Secondary Data Review of Decontamination Methods for Aqueous Film-Forming Foam (AFFF) in Firefighting Equipment

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Abstract

State and national policies are driving efforts to phase out aqueous film-forming foam (AFFF) that contains per- and polyfluoroalkyl substances (PFAS). AFFF is used to extinguish flammable liquid fires at airports, military complexes, industrial facilities, and municipal firefighting departments. Washington's law regarding Firefighting Agents and Equipment (Chapter 70A.400 RCW) set tiered restrictions on AFFF manufacture, sale, and use in training. In response, Washington's local fire authorities requested guidance from the Washington State Department of Ecology (Ecology) on the best practices to transition away from AFFF.

Ecology conducted a secondary data review on the best practices for decontaminating firefighting equipment before switching from AFFF to fluorine-free foam (F3). This secondary data review will inform Ecology's guidance to local fire authorities. Only studies with the stated purpose of evaluating the decontamination of firefighting equipment that had contacted AFFF were selected for review. All data reviewed was generated by test methods with established quality requirements. Reviewed findings indicate that cleaning agents work better than rinsing with plain water alone. However, the cleaning agents used did not completely remove all PFAS from firefighting equipment. Methods to completely decontaminate firefighting equipment are still needed to prevent residual PFAS from contaminating F3 replacements.

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Background

Purpose

In 2018, Washington's law regarding Firefighting Agents and Equipment – Toxic Chemical Use (Chapter 70A.400 RCW) set tiered restrictions on the manufacture, sale, and use for training of aqueous film-forming foam (AFFF) that contains per- and polyfluoroalkyl substances (PFAS). A restriction on the sale of AFFF containing PFAS in Washington began on January 1, 2024. Starting June 1, 2025, it will no longer be legal to dispense AFFF containing PFAS at airports in Washington. State and national policies require a transition from AFFF to fluorine-free foam (F3) to extinguish flammable liquid, Class B fires. In response, Washington's local fire authorities requested guidance from Ecology on the best practices to transition from AFFF to F3.

This secondary data review was performed to inform Ecology's guidance to local fire authorities on the best practices to decontaminate their firefighting equipment before switching from AFFF to F3.[1] Ecology's guidance document is meant to assist local fire authorities' individual decision-making and does not set any standards, limitations, or requirements to comply with Washington's law.

This review was performed based on Environmental Protection Agency (EPA) guidance for evaluating the quality of secondary data (EPA 2012), EPA New England's guidance for projects using secondary data (EPA NE 2009), and EPA's Checklist for the Assessment of Existing Information/Secondary Data (Appendix A). Existing secondary data was assessed to review methods for decontaminating AFFF firefighting equipment. The goal of this review was to evaluate studies that meet specific selection criteria for the study design, type of data, and study methods.

Introduction

PFAS have been widely used in AFFF because they are highly effective at extinguishing flammable liquid, Class B fires. They form a vapor-sealing barrier to suffocate flames and suppress ignition. PFAS are strongly amphiphilic, meaning they have both hydrophobic and hydrophilic regions, and tend to self-aggregate into highly stable molecular assemblies at air-liquid and air-solid interfaces (Ramanathan et al. 2013; Lyu et al. 2018). AFFF can create a barrier across the full surface of a flammable liquid, even as it spreads, because of the strong bonds formed in PFAS assemblies.

[1] The use of data for informing guidance that does not set standards, limitations, or requirements did not require a quality assurance project plan.

The amphiphilic nature of PFAS also leads to residual layers of PFAS building up at the liquid-solid interface inside firefighting equipment (Ross and Storch 2020; Horst et al. 2021). PFAS layers form inside firefighting equipment and can be seen in scanning electron images (Lang et al. 2022). These highly resistant surface-associated PFAS are difficult to remove and require special considerations and innovative cleaning methods.

Research into decontamination of firefighting equipment has accelerated in the past several years, initially abroad and now in the U.S., with considerable lessons learned. To effectively switch to F3 without cross-contamination with residual PFAS, careful cleaning and testing of firefighting equipment must take place. If only plain water rinsing is used to clean firefighting equipment, residual PFAS will contaminate replacement F3 (Ross and Storch 2020; Horst et al. 2021; Lang et al. 2022).

Methods

Criteria for Secondary Data

Selected studies must have been performed for the stated purpose of evaluating the decontamination of firefighting equipment that had contacted AFFF. To qualify for review, secondary data must have been generated through reference PFAS analytical methods published by EPA (Table 1). The laboratory performing the PFAS analysis must have met quality assurance requirements for the test method through a federal or state-recognized environmental laboratory certification or accreditation body. At a minimum, secondary data must have a documented quality assurance (QA) summary indicating whether data quality objectives were met. The QA summary will be assessed for details on method blanks, laboratory control samples, matrix spike and matrix spike duplicates, extracted internal standards, and associated recovery limits.

Table 1. Analytical methods for per- and polyfluoroalkyl substances (PFAS) with established quality assurance criteria recommended by the Environmental Protection Agency (EPA).

Parameter	Method
PFAS (18 compounds)	EPA 537: Determination of Selected PFAS in Drinking Water by SPE and LC/MS/MS
PFAS (25 compounds)	EPA 533: Determination of PFAS in Drinking Water by Isotope Dilution Anion Exchange SPE and LC/MS/MS
PFAS (24 compounds)	EPA 8327: PFAS Using External Standard Calibration and MRM LC/MS/MS
PFAS (40 compounds)	Draft EPA 1633: Analysis of PFAS in Aqueous, Solid, Biosolids, and Tissue Samples by LC/MS/MS

SPE: Solid Phase Extraction
LC/MS/MS: Liquid Chromatography Tandem Mass Spectrometry
MRM: Multiple Reaction Monitoring

Data selected for review may have been validated following EPA or Department of Defense (DoD) guidelines. Guidelines may include Data Review and Validation Guidelines for PFAS Analyzed Using EPA Method 537 (EPA 2018), PFAS: Reviewing Analytical Methods Data for Environmental Samples Technical Brief (EPA 2019), or Module 3: Data Validation Procedure for PFAS Analysis by Quality Systems Manual Table B-15 (DoD 2020).

Selection of Secondary Data

In 2020, DoD's Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) began funding studies to demonstrate and validate methods to clean firefighting equipment used with AFFF. Below are the four studies that were selected for review:

- Clean or Replace? Decontamination Framework for Firefighting Equipment and Hangers and Disposal of PFAS-Impacted Waste. Study ER20-5361. Principal Investigator: U.S. Environmental Protection Agency.
- Remediation of AFFF-Impacted Fire Suppression Systems Using Conventional and Closed-Circuit Desalination Nanofiltration. Study ER20-5369. Principal Investigator: Colorado School of Mines.
- Demonstration and Validation of Environmentally Sustainable Methods to Effectively Remove PFAS from Fire Suppression Systems. Study ER20-5364. Principal Investigator: Arcadis. Publication by Lang et al. (2022).
- Sustainable Firefighting System Cleanout and Rinsate Treatment using PerfluorAd. Study ER20-5370. Principal Investigator: CDM Smith.

In 2021, Connecticut's (CT) Department of Energy & Environmental Protection (DEEP) funded pilot studies to demonstrate and validate methods to clean firefighting equipment used with AFFF. Both AFFF decontamination demonstration studies were selected for review:

- AFFF Decontamination Demonstration Project using PerfluorAd (AECOM 2022). Principal Investigator: AECOM and TRS.
- AFFF Decontamination Demonstration Project using FluoroFighter (Arcadis 2022). Principal Investigator: Arcadis.

In 2023, a case study was published on methods to flush home plumbing pipes contaminated with AFFF (Szabo et al. 2023). Home plumbing materials assessed included copper, polyvinyl chloride (PVC), and cross-linked polyethylene (PEX). The study did not include stainless steel, the main component of firefighting equipment, and therefore did not qualify for review.

Results

Data review checklists for studies with published reports are presented in Appendix A (Tables A-1 – A-3). While none of the studies demonstrate full decontamination of firefighting equipment, they indicate that cleaning agents are more effective than plain water rinsing. One study's results indicate that successive treatments with PerfluorAd decreased the release of PFAS from five firefighting vehicles by 99.6 to 99.9% from the first rinse to the final rinse (Table A-1). One study's results evaluating FluoroFighter indicate that the cleaning agent decreased the release of PFAS from a firefighting vehicle system by 98.9% from the first rinse to the final rinse (Table A-2). A laboratory study of pipe samples indicated that the FluoroFighter cleaning agent removed nearly twice as much total PFAS than soaking with water alone (Table A-3). Since PFAS are valued for water resistance, it makes sense that cleaning agents would be more effective than plain water rinsing at removing residual PFAS from firefighting equipment.

The following studies have anticipated completion dates in 2024 and do not have published reports of decontamination findings at the time of this review:

- Clean or Replace? Decontamination Framework for Firefighting Equipment and Hangers and Disposal of PFAS-Impacted Waste. Study ER20-5361. Principal Investigator: U.S. Environmental Protection Agency.
- Remediation of AFFF-Impacted Fire Suppression Systems Using Conventional and Closed-Circuit Desalination Nanofiltration. Study ER20-5369. Principal Investigator: Colorado School of Mines.
- Sustainable Firefighting System Cleanout and Rinsate Treatment using PerfluorAd. Study ER20-5370. Principal Investigator: CDM Smith.

Conclusions

- Studies show that specially designed PFAS cleaning agents are more effective than plain water rinsing at reducing residual PFAS levels released from firefighting equipment that had previously contained AFFF.
- Studies have yet to publish any decontamination methods that can fully remove residual PFAS from interior surfaces of firefighting equipment that had contained AFFF.
- Studies have yet to show that any decontamination methods are effective at preventing residual PFAS from contaminating replacement F3.
- Levels of "cleanliness" cannot be determined because no standardized sampling or test method is available to evaluate residual PFAS on interior surfaces of firefighting equipment.

Recommendations

Based on the data review findings, Ecology guidance should recommend using cleaning agents to clean AFFF firefighting equipment before switching to F3. PerfluorAd or FluoroFighter are two commercially available examples of cleaning agents that have shown some success when used in a double or triple application cycle. Both cleaning agents are glycol-based. Ecology does not endorse or sponsor any specific commercial product or service.

References

AECOM. 2022. AFFF Fire Truck and Foam Unit Decontamination Summary Report. Prepared for and published by Connecticut Department of Energy and Environmental Protection. https://portal.ct.gov/DEEP/Remediation--Site-Clean-Up/Contaminants-of-Emerging-Concern/PFAS-in-Class-B-Firefighting-Foam#trailerpilot

Arcadis. 2022. Trailer Demonstration Project Summary Report. Prepared for and published by Connecticut Department of Energy and Environmental Protection. https://portal.ct.gov/DEEP/Remediation--Site-Clean-Up/Contaminants-of-Emerging-Concern/PFAS-in-Class-B-Firefighting-Foam#trailerpilot

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Szabo, J., S. Witt, N. Jojda, D. Schupp, M. Magnuson. 2023. Flushing Home Plumbing Pipes Contaminated with Aqueous Film-Forming Foam Containing Per- and Polyfluoroalkyl Substances. Journal of Environmental Engineering 149(9): 05023007
https://ascelibrary.org/doi/abs/10.1061/JOEEDU.EEENG-7315

Appendix A. Secondary Data Review Checklists

Table A-1. Secondary data review checklist for the AFFF Decontamination Demonstration Project using PerfluorAd.

Criteria	Study Information
Principal Investigator	AECOM and TRS
Source/Author	Report written by AECOM for Connecticut Department of Energy and Environmental Protection (CT DEEP) & Department of Emergency Services and Public Protection (DESPP) (AECOM 2022)
Contractor	AECOM Technical Services Inc., Rocky Hill, CT
Publication Info	State of Connecticut official website
Publisher	State of Connecticut DEEP
Date Published	May 2022
Publication Location	Publicly available at portal.ct.gov
Report Format	Adobe .pdf version of the report of contracted work to State entity
Data Format	Full laboratory report from Eurofins Lancaster Laboratories
Established Quality Assurance Plan	Standard operating procedure for sample collection and testing submitted to and approved by CT DEEP.
Source of Data	Eurofins Lancaster Laboratories Environmental (DoD ELAP certified for PFAS analyses of aqueous samples by method EPA 537)
Quality Assurance Summary Report	Method blanks, Laboratory Control Samples, Matrix Spike and Duplicate, Extracted Internal Standards, Continuing Calibration Verification
Test Method Information	Method EPA 537 Modified to include isotope dilution compliant with DoD QSM 5.3 Table B-15. Samples were assessed before and after total oxidizable precursor (TOP) assay. Data generated after TOP assay did not meet the selection criteria of this review.
Design Information & Data Integrity	Study performed on 2 AFFF trailers and 3 firefighting trucks containing 1%–3% AFFF. Application of PerfluorAd was performed differently among the trailers and trucks. Samples of rinsate were collected after each of three to five successive PerfluorAd applications. No samples were collected from the interior surface of the firefighting equipment. No samples of refilled replacement F3 were collected to assess residual PFAS that may contaminate future F3 applications.
Decontamination Extent & Limitations	Results from rinsate samples indicate that successive treatments with PerfluorAd decreased the release of PFAS from the system. Compared to the first rinse, PFAS concentrations were 99.6 to 99.9% less in the final rinse for the five vehicles. The total PFAS concentrations in the first rinse ranged from 545,360 ppt to 15,407,000 ppt compared to the last rinse, from 581 ppt to 3,481 ppt for the five vehicles. It is unknown whether application of PerfluorAd fully decontaminated all PFAS present in the system.

Table A-2. Secondary data review checklist for the AFFF Decontamination Demonstration Project using FluoroFighter.

Criteria	Study Information
Principal Investigator	Arcadis
Source/Author	Report published by Arcadis on behalf of Connecticut Department of Energy and Environmental Protection (CT DEEP) & Department of Emergency Services and Public Protection (DESPP) (Arcadis 2022)
Contractor	Arcadis U.S. Inc., Highlands Ranch, CO
Publication Info	Trailer Demonstration Project Summary Report, Winsted Trailer
Publisher	State of Connecticut DEEP
Date Published	August 2022
Publication Location	Publicly available at portal.ct.gov
Report Format	Adobe .pdf version of the report of contracted work to State entity
Data Format	Full laboratory report from Eurofins Lancaster Laboratories
Established Quality Assurance Plan	Standard operating procedure for sample collection and testing submitted to and approved by CT DEEP.
Source of Data	Eurofins Lancaster Laboratories Environmental (DoD ELAP certified for PFAS analyses of aqueous samples by method EPA 537)
Quality Assurance Summary Report	Method blanks, Laboratory Control Samples, Matrix Spike and Duplicate, Extracted Internal Standards, Continuing Calibration Verification
Test Method Information	Method EPA 537 Modified to include isotope dilution compliant with DoD QSM 5.3 Table B-15. Samples were assessed before and after total oxidizable precursor (TOP) assay. Data generated after TOP assay did not meet the selection criteria of this review.
Design Information & Data Integrity	Study representative of 1 firefighting truck containing 1-3% AFFF. Samples of rinsate were collected in alternate steps starting with water rinsing and then FluoroFighter application. No samples were collected from the interior surface of the firefighting equipment. No samples of refilled replacement F3 were collected to assess residual PFAS that may contaminate future F3 applications.
Decontamination Extent & Limitations	Results from rinsate samples indicate that successive treatments with FluoroFighter decreased the release of PFAS from the system. Compared to the first rinse, PFAS concentrations were 98.9% less in the final rinse (7,606,700 ppt compared to 1,443 ppt total PFAS). A comparison of the alternating water and FluoroFighter rinsing indicates that FluoroFighter removed up to 5 times more PFAS than water (748,640 ppt compared to 127,649 ppt total PFAS) in the first application. It is unknown whether application of FluoroFighter fully decontaminated all PFAS present in the system.

Table A-3. Secondary data review checklist for the Demonstration and Validation of Environmentally Sustainable Methods to Effectively Remove PFAS from Fire Suppression Systems.

Criteria	Study Information
Principal Investigator	Arcadis
Source/Author	Arcadis (US, UK, AUS locations), Johnsie Lang, Jeffrey McDonough, TC Guillette, Peter Storch, John Anderson, David Liles, Robert Prigge, Jonathan Miles, Craig Devine (Lang et al. 2022)
Contractor	None
Publication Info	Journal article published in Chemosphere vol. 308 part 2, 136254
Publisher	Elsevier
Date Published	December 2022
Publication Location	Publicly available via Elsevier at sciencedirect.com
Report Format	Adobe .pdf version of the journal article
Data Format	Not provided
Established Quality Assurance Plan	Unknown
Source of Data	PFAS analysis by ALS Environmental (New South Wales, Australia), McGill University (Quebec, Canada), Eurofins Test America (Sacramento, CA), and Pace Analytical (Baton Rouge, LA) using LC-MS/MS. ALS Environmental Australia, Eurofins Test America, Pace Analytical are DoD ELAP certified for PFAS analyses of aqueous samples.
Quality Assurance Summary Report	Field blanks
Test Method Information	Method EPA 537 Modified to include isotope dilution compliant with DoD QSM 5.3 Table B-15. Samples were assessed before and after total oxidizable precursor (TOP) assay. Data generated after TOP assay did not meet the selection criteria of this review.
Design Information & Data Integrity	Study performed on fire suppression system pipe that held AFFF. Cut pipe sections were submerged in FluoroFighter, methanol, and water, with and without sonication. Samples of treatment rinse were collected, but no samples were collected from the interior surface of the firefighting piping. No samples of pipe contacting replacement F3 were assessed for residual PFAS that may contaminate future F3 applications.
Decontamination Extent & Limitations	A documented quality assurance summary or a lab data packet was not provided, so data quality is unknown. Results from five treatment rinse samples indicate that FluoroFighter removed almost double the PFAS than water on average (1,023,000 ppt compared to 522,000 ppt total PFAS). It is unknown whether application of FluoroFighter fully decontaminated all PFAS present in the pipe sections.