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The Imperative for the Canadian Armed Forces to Transition From PFAS to F3

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AIM

1. This paper will inform the Canadian Forces Fire Marshall (CFFM) and the Assistant Deputy Minister – Infrastructure and Environment (ADM(IE)) on the implications of continuing to use Per/Poly Fluoro Alkyl Substances (PFAS) – containing Aqueous Film Forming Foams (AFFF) within the Canadian Forces Fire Service and the imperative to transition to Fluorine Free Foam (F3).

INTRODUCTION

2. The Environmental Health Director of the United States (US) Centre for Disease Control has described the class of chemicals called PFAS as "one of the most seminal public health challenges for the next decade".[1] In 2018, Maclean's magazine cited the PFAS issue for Canada as having "the potential to be the Flint water crisis and the DDT crisis after the Second World War rolled into one."[2] For the Canadian Armed Forces (CAF), PFAS contamination and associated health issues have the potential to threaten our ability to train and operate, and by consequence, the capabilities of the different components of the CAF that the Canadian Forces Fire Services support.

What is PFAS-containing AFFF?

3. Annex A contains a detailed description of PFAS's physical, chemical, toxicological and performance characteristics. PFAS, as a class of chemicals, represents a substantial liability to the CAF due to its inherent chemical qualities associated with its carbon-fluorine (C-F) bonds and polar functional groups. These qualities include substantial thermal stability, high surface tension levelling, a tendency to bioaccumulate, environmental persistence and mobility in water. These properties have resulted in PFAS being used in a broad variety of applications and industries, but for the CAF, the most important role is that of a fluorosurfactant in fire-extinguishing foam. Very few of the 4700 chemicals that comprise this class have undergone the rigorous testing required of the Toxic Substance Control Act, and the negative effects of these chemicals have started to come to light in the past two decades. While acute toxicity of PFAS is usually minimal, chronic toxicity and bioaccumulation are especially concerning. Additionally, when it comes to regulation of these substances, there are orders of magnitude deviation in acceptable threshold limits, both between and within countries.

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[1] Christopher Knaus, "Toxic Firefighting Chemicals 'the Most Seminal Public Health Challenge,'" *The Guardian*, October 18, 2017, sec. Australia news, https://www.theguardian.com/australia-news/2017/oct/18/toxic-firefighting-chemicals-the-most-seminal-public-health-challenge.
[2] Daniel Macfarlane, "These Chemicals in North American Waters Could Spark a Health Crisis in Canada," *Macleans.Ca* (blog), November 1, 2018, https://www.macleans.ca/opinion/these-chemicals-in-north-american-waters-could-spark-a-health-crisis-in-canada/.

4. Certain well-studied PFAS have been associated with negative reproductive, developmental, carcinogenic, immunological, neurological, endocrinal, hepatic and renal function effects. Firefighters, in particular, have been found to have much higher levels of these compounds within their bodies, and there are growing efforts to routinely test and track their blood levels in order to determine and document potential exposures. PFAS's environmental transformation results in a wide variety of intermediaries and very stable fluorinated end products, some of which can have more substantial negative effects than the original fluorosurfactants. Due to the very high thermal stability of the C-F bond, low threshold levels, high mobility and persistence, PFAS remediation is especially difficult and expensive, with many potential remediation technologies not yet deemed viable.

What are viable PFAS-containing AFFF alternatives?

5. Annex B contains a detailed description of F3's physical, chemical, toxicological and performance characteristics. F3 is not one class of chemicals, but several different classes, mixed in a variety of formulations to provide the required physical, chemical and performance properties sought. As they lack fluorine, they do not have positive spreading coefficients, and are unable to act as a film-forming surfactant, but rather rely on foam bubble quality to suppress fuel vapour. This aspect hinders performance in extinguishing Class B fires, in comparison to PFAS-containing AFFF. In addition to the inability to act as a film-forming surfactant, F3s generally differ on other properties, such as viscosity, flow mechanics, and expansion ratios, which prevent them from being a "drop-in" replacement. In the last 40 years since their development, they have substantially increased their performance. Certain technologies, such as compressed air foam and Ultra High Pressure (UHP) have resulted in substantial increases in F3 performance. Despite achieving certification under several stringent firefighting foam certifications, F3s have been unable to satisfy the very stringent requirements established in the MIL-PRF-24385.

6. In terms of toxicity, F3s are generally an order of magnitude more acutely toxic than PFAS alternatives, with high Biological Oxygen Demand (BOD) values. When it comes to chronic environmental toxicity, due to the multiple classes of chemicals, there is a broader range of characteristics from "Chronic 2 - Toxic to aquatic life with long-lasting effects" to "Not Chronically Toxic". Disposal options are generally simpler and less costly, but due to their high acute toxicity and significant BOD, special care is required in order to avoid enclosed waterways, or it may result in large losses of biota. An important differentiation is that many F3s do not produce persistent degradation end products, like PFAS.

7. Human health toxicity represents an area of future research for many F3s, but high log Kow (Octanol / Water co-efficient) values indicate a potential to bioaccumulate in some formulations. Overall, F3s represent a lower potential for negative human health effects than PFAS. When selecting an F3 for transition, it is important to not solely rely on performance parameters, but numerous other factors, such as acute/chronic toxicity,

human health hazards and environmental persistence must be fully assessed. While other alternatives to F3 exist, they are not deemed as viable, either due to their fluorine-based elemental composition (Film-forming fluoroprotein foam (FFFP) or Fluoroprotein foam (FP)) or relatively inferior performance (Protein foam (P) or Synthetic foam (S)) on class B fires.

CONTEXT

US military use of PFAS-containing AFFF

8. For the US Navy, from 1940-1970, they primarily used Protein Foam as their Class B fire-extinguishing agent, until shortly after the 1967 fire on the USS Forrestal off (Figure 1, below). Protein foam had sufficient burn-back resistance, but slow fire knockdown.[3] AFFF was developed in the 1960s to make up for this shortfall, with the initial MILSPEC 24385 issued in 1969, and the first qualified product in 1970.[4] This MILSPEC included key physical, chemical and performance requirements as outlined in Annex D.[5]

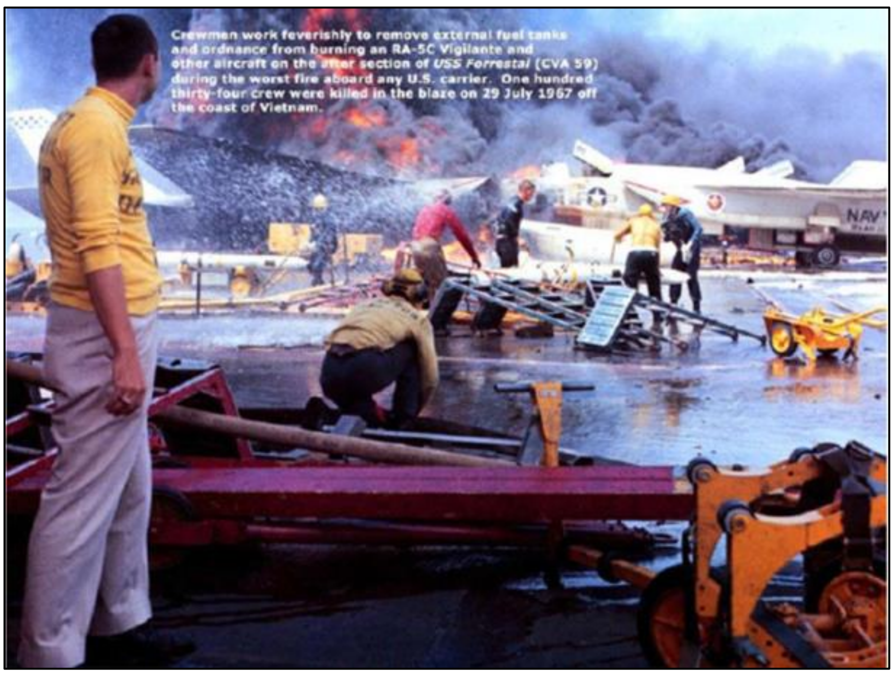

Figure 1: Fire aboard the US Aircraft Carrier, USS Forrestal in 1967
Source: Nelson, H., *AFFF Alternatives: Art of the Possible*, 21.

9. The US is coming to grips with the effects of PFAS. As of October 2021, the US Department of Defense (DOD) has already completed detailed PFAS testing at 63

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[3] *Ibid*., 21.
[4] *Ibid*., 22.
[5] *Ibid*., 23.

different military installations.[6] From this, as per Figure 2, below, 703 US DOD sites were identified with known or suspected discharges of PFAS. Of these, 64 had PFAS levels exceeding 100,000 ng/L and 14 of which had levels exceeding 1,000,000 ng/L (More than 14,000 times as much as the US Environmental Protection Agency (EPA) regulatory levels of 70 ng/L).[7] Of the sites with the highest levels of PFAS contamination, nine are in the process of having remediation plans developed.[8] When this information is combined with known drinking water contamination and other known sites, the number of PFAS-contaminated sites explodes to 2,854 identified sites, as per Figure 3, below.[9]

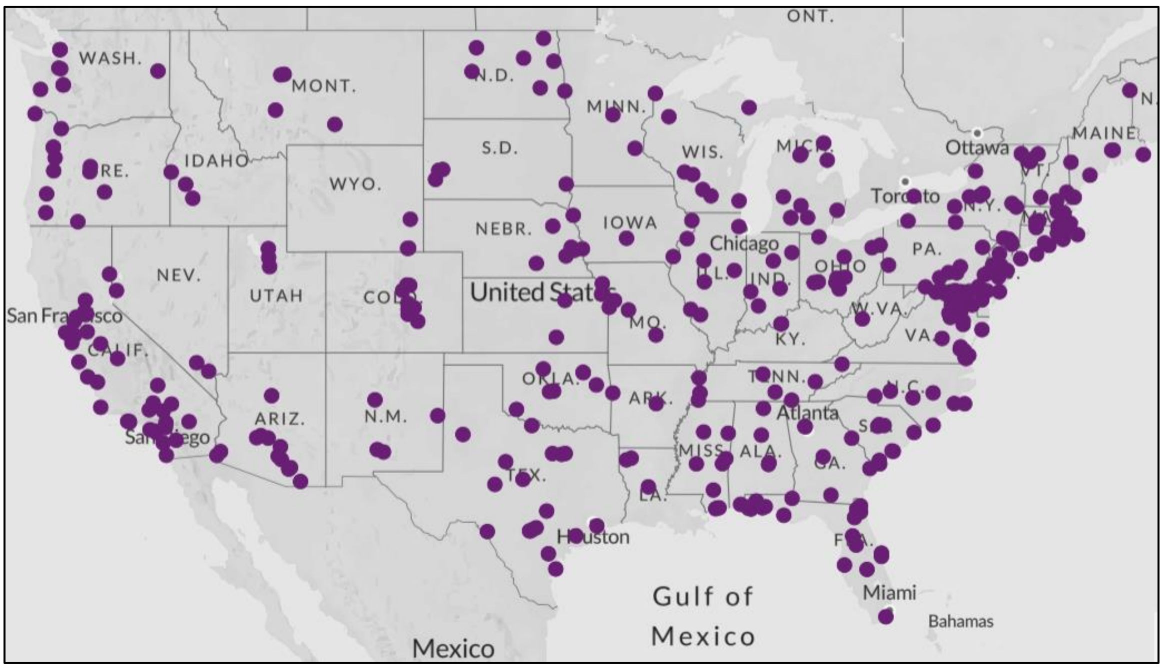

Figure 2: US DOD sites with known or suspected discharges of PFAS
Source: Environmental Working Group, *PFAS Contamination Crisis: New Data Show 2,854 Sites in 50 States.*

[6] Hayes, Jared and Inouye, Brandin, "At the Most Contaminated Military Sites, Little to No Progress in Cleaning up 'Forever Chemicals' | Environmental Working Group," accessed January 28, 2022, https://www.ewg.org/news-insights/news/most-contaminated-military-sites-little-no-progress-cleaning-forever-chemicals.
[7] *Ibid*.
[8] *Ibid*.
[9] Environmental Working Group, "PFAS Contamination Crisis: New Data Show 2,854 Sites in 50 States," accessed January 28, 2022, http://www.ewg.org/interactive-maps/pfas_contamination/.

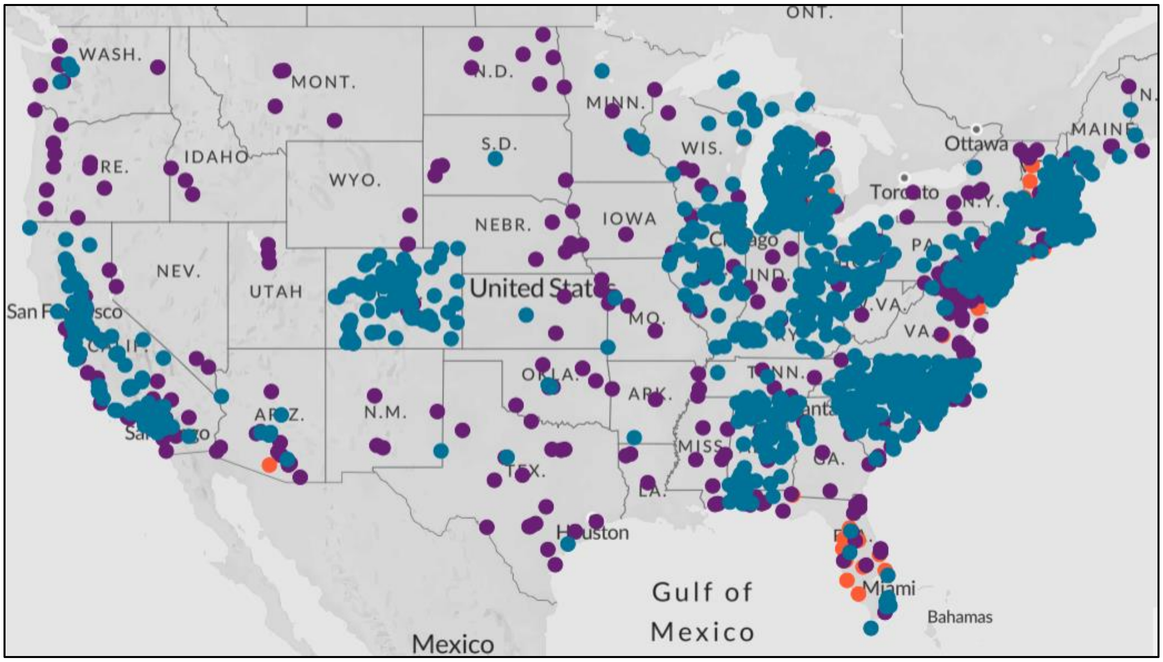

Figure 3: PFAS contamination in the US
(purple - military sites, blue - drinking water, orange - other known sites)
Source: Environmental Working Group, *PFAS Contamination Crisis: New Data Show 2,854 Sites in 50 States.*

10. The US DOD has gone so far as to pass into law the phase-out and replacement of PFAS containing AFFF over the next 30 months. The excerpt, below, was taken from the US National Defence Authorization Act for 2020:

> SEC. 322. REPLACEMENT OF FLUORINATED AQUEOUS FILM-FORMING FOAM WITH FLUORINE-FREE FIRE-FIGHTING AGENT.
>
> (a) USE OF FLUORINE-FREE FOAM AT MILITARY INSTALLATIONS.—
>
> (1) MILITARY SPECIFICATION.—Not later than January 31, 2023, the Secretary of the Navy shall publish a military specification for a fluorine-free fire-fighting agent for use at all military installations and ensure that such agent is available for use by not later than October 1, 2023.
>
> (b) LIMITATION.—No amount authorized to be appropriated or otherwise made available for the Department of Defense may be obligated or expended after October 1, 2023, to procure fire-fighting foam that contains in excess of one part per billion of perfluoroalkyl substances and polyfluoroalkyl substances.
>
> (c) PROHIBITION ON USE.—Fluorinated aqueous film-forming foam may not be used at any military installation on or after the earlier of the following dates:

(1) October 1, 2024.
(2) The date on which the Secretary determines that compliance with the prohibition under this subsection is possible.

11. For the US DOD, the Strategic Environmental Research and Development Program (SERDP) is taking the lead on the development of a replacement military specification for F3 and doing the practical performance evaluations of existing foams to ensure that they meet the required performance metrics.

12. Furthermore, within the US civilian realm, the recently passed US Federal Aviation Authorization (FAA) Act 2018, removed the requirements for the use of PFAS-containing AFFF at FAA airports.[10] Moreover, on 1 October 2020, The PFAS Action Act of 2019 came into effect. This act designates certain PFAS as hazardous substances (mandating remediation of environmental releases), directing the EPA to conduct comprehensive toxicity testing and issue guidance on minimizing the use of PFAS-containing firefighting foam. Full details of this act are included in Annex C.[11]

13. The CAF must start its' transition now, or will soon find itself using obsolete equipment and foams that are incompatible with the equipment, training and doctrine of our largest ally. This would severely hamper our ability to contribute firefighting services to a US-led coalition effort.

Australian transition to F3

14. Australia has had significant struggles with PFAS contamination. As per Figure 4, below, at the Australian Defence Forces (ADF) helicopter base at Oakey, some 1.43 million litres of AFFF was discharged into the environment over a 25 year timespan.[12] This contamination has affected agricultural land and groundwater for the urban township nearby, resulting in a class-action lawsuit by affected residents against the ADF.[13] Similarly, other ADF bases have been affected including Edinburgh (SA), Townsville (Qld), Amberley (Qld), Williamtown (NSW) and Katherine (Qld).[14] Accordingly, Australia was one of the first countries to make a large-scale transition from PFAS to F3, with the Queensland Fire and Emergency Service having made the transition to F3 over a decade ago.[15]

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[10] Klein, R.A., "Fluorine-Free Firefighting Foams (3F) – Viable Alternatives to Fluorinated Aqueous Film-Forming Foams (AFFF)," White Paper (Rome, Italy: International POPs (Persistent Organic Pollutant) Elimination Network, September 17, 2018), 7.
[11] Debbie Dingell, "All Info - H.R.535 - 116th Congress (2019-2020): PFAS Action Act of 2019," legislation, January 13, 2020, 2019/2020, https://www.congress.gov/bill/116th-congress/house-bill/535/all-info.
[12] Klein, R.A., "Fluorine-Free Firefighting Foams (3F) – Viable Alternatives...," 34.
[13] *Ibid.*, 34.
[14] *Ibid.*
[15] *Ibid.*

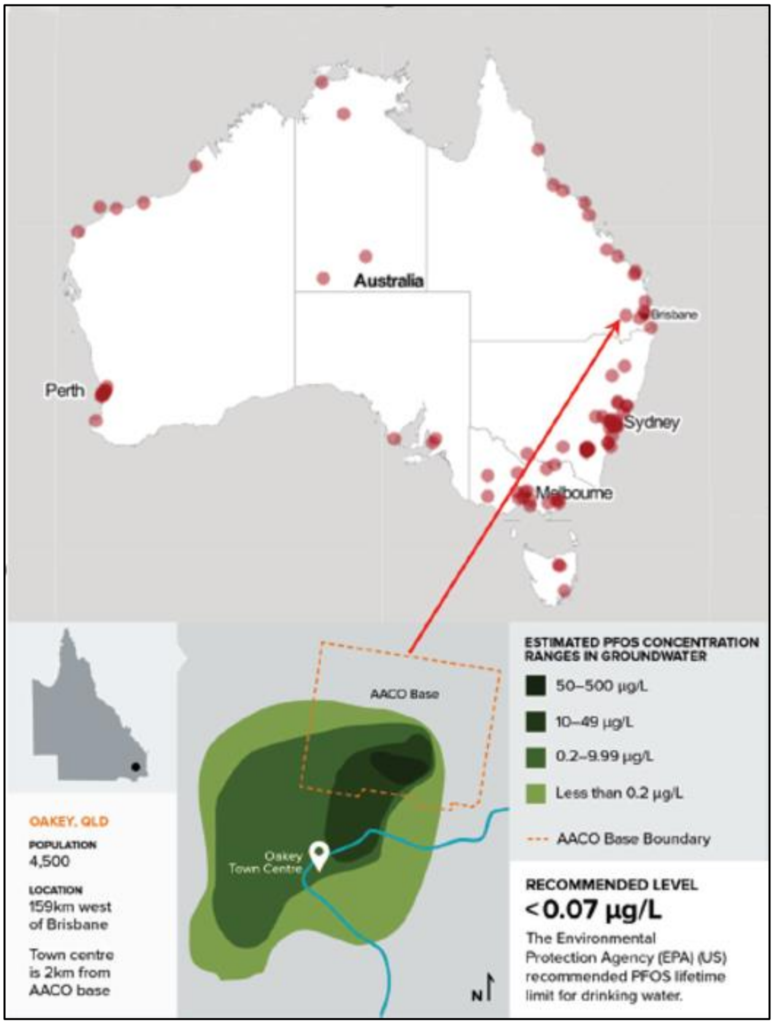

Figure 4: Australia, Oakey Army Aviation Centre PFOS contamination plume (Red dots indicate sites under investigation for elevated levels of PFAS)
Source: Klein, R.A. et al., *Perfluorohexane Sulfonate (PFHxS)—Socio-Economic Impact, Exposure, and the Precautionary Principle,* 22.

Other organizations transitioning to F3

15. The International Persistent Organic Pollutants (POP) Elimination Network (IPEN) has produced a comprehensive list of other known end-users that have transitioned to F3, as follows:

> All of the 27 major Australian airports have transitioned to fluorine-free firefighting (F3) foams, as have the following major hub airports: Dubai, Dortmund, Stuttgart, London Heathrow, Gatwick, Edinburgh, Manchester, London City, Leeds-Bradford, Copenhagen, and Auckland, and elsewhere in Europe such as Billund, Guernsey, Bristol, Blackpool, Köln-Bonn.

Private sector companies using F3 foams include: BP, ExxonMobil, Total, Caltex, Gazprom, Statoil, BHP Billiton, Bayern Oil, 3M, BASF, Chemours, AkzoNobel, Stena Line, Pfizer, Lilly, Weifa, JO Tankers, and ODFJEL. In the oil and gas sector, F3 foams are being used extensively, with Statoil in Norway having transitioned to F3 foams throughout all of its operations. Some military users, including the Danish and Norwegian Armed forces, have moved to F3 foams.[16]

16. Figure 5, below, shows the breakdown by both sector and country that have transitioned to F3 use from PFAS.

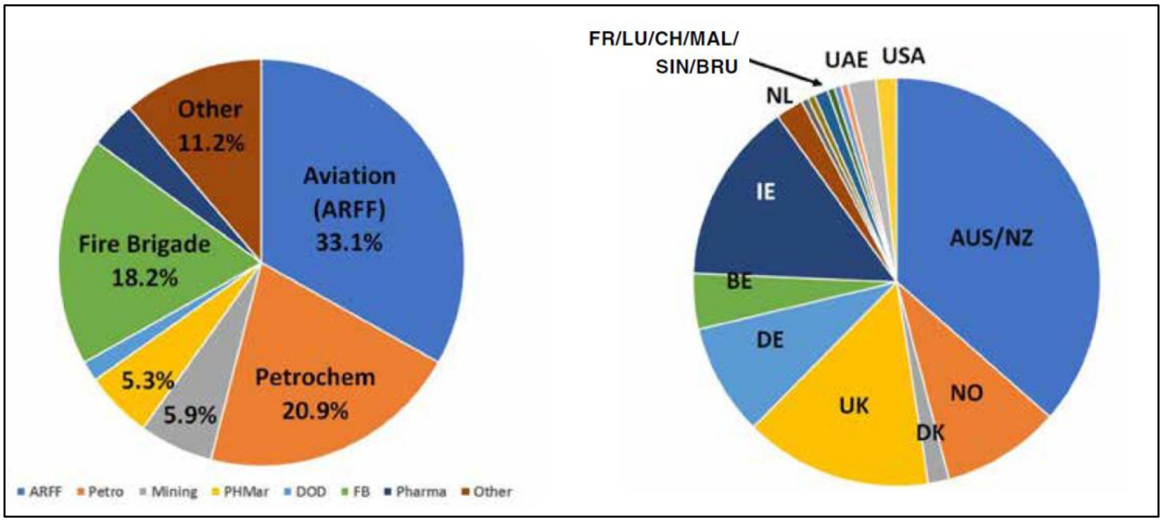

Figure 5: Fluorine-Free Foam use by sector and country
Source: Klein, R.A. et al., *The Global PFAS Problem: Fluorine Free Alternatives as Solutions. Firefighting foams and other sources - going fluorine-free,* 28.

Non-CAF Canadian transition to F3

17. Canadian civil aviation is a significant user of firefighting foam, protecting the lives of millions of Canadian passengers. Nonetheless, on 21 June 2019, the Minister of Transport authorized the following:

"This exemption would allow Canadian airport operators to elect to transition to a fluorine-free foam which is more environmentally friendly and which is currently available on the market and used in other countries. All Canadian airport operators exercising the privileges of this exemption

[16] Klein, R.A. and Holmes, Nigel, "The Global PFAS Problem: Fluorine Free Alternatives As Solutions. Firefighting Foams and Other Sources - Going Fluorine-Free" (Stockholm Convention 9th Conference of the Parties (COP9), Geneva, Switzerland: International Persistent Organic Pollutants Elimination Network, 2019), 27.

will be required to meet the revised Underwriters Laboratories of Canada CAN/ULC-S563 once published."[17]

18. Following this, several Canadian airports have transitioned to F3, including Toronto's Billy Bishop Toronto City Airport,[18] Ottawa Airport, and Toronto's Pearson International Airport.[19]

19. To put this in context, some of the largest airports, aviation and industrial sectors, private companies, allied nations and their militaries have transitioned away from PFAS. There is no reason the CAF cannot do the same.

DISCUSSION AND ANALYSIS

Why does the CAF continue to use PFAS-containing AFFF?

20. When it comes to the CAF rationale to use PFAS-containing AFFF two factors predominate: fire suppression effectiveness and interoperability.

21. When it comes to the operational application of AFFF, slight delays in extinguishment can have significant impacts on either the loss of an asset or the loss of life. Accordingly, fire response crews seek to use the best products available. As per Annex B, while there has been considerable progress to date on F3s and they have met many of the international standards outlined in Figure 6, below, (such as UL-162, EN-1568, ICAO and IMO 13120) they have not met the US MILSPEC (MIL-PRF-24385).

[17] Nicholas Robinson - Director General Civil Aviation, "Exemption from Paragraph 323.08(1) of the Aircraft Fire Fighting at Airport and Aerodromes Standards Made Pursuant to Section 303.08 of the Canadian Aviation Regulations" (Ottawa, ON, Canada, June 21, 2019), 1.
[18] "An Airport Goes Fluorine-Free," Fire Fighting in Canada, April 15, 2021, https://www.firefightingincanada.com/an-airport-goes-fluorine-free/.
[19] Dunning, Maj Rick, telephone conversation with author, December 22, 2021.

	MIL-PRF-24385	ICAO	IMO 1312	EN 1568-3	UL162	NFPA 11 Annex F
			Pool fire test			
Fuel	Gasoline	Jet A, Kerosene	Heptane	Heptane	Heptane	Gasoline
Test pan area [m²]	Circular 2.6, 4.6	Circular 2.5, 4.8, 7.32	Square, 4.5	Circular, 4.5	Square 4.6	Square 9
Vertical Back Board (BB)	no	no	1 m high	no or 1 m high	no	no
Substrate	water	water	sea water	water	water	water
Preburn time (sec)	10 sec	60 sec	60 ± 5 sec	60 ± 2 sec	60 sec	60 sec
Foam application	Forceful @6.89 bar	Forceful @7 bar	Gentle with BB @6.3 bar	Gentle with BB for P, S @6.3 bar Forceful for AFFF, FFFP, FP, F3 @6.3 bar	N/A	Gentle @6.89 bar
Nozzle	NFS	UNI 86	UNI 86	UNI 86	Hose	
Flow rate [l/min]	7.57 l/min	11.4 l/min	11.4 l/min	11.4 l/min	18.6 or 11.6	22.7
application density[l/minm²]	1.65 or 2.91	1.56, 2.38 or 4.56	2.53	2.53	4 or 2.4	
Spray Duration	90 sec	120 sec	300 sec	300 sec for gentle 180 sec for forceful	180 sec	300 sec
Extinguish time	≤50 sec for 2.6 m² ≤50 sec for 4.6 m²	≤ 60 sec suppression with minute flames ≤ 120 sec total extinguishment	≤300 sec	≤300 sec for gentle Class III ≤90 sec for forceful Class I+ ≤180 sec for forceful Class I ≤240 sec for forceful Class II	≤180 sec	≤300 sec
			Torch Test			
Torch Test	No	No	No	No	yes	yes
			Burnback test			
Burnback test fuel	Gasoline	gasoline or Kerosene	same fuel	same fuel	same fuel	same fuel
Pot size [m]	0.3 dia 0.05 high	0.3 dia 0.2 high	0.3 dia 0.15 high	0.3 dia 0.25 high	0.3 dia pipe	0.3 dia pipe
Drainage time (sec)	60 sec	120 sec	300 sec	300 s	540 sec	15 min
Measurement	Visual determination of 25% by area	Visual determination of 25% by area	visually or by thermal radiation measurements	visually or by thermal radiation measurements	Visual determination of 20% by area	
25% burnback time	360 sec	300 sec	900 sec	for Class I, II, III for gentle 900 sec for Level B 600 sec for Level C 300 sec for Level D for Class I, II forceful 600 sec for Level A	20% burnback time 300 sec	5 min burback area ≤ 0..25 m²

Figure 6: Summary of test protocols of major firefighting foam standards

Source: Hassan, R. et al., *Assessment of non-fluorinated firefighting foams: foam performance and ecotoxicity*, 18.

22. While it can be argued that F3s failed to meet this MILSPEC due to the absence of a positive spreading coefficient (and hence the ability to act as a fluorosurfactant); there are some legitimate fire suppression performance deficiencies that need to be overcome. The 30-second extinguishment test, outlined in Annex D, remains elusive, as per Figure 7, below (however in 2003, one 3M formulation extinguished the fire within 10/18

35 seconds).[20] From independent SERDP trials, on average, the F3s took approximately 1.5 to 2 times as long as PFAS-containing AFFF to extinguish spill fires. When it comes to film-forming and sealability, the lack of ability to act as a fluorosurfactant means that it is common to have fuel vapour transport through the foam layers.[21] Finally, PFAS-containing AFFF generally has better burn back resistance than F3s, and F3s usually required 1.5 to 3 times increased application rates to achieve the similar performance of PFAS-containing AFFF.[22] Despite these deficiencies, SERDP assessed that "application rate [of F3s] and training will be key to success".[23] Additionally, with trials with different technologies, (as per annex B), such as compressed air foam and UHP, substantial increases in performance of F3s are achieved.

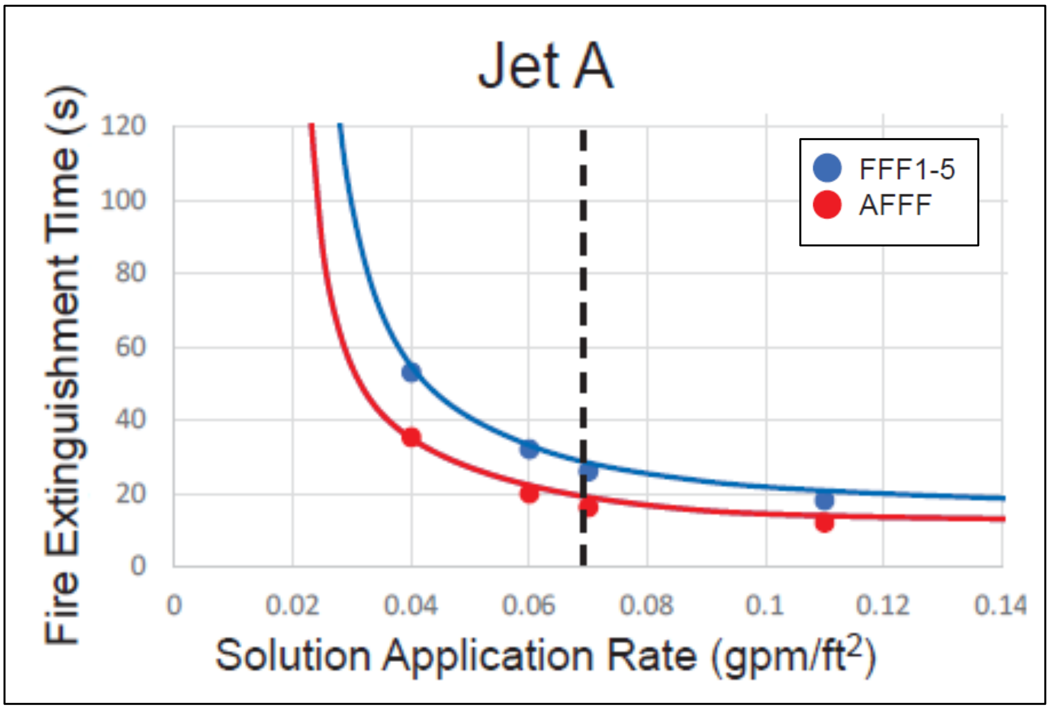

Figure 7: SERDP test results for extinguishment times of PFAS-containing AFFF and F3 type foams

Source: Chauhan, S., *Managing AFFF Impacts to Subsurface Environments and Assessment of Commercially Available PFAS-Free Foams*, 48.

23. It is also worth doing the detailed assessment as to whether the MIL-PRF-24385 actually reflects the bona fide requirements of the CAF, or whether this is an outline of the performance parameters that are available from certain PFAS-containing AFFFs, as the two are not necessarily the same. This was echoed by the Materials Solutions

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[20] Rokib Hassan et al., "Assessment of Non-Fluorinated Firefighting Foams: Foam Performance and Ecotoxicity," 2020, 28, https://epe.lac-bac.gc.ca/100/201/301/weekly_acquisitions_list-ef/2021/21-33/publications.gc.ca/collections/collection_2021/cnrc-nrc/NR24-49-2020-eng.pdf.

[21] *Ibid*., 28.

[22] *Ibid*.

[23] Jerry Back and Jensen Hughes, "What Are the Actual Firefighting Capabilities of the Best Commercially Available PFAS-Free Foams in DoD Applications," 10.

Working Group (which consisted of primarily US DOD representatives) in 2019, at the AFFF alternatives summit, when they stated that the "MIL-PRF-24385 will need to be updated and/or bifurcated … in order to effectively transition F3 products.".[24] From this, it is evident that the adherence in doctrine and regulation to the MIL-PRF-24385 (as currently written) and the transition to F3 are mutually exclusive.

24. When it comes to interoperability, adherence to NATO Standardization Agreements (STANAG) is very useful for the CAF in ensuring its' interoperability with allies. STANAG 3712 - Crash Fire Rescue (CFR) specifically stipulates that "Aqueous film-forming foam agents shall meet the requirements of U.S. Military Specification MIL-F-24385."[25] Additionally, our own internal regulations, the Canadian Force Fire Marshall Directive (FMD) 2003, stipulates that "Aqueous Film Forming Foam (AFFF) agents shall meet the requirements of U.S. Military Specification MIL-F-24385…"[26] As such, by the ratification of STANAG 3712, and internal regulations, the CAF is chained to the MIL-PRF-24385, which precludes a transition to F3 products; as such, either the MILSPEC, STANAG, and/or FMD 2003 must change to accommodate F3 products.

What is the impact of the CAF continuing to use PFAS-containing AFFF?

25. For the CAF, the failure to transition from PFAS-containing AFFF to F3 will result in decreased firefighter proficiency (due to a lack of realistic training), continued contamination of surface water, groundwater, and soils (along with their associated impacts on human health and the environment) both on military establishments (and in their vicinity) and unaffordable remediation costs and potential litigation that will threaten the CAF's reputation and cripple the organization's ability to train and operate.

26. Maintaining firefighter proficiency, through realistic training, is essential for real-world operational performance. This was especially highlighted during the 2021 SERDP symposium where novice firefighters tried to extinguish class B fires using F3: they lacked technique, they punched holes in the foam blanket, and were slow at first, but following practice and gaining finesse, significantly improved their abilities to fight Class B fires[27]; however, the CAF's continued adherence to PFAS-containing AFFF severely hinders this ability to gain finesses and experience. Not only have CAF firefighters been prohibited from training or recertification using AFFF[28] for over a decade, in many cases, such as at Canadian Forces Base (CFB) Edmonton, they are also prevented from using water-only training at established firefighting training areas. This is due to the propensity for existing PFAS-contaminated groundwater plumes to further expand when substantial volumes of water are added. A transition to an appropriately selected F3, coupled with

[24] Nelson, Dr. Herb, "AFFF Alternatives...," 56.
[25] Moreno, VAdm Juan, "STANAG 3712 CFR (Edition 7) - AIrcraft Rescue and Fire-Fighting (ARFF) Services Identification Categories NSA0235(2010)CFR/3712" (NATO Standardization Agency, March 2, 2010), 6.
[26] Canadian Forces Fire Marshall, "Canadian Forces Fire Marshall Directive FMD 2003 - Airport Category and Minimum Response Strength for Fire Fighting," September 2019, 5.
[27] Back and Hughes, "What Are the Actual Firefighting Capabilities...," 13–14.
[28] Canadian Forces Fire Marshall, "FMD 2003 - Airport Category and Minimum Response Strength...," 5.

remediation of existing sites, would allow not only a resumption of water-based training but relevant foam-based training as well.

27. In response to the widely-published negative effects associated with Perfluorooctanesulfonic Acid (PFOS) and Perfluorooctanoic acid (PFOA), (colloquially referred to as C8), the CAF's strategy has been to shift to products that use shorter-carbon-chain fluorosurfactants. These shorter chain products often lack comprehensive toxicological data and include industry claims of decreased environmental and human health effects. For example, the CAF is currently migrating towards C6 type products, such as PFHxS; however, as seen in Figure 14, in Annex A, below, new evidence is showing that these products may be worse than their predecessors (such as PFHxS having a 50% greater bioelimination time than PFOS)[29]. Furthermore, as per Figure 8, below, as the length of the carbon backbone of the fluorosurfactant decreases, solubility (and hence mobility in groundwater), increases. Continuing this trend for the CAF will only result in larger areas of contamination, continued phasing out of products as they are studied and regulated, and increasing health effects for those who are exposed.

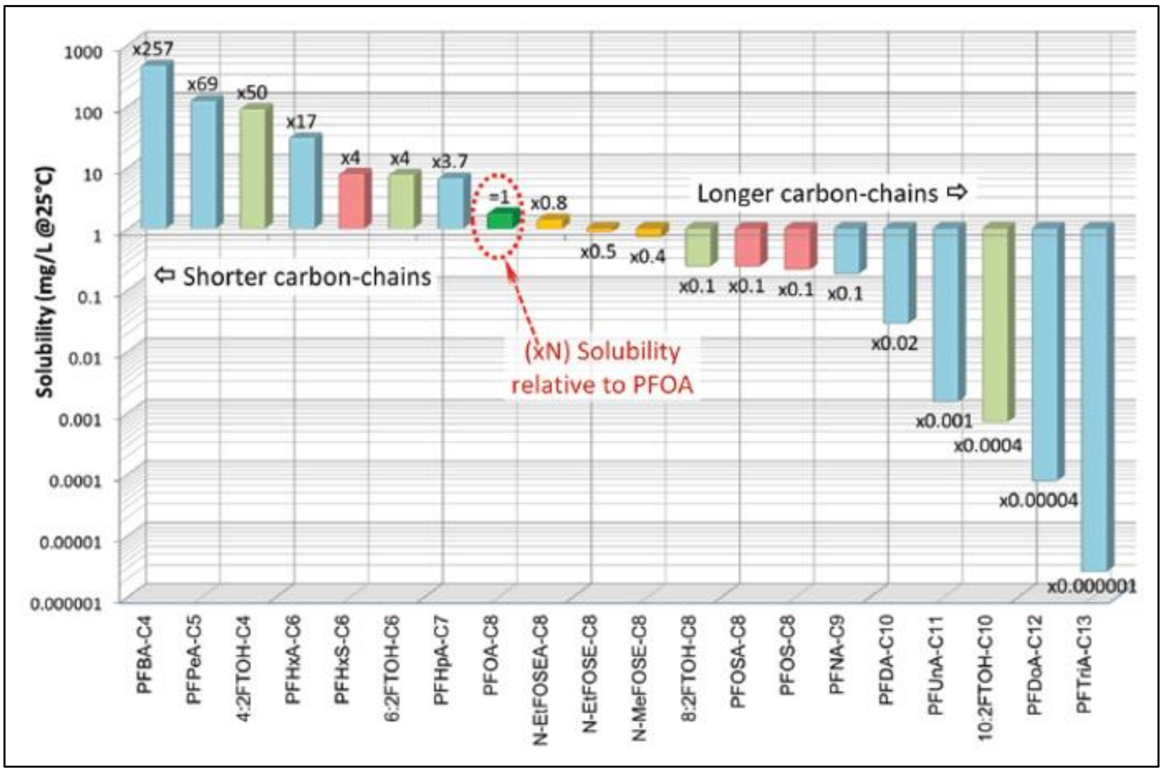

Figure 8: Relative solubility of PFAS plotted by carbon-backbone length

Source: Klein, R.A. et al., *Perfluorohexane Sulfonate (PFHxS)—Socio-Economic Impact, Exposure, and the Precautionary Principle*, 36.

[29] Klein, R.A. and Holmes, Nigel, "Perfluorohexane Sulfonate (PFHxS)—Socio-Economic Impact, Exposure, and the Precautionary Principle.," in *White Paper for the Stockholm Convention Persistent Organic Pollutants Review Committee (POPRC-15).* (Rome Italy: International Persistent Organic Pollutants Elimination Network, 2019), 21.

28. This process of substitution of one chemical, for another, that also turns out to be persistent, bioaccumulative and toxic is referred to by the US National Research Council as "regrettable substitution". The most appropriate methodology for the CAF to avoid regrettable substitution is to follow the precautionary principle. The United Nations directs the application of the precautionary principle as follows:

> The precautionary principle applies where scientific evidence is insufficient, inconclusive or uncertain and preliminary scientific evaluation indicates that there are reasonable grounds for concern that the potentially dangerous effects on the environment, human, animal or plant health may be inconsistent with the high level of protection chosen.[30]

29. The CAF's strategy of selecting shorter chain fluorosurfactants does not respect this principle; rather, the precautionary principle engenders the CAF to use products that do not contain the essential chemical bonds that are the root of this potential hazard. This is further expanded in Figure 9, below. In this regard, the transition to a carefully selected and rigorously-tested F3 is aligned with the precautionary principle.

ASSESSMENT OF FIREFIGHTING FOAMS AGAINST THE PRECAUTIONARY PRINCIPLE ELEMENTS

Assessment element	Persistent toxic compounds	Non-persistent toxic compounds
Spatial scale of the threat	Local, regional, state-wide, national & global threat via dispersion and long-range transport. Wide dispersal over the long-term through air, soils, surface water & groundwater.	Immediately adjacent areas likely to be adversely affected. Wider dispersion & impacts limited by short half-life and rapid biodegradation.
Magnitude of possible impacts	Wider socio-economic, environment & human health impacts through high-level or enduring low-level exposure & increasing build-up over time including by bioaccumulation/ bioconcentration.	Local aquatic environment impacts & short-term direct exposure risks. Mitigation by rapid biodegradability.
Perceived value of the threatened environment	High perceived values for natural environment including food-chain, socio-economic values & long-term human health.	High perceived value for local natural environment. No significant lasting socio-economic or health implications.
Temporal scale of possible impacts	Long-term exposure - Effects lasting decades to inter-generational.	Short-term - Weeks to months.
Manageability of possible impacts	Very difficult to impossible to manage once chemicals have been released. Very high cost of remediation. Flow-on economic & social impacts at local & broader levels. Small spills contribute to build-up & wider exposure in the long-term.	Local relatively short-duration treatment or natural biodegradation & recovery processes. Low to moderate costs.
Public concern & scientific evidence	Worldwide established concerns & mounting scientific evidence of adverse social, economic, human health and environmental effects for PFAS. Uncertainty about the identity & safety of proposed alternative fluorinated & other persistent compounds with rapidly growing evidence of adverse effects.	Limited concern based on well-established evidence & knowledge of the behavior & effects of components.
Reversibility of possible impacts	Not reversible, very long-term or high cost for remediation where possible.	Reversible with basic remediation or natural recovery.

Figure 9: Assessment of firefighting foams against the precautionary principle elements

Source: Klein, R.A., *Fluorine-free firefighting foams (3F) – Viable alternatives to fluorinated aqueous film-forming foams (AFFF)*, 32.

[30] Jens Erik Fenstad and Koïchiro Matsuura, "The Precautionary Principle; 2005," *United Nations Educational, Scientific and Cultural Organization - World Commission on the Ethics of Scientific Knowledge and Technology*, March 2005, 52.

30. Furthermore, PFAS usage as a class of chemicals is likely to be increasingly controlled within Canada. In April 2021, the following amendments were proposed to the Canadian Environmental Protection Act (CEPA), 1999 to:

> …move forward with activities to address the broad class of per- and polyfluoroalkyl substances (PFAS) because scientific evidence to date indicates the PFAS used to replace regulated PFOS, PFOA, and long-chain PFCAs (LC-PFCAs) may also be associated with environmental and/or human health effects.[31]

31. These activities include continuing to invest in research and monitoring of PFAS, collecting and reviewing information to form a class-based approach and reviewing policy documents in other jurisdictions.[32] This aligns with advice from the Stockholm Convention of POPs which recommends "against the use of other PFAS in firefighting foams" and avoiding regrettable substitutions of other PFAS that could have similar hazard profiles and properties, with commensurate results.[33]

32. Additionally, potential litigation and loss of reputation are legitimate concerns. Class-action lawsuits have been brought against the ADF at Oakey for their significant losses of resources, amenity, land value and human health impacts.[34] The CAF has already tested a significant number of its bases, with identified contamination existing in bases or sites located in Cold Lake, Edmonton, Moose Jaw, Dundurn, Winnipeg, Trenton, North Bay, Mountain View, Alert[35] and Baden (Germany), among others.[36] While the full costs of remediation for all of these sites have not yet been established, the estimated remediation costs for CFB Edmonton alone (as identified in para 7 of Annex A) (which are in excess of $30M) are alarming. Furthermore, the CAF is already subject to a claim by a group of 12 citizens in North Bay for PFAS contamination of the surrounding area.[37]

What is required for the CAF to transition to F3?

33. Due to the wide variety of available F3 products available (and the varying ecotoxicity and bioaccumulative effects), it is essential that a replacement product for PFAS-containing AFFF be carefully selected based on performance, socioeconomic, environmental and human health considerations. In order to do this, a multi-disciplinary panel of Subject Matter Experts (SME)s must be convened to properly delineate assessment factors, conduct appropriate literary reviews, identify potential second and

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[31] Public Works and Government Services Canada Government of Canada, "Canada Gazette, Part 1, Volume 155, Number 17: GOVERNMENT NOTICES" (Government of Canada, Public Works and Government Services Canada, Integrated Services Branch, Canada Gazette, April 24, 2021), https://canadagazette.gc.ca/rp-pr/p1/2021/2021-04-24/html/notice-avis-eng.html#nl5.
[32] *Ibid*.
[33] *Ibid*.
[34] Klein, R.A., "Fluorine-Free Firefighting Foams (3F) – Viable Alternatives...," 34.
[35] McManus, Jacki, "RE: Draft Outline for PFAS Transition Service Paper," January 19, 2022.
[36] Dunning, Maj Rick, telephone conversation with author, December 22, 2021.
[37] The Corporation of the City of North Bay and Her Majesty the Queen in Right of Ontario, Ontario Superior Court of Justice, North Bay, Court File No. CV-19-108.

third-order effects (such as equipment modifications or system reconfigurations), establish timelines and resource requirements. This panel should consist of (at a minimum) CAF representatives from DCS, Environmental Legal Advisors, Real Property Operations Group, the CFFM's office, the Surgeon General's office, Level 1 (L1) Environmental advisors and potentially affected operations personnel. Annex E identifies several areas that require further research when transitioning to F3s that this panel should investigate. Following the decision to transition, there will also be a requirement to develop new training tactics and doctrine for firefighters[38], as well as modifications to existing firefighting training infrastructure. It is essential that this transition be done in a very deliberate and comprehensive manner in order to avoid continued regrettable substitution.

CONCLUSION

34. The essence of this service paper has set out to address why the CAF should transition from PFAS-containing AFFF to F3. PFAS can be characterized by its inherent properties of high thermal stability, surface tension levelling, a tendency to bioaccumulate, widespread mobility and very strong environmental stability. It can achieve the highest performance ratings as a thermally stable film-forming fluorosurfactant. Despite limited acute toxicity, its fluorine-containing fluorosurfactants, intermediaries and degradation endpoints are incredibly persistent in the environment and humans, due to long bioelimination times. These are associated with adverse side effects in humans including carcinogenic, endocrinal, neurological, immune, reproductive, and impaired renal and hepatic functions. Additionally, PFAS regulatory thresholds vary substantially between and within countries. Finally, there are limited viable remediation options and costs are exorbitant.

35. Overall, F3 represents a much broader number of classes of chemicals than PFAS-containing AFFF. The absence of the C-F bond means that F3 is unable to act as a film-forming fluorosurfactant. There are several other physical differences in F3 that prevent them from being a "drop-in" solution. In terms of unit cost, F3 is marginally less expensive than PFAS-containing AFFF. When it comes to toxicity, although variations are substantial, F3 are approximately an order of magnitude more acutely toxic than PFAS-containing AFFF, but generally have similar BOD and COD, which can have significant effects on aquatic biota. Chronic toxicity also varies substantially and there is limited data on F3 human health hazards. F3's degradation end-products generally have much shorter environmental half-lives than their PFAS counterparts. This leads to simpler and more cost-effective remediation methods. Finally, while other types of extinguishing agents exist, they are either also fluorinated (which brings the same persistence and toxicological consideration from their degradation endpoints) or generally have inferior performance compared to F3 on Class B fires.

36. Worldwide, a number of states and organizations have successfully transitioned to F3, including many large civilian airports, industrial sectors and private companies. Many

[38] Dunning, Maj Rick, "RE: Draft Outline for PFAS Transition Service Paper," January 21, 2022.

of Canada's allies have transitioned their civilian aviation sectors and militaries to F3. Additionally, the US has passed laws to enact this transition in 2024.

37. The CAF has continued to use PFAS-containing AFFF primarily for its fire suppression effectiveness and interoperability within NATO. However, the MIL-PRF-24385 standard is mutually exclusive to F3s at this time, and some US DOD organizations have called for it to be bifurcated to include an F3 standard.

38. If the CAF continues to use PFAS-containing AFFF, firefighter proficiency will continue to decrease and there will continue to be substantial soil and water contamination. This will exacerbate concerns of human and environmental health, incur exorbitant remediation costs, and create risks of reputational loss and litigation. The CAF's current strategy of using shorter chain fluorosurfactants violates the precautionary principle and is an example of regrettable substitution that will result in greater negative effects and higher costs in the long term. Additionally, multiple Canadian and US agencies are further regulating PFAS, which may limit the availability and potential usage of PFAS-containing AFFF. This can be corrected through transitioning to F3s.

39. For the CAF to successfully transition to F3, the process must be done carefully and deliberately, collaboratively involving affected stakeholders to determine selection criteria and elucidate potential second and third-order effects. This must also be met with strategic direction, policy modification and resourcing. If the CAF successfully transitions to F3, it will reap benefits of reduced legal, reputational and financial liability, lower remediation costs and decreased human and environmental impacts.[39] It is imperative upon the CAF to transition to F3 now.

RECOMMENDATIONS

40. The CAF must provide blood testing to determine and document potential exposure to PFAS for each CAF and DND firefighter during an annual physical exam.

41. The CAF must reassess as to whether the MIL-PRF-24385, as written, reflects the bona fide fire suppression requirements needed. If not, the CAF should either support the re-write of this standard, adopt an alternate appropriate standard or support amendments to STANAG 3712 and FMD 2003.

42. The CAF must convene a multi-disciplinary panel of SMEs into an *ad hoc* task force in order to properly delineate assessment factors for a replacement F3 product, conduct appropriate literary reviews, identify potential second and third-order effects, establish timelines and resourcing requirements. This panel should consist of CAF representatives from DCS, Environmental Legal Advisors, Real Property Operations Group, the CFFM's office, the Surgeon General's office, Level 1 Environmental advisors and potentially affected operations personnel.

[39] Klein, R.A. and Holmes, Nigel, "The Global PFAS Problem...," 27.

43. The CAF must establish and implement a timeline for the transition from PFAS-containing AFFF to F3. This must be accompanied by an appropriate broad communication strategy, financial resourcing (for items such as equipment modifications, system reconfigurations or infrastructure alterations) and doctrinal/regulation changes that will prohibit the continued usage or procurement of PFAS-containing AFFF.

Annex A: Physical, chemical, toxicological and performance characteristics of PFAS
Annex B: Physical, chemical, toxicological and performance characteristics of F3
Annex C: Summary of the US PFAS Action Act 2019
Annex D: MIL-PRF-24385 – Chemical, Physical and performance requirements
Annex E: Areas for future research

ANNEX A

PHYSICAL, CHEMICAL, TOXICOLOGICAL AND PERFORMANCE CHARACTERISTICS OF PFAS

1. PFAS refers to a group of approximately 4700 anthropogenic chemicals,[40] originally developed in the 1940s,[41] with a hydrophobic (water-repelling) aliphatic[42] (open-chain) linked carbon backbone structure, typically 2 to 16 carbon atoms long, partially or fully saturated with carbon-fluorine bonds and a hydrophilic (having a strong affinity for water)[43] polar terminal group (such as carboxylic acid or a sulfonate).[44] This carbon-fluorine bond, the strongest in organic chemistry,[45] gives many of the properties to this group such as high thermal stability, water and oil repellent qualities, high surface tension levelling[46], a tendency to bioaccumulate, and very strong environmental stability.[47] Figure 10 and Figure 11 below show some of the most commonly used PFAS by the Canadian Armed Forces, specifically PFOS, PFOA and PFHxS (although it should be noted that the CAF have since phased out the use of PFOS and PFOA due to stringent regulations on their usage, and cessation of production in 2002)[48].

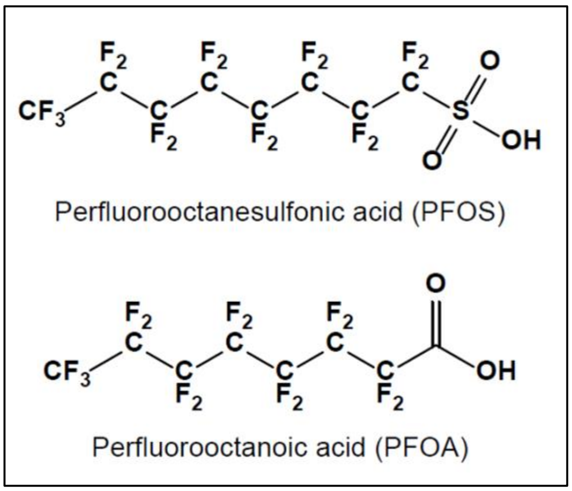

Figure 10: Two-dimensional structures of PFOS and PFOA
Source: Hassan et al., *Assessment of non-fluorinated firefighting foams*, 12.

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[40] Government of Canada, "Canada Gazette, Part 1, Volume 155, Number 17..."
[41] Klein, R.A., "Fluorine-Free Firefighting Foams (3F) – Viable Alternatives...," 51.
[42] Sen. Inhofe, James M., "National Defense Authorization Act for Fiscal Year 2020," Pub. L. No. S.1790, 1120 (2019), 113, https://www.congress.gov/bill/116th-congress/senate-bill/1790/all-info.
[43] n.d., "Hydrophilic Definition & Meaning - Merriam-Webster," accessed January 24, 2022, https://www.merriam-webster.com/dictionary/hydrophilic.
[44] Klein, R.A. and Holmes, Nigel, "The Global PFAS Problem...," 77.
[45] *Ibid*.
[46] Klein, R.A., "Fluorine-Free Firefighting Foams (3F) – Viable Alternatives...," 51.
[47] n.d., "Per- and Polyfluoroalkyl Substances (PFASs)," accessed January 21, 2022, https://www.serdp-estcp.org/Featured-Initiatives/Per-and-Polyfluoroalkyl-Substances-PFASs.
[48] *Ibid*.

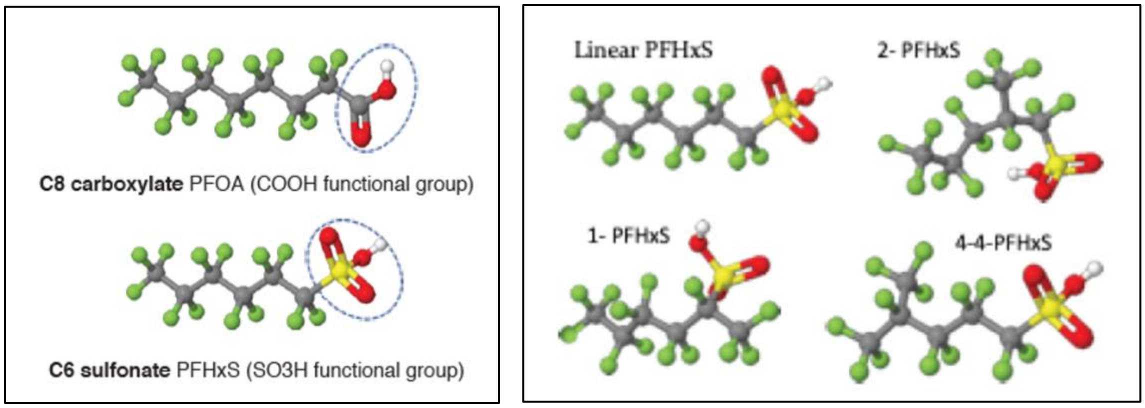

Figure 11: Three-dimensional structures of PFOA and PFHxS and its isomers (grey-carbon, green-fluorine, yellow-sulfur, red-oxygen, white-hydrogen)
Source: Klein, R.A. et al., *Perfluorohexane Sulfonate (PFHxS)—Socio-Economic Impact, Exposure, and the Precautionary Principle*, 21.

2. Due to their inherent properties, PFAS are used in a wide variety of products and applications, such as surfactants, repellents, waterproofing of textiles (such as carpets, furniture and clothing)[49], non-stick cookware, hydraulic and lubricant oils,[50] food packaging, firefighting foam as well as other industrial and consumer applications.[51]

3. For the CAF, the principal PFAS use of concern is that of a fluorosurfactant, as the key film-forming ingredient (as per Figure 13, below), in Class B firefighting foams[52] (also referred to as AFFF), used previously for both training until 2010 (no longer conducted as per Fire Marshall Directive 2003[53]) and currently for the operational extinguishing of liquid hydrocarbon fires. The fluorosurfactant helps to extinguish the fire by lowering surface tension and sealing the surface of the liquid fuel with a film that aids to reduce the vaporization of the fuel, while the foam on top helps to cool the fuel, suppress fuel vapour and prevent re-ignition.[54] Figure 12 (below) identifies two different types of fires and the different types of foams that are available to extinguish them.

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[49] Government of Canada, “Canada Gazette, Part 1, Volume 155, Number 17...”
[50] Klein, R.A., “Fluorine-Free Firefighting Foams (3F) – Viable Alternatives...,” 51.
[51] “U.N. Expert Committee Recommends Global Elimination of Toxic Chemical Harming Health of Firefighters | IPEN,” accessed January 18, 2022, https://ipen.org/news/un-expert-committee-recommends-global-elimination-toxic-chemical-harming-health-firefighters.
[52] Klein, R.A., “Fluorine-Free Firefighting Foams (3F) – Viable Alternatives...,” 51.
[53] Canadian Forces Fire Marshall, “FMD 2003 - Airport Category and Minimum Response Strength...,” 5.
[54] Nelson, Dr. Herb, “AFFF Alternatives...,” 22.

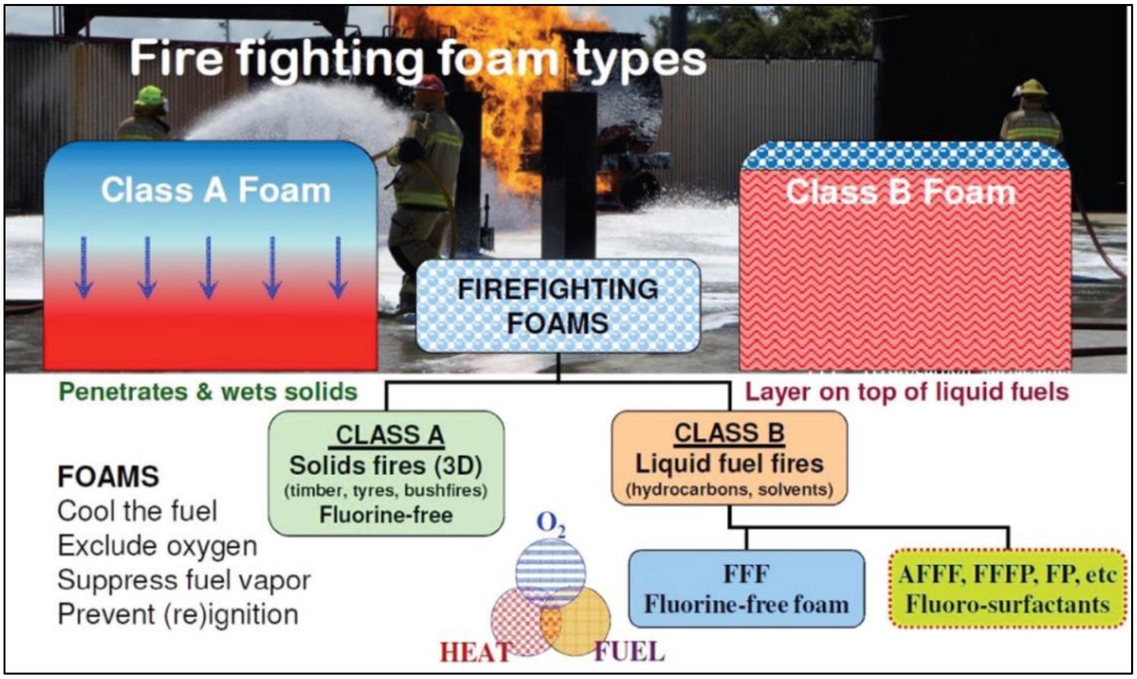

Figure 12: Class A and B firefighting foam types
Source: Klein, R.A., *Fluorine-Free Firefighting Foams (3F) – Viable Alternatives to Fluorinated Aqueous Film-Forming Foams (AFFF)*, 19.

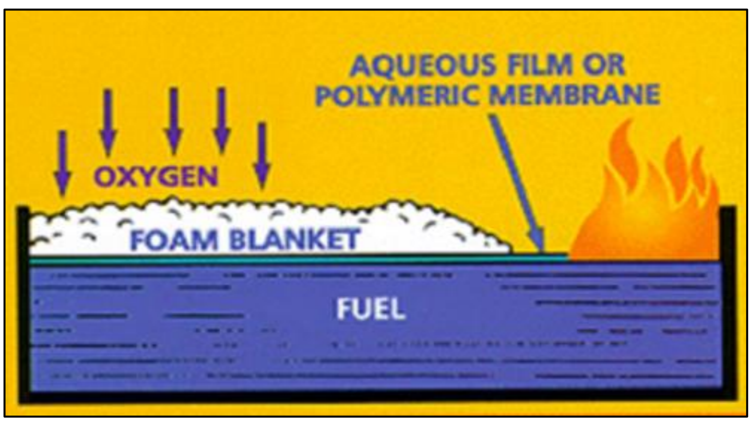

Figure 13: Role of fluorosurfactants in AFFF when applied to Class B fires
Source: Nelson, H., *AFFF Alternatives: Art of the Possible*, 22.

4. When addressing the properties of PFAS, based on PFAS compounds with substantial research into them, they demonstrate the following characteristics:[55]

a. They are environmentally mobile (due to the hydrophilic functional groups that allow them to move widely with both surface and groundwater) and persist in the environment (they do not readily fully

[55] Klein, R.A. and Holmes, Nigel, "Perfluorohexane Sulfonate...," 20.

degrade under normal conditions and within organisms, due to the C-F bonds).

b. They have been detected in humans (including umbilical cord blood and breast milk), wildlife and environmental media worldwide (such as drinking water, ice cores from the Arctic, soils, sediments, the oceans, the atmosphere, indoor air, and dust).

c. They biomagnify in food chains, which results in increased exposure for organisms higher in the food chain (such as humans, polar bears, whales, or seals).

d. They are associated with a range of adverse effects on human health (such as effects on the liver, birth weight, metabolism, and the immune system) and the environment.

5. Very few of the 4700 chemicals have undergone rigorous testing for chronic toxicity, as they were already on the market when the 1976 Toxic Substances Control Act was passed in 1976, and they were exempted or "grandfathered" from having to complete the rigorous testing this act required.[56] While there is substantial data on a few select PFAS, such as PFOA, PFOS and PFHxS, there is the realization that the manufacturing, discharge and breakdown of all PFAS have the potential for adverse socio-economic, health and environmental effects.[57] When it comes to assessing toxicity, this is usually divided between acute (generally defined as relating to exposure of less than 96 hours)[58] toxicity and chronic toxicity.

a. In terms of acute toxicity, most of the PFAS themselves within the AFFFs are generally listed as Not Acutely Toxic (NAT);[59] however, some of the other components within a mixture can be fairly acutely toxic, such as Diethylene Glycol Monobutyl Ether, a subcomponent of the AFFF used in Hangar 2 at CFB Edmonton,[60] whose vapours have a substantially lower 8-hour Threshold Limit Value (TLV) than Carbon Monoxide.[61]

b. In terms of chronic toxicity, PFAS is especially concerning. When it comes to thresholds of acceptable levels in water, there is far from unanimous agreement on what is acceptable, and what is prescribed is very, very low. The US EPA has issued a long-term health advisory of 70

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56 Rebecca Trager9 June 2016, "Explainer: Toxic Substances Control Act," Chemistry World, accessed January 24, 2022, https://www.chemistryworld.com/news/explainer-toxic-substances-control-act/1010187.article.
57 Klein, R.A. and Holmes, Nigel, "Perfluorohexane Sulfonate...," 20.
58 Klein, R.A., "Fluorine-Free Firefighting Foams (3F) – Viable Alternatives...," 31.
59 Hassan et al., "Assessment of Non-Fluorinated Firefighting Foams...," 61.
60 National Foam, "Safety Data Sheet – NMS#210 Aer-O-Water®C6 3EM 3% Aqueous Film Forming Foam Concentrate (AFFF)," November 2, 2016, 3.
61 OAR US EPA, "Carbon Monoxide's Impact on Indoor Air Quality," Overviews and Factsheets, July 31, 2014, https://www.epa.gov/indoor-air-quality-iaq/carbon-monoxides-impact-indoor-air-quality.

nanograms (ng) / litre (L) for PFOS and PFOA[62]; however, individual states can establish their own thresholds, such as the State of New Jersey which is being established at 14 ng/L for PFOS or PFOA.[63] Canada's drinking water screening values for PFOA and PFOS are three and nine times as high as those of the US EPA, at 200 ng/L and 600 ng/L, respectively.[64] To put this in perspective, lead in drinking water, (which sparked the recent Flint, Michigan water crisis) while desired to keep levels as low as reasonably allowable, is permitted under Health Canada's new guidelines in concentrations up to 25 times as much as PFOA at 5,000 ng/L or 0.005 mg/L.[65]

c. Once PFAS has entered the body through any of a number of potential means, it has nefarious effects. In animal-based laboratory studies, PFAS is associated with reproductive, developmental, endocrine, liver, kidney, and immunological effects.[66] As a carcinogen, the International Agency for Research on Cancer classifies PFOA, as a Class 2B carcinogen with particular risk for testicular and kidney cancers.[67] The risk profile also links PFOA exposure with "high cholesterol, inflammatory diseases, ulcerative colitis, thyroid disease, immune effects, pregnancy-induced hypertension, endocrine disruption and impaired neuro- as well as reproductive development."[68] Additionally, as research on this group of chemicals increases, new insights about adverse health effects are coming from the peer-reviewed scientific literature. Further to this, the U.S. Agency for Toxic Substances and Disease Registry's Toxicological Profile came to the conclusion "that health advisory levels for PFOA and other evaluated PFAS far exceed health protective standards based on sensitive health endpoints such as immune effects."[69]

d. As per Figure 14, below, these compounds also have very long half-lives in humans, with these compounds remaining within a person's body for decades.

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[62] Klein, R.A., "Fluorine-Free Firefighting Foams (3F) – Viable Alternatives...," 46.
[63] Nelson, Dr. Herb, "AFFF Alternatives...," 46.
[64] Health Canada, "Guidelines for Canadian Drinking Water Quality - Summary Table," guidance, October 22, 2014, 17, https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/water-quality/guidelines-canadian-drinking-water-quality-summary-table.html.
[65] *Ibid.*, 14.
[66] Klein, R.A. and Holmes, Nigel, "Perfluorohexane Sulfonate...," 20.
[67] Klein, R.A., "Fluorine-Free Firefighting Foams (3F) – Viable Alternatives...," 4.
[68] *Ibid.*, 4.
[69] *Ibid.*

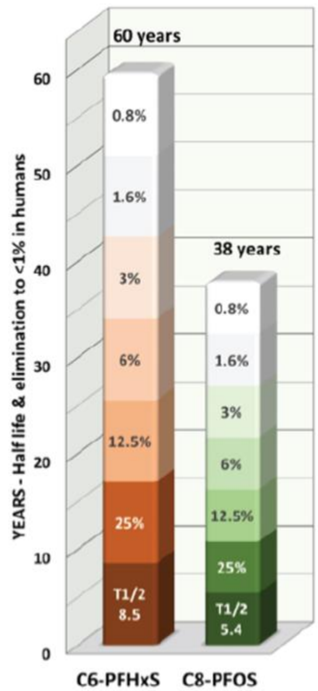

Figure 14: Human bio-elimination of PFHxS and PFOS
Source: Klein R.A. et al., *Perfluorohexane Sulfonate (PFHxS)—Socio-Economic Impact, Exposure, and the Precautionary Principle*, 21

e. Given the significant chronic toxicity and long bio-elimination of PFAS, it is not surprising these are of significant concern to those who encounter it frequently: firefighters. In a study based in Australia, as per figure 15 below, firefighter blood levels for PFOS and PFHxS were found to be many times higher than the median values for the general population.[70]

[70] Klein, R.A. and Holmes, Nigel, "Perfluorohexane Sulfonate...," 25.

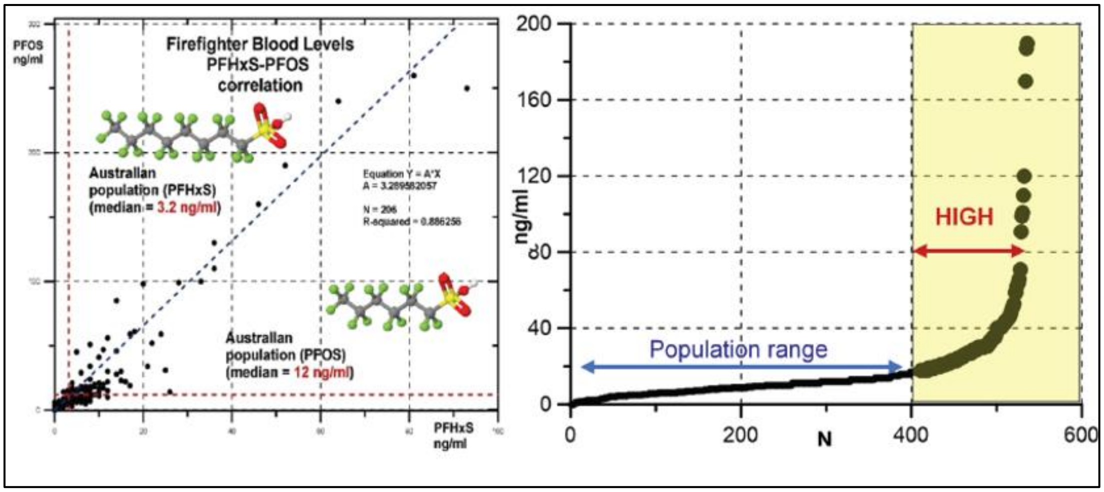

Figure 15: PFHxS in Australian firefighters' blood (left) and range (right) of values (yellow) compared to the general population (white)

Source: Klein R.A. et al., *Perfluorohexane Sulfonate (PFHxS) — Socio-Economic Impact, Exposure, and the Precautionary Principle*, 26.

f. Furthermore for our largest ally, in order to come to grips with its effect on its' firefighters, the 2020 U.S. National Defense Authorization Act, Section 707, specifically tasked the Secretary of Defense as follows:

> Beginning on October 1, 2020, the Secretary of Defense shall provide blood testing to determine and document potential exposure to perfluoroalkyl and polyfluoroalkyl substances (commonly known as ''PFAS'') for each firefighter of the Department of Defense during the annual physical exam conducted by the Department for each such firefighter.[71]

g. As the leading countries of the world begin to grapple with the consequences of this workplace-related exposure, the CAF needs to ensure they are appropriately testing, documenting and supporting our firefighters. The DND must perform annual blood tests on all CAF and DND firefighters for PFAS exposure.

6. While this paper has established the significant persistence of PFAS in the human body, its long-term presence in the environment is no less concerning. It undergoes long-range atmospheric and oceanic transport for thousands of kilometres, polluting large bodies of water and a wide range of plants and animals.[72] While manufacturers of these products will claim that they "degrade" in the environment, PFAS are quite resistant to biodegradation, photooxidation, direct photolysis and hydrolysis.[73] Rather, what is actually occurring is a transformation to yield very stable fluorinated end-point

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[71] Sen. Inhofe, James M., National Defense Authorization Act for Fiscal Year 2020, 245.
[72] Klein, R.A. and Holmes, Nigel, "Perfluorohexane Sulfonate...," 22.
[73] n.d., "Per- and Polyfluoroalkyl Substances..."

substances, which do not degrade further.[74] Along this pathway, a number of fluorinated intermediaries can be created, such as ketones, aldehydes and fluorotelomer acids that can potentially have greater adverse effects than either the end-point or starting PFAS substances.[75]

7. When it comes to remediation of persistent PFAS contamination, this is especially difficult and costly. Globally, industry and academic experts have estimated the PFAS contamination clean-up bill at between $30 billion and $1 trillion USD.[76] Within the CAF, staff within DCS have identified up to 28 different remediation technologies that could be used, although only half are deemed viable at this point in time. Some of the viable options include incineration, thermal desorption, containment, stabilization, electrochemical oxidation, and sorption.[77] Given the incredible strength and stability of the C-F bond, (which is only molecularly destroyed at 1,440 °C)[78], this can be a very costly endeavour, with incineration and thermal desorption costing approximately $600-$1000 CAD/tonne of soil. These high costs, combined with the high mobility of these compounds in both surface and sub-surface water, and the incredibly low threshold required to contaminate media, can result in exorbitant costs for remediating small areas.

8. For example, CFB Edmonton used to conduct AFFF training in the base Fire Fighting Training Area (see Figure 17, below) with PFAS-containing AFFF. The seeping of PFAS containing AFFF into the groundwater resulted in substantial contamination of the surrounding area, as per Figure 18, below. When Dillon Consulting and Stantec Consulting were hired to assess remediation options, they identified approximately an impacted area of 177,997m^2 of impacted groundwater[79] and 17,160 m^3 of contaminated soil[80] (Above Health Canada screening values). Excavation and containment only of this 29,200 metric tonnes of soil were estimated to cost approximately $3.6 million CAD[81]; this does not account for the upwards of $29 million CAD that would be required for incineration or thermal desorption (based on the aforementioned rates) as well as additional costs for transport to a treatment site or mobilization costs.

[74] Klein, R.A., "Fluorine-Free Firefighting Foams (3F) – Viable Alternatives...," 31.
[75] *Ibid*., 31.
[76] Klein, R.A. and Holmes, Nigel, "The Global PFAS Problem...," 80.
[77] Cushings, Pam, "PFAS Remediation Technology Overview" (Ottawa, October 21, 2021), 4–8.
[78] Phelps, Lara, "PFAS Thermal Treatment – Exploring Traditional and Innovative Solutions," 10.
[79] Cooper, Ian and Corrin, Natasha, "Phase III Environmental Site Assessment and Human Health Preliminary Quantitative Risk Assessment - Fire Fighting Trianing Area - 3 CDSB Edmonton, Alberta," Risk Assessment (Ottawa, ON, Canada, March 31, 2016), 7.
[80] McColl, Dave, "PFAS Delineation and Mitigation Options – Revised Draft Report - Fire Fighting Training Area at 3 CDSB Edmonton" (Edmonton Alberta: Dillon Consulting, October 18, 2019), 10.
[81] *Ibid*., 38–39.

Figure 17: Firefighter training using PFAS containing AFFF at CFB Edmonton

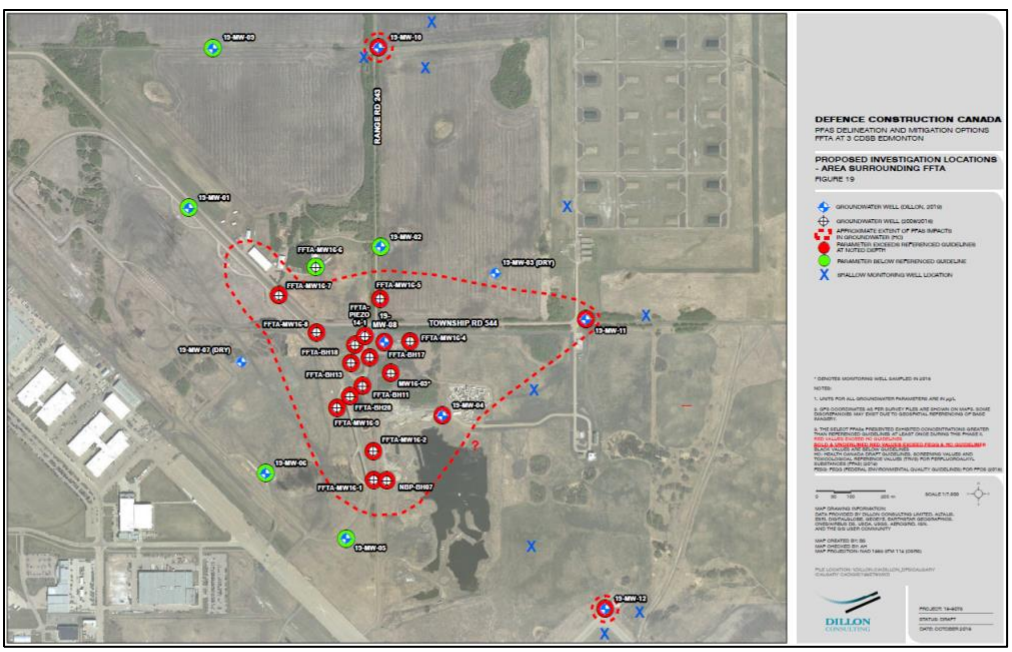

Figure 18: Map of PFAS contaminated groundwater in the vicinity of the Fire Fighter Training Area at CFB Edmonton

Source: McDoll, D., *PFAS Delineation & Mitigation Options*, 81.

ANNEX B

PHYSICAL, CHEMICAL, TOXICOLOGICAL AND PERFORMANCE CHARACTERISTICS OF F3

1. F3 is not one group of chemicals but rather a number of different classes of chemicals that include alkyl sulphates, alkyl betaines, amphoteric surfactants, non-ionic surfactants and amines. Figure 19 below, shows the chemical structure of some of these alternatives.

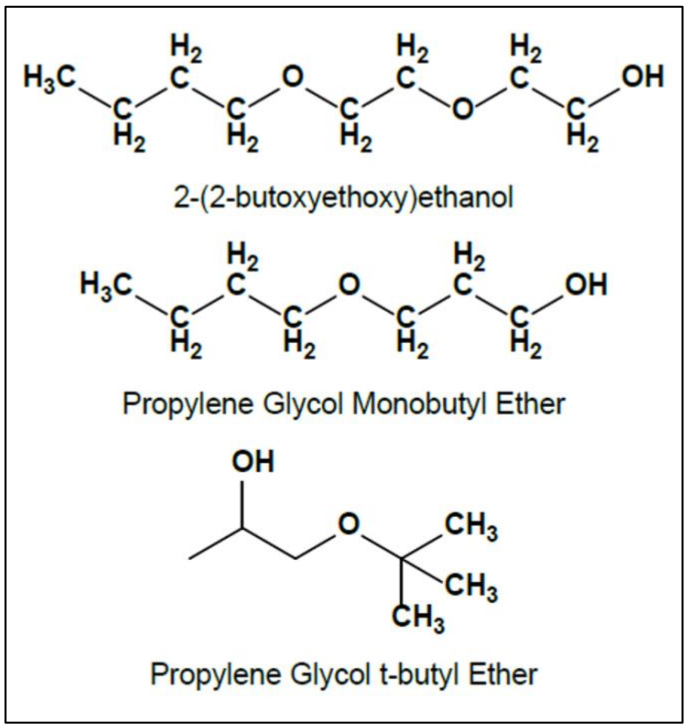

Figure 19: Two-dimensional structure of alternative fluorine-free chemicals
Source: Hassan, R. et al., *Assessment of non-fluorinated firefighting foams*, 19.

2. Some of the first F3 formulations were invented by a 3M scientist, Ted Schaefer, in 1982. Interestingly enough, F3 was developed while trying to develop a training foam for the Royal Canadian Air Force (RCAF) that would permit them to extinguish the fire, without leaving a residue, and that would allow the burn areas to be re-ignited shortly thereafter, hence allowing more training in a compressed amount of time.[82]

3. One of the limiting characteristics of F3 (due to the lack of fluorine implied with the name) is that they are unable (at least to date) to act as a film-forming surfactant.[83] Their primary performance is based on the bubble quality of the foam that covers the combustible fuel, although there is still some uncertainty regarding details of the fire

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[82] Klein, R.A., "Fluorine-Free Firefighting Foams (3F) – Viable Alternatives...," 64.
[83] Nelson, Dr. Herb, "AFFF Alternatives...," 24.

suppression mechanism.[84] Over the past four decades, the performance of F3 has continued to improve, and certain technologies such as Compressed Air Foam and Ultra High Pressure have drastically reduced extinguishment time (by an average of 47%)[85] and increased burn back times (by an average of 34%).[86] Increasing technology maturity has resulted in some formulations of F3 achieving certification under several stringent firefighting foam certification programs, specifically[87]:

a. Underwriters Laboratories (UL162) - Standard for Foam Equipment and Liquid Concentrates.

b. BS EN 1568 - Fire extinguishing media – Foam concentrates.

c. International Civil Aviation Organization (ICAO) - Airport Services Manual Doc 9137-AN/898 Part 1 - Rescue and Firefighting, Fourth Edition.

d. International Maritime Organization (IMO) 1312 - Revised guidelines for the performance of foam concentrates.

4. Despite this strong performance in many fields, it is worth noting that so far, during testing by the US DOD SERDP, no F3s have demonstrated the required performance necessitated of US MILSPEC 24385;[88] One key aspect of this is the required extinguishment time of less than 50 seconds for a $2.6m^2$ liquid fuel pool fire for which F3s currently cannot satisfy.[89] Additionally, critics of this MILSPEC argue that the required minimum spreading coefficient contained therein inherently predicates a PFAS-containing AFFF, as F3 does not contain fluorine, does not have positive spreading coefficients, and cannot act as a fluorosurfactant for film formation.[90] They contend that on low surface tension hydrocarbon fires (such as n-hexane or iso-octane), where film formation with fluorosurfactants does not occur, F3s outperform their PFAS-containing AFFF counterparts.[91]

5. In addition to the lack of ability to act as a film-forming surfactant, F3s differ on several other physical properties. Generally, F3s are much more viscous, often exhibiting non-Newtonian flow mechanics.[92] Generally, they have a lesser foam expansion ratio than PFAS containing AFFF, requiring discharge rates to be increased by as much as

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[84] *Ibid*., 54.
[85] Chauhan, Dr. Satya, "Managing AFFF Impacts to Subsurface Environments and Assessment of Commercially Available PFAS-Free Foams," 23.
[86] *Ibid*., 23.
[87] Klein, R.A., "Fluorine-Free Firefighting Foams (3F) – Viable Alternatives...," 47.
[88] Nelson, Dr. Herb, "AFFF Alternatives...," 23.
[89] Chauhan, Dr. Satya, "Managing AFFF Impacts to Subsurface Environments...," 19.
[90] Klein, R.A., "Fluorine-Free Firefighting Foams (3F) – Viable Alternatives...," 20.
[91] *Ibid*., 20.
[92] Nelson, Dr. Herb, "AFFF Alternatives...," 35.

50% to 100%.[93] As this is a diverse mix of groups of chemicals, other physical factors also affect performance, such as pH, corrosion, interfacial tension, oleophobicity, foam stability and temperature dependence.[94] All of this is to reinforce that F3s are not simply "drop-in" replacements for PFAS AFFF, and various aspects of existing configurations would need to be modified to accept them, such as increased aspiration rates, increased flow rates, larger tank sizes, and modified nozzle diameters.[95]

6. Not only does F3 differ on physical parameters, but it also differs in unit cost, as per Figure 20, below, usually costing less than PFAS-containing AFFF that meets the US Military Specification (MILSPEC) 24385. While the difference of a few dollars per litre may sound trivial, this is greatly magnified when hundreds of thousands of litres of product are purchased annually to support both operational and future training requirements.

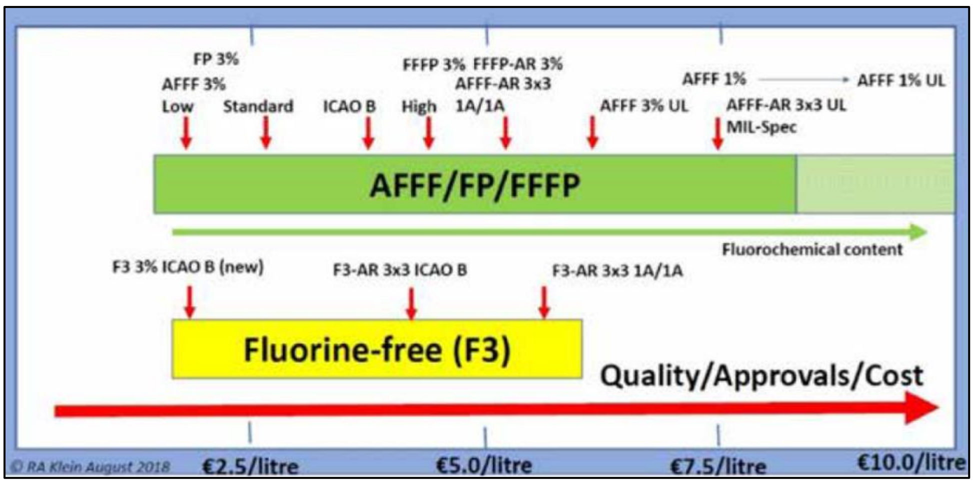

Figure 20: Typical Market costs of fluorinated vs fluorinated firefighting agents
Source: Klein, R.A. et al., *The Global PFAS Problem: Fluorine Free Alternatives As Solutions*, 27.

7. More important than F3s differences in physical properties or cost from PFAS-containing AFFF are its toxicological and environmental persistence qualities. In terms of acute toxicity, F3 is generally more acutely toxic than PFAS-containing AFFF (by approximately an order of magnitude)[96], although it should be noted that there is substantial variation based on formulations;[97] however, when one is trying to evaluate the impact on the environment, especially aquatic environments, it can be useful to evaluate both Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD), as these can result in immediate damage to plants and animals in a waterbody by reducing available dissolved oxygen. In this regard, PFAS-containing AFFF and F3 are very

[93] *Ibid*., 59.
[94] *Ibid*., 65.
[95] *Ibid*., 59.
[96] Chauhan, Dr. Satya, "Managing AFFF Impacts to Subsurface Environments...," 25.
[97] Hoverman, Jason, "Aquatic Systems as a Tool for Evaluating the Toxicity of PFAS-Free AFFF" (SERDP-ESTCP Symposium, Purdue University, West Lafayette, Indiana, 2021), 29.

similar, with the mean values (based on 90 different commercially available products) for F3 being lower than PFAS-containing AFFF, as per Figure 21 below.

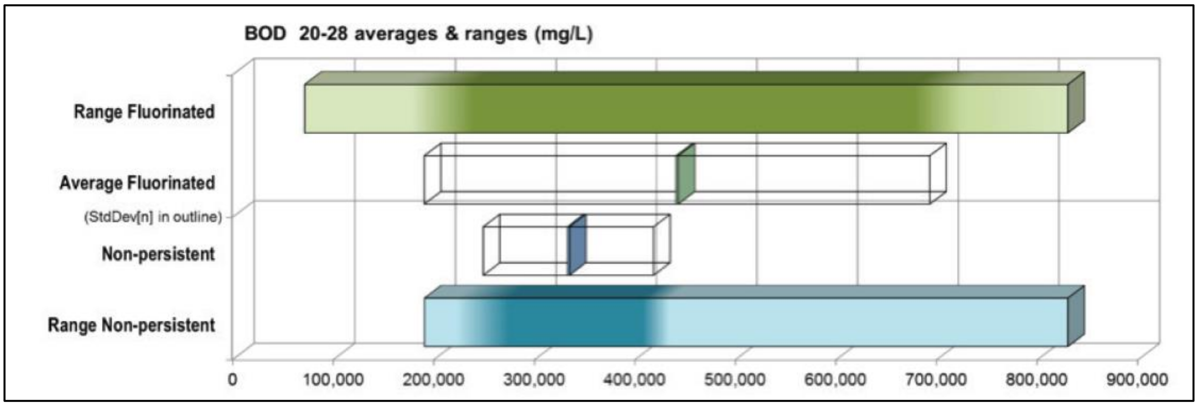

Figure 21: Comparison of BOD between fluorinated and non-fluorinated firefighting extinguishing agents

Source: Klein, R.A., *Fluorine-free firefighting foams – Viable alternatives to fluorinated aqueous film-forming foams*, 29.

8. When it comes to chronic environmental toxicity, while it needs to be acknowledged that there is substantial variation due to a broader set of formulations and different groups of base chemicals,[98] This is evident in Figure 22, below, which shows a detailed assessment of ecotoxicity (using the Globally Harmonized System of Classification and Labelling of Chemicals (GHS) ratings for toxicity) 12 different F3 products by 7 different manufacturers. Within this group of F3s, there are products with no acute toxicity or chronic toxicity, while at the same time, there are products with ratings of Acute 1 ("Very toxic to aquatic life") and chronic 2 ("Toxic to aquatic life with long-lasting effects").[99] Generally, F3 produces reduced long-term effects compared to PFAS-containing AFFF (caused primarily by the lack of C-F bonds which links with persistence).[100] Due to the inherent lack of persistence of most F3, disposal and remediation options are simpler and much more cost-effective and include such options as on-site biodegradation in effluent holding ponds, treatment in local wastewater treatment plants or irrigation to open ground to biodegrade.[101] The important aspects of disposal options (in order to prevent aquatic biota damage from BOD and COD) are ensuring selected remediation methods are not close to an enclosed waterway (such as a shallow stream, waterhole or dry-season stream).[102]

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[98] Hoverman, Jason, 29.
[99] Hassan et al., "Assessment of Non-Fluorinated Firefighting Foams...," 44.
[100] Klein, R.A., "Fluorine-Free Firefighting Foams (3F) – Viable Alternatives...," 30.
[101] *Ibid*., 37.
[102] *Ibid*., 37.

FLUORINE FREE FOAMS					
Company	Brand	Mixture-Acute Low %	Mixture-Acute High %	Mixture-Chronic Low %	Mixture-Chronic High %
E	E2	Acute 3	Acute 1	NCT	Chronic 2
	E3	Acute 3	Acute 2	NCT	Chronic 2
	E1	Acute 3	Acute 2	NCT	Chronic 2
B	B1	Acute 3	Acute 2	NCT	Chronic 3
	B2	Acute 3	Acute 2	NCT	Chronic 3
D	D1	Acute 3	Acute 2	NCT	Chronic 3
C	C1	Acute 3	Acute 3	NCT	NCT
F	F1 and F2	NAT	Acute 3	NCT	NCT
A	A1	NAT	Acute 3	NCT	NCT
	A2	NAT	NAT	NCT	NCT
C	C2	NAT	NAT	NCT	NCT

Figure 22: Hazard category ranking of fluorine-free and fluorinated foams (NAT = No acute toxicity, NCT = No chronic toxicity)

Source: Hassan. R. et al., *Assessment of non-fluorinated firefighting foams: foam performance and ecotoxicity*, 59.

9. When it comes to human health hazards of F3, this is an area identified for further research. For example, in the study cited in Figure 22, above, 7 of the 12 products selected (B1, B2, C1, D1, E1, E2 and E3) had Log Kow (Octanol/Water coefficients) values > 4, indicating a potential to bioaccumulate.[103] Unfortunately, this study and the others referenced for this paper have not evaluated human health hazards of F3s in detail;[104] however, it is recognized that chemically stable, environmentally persistent substances (such as PFAS), are more likely to be chronically toxic than those that do not exhibit these characteristics.[105] The National Resource Council of Canada, in doing a detailed assessment of non-fluorinated firefighting foams in 2020, concluded that "While fluorine-free foams may have a higher impact on aquatic life, the persistence of fluorinated foams results in a greater impact on human life due to long-term toxicant migration into water and food sources."[106] Overall, what is important when selecting an F3, is to not only select based on performance parameters but also consider acute and chronic toxicity, as well as human health hazards associated with bioaccumulation.

10. In addition to F3, Klein et al. have described other potential alternatives, that are briefly mentioned below, but will not be assessed in detail, due to their either fluorine-based composition (with similar issues to PFAS AFFF with their degradation end products or intermediaries) or relatively inferior performance to F3:[107]

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[103] Hassan et al., "Assessment of Non-Fluorinated Firefighting Foams...," 62.
[104] *Ibid*., 63.
[105] Klein, R.A., "Fluorine-Free Firefighting Foams (3F) – Viable Alternatives...," 31.
[106] Hassan et al., "Assessment of Non-Fluorinated Firefighting Foams...," 27.
[107] Klein, R.A., "Fluorine-Free Firefighting Foams (3F) – Viable Alternatives...," 19.

a. Film-forming fluoroprotein foam concentrates (FFFP) with added fluorinated surfactants and the ability to form an aqueous film on the surface of some hydrocarbon fuels.

b. Fluoroprotein foam concentrates (FP) with added fluorinated surfactants.

c. Protein foam concentrates (P) are derived from hydrolyzed protein materials. Historically, protein foams have had sufficient burn-back resistance, but slow fire knockdown, due to reduced flow and spreading capabilities.[108]

d. Synthetic foam concentrates (S) are based upon mixtures of hydrocarbon surfactants other than a fluorinated surfactant or hydrolyzed protein.

[108] Nelson, Dr. Herb, "AFFF Alternatives...," 21.

ANNEX C

SUMMARY OF PFAS ACTION ACT 2019

H.R.535 - PFAS Action Act of 2019[109]

Sponsor: Rep. Dingell, Debbie [D-MI-12] (Introduced 01/14/2019)
Committees: House - Energy and Commerce; Transportation and Infrastructure | Senate - Environment and Public Works
Committee Meetings: 05/15/19 10:30 AM
Committee Reports: H. Rept. 116-364
Committee Prints: H.Prt. 116-45
Latest Action: Senate - 01/13/2020 Received in the Senate and Read twice and referred to the Committee on Environment and Public Works. (All Actions)
Roll Call Votes: There have been 5 roll call votes

This bill revises several environmental laws and requires the Environmental Protection Agency (EPA) to regulate perfluoroalkyl and polyfluoroalkyl substances, commonly referred to as PFAS. These substances are man-made and may have adverse human health effects. A variety of products contain the compounds, such as nonstick cookware or weatherproof clothing.

(Sec. 2) The bill designates certain PFAS as hazardous substances, thereby requiring remediation of releases of those PFAS into the environment. Within five years, the EPA must determine whether the remaining PFAS should be designated as hazardous substances, individually or in groups.

The bill exempts public agencies or private owners of public airports that receive federal funding from liability for remediation of certain releases of PFAS into the environment resulting from the use of aqueous film-forming foam.

(Sec. 3) The EPA must require that comprehensive toxicity testing be conducted on all PFAS. These rules shall require the development of information by any person who manufactures, processes, or intends to manufacture or process PFAS. The bill also provides guidelines for the development of these rules, including the methodologies and protocols to be used.

The bill revises when any PFAS may be exempt from testing or information submission and requires the EPA to publish a list of all exempt PFAS.

(Sec. 4) Currently, unless requirements for an exemption are met, persons planning to manufacture a chemical substance not listed on the EPA's inventory list or manufacture or process a chemical substance for a significant new use must comply with certain notification requirements. The bill prohibits PFAS from being exempted from these requirements.

[109] Dingell, "All Info - H.R.535 - 116th Congress (2019-2020)."

For five years, the EPA shall prohibit the manufacture, processing, and distribution of PFAS not listed on the EPA's inventory list or the manufacture or processing of PFAS for a significant new use.

(Sec. 5) The bill requires the EPA to promulgate a national primary drinking water regulation for certain PFAS.

The EPA must publish a health advisory for PFAS not subject to a national primary drinking water regulation.

(Sec. 6) The bill prohibits the EPA from imposing financial penalties for the first five years for a violation of a national primary drinking water regulation with respect to PFAS.

(Sec. 7) The EPA must establish a grant program to assist community water systems with the costs associated with treating water contaminated by PFAS.

(Sec. 8) In relation to the regulation of toxic air pollutants, the EPA must (1) issue a final rule adding certain PFAS to the list of hazardous air pollutants, and (2) revise the list of air pollution sources within 365 days after issuing the rule to include categories and subcategories of major sources and area sources of PFAS. Within five years, the EPA must determine whether to issue a final rule adding the remaining PFAS to the list of hazardous air pollutants.

(Sec. 9) The EPA must regulate the disposal procedures for materials containing PFAS or aqueous film-forming foam. For criminal penalty purposes, materials containing PFAS shall be considered hazardous waste.

(Sec. 10) The bill requires the EPA to (1) revise the Safer Choice Standard of the Safer Choice Program to identify the requirements that specified products (e.g., cooking utensils) must meet in order to be labeled with a Safer Choice label, including a requirement that any such product does not contain PFAS; or (2) establish a voluntary label available for use by any manufacturer of any specified product that the EPA has reviewed and found does not contain any PFAS. The Safer Choice Program helps consumers and businesses find products with safer chemical ingredients through Safer Choice labels.

(Sec. 11) The EPA must issue guidance on minimizing the use by first responders of firefighting foam and other related equipment containing any PFAS, without jeopardizing firefighting efforts.

(Sec. 12) The EPA must investigate methods to prevent contamination by specified PFAS of surface waters, including those used for drinking water.

(Sec. 13) The bill requires an owner or operator of an industrial source that introduces PFAS into treatment works (systems that treat municipal sewage or industrial wastes) to provide specified notices to such treatment works, including the identity and quantity of such PFAS.

(Sec. 14) The EPA must establish a website containing specified information relating to the testing of household well water, including a list of certified laboratories that analyze samples.

(Sec. 15) The EPA must develop a risk-communication strategy to inform the public about the hazards of PFAS.

(Sec. 16) The bill authorizes the drinking water state revolving fund program to provide assistance to the Virgin Islands, the Commonwealth of the Northern Mariana Islands, American Samoa, and Guam to address emerging contaminants, with a focus on PFAS.

(Sec. 17) Finally, based on results of biennial reviews related to the discharge of PFAS from point sources that are not publicly owned treatment works, the EPA shall, for certain measureable PFAS, add the PFAS to the list of toxic pollutants, or establish effluent limitations and pretreatment standards.

Within two years of the enactment of this bill, the EPA must publish human health water quality criteria for certain PFAS.

The EPA shall award grants to owners and operators of publicly owned treatment works to help implement the pretreatment standards for PFAS developed by the EPA.

MIL-PRF-24385 – CHEMICAL, PHYSICAL AND PERFORMANCE REQUIREMENTS

TABLE I. *Chemical and physical requirements for concentrates or solutions.*

Requirement	Values		Applicable publication	Test paragraph
	Type 3	Type 6		
Refractive index, minimum	1.3630	1.3580	–	4.7.1
Viscosity, centistokes			ASTM D445-74	4.7.2
Maximum at 5 °C	20	10		
Minimum at 25 °C	2	2		
Hydrogen ion concentration (pH)	7.0 to 8.5	7.0 to 8.5	–	4.7.3
Spreading coefficient, minimum	3	3	–	4.7.4
Foamability:				
Foam expansion, minimum	5.0	5.0	NFPA STD 412	4.7.5
Foam 25% drainage time, minutes, minimum	2.5	2.5	NFPA STD 412	4.7.5
Corrosion rate:				
General				
Cold rolled, low carbon steel (UNS G10100), milli in/yr, maximum	1.5	1.5	ASTM E527	4.7.7
Copper-nickel (90-10) (UNS C70600), milli in/yr, maximum	1.0	1.0	ASTM E527	4.7.7
Nickel-copper (70-30) (UNS N04400), milli in/yr, maximum	1.0	1.0	ASTM E527	4.7.7
Bronze (UNS C90500), milligrams, maximum	100	100	ASTM E527	4.7.7
Localized, corrosion-resistant (CRES) steel, (UNS S30400)	No pits	No pits	–	4.7.7
Total halides, p/m, maximum	500	250	ASTM D1821	4.7.8
Dry chemical compatibility, burn-back, resistance time, seconds, minimum	360	360	–	4.7.9
Environmental impact:				
Toxicity, LC_{50}, mg/L, minimum	500	1000	–	4.7.12.1
COD, mg/L, maximum	1000K	500K	–	4.7.12.2
$\frac{BOD_{20}}{COD}$, minimum	.65	.65	–	4.7.12.3

TABLE II. *Fire performance.*

	AFFF solutions, percent		
	1.5% of Type 3 3% of Type 6	3% of Type 3 6% of Type 6	15% of Type 3 30% of Type 6
	(Fresh and sea)	(Fresh and sea)	(Sea)
28 ft^2 fire (see 4.7.13.1):			
Foam application time to extinguish, seconds, maximum	45	30	55
Burnback time of resulting foam cover, seconds, minimum	300	360	200
50 ft^2 fire (see 4.7.13.2):			
Foam application time to extinguish, seconds, maximum		50(Sea only)	
Burnback time of resulting foam cover, seconds, minimum		360	
40-second summation, minimum		320	

ANNEX E

AREAS THAT REQUIRE FURTHER RESEARCH

1. As F3 has only existed half as long PFAS-containing AFFF, and many of the negative aspects of PFAS-containing AFFF have only come to light in the last 20 years (leading to substantial efforts to develop new higher-performance F3 formulations), there are many unknowns associated with F3s. Some of the unknowns that require further research into their potential to become an issue include:

a. What are the interactions between F3 and other extinguishing agents, such as PFAS-containing AFFF, dry chemicals (such as Potassium Bicarbonate)?[110] Are these effects synergistic, neutral or antagonistic?

b. Additionally, on many CAF bases, due to the high costs and limited availability of CFR ARFF vehicles, local arrangements may exist that allow the CAF to support a local community or airport *in extremis*, with firefighting support.[111] In these instances, it is important to ensure that any products that the CAF are using do not have an antagonistic effect with products used by a local community.[112] Research is required into what products these local communities are using, and what the effects are if combined with CAF F3?

c. What are the fate and transport, environmental persistence, toxicity to plants or humans, not only of the primary compounds in F3 but of their many other chemical constituents in formulations?[113]

d. Can modifications be made to F3 mixtures to modify physical parameters and increase performance, such as decreasing viscosity, increasing foam stability, improving saltwater performance and improving flow across the fuel-fire interface?[114]

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[110] Dunning, Maj Rick, interview.
[111] McManus, Jacki, "RE: Draft Outline for PFAS Transition Service Paper," January 19, 2022.
[112] Dunning, Maj Rick, interview.
[113] Nelson, Dr. Herb, "AFFF Alternatives...," 12.
[114] *Ibid*., 12.

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