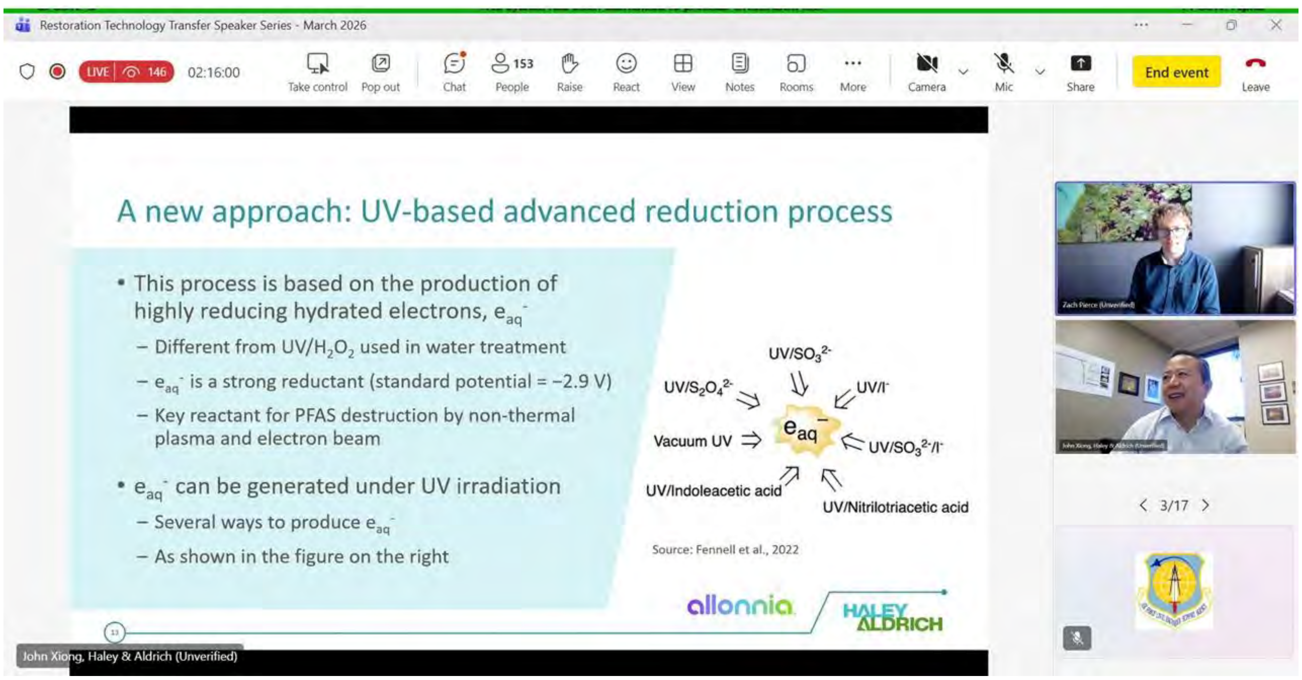
Field Demonstration of an Innovative Closed-Loop Treatment Train for Per- and Polyfluoroalkyl Substances (PFAS) in Groundwater

Presenters: Dr. John Xiong (Haley & Aldrich) & Zach Pierce (Allonnia)

This webinar presented results from an innovative treatment train for PFAS remediation in groundwater. The treatment train includes two main steps, 1) surface active foam fractionation (SAFF) for PFAS removal and concentration and 2) an ultraviolet (UV)/sulfite-based EradiFluor for PFAS destruction. PFAS in the feedwater were removed through SAFF processes, where PFAS were concentrated into a small volume of foamate waste. The generated SAFF foamate, which is highly enriched in PFAS but with reduced volume, were subsequently destroyed using EradiFluor. The effluent from the PFAS destruction treatment was be sent back to the influent of the overall process to achieve “closed-loop” treatment, eliminating the need for offsite waste disposal. Field results showed that 1) PFAS in groundwater were effective removed by the SAFF; 2) Near-complete destruction of PFAS (including long-, short-, and ultrashort-chain) was achieved with EradiFluor based on target PFAS analysis, fluorine mass balance, and total organic fluorine analysis; 3) “closed-loop” PFAS treatment was achieved using the treatment train; 4) the system operates under ambient pressure and near-room temperature and therefore requires low energy; and 5) the system performs reliably with high operation uptime.



Dr. John Xiong and Zach Pierce discuss the new approach to PFAS destruction using UV reduction.

This event and future events are updated and posted on the AFIT website at: https://www.afit.edu/CE/index.cfm.

POCs:
Joseph Dimisa, AFIT (joseph.dimisa@us.af.mil)
C.J. Garcia, CTR, Booz Allen Hamilton (carlos.garcia.56.ctr@us.af.mil)
Kurt Lee, AFCEC/CZPR (kurt.lee.3@us.af.mil)

Webinar Structure

	[Restoration Technology Transfer Webinar Series – eDASH Archive]()
5 min	Welcome and Administrative Business
30 min	*Field Demonstration of Closed-Loop PFAS Treatment in Groundwater Using an Innovative Treatment Train;* Haley & Aldrich and Allonnia
10-15 min	Questions and Answers
5 min	Final Thoughts

Field Demonstration of Closed-Loop PFAS Treatment in Groundwater Using an Innovative Treatment Train

John Xiong, Ph.D., P.E., Haley & Aldrich
Zach Pierce, P.E., Allonnia

March 2026

Outline

1 Introduction

2 PFAS removal using SAFF

3 PFAS destruction by EradiFluor

4 Field demonstration

5 Q/A

PFAS removal using SAFF

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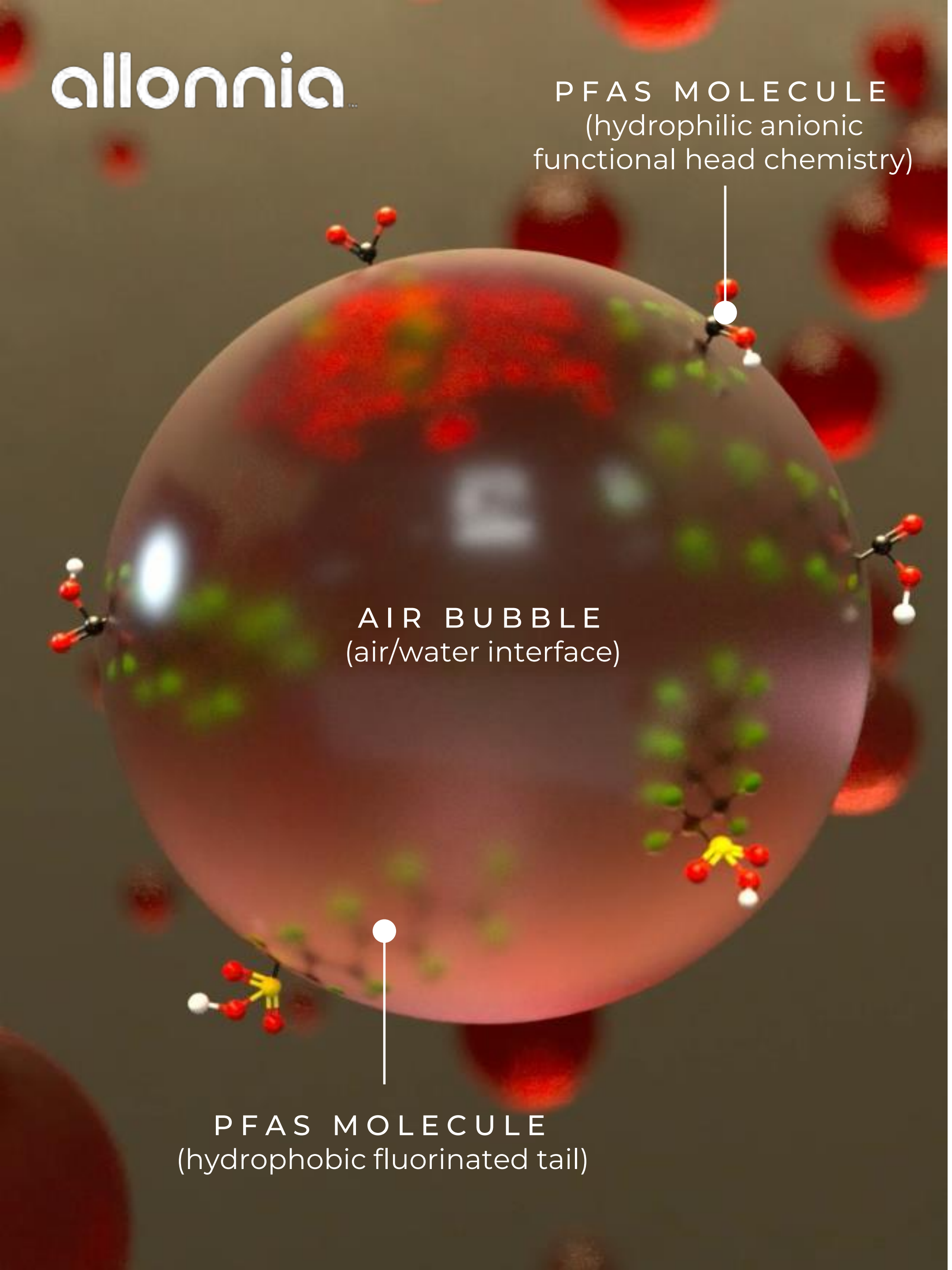


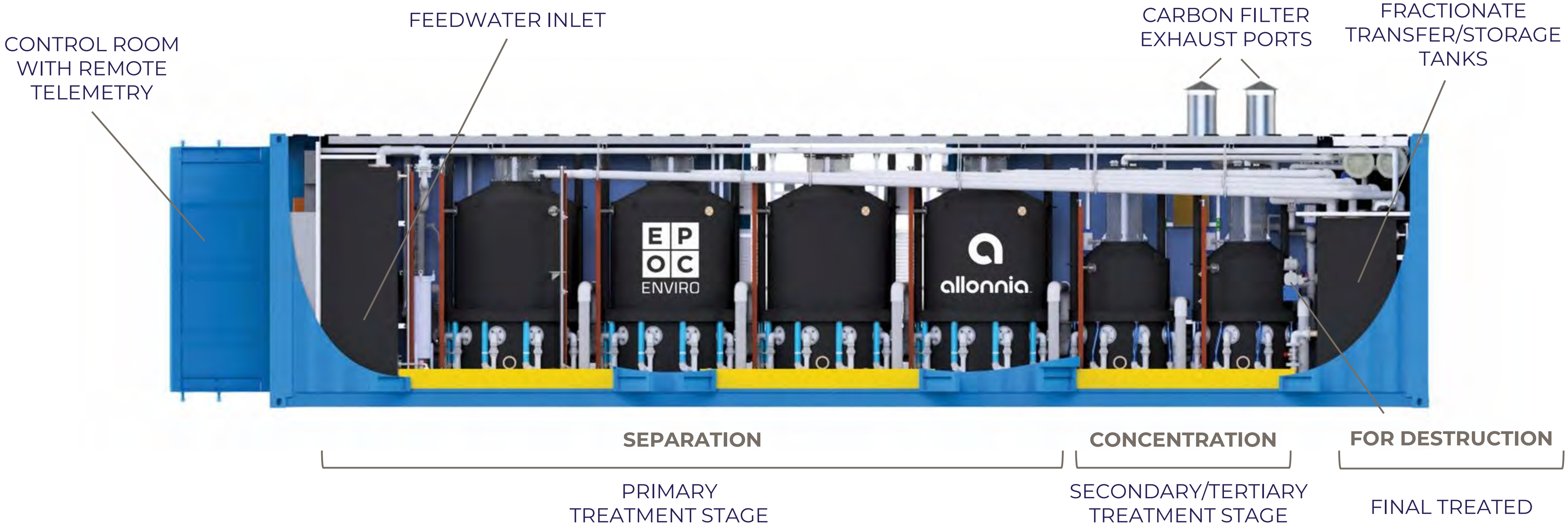
SAFF Separation Mechanism

Rising air bubbles separate PFAS to surface

- Hydrophilic head: orients in water
- Hydrophobic tail: orients in air-bubble

The SAFF40®

Containerized solution with high flow-through capabilities



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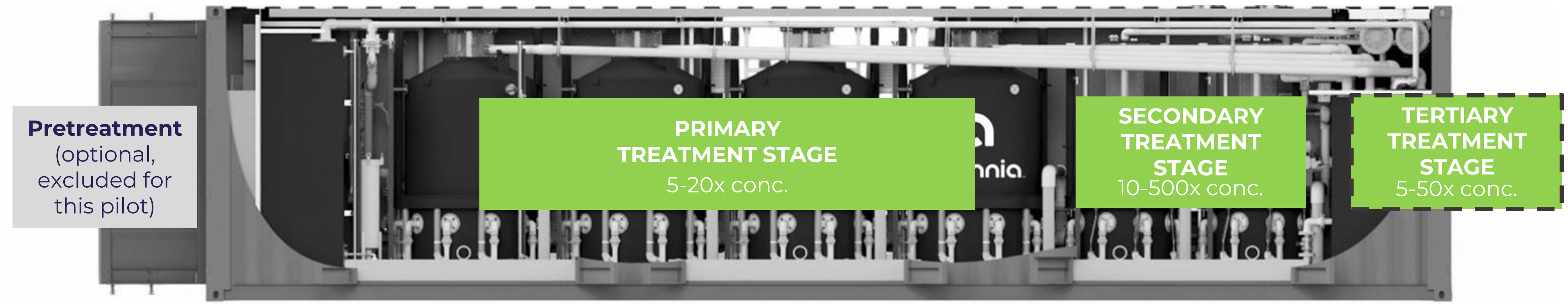
SAFF® Performance
Concentration Before Destruction

Volume of water treated by SAFF: 214,508 gal

Concentrated PFAS solution after SAFF sent for destruction: 162 gal



SEPARATION

CONCENTRATION

For this pilot demonstration, the SAFF40 system generated 1 gallon of wastewater for destruction for every 1,324 gallons treated.

Depending on treatment characteristics and foaming additive use, waste volumes could be lower. For example, the SAFF40 has concentrated influent volume by over 9,000x-54,000x for other groundwater projects using different foaming additives.

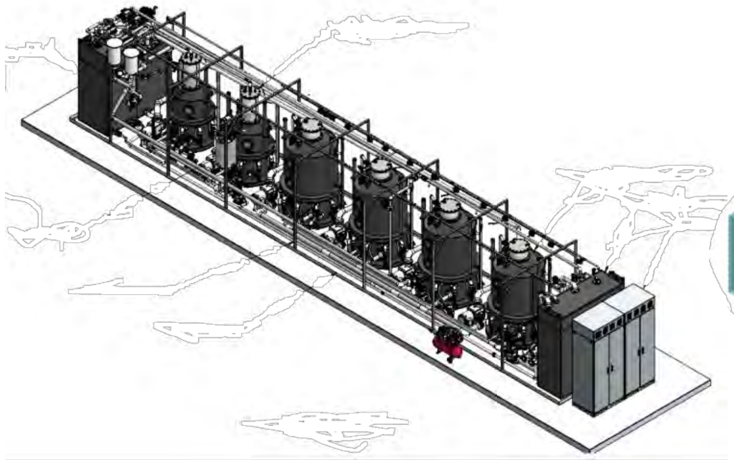
SAFF® Deployment

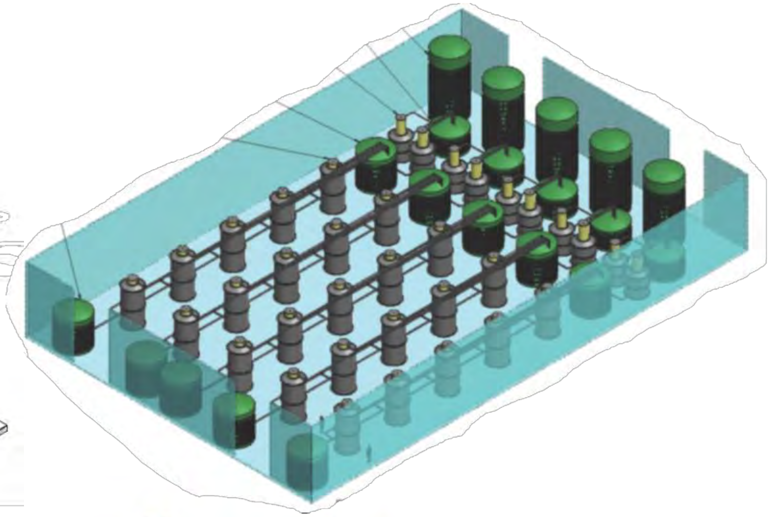
45+ SAFF® units globally including 27 in the USA.

Multiple configurations available.

Continuous improvement & innovation.

Boston Based Laboratory, Deployable Field Team.





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PFAS destruction by EradiFluor

Existing separation technologies leave behind concentrated waste

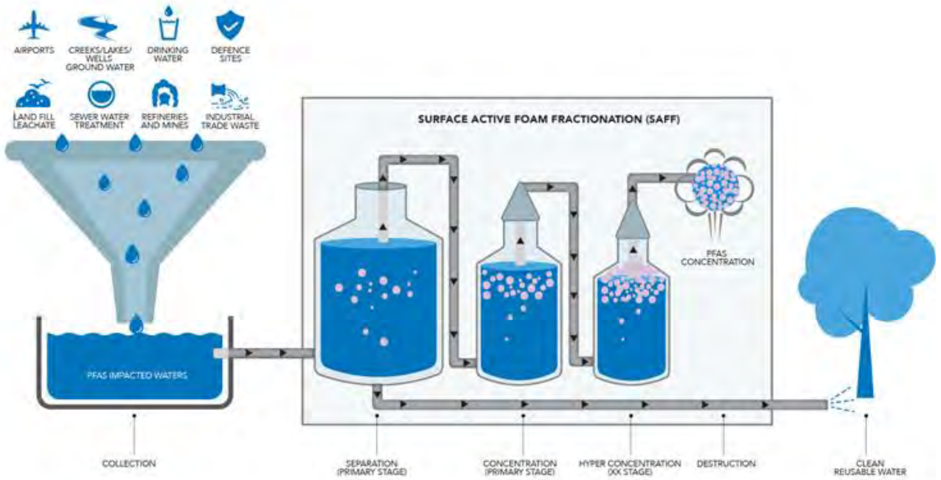
Conventional technology

Granular activated carbon

Membrane filtration

Ion exchange resin

Recent developments



OPEC

Foam fractionation

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There are few options for disposal of PFAS waste

Source: EPA, 2024. Interim guidance on the destruction and disposal of perfluoroalkyl and polyfluoroalkyl substances and materials containing perfluoroalkyl and polyfluoroalkyl substances – Version 2 (2024).

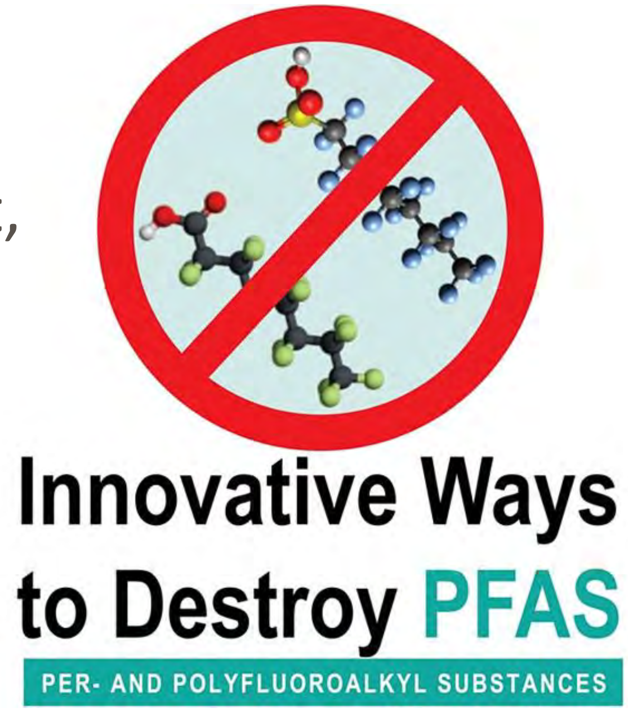
Incineration

Landfill

Deep well injection

There is a growing need for PFAS destructive technologies

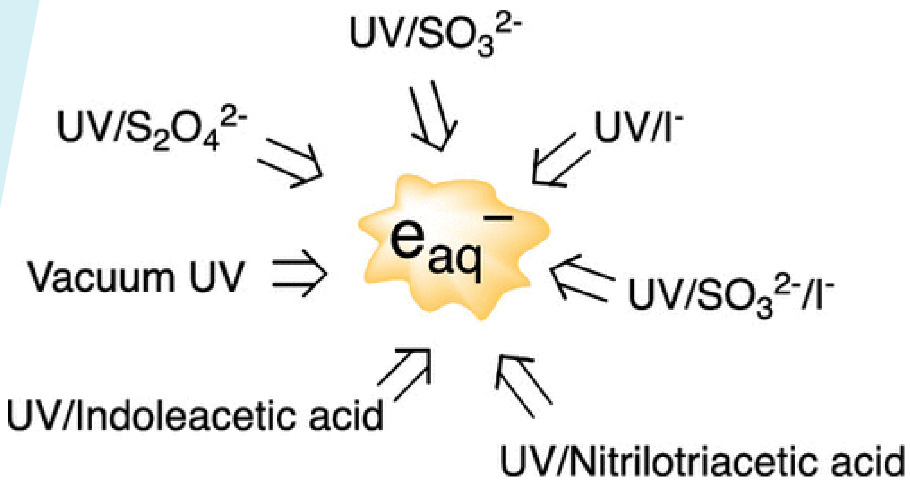
- Regulations on PFAS are evolving
- Several destructive technologies are under development, and some have moved to commercial application:
  - Supercritical water oxidation
  - Hydrothermal alkaline treatment
  - Electrochemical oxidation
  - Plasma technology
  - Electron beam



EPA launched a technical challenge
for innovative ways to destroy PFAS in 2020

A new approach: UV-based advanced reduction process

- This process is based on the production of highly reducing hydrated electrons, e_{aq}^-
  - Different from UV/H_2O_2 used in water treatment
  - e_{aq}^- is a strong reductant (standard potential = −2.9 V)
  - Key reactant for PFAS destruction by non-thermal plasma and electron beam
- e_{aq}^- can be generated under UV irradiation
  - Several ways to produce e_{aq}^-
  - As shown in the figure on the right

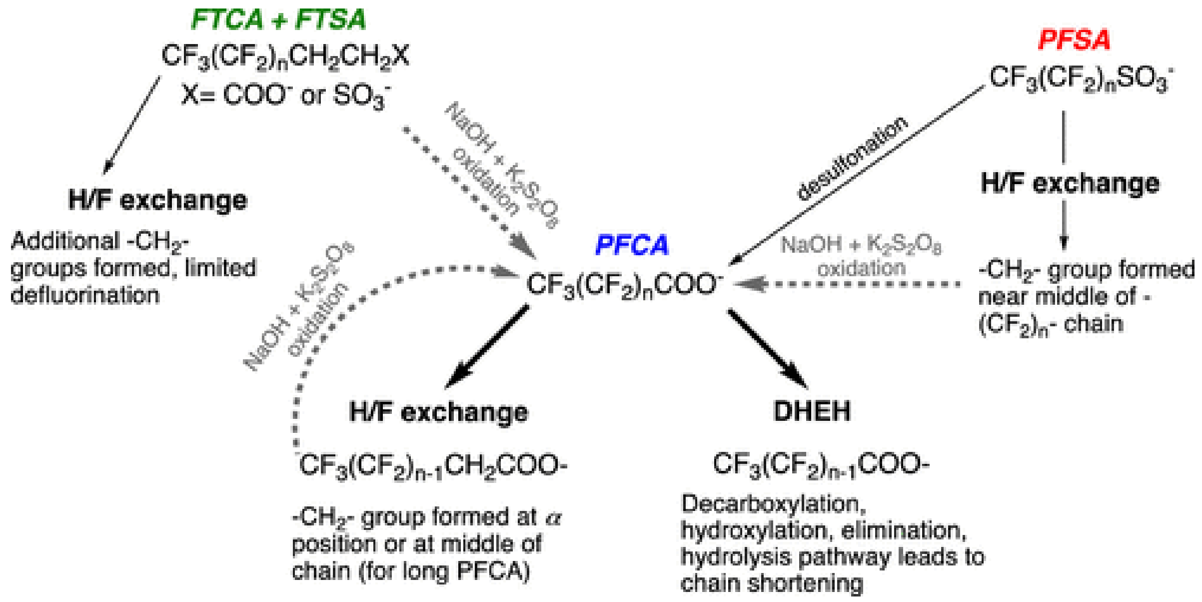


Source: Fennell et al., 2022

Mechanism of PFAS destruction by hydrated electrons

- Two PFAS defluorination pathways are identified:
  - H/F atom exchange
    - $-CF_2-$ group to $-CH_2-$ group
    - Produces polyfluorinated products
  - DHEH
    - Shorten one $-CF_2-$ group each step
    - Deeper defluorination
    - Mostly occur to PFCAs

DHEH = Decarboxylation, hydroxylation, elimination, hydrolysis



Source: Fennell et al., 2022

EradiFluor - PFAS destruction system

- Haley & Aldrich designed and constructed this PFAS treatment system
  - UV/sulfite-based treatment process
  - Mobile, on-site treatment unit
  - Ambient reaction conditions
  - Control/monitoring components
- Concentrated PFAS streams were treated under field conditions

View from the rear of the trailer

Field demonstration of SAFF + EradiFluor for close-loop PFAS removal and destruction

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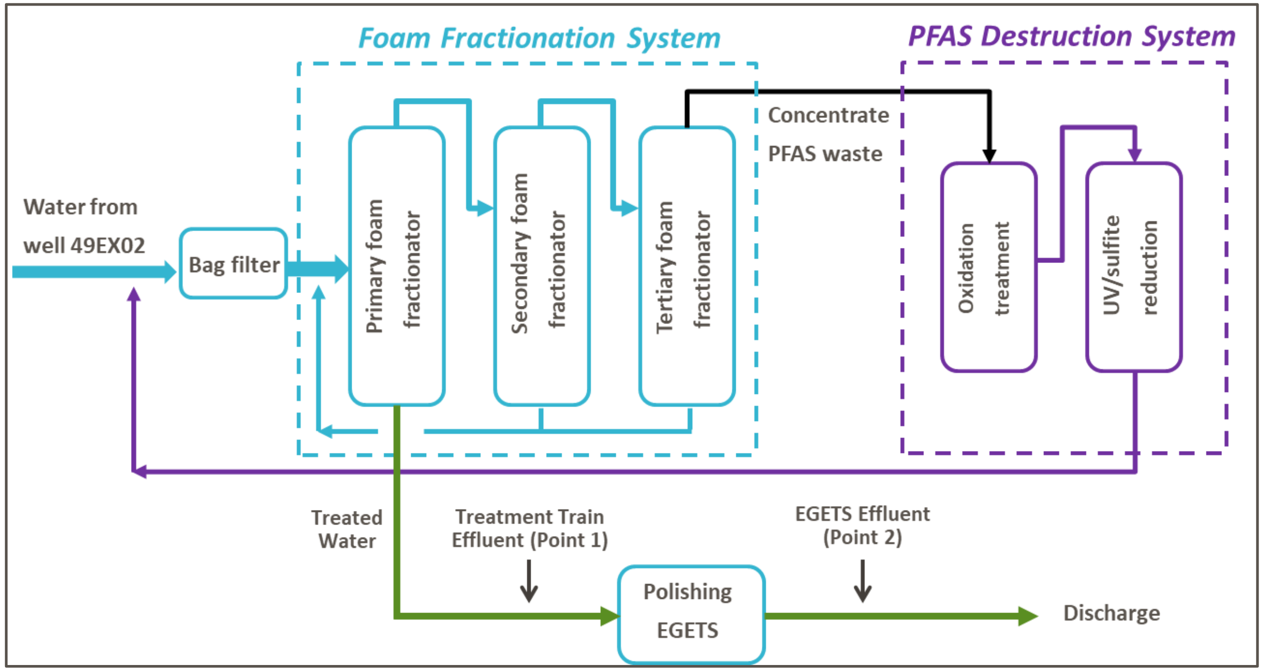
Treatment train demonstration at a SoCal DoW site



An innovative treatment train combining foam fractionation (SAFF) and EradiFluor was demonstrated for PFAS removal and destruction in groundwater at a SoCal DoW site.

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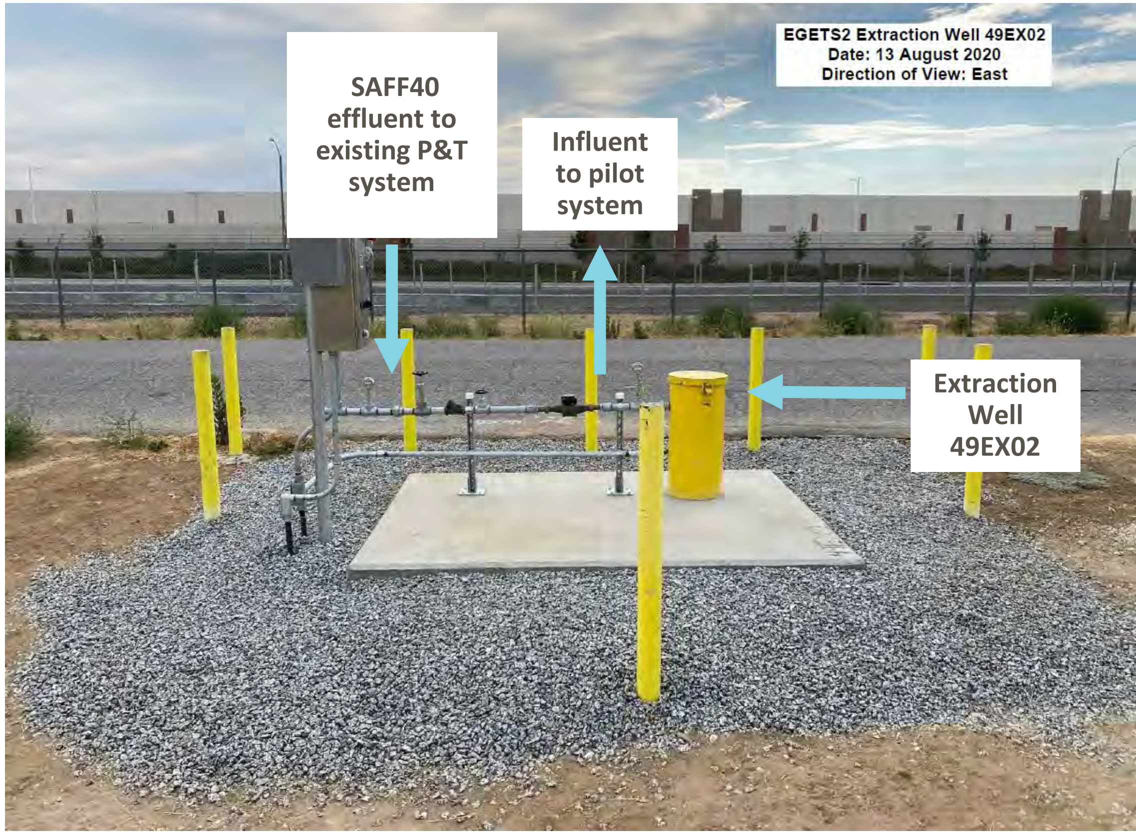
Field demonstration site condition

- Former Air Force Base
  - Groundwater impacted by PFAS
  - Existing pump & treat system
  - Extraction wells by site boundary
- Groundwater data (e.g., PFAS) are favorable for demonstration
  - PFOA + PFOS > 10 ppb
  - VOCs are mostly ND
- Used an existing groundwater extraction well
  - Groundwater was pumped from the well
  - Sent to SAFF40 for treatment
  - Foam fractionate was destroyed by EradiFluor
  - SAFF40 effluent sent back to the existing line
- Concrete pad and electrical connection are available
  - Temporary power drop and transformer installed



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Field operation

- Treatment train operated in March to May 2025
  - Operated at about 8 gpm
  - Total volume treated: 214,508 gallons of groundwater
- Two operating phases for SAFF operation
  - Phase I: Without surfactant booster
  - Phase II: With non-toxic food grade surfactant booster, to enhance foaming and PFAS removal
  - Secondary and tertiary foam fractionation
- Five batches of foam fractionate concentrate were treated by EradiFluor
  - Estimated surfactant booster concentration 1.7 g/L
- Several site tours by
  - DoD representatives
  - Regulators from EPA, DTSC, RWQCB
  - Partners

The SAFF® Foaming Process

PRIMARY, SECONDARY, AND TERTIARY FRACTIONATION

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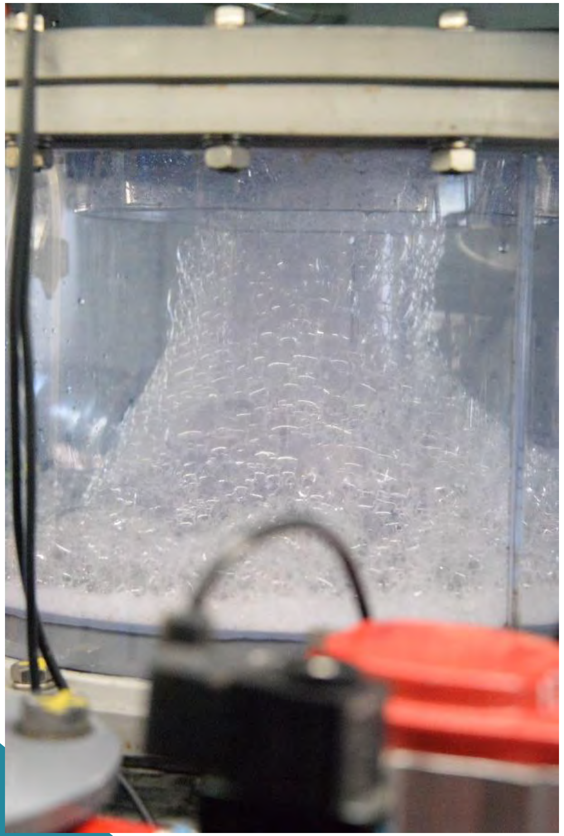
The SAFF® Foaming Process

PRIMARY, SECONDARY, AND TERTIARY FRACTIONATION



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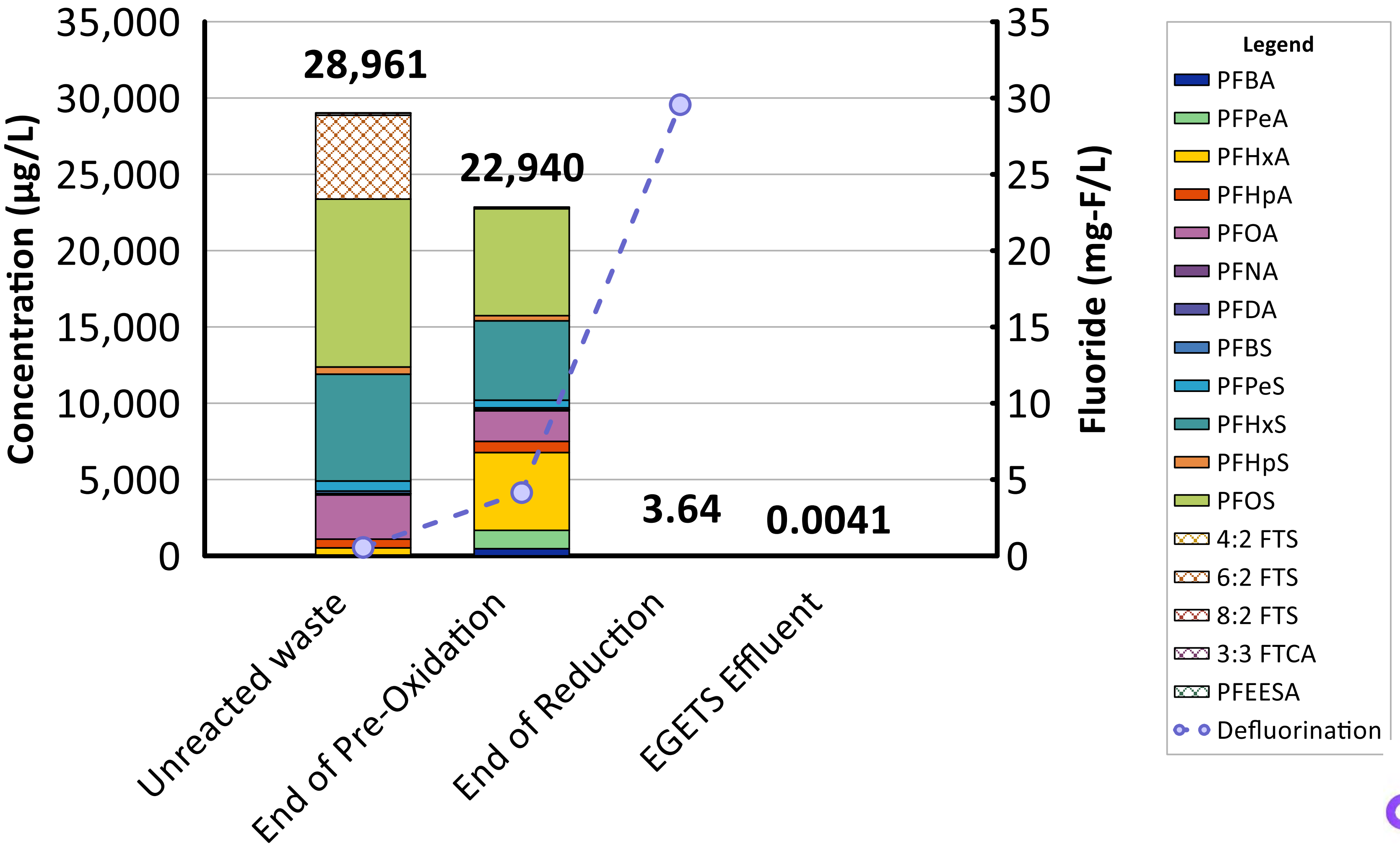
Effective PFAS removal by SAFF with a booster surfactant

	Sample Date:	4/10/2025		4/23/2025		4/30/2025		4/24/2025	PSLs
PFAS	Unit	GW	SAFF®$_{EFF}$	GW	SAFF®$_{EFF}$	GW	SAFF®$_{EFF}$	EGETS$_{EFF}$	
PFBA	ng/L	620	600	610	610	640	610	1.3 J	1800
PFHxA	ng/L	1700	1,700	1600	1,100	1500	1100	0.520 J	990
PFOA	ng/L	1200	190	1300	1.6	1,300 J-	0.700 J	< 0.420	4
PFNA	ng/L	79	1.3 J	86	< 0.410	83	< 0.420	< 0.420	10
PFBS	ng/L	450	250	540	480	580	600	< 0.420	600
PFHxS	ng/L	4000	1600	4400	2.5	4400	1.1 J	0.510 J	10
PFOS	ng/L	9900	93	11000	25	11000	5.80	1.2 J	4
HFPO-DA	ng/L	< 3.9	< 3.1	< 3.9	< 0.320	< 3.9	< 0.330	< 0.330	10

GW = influent groundwater
SAFF®$_{EFF}$ = SAFF® clean water effluent
EGETS$_{EFF}$ = EGETS effluent
PSLs = project screening levels

Effective PFAS destruction in tertiary foamate in the presence of high level of booster surfactant



>99.9 percent of PFAS were destroyed at the end of the reduction step.

Very high concentration (~1.7 g/L) of booster surfactant didn't inhibit the reaction

After the polishing step (on-site GAC system), all residual PFAS were removed to below MCLs.

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Target PFAS analysis show effective PFAS destruction

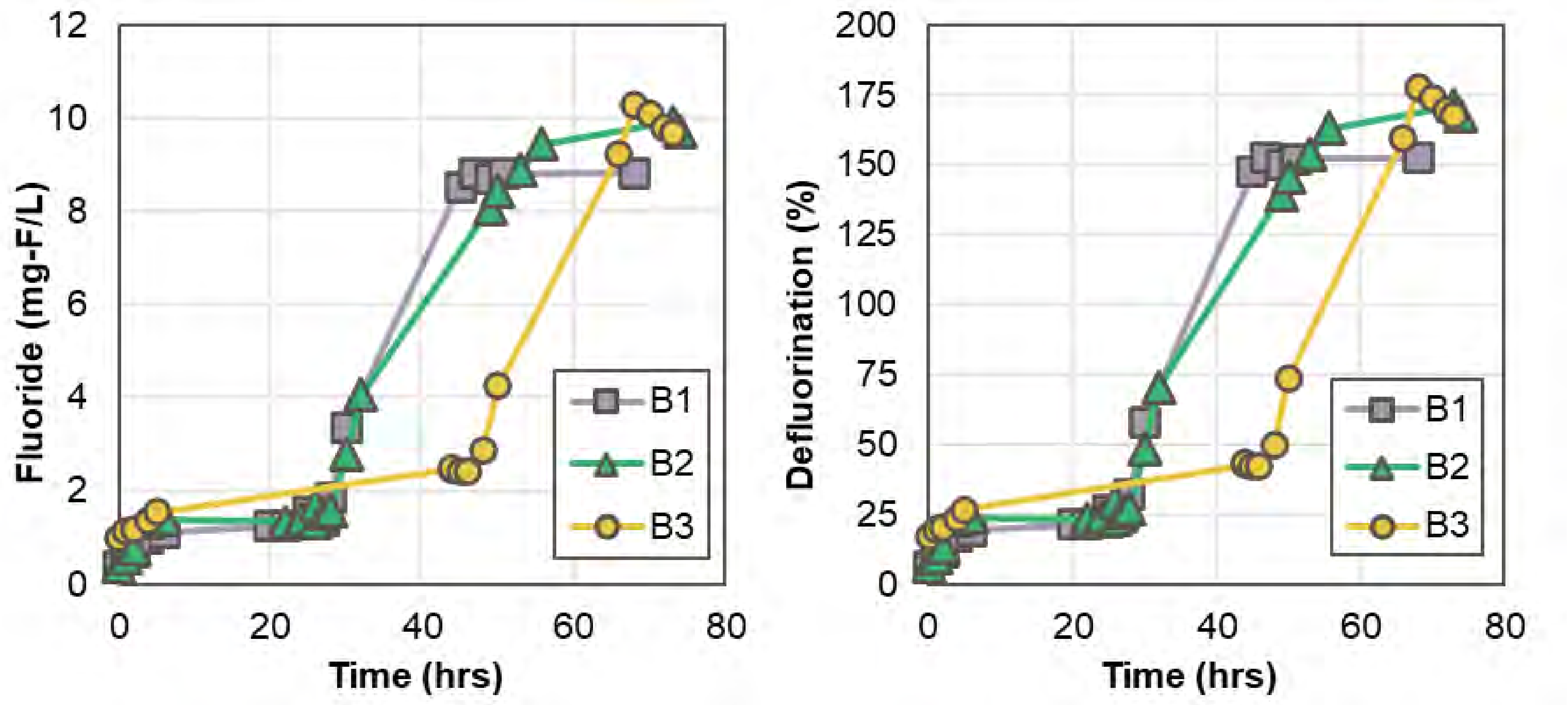
PFAS[1]	No booster: Secondary Foamate			With booster: Tertiary Foamate	
	Batch				
	B1	B2	B3	B4	B5
PFBA	99.995	> 99.968	> 99.972	99.998	> 99.995
PFPeA	> 99.995	> 99.99	> 99.99	99.998	> 99.999
PFHxA	> 99.998	> 99.998	99.98	99.998	99.998
PFHpA	> 99.99	> 99.99	99.97	99.997	99.995
PFOA	99.998	99.999	99.98	99.996	99.99
PFNA	99.996	99.997	99.96	99.99	99.99
PFDA	> 99.998	> 99.992	NA	NA	> 99.99
PFBS	77	67	52	98	> 99.991
PFPeS	98	99	92	99.99	> 99.998
PFHxS	99.99	99.996	99.7	99.996	99.9997
PFHpS	99.993	99.998	99.99	99.995	> 99.998
PFOS	99.997	99.998	99.996	99.99	99.999
6:2 FTS	99.995	99.992	99.99	99.999	99.999
8:2 FTS	NA	99.99	> 99.8	99.99	> 99.99
PFMBA	NA	NA	> 99.7	NA	> 99.99

Notes:

[1]Only PFAS detected by EPA Method 1633 are shown. PFAS that were non-detect are not included.

NA = not applicable due to non-detect concentration in the untreated waste and at the end of pre-oxidation.

PFAS destruction product fluoride was detected to show effective PFAS destruction (Phase I operation)



Note: Phase I = No surfactant booster.

Limited to secondary foam fractionation. Secondary foamate produced.

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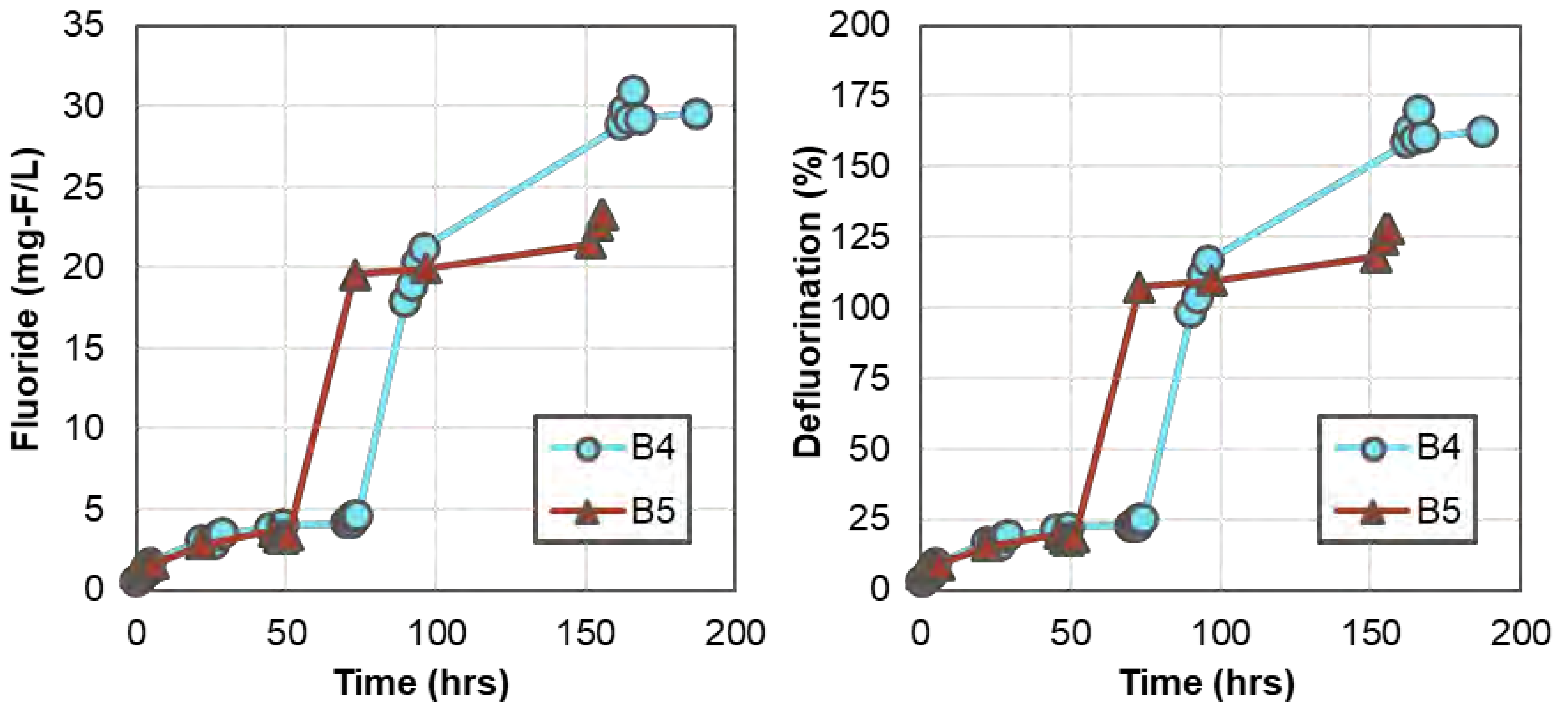
PFAS destruction product fluoride was detected to show effective PFAS destruction (Phase II operation)



Note: Phase II = With surfactant booster.

Tertiary foam fractionation achieved. Tertiary foamate produced.

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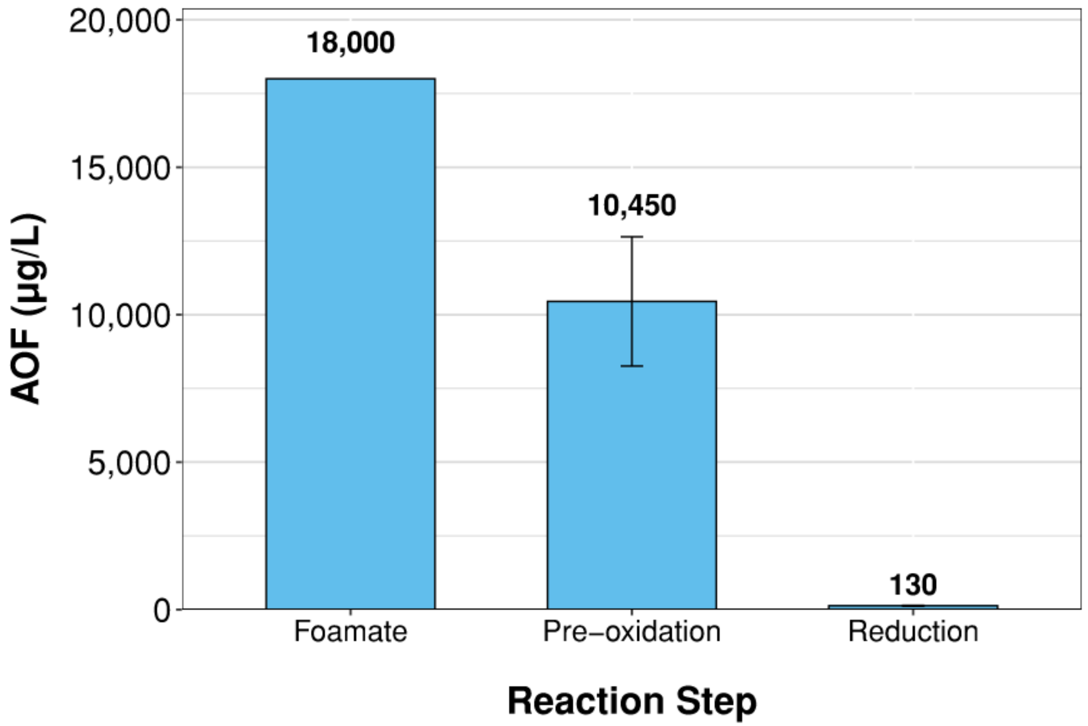
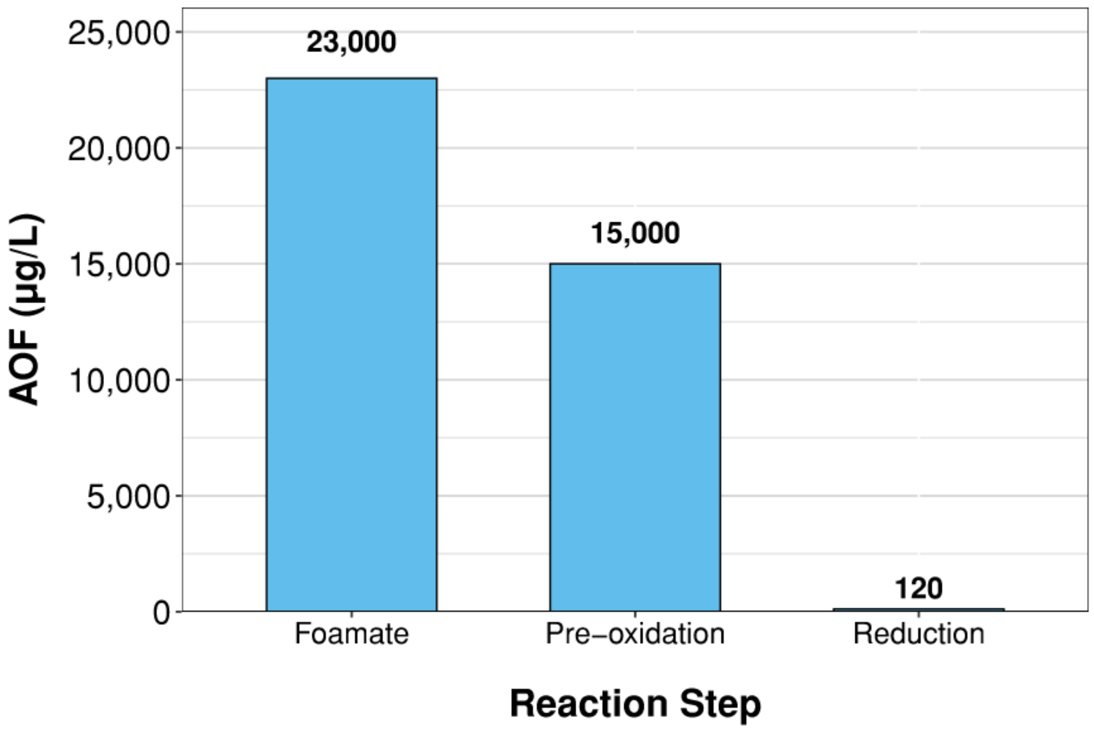
Adsorbable organic fluorine (AOF) measurements provide another line of evidence showing effective PFAS destruction





Closed-loop treatment by sending EradiFluor effluent to the influent of foam fractionation

Parameter	Unit	SAFF®40 Influent GW[1]	EradiFluor (tertiary foamate) Influent	EradiFluor (tertiary foamate) Effluent	SAFF®40 Mixed Effluent[2]
PFBA	ng/L	615	130,000	9	613
PFPeA	ng/L	1,450	63,000	17	1,446
PFHxA	ng/L	1,650	390,000	85	1,645
PFHpA	ng/L	695	595,000	34	693
PFOA	ng/L	1,250	2,400,000	89	1,247
PFNA	ng/L	83	91,000	7	82
PFBS	ng/L	495	120,500	2,400	501
PFPeS	ng/L	610	585,000	64	608
PFHxS	ng/L	4,200	6,100,000	103	4,188
PFHpS	ng/L	280	445,000	16	279
PFOS	ng/L	10,450	12,000,000	345	10,420
4:2 FTS	ng/L	33	< 130,000	62	33
6:2 FTS	ng/L	3,600	5,000,000	31	3,589
8:2 FTS	ng/L	160	140,000	2	160

[1]These SAFF®40 influent groundwater samples did not contain EradiFluor effluent. One sample collected after EradiFluor effluent addition was omitted
2Thirty gallons of EradiFluor™ effluent were diluted into ~10,000 gallons of SAFF®40 influent groundwater

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Closed-loop treatment by sending EradiFluor effluent to the influent of foam fractionation (cont'd)

Parameter	Unit	SAFF®40 Influent GW[1]	EradiFluor (tertiary foamate) Influent	EradiFluor (tertiary foamate) Effluent	SAFF®40 Mixed Effluent[2]
Fluoride	mg/L	0.31*	2,000	26†	0.4
Nitrate (as N)	mg/L	7	1,000	2.2	7
Sulfate	mg/L	94	13,000	42,000	220
DOC	mg/L	0.76	4,000	12	0.8
TOC	mg/L	0.86	4,000	13	0.9

[1]These SAFF®40 influent groundwater samples did not contain EradiFluor effluent. One sample collected after EradiFluor effluent addition was omitted
2Thirty gallons of EradiFluor™ effluent were diluted into ~10,000 gallons of SAFF®40 influent groundwater

- Residual PFAS in EradiFluor was sent back to SAFF influent for further treatment.
- The diluted effluent has similar water chemistry as influent groundwater.
- Zero waste discharge from EradiFluor.
- Approved by regulatory agencies.

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Projected cost for a full-scale system (520 gpm)

Cost Element	Details	Projected costs for permanent SAFF® system		Projected costs for permanent EradiFluor System	Projected annual costs for a mobile EradiFluor
		SAFF®	GAC Polish		
CAPITAL COSTS					
System Design and Installation	Labor, Equipment & Materials	$12,040,000	$1,351,000	$1,432,000	---
Daily rental rate	---	---	---	---	$2,620
Mobilization and demobilization	---	---	---	---	$50,000
	Subtotal	$12,040,000	$1,351,000	$1,432,000	$571,600
OPERATIONS AND MAINTENANCE (O&M) COSTS (ANNUAL)					
System O&M and Groundwater Sampling[8]	Labor	$250,000	$75,000	$176,800	$176,800
	Equipment & Materials	$87,500	$403,000	$127,200	$127,200
	Electricity	$75,850	$5,000	$15,000	$15,000
	Analytical	$11,400	$5,700	$20,000	$20,000
	Subcontractors	$13,200	$40,000	$20,000	$20,000
	Subtotal	$437,950	$528,700	$359,000	$359,000

Summary

- Field demonstrations were successfully conducted
  - SAFF effectively removed most of PFAS
  - Polishing step (GAC) further removed residual PFAS
  - Near-complete destruction was achieved based on
    - Target PFAS analysis
    - Fluoride generation
    - AOF analytical results
- High level of booster surfactant no impact on PFAS destruction
- Closed-loop zero waste treatment

Acknowledgements

AIR FORCE CIVIL ENGINEER CENTER

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John Xiong, Ph.D., P.E.
Raul Tenorio, Ph.D.
Sydney Tumberger
Riley Arthur
Sarah Mass, P.E.
Jacob Chu, Ph.D., P.E.
Darrin Costantini
Mike Calhoun, PG
Yida Fang, Ph.D., P.E.

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Zach Pierce, P.E.
Jason Hnatko, Ph.D.
Andrew Punsoni
Casey Comer
Rachel Gates
L'Oreal Sammuels
Aaron Dykema

Questions?

John Xiong, Ph.D., P.E.
Principal
jxiong@haleyaldrich.com
Haley & Aldrich, Inc. I Costa Mesa, CA

Zach Pierce, P.E.
Environmental Engineer
zpierce@allonnia.com
Allonnia I Portland, ME

Find out more at:

Project summary webpage:

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