestic cookware, but not in firefighting foams nor other firefighting applications.

All major fluorotelomer manufacturers met the US EPA PFOA Stewardship Program 2006-2015 requirements of virtually eliminating PFOA (down to ppb levels) from fluorotelomer surfactants by transitioning to environmentally more benign high purity (≥98.5%) short-chain C6 alternatives by end of 2015. Only C6-PFAS are now being used in all fluorinated firefighting foam concentrates by all main manufacturers (outside China and perhaps Russia). The remaining percentage consists predominantly of C4 fluorosurfactants, improving environmental outcomes and complying with both the US EPA PFOA Stewardship Program and the EU REACH Regulation 2017/1000 requirements for residual trace below 25ppb PFOA and its salts, and below 1,000ppb of any PFOA related substances including precursors.

As PFOA is listed as a Persistent Organic Pollutant under the UN Stockholm Convention, FPA Australia recommends that any C8 fluorinated firefighting foams containing PFOA and/or its related substances should be immediately removed from service and sent to an authorised regulated waste facility for safe disposal according to local regulatory requirements.

PerFluoroHexane Sulfonate (PFHxS)

PFHxS is a Perfluorosulfonic acid (PFSA) (part of the PFAS family derived from ECF process) and was listed as a POP by the UN Stockholm Convention in 2022.

FPA Australia recommends that any C8 fluorinated firefighting foams containing PFHxS and/or its related substances including PFOS should be immediately removed from service and sent to an authorised regulated waste facility for safe disposal according to local regulatory requirements.

C6 fluorotelomers

Scientific research has shown that although still persistent, C6-foams are categorised as non-bioaccummulative, non-toxic, and environmentally more benign than C8 fluorochemicals including PFOS, PFHxS and PFOA.

Scientific research indicates that C6-PFAS are not bioaccumulative, not carcinogenic, not genotoxic, not endocrine disruptors, not developmental toxins nor mutagenic and they exhibit low toxicity to humans and aquatic environments.

C6-foams meeting the US EPA PFOA Stewardship Program and the REACH Regulation (EU) 2017/1000 are widely considered safe for continued emergency use across most of Australia, except Queensland and South Australia.

The Australian Department of Health, Expert PFAS health panel concluded in its May 2018 advice that

> *“There is no current evidence that supports a large impact on an individual’s health”*

from C6 fluorotelomers and

> *“In particular, there is no current evidence that suggests an increase in overall cancer risk” from C6 PFAS use.*

This health report confirmed that

> *"Differences between those with the highest and lowest exposures are generally small, with the highest groups generally still being within the normal ranges for the whole population. There is mostly limited or no evidence for an association with human disease accompanying these observed differences."*

It concluded

> *"Our advice to the Minister in regards to public health is that the evidence does not support any specific biochemical or disease screening, or health interventions, for highly exposed groups, except for research purposes."*

US EPA Stewardship Program and REACH Regulation (EU) 2017/1000 compliant C6 fluorotelomer surfactant-based foams:

- Do not break down to PFOS, PFHxS, PFOA or chemicals currently listed or suspected of being POPs or persistent, bioaccumulative and toxic (PBT) substances
- Although persistent, C6-foams are not made with chemicals currently considered to be bioaccumulative or toxic by the environmental authorities
- Are not listed by the Stockholm Convention or European Chemicals Agency (2023) list of substances of high or very high concern (VHC).

Importantly, C6-foams retain fast, effective, reliable and efficient firefighting performance under the most challenging conditions, in most cases equivalent to C8-foams without increased fluorochemical content. Equivalency has been verified using the MilSpec 24385F (2020) foam test standard and UL 162 listings.

Luz, Anderson et al (2019) C6-PFAS (PFHxA) toxicity research confirmed

> *"Sufficient data exist to conclude that PFHxA is not carcinogenic, is not a selective reproductive or developmental toxicant, and does not disrupt endocrine activity. Collectively, effects caused by PFHxA exposure are largely limited to potential kidney effects, are mild and/or reversible, and occur at much higher doses than observed for perfluorooctanoic acid (PFOA). A chronic human-health-based oral reference dose (RfD) for PFHxA of 0.25 mg/kg-day was calculated."*

The Pt.II 2019 study confirmed

> *"In this paper, we apply this RfD in human health-based screening levels calculations, and derive a drinking water lifetime health advisory of 1400μg/L and a residential groundwater screening level for children of 4000μg/L."*

Concluding

> *"PFHxA and related fluorotelomer precursors currently appear to present negligible human health risk to the general population and are not likely to drive or substantially contribute to risk at sites contaminated with PFAS mixtures."*

Occupation of firefighting confirmed as carcinogenic

Firefighting as an occupation has been declared as carcinogenic by the highly respected International Agency for Research on Cancer (IARC) in Jun.2022, announcing

> *"The [IARC] working group evaluated occupational exposure as a firefighter as carcinogenic to humans (Group 1) on the basis of sufficient evidence for cancer in humans."*

This covered mesothelioma and bladder cancer, with limited evidence for cancers of colon, prostate, testis, skin and non-hodgkins lymphoma.

“There was strong mechanistic evidence for occupational exposure exhibiting multiple key characteristics of carcinogens in exposed humans.”

The Lancet confirmed this evaluation was principally based on exposures associated with fighting structure and wildland fires (where Class B foams are not used – neither PFAS nor PFAS-free foams), and employment as a firefighter.

IARC confirmed

“Occupational exposure as a firefighter is complex. Firefighters respond to various types of fire (e.g. structure, wildland, and vehicle fires) and non-fire events (e.g. vehicle accidents, medical incidents, hazardous material releases, and building collapses). They may be exposed to a mixture of combustion products (e.g. polycyclic aromatic hydrocarbons, particulates), chemicals in firefighting foams, flame retardants, diesel exhaust, building materials, and other hazards, such as night shift work and ultraviolet radiation. Changes in types of fire, building materials, personal protective equipment, and roles and responsibilities among firefighters have resulted in significant changes in firefighter exposures over time.”

PFAS have often been regarded as the main problem associated with fire-fighting foams, but Class B liquid fuel fires where foam is used are generally quite rare, particularly compared to structural, vehicle and bush/wildland fires.

It is more probably other agents of combustion which are more insidious and harmful to our health, for example, smoke, other breakdown products of the fire, fuels like benzene, diesel exhaust, formaldehyde, building materials including plastics, asbestos; UV radiation and many other exposure hazards.

2019 scientific smoke research by US Centre for Disease Control (Fent) confirmed firefighter cancers can occur from contamination or skin exposure to harmful fire breakdown products found in smoke and firewater run-off created from burning common structure materials.

These fire breakdown products frequently contain known carcinogens including Polycyclic Aromatic Hydrocarbons (PAHs) and Volatile Organic Compounds (VOCs), benzene, formaldehyde and others.

This study reported dermal absorption through skin as an important source of firefighter carcinogen exposure, even when Self Contained Breathing Apparatus (SCBA) is worn during structural fires, but often not during overhaul when inhalation is a source, and where Class B foams are not normally used – whether containing PFAS or PFAS-free.

This study concluded:

“Thus, the findings here support previous work suggesting that dermal absorption plays an important role in the accumulation of toxicants during firefighting.”

“Several studies have documented increased excretion of PAH and/or benzene metabolites in urine or breath following structural firefighting.”

It continued

“Firefighters’ exposure to chemical carcinogens, particularly those associated with by-products of combustion, has been postulated as a contributor to this increased risk”.

Interestingly no mention of PFAS.

These findings confirmed a 2018 UK firefighter study where

“The aim of this study was to conclusively demonstrate the elevated occupational exposure of firefighters to individual carcinogenic PAHs. …including benzo[a]pyrene (B[a]P), 3-MCA, and 7,12-dimethylbenz[a]anthracene. PAHs were determined on body surfaces (e.g., hands, throat), on PPE including helmets and clothing, and on work surfaces. The main exposure route would appear to be via skin absorption.”

Monash University's 2014 Australian Firefighter study found testicular cancer increases were likely caused by inhalation and skin absorption of volatile breakdown products from fires.

Seventy-nine percent of firefighter responses were structural, vehicle and bush fires without fluorinated foam usage.

No current scientific evidence suggests short-chain ≤C6-PFAS including PFHxA, cause harm to human health or the environment. Persistence and mobility alone are not categorised as *harmful*.

Short-chain C6-PFASand precursors studies by Australian Industrial Chemicals Introduction Scheme (AICIS, formerly NICNAS) are categorised as *persistent, non-bioaccumulative, non-toxic*.

The Inventory Multi-tiered Assessment and Prioritisation (IMAP) framework, Tier II human health assessment confirmed:

> *"the public risk from direct use of these [C6-PFAS] chemicals is not considered to be unreasonable."*

Occupational risk characterisations similarly concluded:

> *"…workers are not expected to be exposed to the high doses of the chemicals (PFHxA and PFBA) at which developmental effects were noted in mice. Therefore, the chemicals are not considered to pose an unreasonable risk to workers' health."*

Australian firefighter health survey shows PFAS impacts generally low

A 2020 University of Queensland (UQ) study of 799 Australian aviation firefighters and vehicle technicians across 27 Australian airports showed health impacts from PFAS were generally low. They sampled 40 PFAAs (PFCA and PFSA sub-groups of PFAS) in blood serum, which were mostly not detected or in less than 15% participants, which included PFHxA, PFBA, 10:2, 8:2, 6:2 and 4:2 FTS.

Six PFAS were detected in 90% of participants, which were all long chain C8-PFAS(PFOA, PFNA, PFDA, PFHxS, PFHpS and PFOS). These were already widely restricted from use and no longer manufactured.

Half of these strongly correlated to Lightwater™ AFFF (PFOS, PFHxS and PFOA).

Maximum 95th percentile blood serum levels recorded included:

- PFOS 80µg/L or parts per billion (ppb)
- PFHxS 45ppb
- PFOA 3.5ppb.

Participants starting work pre-2005 had higher PFOS, PFHxS and PFHpS levels (as expected) than Australia's general population, which strongly correlated with pre-2005 Lightwater™ AFFF use.

Participants starting post-2005 had concentrations similar to the general population, confirming:

> *"Participants had PFOA concentrations similar to general population, indicating no increased exposure through occupational activities to this chemical." Comparisons of serum concentration for 130 ARFFS (Airport Rescue and FireFighting Services) participants between previous 2013 and 2019 serum sampling, showed average decreases of 58% PFOA, 42% PFHxS, 45% PFHpS and 49% PFOS. The study recognised "This suggests that substitution of 3M LightWater AFFF has been a successful measure to reduce occupational exposure in participants who started working after 2005."*

Minimal ongoing occupational PFAS exposure was evidenced from C8 fluorotelomer AFFFs that were in use until 2010. This longitudinal study confirmed no significant associations over time in cholesterol (HDL, LDL) or urate (kidney) functions with PFAS concentrations.

"Overall health associations found were relatively small and did not result in an increased risk of out-of-range (potentially abnormal) values across the serum PFAA concentrations in this study."

Firefighter concerns regarding potential adverse effects on their health seemingly result more from exposure to fire breakdown products than PFAS.

Concerns can lead to *false alarms* regarding continued safe use of high purity C6-foams which save lives and limit destruction from major fires.

Associated Frequently Asked Questions (FAQ) to this Univeristy of Queensland study confirmed:

"any exposure from PFAS coatings of PPE worn by ARFFS staff at work, is negligible compared to their exposure to PFAS through daily life."

Tightening regulatory PFAS restrictions in most countries are focused around firefighter training use (requiring containment, collection, F3 usage and safe disposal) while C6-foams are widely permitted for emergency fire use.

Health impacts in PFAS affected communities

A major health study by Australian National University (ANU) in Dec.2021 examined human health effects of relatively high PFAS-exposure communities resulting from extensive AFFF contamination over decades from nearby Australian Defence sites at:

- Katherine, Northern Territory
- Oakey, Queensland
- Williamtown, New South Wales.

Comparisons of PFAS blood levels and health outcomes for people living or working in these towns were conducted with similar communities without known environmental PFAS contamination (comparison communities).

Blood serum levels from more than 2,500 participants reported contained:

- PFOS 470ng/ml or ppb
- PFHxS 523ppb;
- PFOA 16.1ppb.

The study concluded:

"The [PFAS] effects are small and unlikely to lead to poor health outcomes."

Confirming lipids, cholesterol (HDL, LDL), kidney, liver and thyroid function biomarkers did not change markedly in sensitivity analyses with PFAS concentrations or communities. It also found

"limited evidence to support a contributing link between PFAS exposure and most adverse health outcomes included in the study. For most of these outcomes, the differences in rates between PFAS affected and comparison communities were relatively small. The evidence for other adverse health outcomes was limited. …People living in all three PFAS affected communities, irrespective of PFAS serum concentrations were more likely to have experienced psychological distress than those who lived in comparison communities. In other similarly PFAS affected communities, the overall findings relating to PFAS exposure are broadly applicable."

This psychological distress presumably derived from anxiety, worry and fear their families may be harmed, based on contaminated drinking water, *blighted* property values and *media hype*.

This Australian National University study confirmed:

> *"The evidence for other adverse health outcomes was limited. For most health outcomes studied, findings were consistent with previous studies that have not identified contributing links between PFAS and health."*

PFHxA and 6:2 FTS were confirmed as not detected in blood serum from any members of exposed or comparative communities.

US Centre for Disease Control (CDC) finds PFAS blood levels dropping

The latest US Center for Disease Control (CDC) 2017-18 NHANES (National Health and Nutrition Examination Survey) blood serum analysis confirmed PFHxA was not detected across the US population in any age group, or any demographic.

Presumably not found because of its short human half-life and excretion via urine, as exposures would have been inevitable from ubiquitous consumer product uses containing C6-PFAS and/or its key breakdown product PFHxA.

The Centre for Disease Control also confirmed a 30% drop in US population blood levels of PFOS and PFOA compared to levels recorded in 2011-12.

US toxicity studies on C6 PFHxA confirmed negligible health risks and margin of safety is high

An important two-part toxicity study on the main C6-PFAS breakdown product PFHxA was conducted in 2019.

Part 1 (Luz et al) confirmed:

> *"Sufficient data exist to conclude that PFHxA is not carcinogenic, is not a selective reproductive or developmental toxicant and does not disrupt endocrine activity. …A chronic human-health-based oral reference dose (RfD) for PFHxA of 0.25mg/kg-day (ppm) was calculated. … This RfD is four orders of magnitude [10,000 times] greater than the chronic oral RfD calculated by US EPA for PFOA." …"To continue to provide the unique function and performance properties [of legacy C8s], manufacturers shifted production to short-chain homologues based on data indicating they had a significantly different and more favourable environmental and human health profile."*
>
> *"Comparatively the acute oral toxicity of PFOA is 3 to 20 fold greater than PFHxA."*

PFHxA was also not classified as endocrine disruptor – in contrast to PFOA.

> *"Collectively, results from in vivo mammalian studies indicate that PFHxA and salts are neither a reproductive nor a developmental toxicant, which is further supported by OECD guideline studies. Multiple studies with PFHxA demonstrate that PFHxA is not genotoxic or mutagenic." It concluded "Overall conclusions support that PFHxA is rapidly eliminated in mammals from the body and is not biologically persistent or bioaccumulative, …This chronic human health toxicity value of 0.25 mg/kg-day is calculated, which qualifies as a 'tier 3' toxicity value per USEPA policy and guidance."*

Part 2 (Anderson et al) of this 2019 study applied this RfD to a human health screening level to

> *"… derive a drinking water lifetime health advisory of 1,400µg/L and a residential groundwater screening level for children of 4,000µg/L."*

It continued

> *“Available PFHxA human serum and urine biomonitoring data, used as a biomarker for general population exposure, demonstrates that the general human population exposures to PFHxA are low.”*

Concluding

> *“Therefore, PFHxA and related fluorotelomer precursors currently appear to present negligible human health risk to the general population and are not likely to drive or substantially contribute to risk at sites contaminated with PFAS mixtures.” …“In terms of relative potency, PFHxA is approximately four orders of magnitude [10,000 times] less toxic than perfluorooctanoic acid (PFOA).” …” This analysis demonstrates that for the general human population, exposures are significantly lower than threshold levels and the margin of safety is high. Eg. estimated daily intake of PFHxA for infants through breastmilk, cereals and formula is 200,000 to 320,000 times lower than the chronic human toxicity values, demonstrating a large margin of safety even for the most sensitive subpopulations.” It confirms “PFHxA does not appear to be bioaccumulative or to biomagnify in higher trophic levels of the food chain.”*

This evidence suggests that C6-foams are safe for continued use to protect life safety including firefighters in major flammable liquid fire emergencies.

The evidence suggests alternative F3-foams could likely struggle in major emergencies causing potentially increased life safety risks and likely increased risk of slower fire extinguishment, resulting in more noxious smoke emissions, greater critical infrastructure damage, greater risk of overflowing containments and thereby increasingly polluting the environment. Particularly when most fires will include PFAS from other sources like furnishings, computers, process equipment, wiring, seals, valving, food and other packaging, PPE, mobile phones and so on irrespective of the foam type used.

FPA Australia strongly recommends decision making assessments should be based on the questions in Important considerations during F3 transitions to help avoid the risk of unintentionally compromised life safety and/or critical asset protections.

Appendix B: F3 Fire Test Results Summary

This Appendix covers a summary of major comparative fire test results using F3-foams, often with C6-foams as a *benchmarker* for comparison.

Eight highly respected organisations have conducted detailed and rigorous testing:

- B1 – NFPA 403:2018 Aircraft Rescue and FireFighting Services at airports Standard
- B2 – NFPA Research Foundation (NFPA-RF) Testing Report - Jan. 2020 – Evaluation of Fire Protection Effectiveness of F3s
    - NFPA-RF 2022 Fire Services Roadmap
- B3 – US Naval Research Laboratory (NRL) 28ft2 (2.6m2) pool fire testing – May 2020
    - US NRL – Fuel evaluations, gasoline v heptane, Jun.2019
    - US NRL – Influence of fuel on foam degradation, 2017
    - US NRL – Fuel surface cooling, 2015
- B4 – Battelle (US Dept. Energy) SERDP & ESTCP webinar series #120 Assessment of Commercially Available PFAS-free Foams - Oct.2020
- B5 – Sweden Research institute (Ri.SE) – Fire test performance of 11x F3s, varying fuels, water and foam generation techniques - Feb. 2022
- B6 – US Federal Aviation Administration (FAA) – Fluorine Free Foam Testing Report DOT/FAA/TC-22/23 - Jul. 2022
    - FAA Cert Alert 21-05 – Safety concerns with F3-foams, Oct. 2021
    - FAA Research calculating foam quantities for Aircraft crash fires, 2012
    - FAA Cert Alert 23-01 – Confirmed New F3-foam MilSpec 32725, Jan. 2023
- B7 – Lastfire testing 2016-2022
- B8 – US Dept. of Defense (DoD) New F3 MilSpec 32725 for land-based operations using freshwater only (Jan.2023) compared with existing AFFF MilSpec 24385F (SH) v4 (Apr.2020).

Most of these independent testing programs reported remarkably similar conclusions.

B1 – NFPA 403:2018 Aircraft Rescue and FireFighting Services at airports Standard

NFPA 403 Annex B.6 explains:

> *"There has been limited full-scale testing of ICAO C foams, but tests to date have reflected extinguishments on Jet A within 1 minute at ICAO Application rates of 0.992 gpm/ft^2 (3.75L/min/m^2). The 0.13gpm/ft^2 (5.5L/min/m^2) application rate requirement for AFFF meeting MilSpec in NFPA 403 is 40% higher."*

Which raises the question:

> *Are alternative ICAO Level B/C F3s still effective at this low 40% safety factor operationally? when considerably less than existing double or triple safety factors currently used by ICAO Level C/US MilSpec approved C6-AFFFs?*

Annex B.6 continues:

> *"Airports adopting ICAO foam concentrates should evaluate equipment requirements any time a switch to a new manufacturer of foam concentrates is considered.*
>
> *Therefore, starting with 2018 edition of NFPA 403, the following application rates by test standard are used:*
>
> - *Mil-F 24385 and ICAO Level C = 0.13gpm/ft^2 or 5.5L/min/m^2*
> - *ICAO Level B = 0.18gpm/ft^2 or 7.5L/min/m^2*
> - *ICAO Level A = 0.20gpm/ft^2 or 8.2L/min/m^2"*

This is of particular concern to Airport Regulatory Authorities and ICAO when extensive comparative fire testing confirms F3-foams deliver inferior fire performance to C6-AFFFs and may be slower, requiring two to three times higher application rates to extinguish test fires on volatile fuels like gasoline and Jet A1.

Recognising many airport carparks, often multi-storey, are filled with vehicles containing significant quantities of gasoline, safety consideration should be significantly higher than 40 percent. This should be at least double confirming operational use at 7.5L/min/m^2 or above for ICAO Level B approved F3-foams (not 5.5L/min/m^2 as it is currently).

NFPA 403:2018 has increased ARFF response times from two to three minutes placing more pressure on the capabilities of the foam to rapidly extinguish the fire.

For more information, see FAA Research calculating foam quantities for Aircraft crash fires, 2012.

Careful considertion should be given as to whether it is safe for airports to use ICAO Level B F3s at just 5.5L/min/m^2 application rate when current NFPA 403 Standard is recommending all ICAO Level B approved foams be used operationally at 7.5L/min/m^2 to avoid increasing risks to life.

B2 – NFPA Research Foundation (NFPA-RF) Testing Report - Jan. 2020 – *Evaluation of Fire Protection Effectiveness of F3s*

Test criteria used:

- 165 fire tests conducted
- Blind study (foams not identified during testing)
- Based on UL162 protocol *synthetic foam* parameters
- Type II (gentle) delivery for polar solvent fuel
- Type III (forceful) delivery for hydrocarbon fuel
- All foams UL listed – 3 x AR-FFFs (AR-F3s), 2x FFFs (F3s hydrocarbon listed), baseline C6 AR-AFFF
- Fuels used – Heptane, gasoline (MIL SPEC), E10 (gasoline with 10% ethanol added), Polar solvent Isopropyl Alcohol (IPA)

- Ambient temps 60°F (15.6°C) and 85°F (29.4°C)
- Freshwater and salt water
- Lower Aspiration (3-4:1), v higher aspiration (7-8:1)
- Up to 3 discharge densities (application rates).

Results summary

> *"To summarize the results, the baseline C6 AR-AFFF demonstrated consistent/superior firefighting capabilities through the entire test program under all test conditions. For the FFFs in general, the firefighting capabilities of the foams varied from manufacturer to manufacturer making it difficult to develop "generic" design requirements. …The FFFs did well against heptane but struggled against some of the scenarios conducted with IPA and gasoline (both MILSPEC and E10), especially when the foam was discharged with a lower foam quality/aspiration. The FFFs required between 2-4 times both the rates and the densities of the AR-AFFF to produce similar results against the IPA fires conducted in with the Type II [gentle] test configuration. During the Type III [forceful] tests, the FFFs required between 3-4 times the extinguishment density of the AR-AFFF for the tests conducted with MILSPEC gasoline and between 6-7 times the density of the AR-AFFF for the tests conducted with E10 gasoline. From an application rate perspective, the FFFs typically required between 1.5 to 3 times the application rates to produce comparable performance as the baseline AFFF for the range of parameters included in this assessment."*

Type of water: (that is, freshwater versus saltwater) had minimal effect on the firefighting capabilities of the F3s and varied between foams.

The report confirmed

> *"FFFs are not a "drop in" replacement for AFFF. However, some can be made to perform effectively as an AFFF alternative with proper testing and design (i.e., with higher application rates/densities). …FFFs have only the foam blanket to seal-in the vapors. As a result, the capabilities of FFFs will be highly dependent on the characteristics of the foam blanket (which depend on the associated discharge devices as well as the foam type itself). …The results also show that the legacy fuel (heptane) used to list/approve foams, may not be a good surrogate for all hydrocarbon-based fuels. Specifically, some foams struggled against other fuels (like gasoline) as compared to heptane. Going forward, it was recommended that FFFs be tested and listed for a variety of hydrocarbon fuels (e.g., gasoline, E10, Jet A, etc), similar to approach currently used for polar solvent listings/approvals.*
>
> *Ultimately, end users will need to design and install within the listed parameters in order to ensure a high probability of success during an actual event. This applies to the not only to the discharge devices but also to the proportioning systems as well (due to the highly viscous nature of some of the FFF concentrates)."*

Widely considered an assessment of suitability for F3 system transitions.

Results summary

> *“The new fluorine-free foams are similar to the legacy protein foams in that they rely solely on the foam blanket to contain the fuel vapors to extinguish the fire (i.e., fluorine-free foams do not produce a surfactant film on the fuel surface like AFFF).*
>
> *As a result, air-aspirating discharge devices may be required to optimize the capabilities of these products.*
>
> *The research conducted to date suggests that FFFs tend to lose effectiveness when discharged through non-air-aspirating nozzles that produce lower aspirated/aerated foam with expansion ratios less that 4-5 (generally speaking).*
>
> *It is incorrect to assume that these new FFFs are a “drop in” replacement for AFFF even though they may have a specific listing or approval. At this time, there is too much difference between specific FFF's in properties and performance to suggest that the class can be a drop in replacement for the AFFF class of foams. Specific FFF foams maybe used in place of existing specific AFFF foams in fixed systems or portable application, but a detailed evaluation must be completed prior to making that transition as described in this document.*
>
> *In addition, fuel type is a significant variable and needs to be considered during testing and foam selection.*
>
> *Specifically, one pass of a stream of AFFF typically extinguished all the fire in application, including on the far side of smaller obstructions. Conversely, the FFFs tended to leave small holes in the foam blanket and needed more agent to extinguish all of the obstructed fires. In short, the FFFs typically took two passes of foam application to match the single pass of AFFF explaining the 1.5-2 times longer extinguishment times.*
>
> *As a result, these conditions could have been even more pronounced if the tests had been conducted with a flammable liquid like gasoline. … pre-fire planning and training will be key to successful implementation/deployment of these products going forward.*
>
> *Although these new foams are being developed and implemented as environmentally friendly AFFF alternatives, the industry trends will require collection and disposal of these [F3] products in the same manner as AFFF is being handled today. So unfortunately, the ability to train with these foams will have the same cost burden as the legacy AFFFs requiring special facilities and waste containment/collection.*
>
> *As a result, innovative training approaches (e.g.Immersive reality approaches) should be considered/developed to more effectively and efficiently address the increased challenges of transitioning to these new products. Additional training resources will be required to address new foam alternatives (e.g., model procedures, model strategies or tactics with new foams, training facilities, equipment transition, etc.). Special education and training are needed for foam stewardship (e.g., why the transition is needed, why environmental contamination is important.”*

Concluding

> *"Ultimately, end users will need to design and install within the listed parameters in order to ensure a high probability of success during an actual event. This applies to both the discharge devices and proportioning system."*

B3 – US Naval Research Laboratory (NRL) 28ft^2 (2.6m^2) pool fire testing – May 2020

Test criteria used:

- Two leading F3s v AFFF (Mil approved) baseline
- MilSpec MIL-PRF-24385 (AFFF spec)
- Gasoline (alcohol-free) and heptane fuels
- Freshwater only
- Solution flow rates of 2gpm (Std =7.6L/min), 2.5 and 3gpm ((9.5, 11.35L/min respectively).

Results summary

F3-foams extinguished gasoline pool fire in 49 and 78 seconds using 2gpm. While commercial AFFF extinguished the fire under the same condition in 30 seconds.

> *"Performance of the fluorine-free foams improved when the fuel was switched to heptane and when the solution application rate was increased from 2 gpm to 2.5 gpm with both fluorine-free foams extinguishing the fire in 31 seconds. Both fluorine-free foams had slower drainage and slower bubble coarsening than the commercial AFFF. However, foam properties collected do not appear to correlate well with extinction performance. … The inability of the foams and concentrates to meet critical extinction and property metrics for military qualification testing indicate the difficulties of utilizing these commercial products for Navy operations"*

AFFF extinguished heptane at 2gpm in 22 seconds.

US NRL – Fuel evaluations, gasoline v heptane, Jun.2019

Test criteria used:

- AFFF and F3 formulations fire suppression effectiveness on heptane and gasoline pool fires
- Particular attention on divergent effectiveness and its causes.

Results summary

Four leading commercial F3-foams required between 2.5 times more and over six times more F3 than the benchmark C6-AFFF when required to extinguish gasoline fires in 60 seconds.This is inadequate for Defence, as US MilSpec requires extinguishment on gasoline within 30seconds to avert munitions *cook off*. These differences widened as extinction speeds became faster.

Further investigation showed:

> *"Individual major components of gasoline were tested, and the aromatic components were determined to be the source of this difficulty in gasoline fire suppression." Essentially the aromatics extracted surfactants from the F3, prematurely attacking the foam blanket. These aromatics are absent in the widely used fire approval test fuel heptane, but do occur at lower concentrations in Jet A1 aviation fuel, probably explaining why F3s often struggle extinguishing fires involving Jet A1, seeming to cause persistent edge flickers (ICAO extended their extinguishment time to 120 secs in 2014 - from 60secs previously).*
>
> *NRL also found "Two diagnostics that relate valuable information about foam-fuel interaction are a foam degradation test and a fuel-vapor transport test. Foam degradation was evaluated by monitoring the disappearance of a 4 cm thick layer of laboratory generated foam deposited over*

60 ml of 35ºC heptane or gasoline in a 100 ml beaker. There is an increase in bubble size followed by a shrinking of the foam volume. A plot of foam height vs time depicts significant foam degradation differences between the heptane and gasoline fuels."

This research suggests that at higher ambient temperatures, these aromatics would be more volatile and actively vaporising from the fuel, making the fire more intense and difficulty to extinguish, while at the same time diffuse into the F3 foam blanket potentially leading to premature collapse or re-ignition. This is particularly relevant to Jet A1 –flashpoint 38^{o}C - during hot summers, which has been widely experienced in Australia and worldwide 2019-2022.

US NRL – Influence of fuel on foam degradation, 2017

Results summary

"Water evaporation from the foam bubbles can also contribute to degradation. …heat from a fire can dramatically increase the rate of foam degradation through water evaporation."

"For all experiments F3 degraded much faster than AFFF. …Our results showed RF6 degraded faster than AFFF (by factor of 3 at room temperature [20^{o}C] and 12 at elevated temperatures over fuel [50^{o}C]), which may contribute to differences in their firefighting performance."

"As the fuel temperature is raised, there is a higher concentration of fuel vapors beneath the foam than at lower temperatures. This increased concentration at the foam interface can increase the amount of fuel transport through the foam, increasing the rate of foam degradation.…For all experiments F3 degraded much faster than AFFF."

US NRL – Fuel surface cooling, 2015

Results summary

"In this work, we investigate fuel surface cooling by the foam and the resulting reduction in fuel vapor pressure, which depends exponentially on the surface temperature."

"The temperature gradient is initially very large at the interface, transitioning from the boiling temperature of heptane (98.6^{o}C) [8] to room temperature (20^{o}C) in the foam. As a result of the large temperature gradient between the foam and fuel layers, heat conducts very quickly from the fuelto the foam, which reduces the surface temperature of the fuel. As shown in Fig.5a, the interface temperature drops significantly between t = 0 and t = 1 s. With time, the heat conducted from the fuel surface raises the temperature of the adjacent foam, and the temperature gradient reduces (reducing the magnitude of heat conduction)."

The foam cools the hot fuel surface, reducing fuel vapor pressure and mass transport into the fire. Based on this principle, we propose a new fire-suppression mechanism that acts in conjunction with the well-known mechanism wherein the foam forms a physical barrier to the transport of vapor from the fuel surface into the fire."

"Figure 8 shows that the decrease in surface temperature due to both direct and indirect cooling is over 40^{o}C after 1 s, whereas the temperature decreases by only a few ^{o}C with indirect cooling alone. These results support that direct cooling drives the rapid, significant decrease in fuel surface temperature and that indirect cooling is relatively unimportant."

"Fuel surface cooling by the foam and the resulting reduction in fuel vapor pressure, which depends exponentially on the surface temperature. …the interface cools because the two layers are at different temperatures and the cooling by conduction occurs instantaneously"

B4 – Battelle (US Dept. Energy) SERDP & ESTCP webinar series #120 *Assessment of Commercially Available PFAS-free Foams* - Oct.2020

Test criteria used:

- Environmental toxicity
- Corrosivity
- Fire performance (on 28ft^2 fire)
- Compressed Air Foam (CAF)
- Ultra High Pressure
- Functional additives (Dry Chem).

Results summary

- National Defense Authorisation Act (NDAA) demands AFFF phase-out by Oct.2024, but commercially available F3-foams do not meet MilSpec
- F3-foams toxicity order magnitude worse than C6 (exceeds MilSpec)
- Most F3-foams pass biodegradability
- Some F3-foams are very viscous up to 90,000cSt.
- None of F3-foams tested met MilSpec extinguishment time (30seconds). CAF improved ext. time averaging 47%, but still all above 60 seconds (except 1 at 47seconds). CAFs improved control & ext. times and brought closer to MilSpec.
- Most F3-foams met burnback. CAFs improved burnback by 34%, all but 1 exceeding MilSpec. Plan for 100ft^2 Jet A fire testing.

B5 – Sweden Research institute (Ri.SE) – Fire test performance of 11x F3s, varying fuels, water and foam generation techniques - Feb. 2022

Test criteria used:

- 11x leading F3-foams
- Fuels – Jet A1, heptane and diesel
- Water – Fresh and synthetic seawater
- Nozzles – UNI86 (11.4L/min) and CAF (Compressed Air Foam)
- Protocols – ICAO Level B; EN1568-3:2018 and IMO MSC.1/Circ.1312.

Results summary

Only 3 out of 11 F3-foams extinguished ICAO Level B in under 2 minutes, 3 did not extinguish.

Addition of saltwater generally prolonged extinguishment time. Only 2 out of 11x F3-foams passed forceful EN1568-3 with seawater.

> *“None of 11 products outperformed rest. …None met fire test performance requirements in all ref. Standards. Instead they seem to perform best in different niches – certain fuels or water. This highlights the importance of testing in an environment as close to reality as possible.”*

"None of these products managed to reach 99% control of the fire in F2.0. This is assumed to be due to interactions with the fuel causing rapid breakdown of the firefighting foam [heptane under EN1568-3 testing]."

Unsurprisingly diesel was stated as the easiest fuel.

This study found

"radiation induced drainage and evaporation as additional parameters to ordinary drainage."

Use of CAFs shortened F3 extinction times.

Testing also confirmed

"a higher heat flux increases the firefighting foam breakdown." and proposed "the fuel flashpoint could be an indicator of the complexity of firefighting."

It concluded

"All the findings and conclusions point out the importance to perform tests as close to the real fire hazard situation as possible."

B6 – US Federal Aviation Administration (FAA) – Fluorine Free Foam Testing Report DOT/FAA/TC-22/23 - Jul. 2022

Test criteria used:

- 7x F3s v baseline Milspec C6 AFFF
- MilSpec; gasoline; also modified with Jet A 10sec & 90sec preburns; half strength & over-rich; active MilSpec & UNI86 nozzles(2gpm); fixed MilSpec & fixed UNI86 (nozzles (2gpm)
- ICAO level C; also active UNI86 nozzle
- Indoors and outdoors
- Freshwater only.

Results summary:

"None of the F3s evaluated had an equivalent extinguishing performance to AFFF. Whilst other performance metrics or physical characteristics can be met or surpassed the primary metric of concern is fire performance of the foam." Despite two F3s being ICAO Level C approved, no F3 passed the ICAO C tests - indoors or outdoors. "This [C6] AFFF was in fact the only foam examined that was able to meet the ICAO Level C requirements during this series of tests."

"The gasoline fires were significantly more difficult to extinguish and more volatile in their reactions to foam applications. Flareups, fuel pickup, and surface burning were more commonly observed in the gasoline fires compared to the Jet-A fires."

"All the tested F3s exhibited reduced performance with application of dry chemical. Additionally, surface burning was a commonly observed trait of the FFF candidates that is typically not observed with AFFF. …Since dry chemical is a common auxiliary agent and many ARFF vehicles have dual-agent turret nozzles, this quality may pose significant safety issues in a real-world response." …"These newer formulations, referred to as C6 AFFF, are the products currently approved for use at airports nationwide."

The best F3 on MilSpec gasoline extinguishment time was 38% increase over AFFF. F3-foams did best in over-rich (15% induction) tests.

"The test fuel had less of an impact on burnback results than extinguishment results. The quality of the foam generated also significantly impacted the results. Fuel pickup and surface burning were commonly observed when the foam was discharged at a reduced pressure, even with AFFF when not seen in other tests."…"Additionally, extinguishing the fire on the edges of the fire pans and preventing re-ignition in these areas was generally more difficult with F3s than the AFFFs." – more evident and amplified in manual application.

A direct discharge into the pan or change in direction of application frequently caused fire re-ignition in areas of the pan that were previously extinguished or pulled the entire foam blanket away from other areas, causing re-ignition."

FAA testing found five of seven leading F3 concentrates contained high TOF (Total Organic Fluorine) levels of 10-87ppm when tested using US EPA Method 537.1, 2020. Be sure of any laboratory's ability to accurately test specific PFAS, and total PFAS as TOF or TOPA (Total Oxidisable Precursor Assay) at detection levels necessary for your concentrate, foam solutions and rinse-waters.

It concluded

"Overall, none of the tested FFF [F3] candidates can be considered a direct replacement for AFFF without compromising the efficacy of fire extinguishment."

This led to Cert Alert 21-05 being issued.

FAA Cert Alert 21-05 – Safety concerns with F3-foams, Oct. 2021

This Alert *Part 139 Extinguishing Agent requirements* confirmed that

"While FAA and DoD [Department of Defense] testing continues, interim research has already identified safety concerns with candidate fluorine-free products that must be fully evaluated, mitigated, and/or improved before FAA can adopt an alternative foam that adequately protects the flying public. The safety concerns FAA has documented include:

- *Notable increase in extinguishment time;*
- *Issues with fire reigniting (failure to maintain fire suppression); and*
- *Possible incompatibility with other firefighting agents, existing firefighting equipment, and aircraft rescue training and firefighting strategy that exists today at Part 139 air carrier airports.*

While FAA and DoD continue the national testing effort, the FAA reminds all Part 139 airport operators that while fluorinated foams are no longer required, the existing performance standard for firefighting foam remains unchanged (whether that foam is fluorinated or not). Airports that are currently certificated under Part 139 will remain in compliance through use of an approved firefighting foam that satisfies the performance requirements of MIL-PRF-24385F(SH) […F3s were not excluded]."

FAA raised these public safety concerns with F3-foams based on slower extinguishment, re-ignition, lack of compatibility with other agents (Dry Chem and other F3-foams), existing equipment and existing training protocols.

FAA Research calculating foam quantities for Aircraft crash fires, 2012

Results summary

Findings cautioned:

> *"FAA research indicates that when an aircraft is involved in a fuel spill fire, the aluminum skin will burn through in about 1 minute. If the fuselage is intact, the sidewall insulation will maintain a survivable temperature inside the cabin until the windows melt in approximately 3 minutes. At that time, the cabin temperature rapidly increases beyond a survivable temperature of 400°F [204°C]."*

It found

> *"There is also potential for re-ignition of a fuel fire from smoldering fuselage composites."*

Continuing

> *"this composite would self-sustain combustion in as little as 2.5 minutes of exposure to an external pool-type fire. …The pool fire was easily extinguished in all tests. However, extinguishment of the composite combustion was not as easy."*

And

> *"The surface flames were readily extinguished, but smoldering composite combustion was already established."*
>
> *"PKP [Dry Chemical] was effective at extinguishing the surface flames on the composite panels, but it did not extinguish the smoldering composite combustion."*

But

> *"To extinguish …fire fighters applied a continuous stream of AFFF directly on the composite material. After applying AFFF for 3 minutes or more, the smoldering composite combustion was extinguished."*
>
> *"It was concluded that fast response by the fire fighters reduced the chance that smoldering fire will be established. Since fire fighters may have to work in close to the aircraft to control the composite fire, they must be aware of potential re-ignition of fuel under or around the aircraft."*

This becomes particularly relevant when NFPA 403:2018 has extended response times from 2 to 3 minutes, putting increased pressure on the capabilities of the firefighting foams being used to extinguish any aircraft fire rapidly.

FAA Cert Alert 23-01 – Confirmed New F3-foam MilSpec 32725, Jan. 2023

Results summary

FAA accepted airport use of this new F3 specifications once qualification testing is completed and specific F3-foams are added to QPL/QPD.

Also confirmed:

> *"Currently, Certificated Pt.139 airports will not be required by the FAA to transition to the new F3. Airport operators are authorised to continue using QPL MilSpec AFFF".*
>
> *"F3s lack compatibility with other F3s, so they cannot be mixed together."*

Also, F3-foams are not premixable.

> *"Airports using potassium based dry chemical should contact their assigned FAA Airport Certification Safety Inspector to discuss options for ARFF response"*

FAA testing found some F3-foams can be instantly attacked by Dry Chemical applications.

B7 – Lastfire testing 2016-2022

It is difficult to summarise Lastfire results having been conducted on different, often rather *ad hoc* sets of testing (not always realistic to real-life events), to address specific user questions over many years for quite specific storage tank applications.

Complete detailed fire test results are not always publicly available, as distinct from all other test programs listed above with full open access of results. Recommended NFPA operational application rates are also used as test rates in some tests, without specific safety factor recommendations compensating for virtually ideal fire test conditions, which requires consideration.

Noticeably, Lastfire often seems to draw more positive conclusions, often focusing on best F3 outcomes, sometimes from single F3 agent results. It offers an interestingly different approach to other organisation's more rigorous, perhaps more cautious, and wider test programs, although broad conclusions do align with other test data reported.

Lastfire results are summarised from the current NFPA 11:2021 Annex H3.2 and H3.3, which should be contrasted with the results of the NFPA-RF testing program in Annex H2.

For more information, see B1 – NFPA 403:2018 Aircraft Rescue and FireFighting Services at airports Standard).

Test criteria used:

- Small scale test series to EN1568 (Parts 3 and 4) and Lastfire using five F3-foams, C6 and C8-AFFF
- Small scale 5m^2 and 20m^2 spill fires, varying application techniques (inclding plunging [Type 3] semi-aspirated and aspirated monitor nozzles, more gentle [Type 2] medium expansion, Compressed Air Foam System [CAFS] and system pourer /foam chamber)
- Proportioning tests – venturi, in-line and displacement pumped proportioning
- Large scale tank 1mm dia. x 9m tall (100m^2) CAFS application rate 75% of conventional foam delivery
- Long flow 30m and 40m, single F3 on Jet A, conventional (4L/min/m2) and CAF pourer (2L/min/m^2), single F3, both delivering extinguishment
- Subsurface application single F3 on Jet A (based on UL162).
- Vapour suppression tests F3s and C6AFFF under fire and non-fire situations using vapour detectors
- Hybrid monitor test.
- 20m bund flow, single F3 using system pourer with obstructions in path, successfully extinguished using approx. 75% of typical design application rate
- Additional F3 in 11m diameter tank, extinguished using approx. 75% normal design application rate
- Small-scale Lastfire testing of Self-Expanding Foam (SEF) using F3 (premix under CO_2 pressure, activation generates bubbles)

- Variety of fuels used throughout tests, including heptane, gasoline, crude oil, Jet A/A1 and ethanol
- Some tests included saltwater and freshwater. At times compatibility with dry chemical also assessed.

Results summary

> *"LASTFIRE concluded that some FFFs [F3s] are suitable for some applications, including hydrocarbon spill fires and smaller storage tanks subject to validated testing on the specific foam and application device."*

Lastfire's testing programs have resulted in important findings relevant to the application of the new generation F3-foams, but some apply to the post EPA stewardship C6-based formulations including:

- Not possible to be generic in terms of performance of this type of foam concentrate (F3) on any specific fuel.
- Foam performance is dependent on application equipment and foam concentrate and application rate, particularly true of F3-foams, as all work more effectively with aspirated equipment.
- Some F3-foams with high viscosity might require proportioning system modifications to ensure a pick-up rate within acceptable tolerances.
- No foam of any type should be regarded as a *drop in* replacement without full evaluation.
- Compressed Air Foam (CAF) can provide effective extinguishing with F3-foams at lower application rates than conventionally aspirated equipment, subject to validation through testing for a specific set of circumstances.
- It is important that a validated test method specifically relevant to the application is used to determine system design characteristics.
- Smaller tank fires (11m) have shown effective performance can be achieved with some foam and equipment combinations, this has not been validated in larger scale testing.
- It is recognised a major knowledge gap still exists in application of any new generation foam, particularly F3-foams to larger tank fires using large throughput monitors, especially non-aspirating types.
- Further phases of testing are planned.
- Important records to verify what has been done on site, form valuable parts of any results reporting.

B8 – US Dept. of Defense (DoD) New F3 MilSpec 32725 for land-based operations using freshwater only (Jan.2023) compared with existing AFFF MilSpec 24385F (SH) v4 (Apr.2020)

Results summary

- New F3 MilSpec 32725 is not accepted for Naval use, indicating that F3-foams meeting this specification are unsuitable for application in sea water.
- Qualified F3-foams must carry the following warning labels on every drum:

  “This product is not authorized for US Navy Ship Board Use.”

  “Do not mix with other foam concentrates.”

- This F3 standard seems considerably weakened (essentially to ICAO Level B equivalency) by:
- Single 50ft^2 (4.64m^2) fire test uses freshwater and 3gpm nozzle [50% higher application rate] on Jet A in 60 seconds extinction and 270 seconds burnback test (similar to ICAO Level B) not using seawater and 2gpm nozzle on gasoline with 50 seconds extinction and 360 seconds burnback as AFFF MilSpec– a much harder test) - potentially placing lives at increased risk.
- Two passes from three attempts (only 66% success per test) 100% pass rate currently required to pass AFFF MilSpec -eroding important safety factors recommended by NFPA403:2018.
- Twenty-eight foot square (2.6m^2) fire tests use Jet A with 10 seconds preburn - avoids heat build-up so easier to extinguish (not gasoline and 10 seconds preburn of AFFF MilSpec)
- Only two 28ft^2 (2.6m^2) tougher fire tests with gasoline (new and aged [ten days at 65^{o}C] F3 concentrates), 2gpm nozzle, 10 seconds preburn, 60 seconds extinction, 240 seconds burnback in freshwater only (not gasoline, 2gpm nozzle, 10 seconds preburn, 30 seconds extinction and 360 seconds burnback with fresh and seawater as required by AFFF MilSpec). Is that tough enough? Or does it place lives at risk?
- Burnbacks now start after 30 seconds (not within 60 seconds, that is, 55-58 seconds required for AFFF MilSpec) reducing protections for anyone trapped and risking faster re-ignition.
- Dry Chemical compatibility uses Jet A and freshwater (not gasoline and seawater as AFFF MilSpec) making it easier to pass.
- All fire tests conducted from 5^{o}C to 32^{o}C ambient temps allowing much easier pass at 5^{o}C - unrepresentative of realistic year-round conditions.
- Fuel and water base temperatures from 10^{o}C to 32^{o}C allowing easier pass at 10^{o}C – unrepresentative of realistic year-round conditions.
- Wind speed reduced to 5mph (not 10mph in AFFF MilSpec) - so less blanket disturbance, also making test easier to pass.
- Viscous concentrates - kinematic viscosity 300cs [centistokes] at 25^{o}C (not 2cs as for AFFF MilSpec). No requirement at 5^{o}C more relevant operationally (AFFF MilSpec requirement is 20cs at 5^{o}C).

- Corrosion rates now tested with just 10% F3 diluted in 90% seawater (not 90% AFFF diluted in 10% seawater as AFFF MilSpec) – unrealistic for concentrate storage, presumably indicating seawater is less corrosive than F3-foams?
- Aquatic toxicity LC50 requirement now reduced over 16-fold to 30ppm with more tolerant Fathead Minnow specified – a pollution tolerant species (not 500ppm LC50 with more sensitive Killifish required under AFFF MilSpec).
- Very low F3 PFAS content <1ppb potentially unrealistic particularly when five leading F3 concentrates showed 10-87ppm PFAS as Total Organic Fluorine (TOF) using US EPA 537.1 method when tested by FAA in Jul.2022.

  For more information, see B6 – US Federal Aviation Administration (FAA) – Fluorine Free Foam Testing Report DOT/FAA/TC-22/23 - Jul. 2022).
- No F3-foams are currently qualified to this spec (when written mid-July 2023), yet ten C6-AFFF 3% foams qualified to tougher existing MilSpec MIL-PRF-24385F(SH)v4, 2020.
- Existing AFFF MilSpec (24385Fv4, 2020) permits F3 use providing any such F3 has been qualified by passing all the detailed fire performance tests in fresh and saltwater required by this 24385F specification.
- No F3-foams currently can pass these tests even in freshwater only, hence the new F3 MilSpec developed allowing F3-foams to pass, but operational Defence fire conditions do not seem to have changed.
- FAA is not requiring US airports to transition to this new F3 MilSpec.

  For more information, see FAA Cert Alert 23-01 – Confirmed New F3-foam MilSpec 32725, Jan. 2023.
- ICAO Level C requires only a single 7.32m^2 freshwater well aspirated fire test on Jet A1 at similar 1.56L/min/m^2 application density to 1.64L/min/m^2 during AFFF MilSpec 50ft^2 (4.64m^2) fire, but with aspirated foam (not non-aspirated Defence nozzle using gasoline with fresh and seawater).
- New F3 MilSpec 32725's 4.64m^2 application density is considerably higher than ICAO Level C at 2.46L/min/m^2 in freshwater only (equivalent to ICAO Level B).
- ICAO does not require MilSpec's total of 8 fire tests including aged concentrate (10days at 65^{o}C), dry chemical compatibility, rich and 50% lean proportioning fire tests and other important secondary requirements.
- FAA testing in Jul.2022 found two approved to ICAO Level C both failed their indoor and outdoor ICAO Level C fire testing.F3-foams

Understanding how two very different MilSpecs are presumably intended to effectively address the same Defence operational land -based fire conditions raises some concerns.

F3 MilSpec requires higher and slower test application density of 2.46L/min/m^2 on Jet A, essentially equivalent to ICAO Level B 2.5L/min/m^2 intended to achieve successful outcomes, which currently relies upon faster and lower 1.64L/min/m^2 test application densities achieved on more volatile gasoline under AFFF MilSpec, protecting life safety.

Different safety factors seem to have been applied, which could adversely affect lives especially under challenging operational conditions where munitions cook-off may be involved.