# Development of a Cost-Effective and Reliable Destructive Technology for PFAS: A Promising Advanced Reduction Process

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# Acknowledgements

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# Overview

## In this talk

- Discuss why we need PFAS destruction technologies
- Introduce hydrated electrons
- Discuss what **EradiFluor™** is
- Present results from **EradiFluor™** testing

## Take-home messages

- Existing technologies produce concentrated PFAS waste
- Hydrated electrons are effective in destroying various PFAS classes
- A PFAS destruction system, **EradiFluor™**, has been constructed for field applications and shows encouraging results

# Existing separation technologies leave behind a concentrated waste

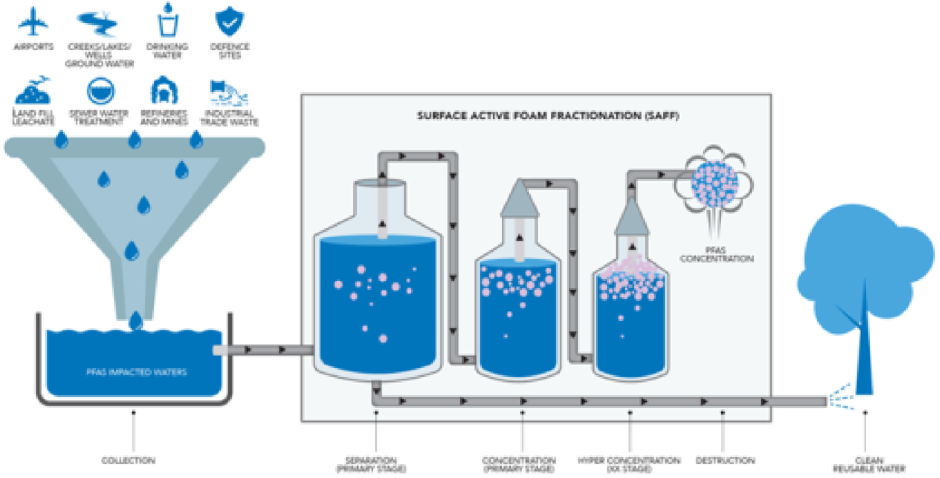
## Conventional technology

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

**Incineration**

**Landfill**


**Deep well injection**

**EPA identified three PFAS waste disposal technologies and each has its obvious disadvantages**

**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).

# There is a growing need for destructive technologies

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


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



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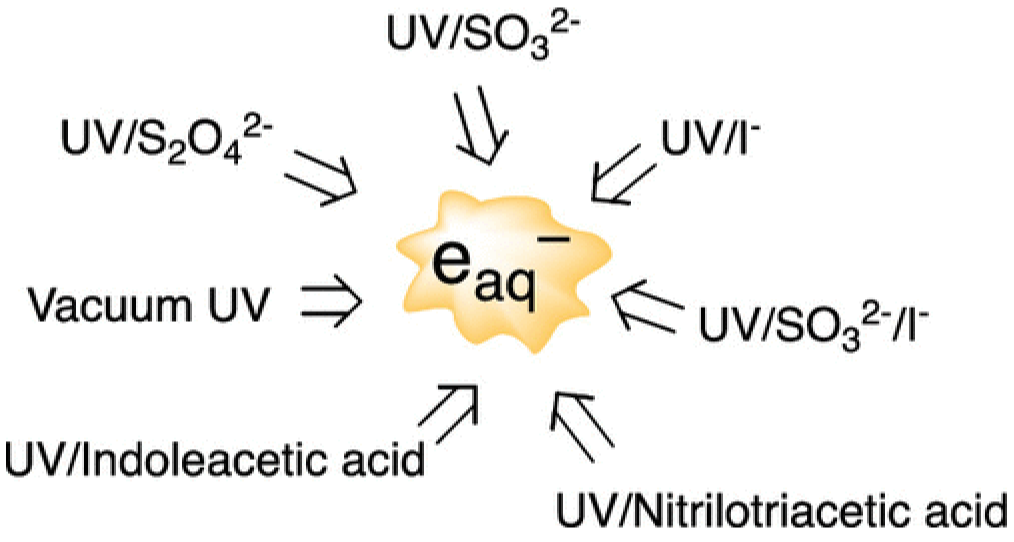
# A new approach: UV-based advanced reduction process

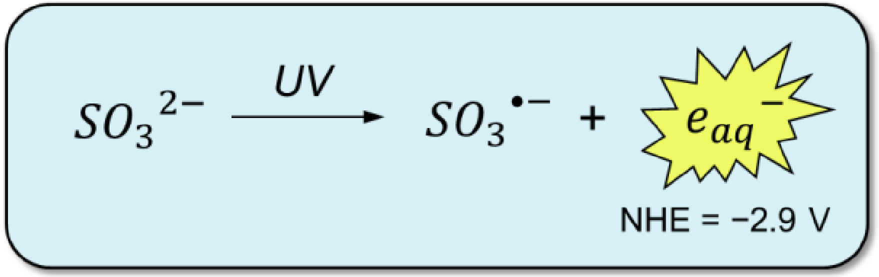
- This process is based on the production of highly reducing hydrated electrons, $e_{aq}^-$
  - Different from $UV/H_2O_2$ used in water treatment
  - $e_{aq}^-$ is a strong reductant (standard potential = −2.9 V)
  - Key reactant for PFAS destruction by non-thermal plasma and electron beam
- $e_{aq}^-$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

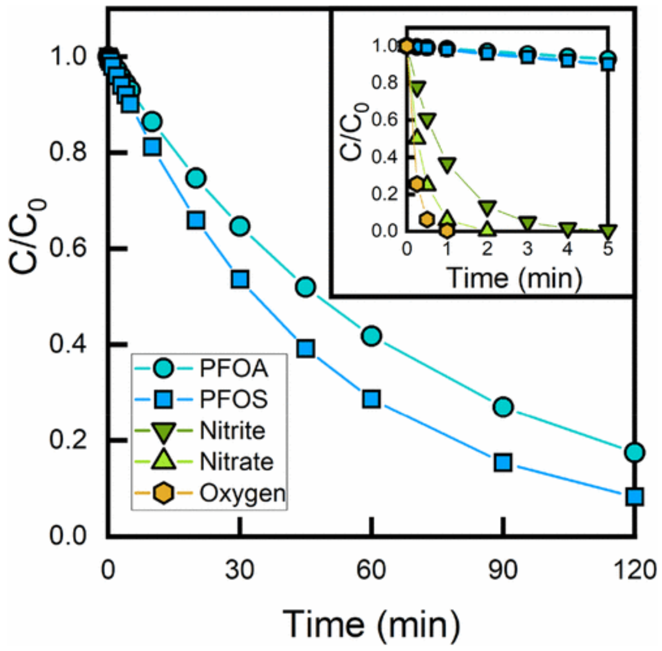



Source: Fennell et al., 2022

# A new approach: UV-based advanced reduction process

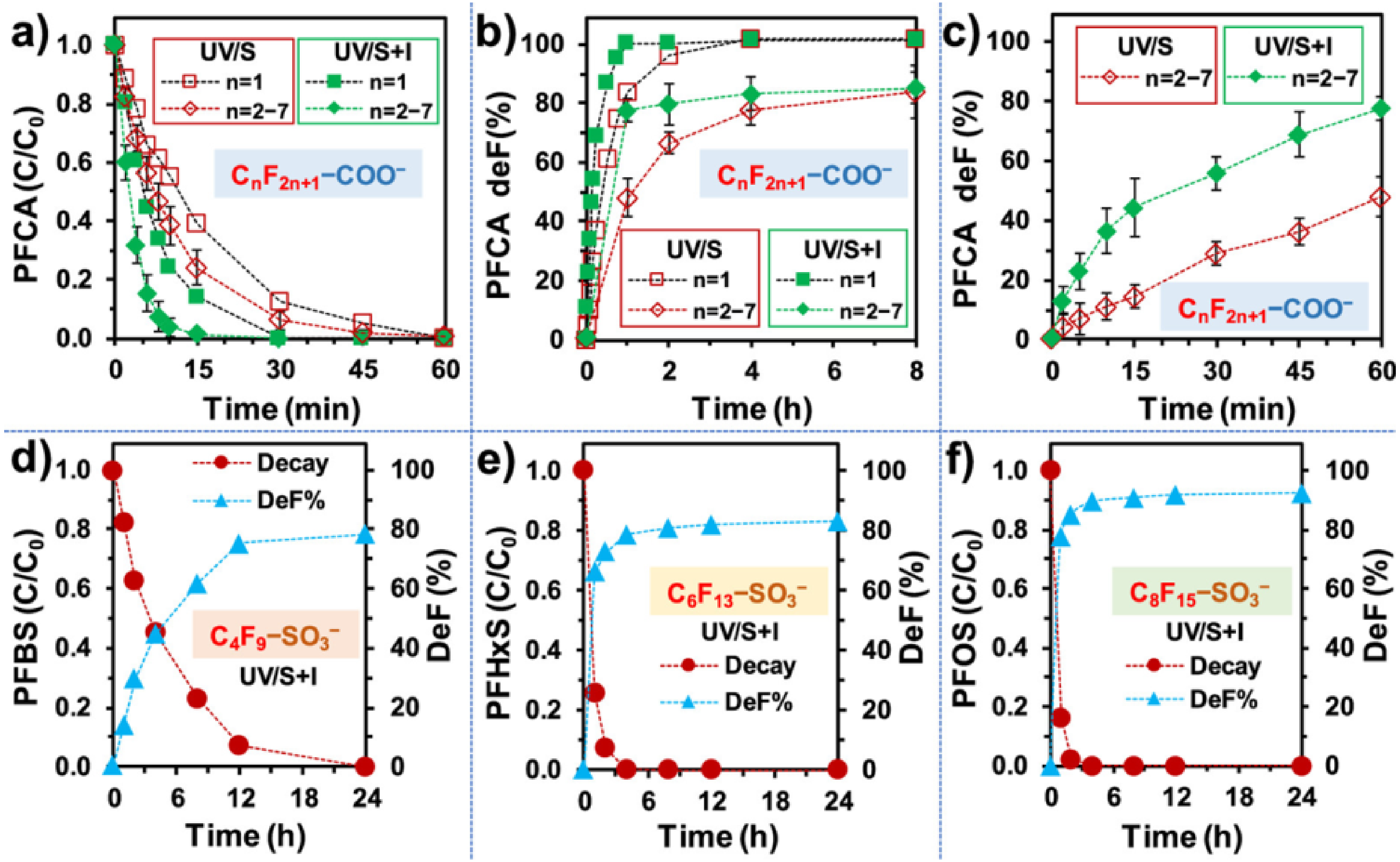
- $e_{aq}^-$ break C-F bond and degrade PFAS compounds
  - Highly effective in PFAS destruction
- $e_{aq}^-$ highly effective for treatment
  - Chlorinated solvents, perchlorate, bromate, nitrate, chromium (VI)
- Certain water constituents may scavenge $e_{aq}^-$
  - Oxygen
  - Nitrate/nitrite




Source: Fennell et al., 2022

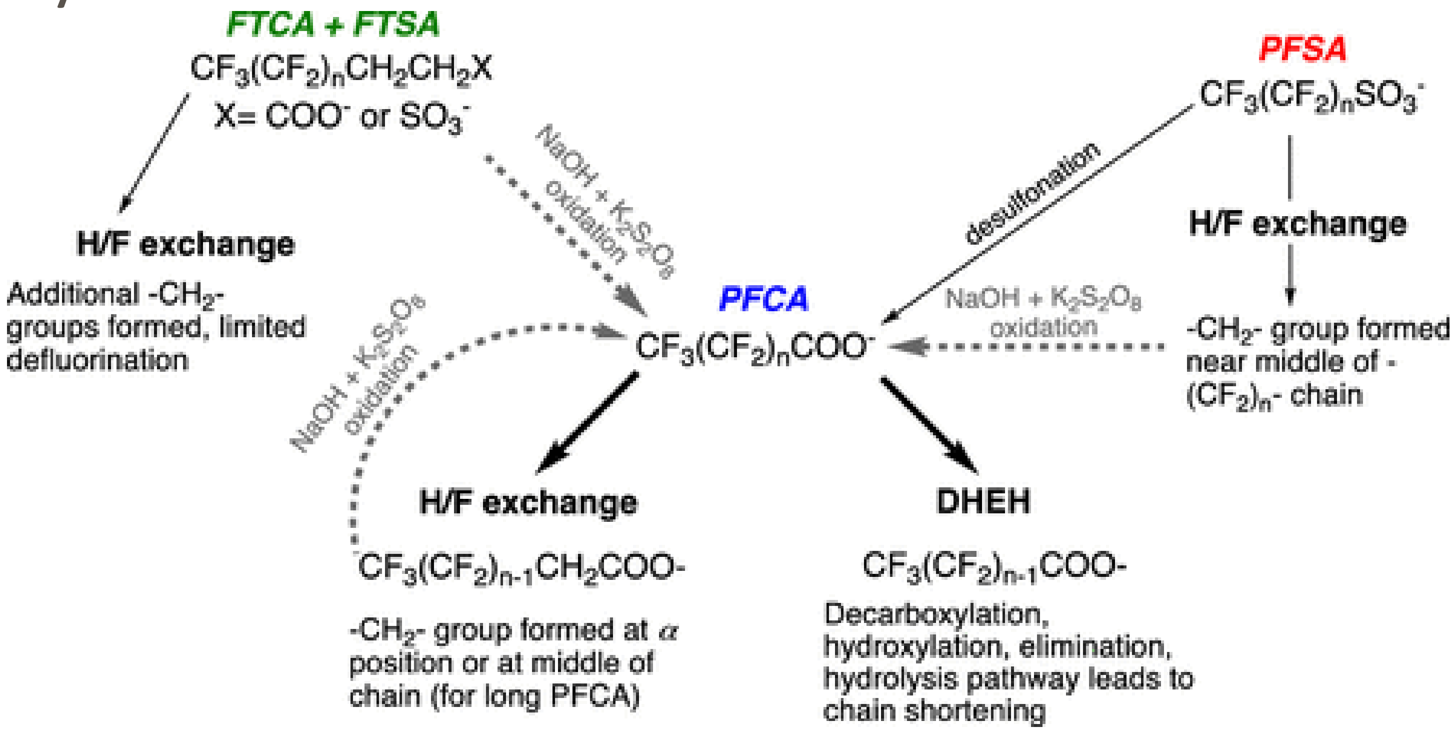
# Laboratory study results showed effective destruction of various PFAS




Source: Liu 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 polyfuorinated products
  - DHEH
    - Shorten one $-CF_2-$ group each step
    - Deeper defluorination
    - Mostly occur to PFCAs




Source: Fennell et al., 2022

DHEH = Decarboxylation, hydroxylation, elimination, hydrolysis

# Findings from laboratory tests

- Hydrated electrons are highly effective in destroying PFAS
- Near-complete destruction of various short-chain and long-chain PFAS
- No harmful byproducts (e.g., perchlorate, bromate)
- The reactive mechanisms are well understood
- Not affected by high salt concentration
- Mild reaction conditions (e.g., temperature, pressure)

# EradiFluor™ - PFAS destruction system

- A PFAS treatment system has recently been designed and constructed
  - UV/sulfite-based treatment process
  - Multiple treatment step available
  - Mobile, on-site treatment unit
  - 30-gallon treatment capacity per batch
  - Near ambient reaction conditions

- Concentrated PFAS streams to be treated under DoD field conditions

*View from the rear of the trailer*

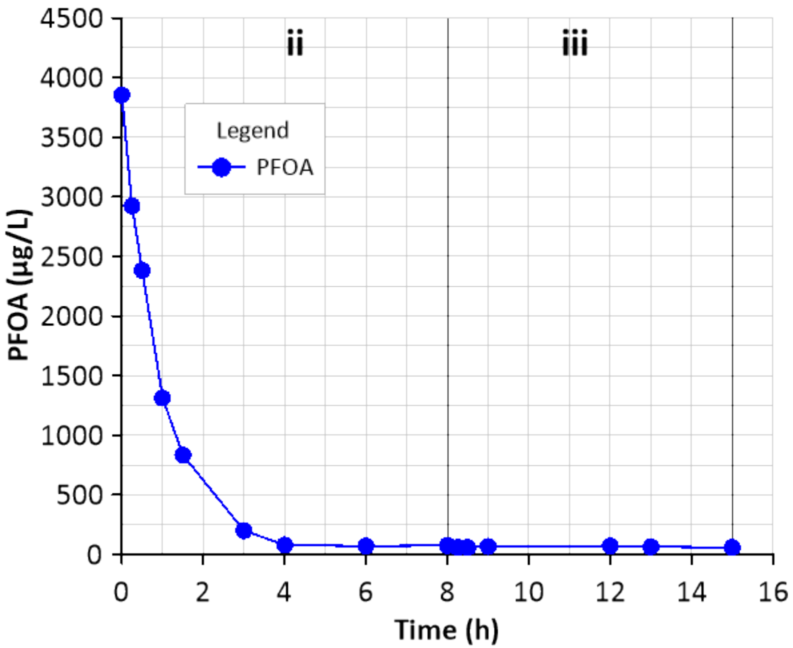
# Simulated waste test

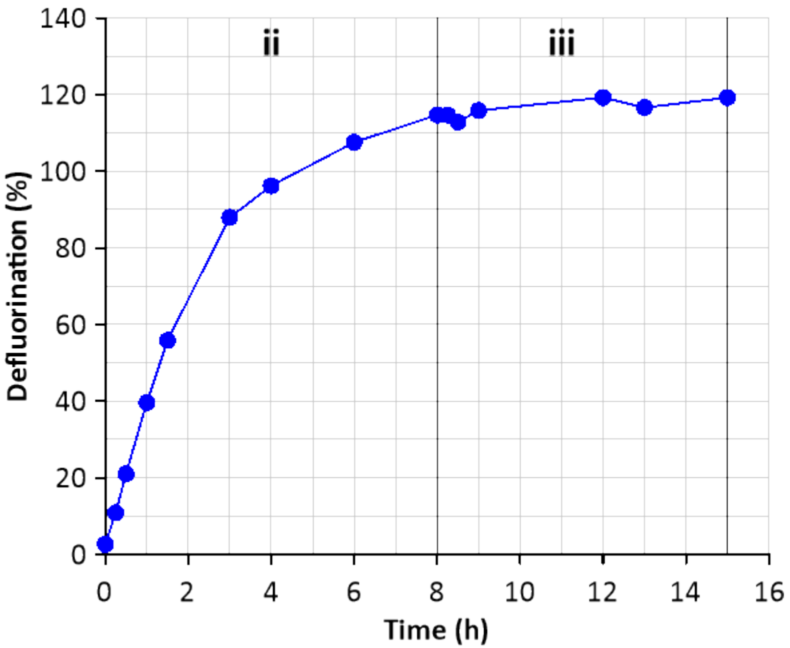
## Method

- **PFOA:** Consumer products, food packaging, fire-fighting foam, and other industrial processes
- 30-gallon batch liquid waste
- Treatment: (II) reduction, (III) post oxidation

## Results

- 99% PFOA degradation
- >100% defluorination was achieved
- Post-oxidation didn't improve defluorination efficiency

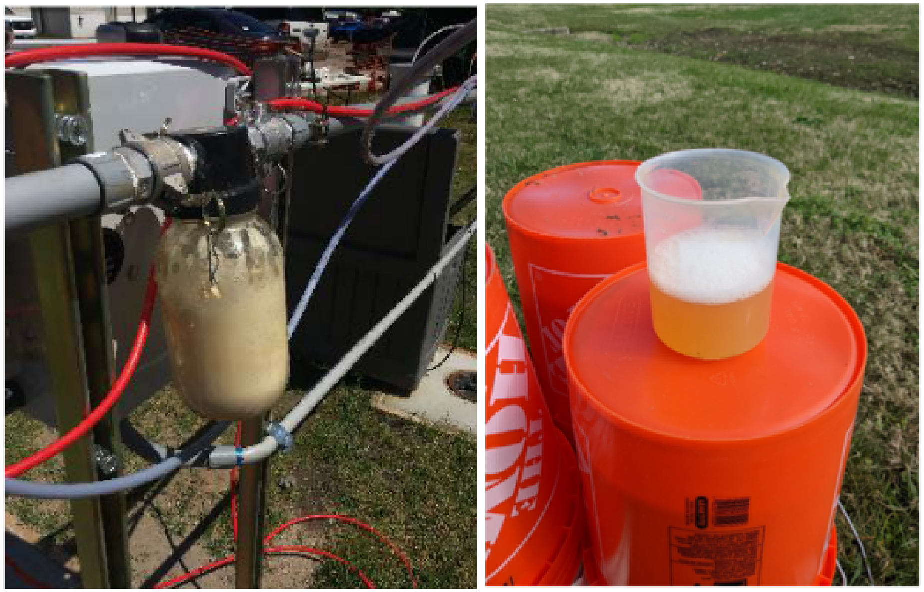



**i** = Pre-oxidation **ii** = Reduction **iii** = Post-oxidation

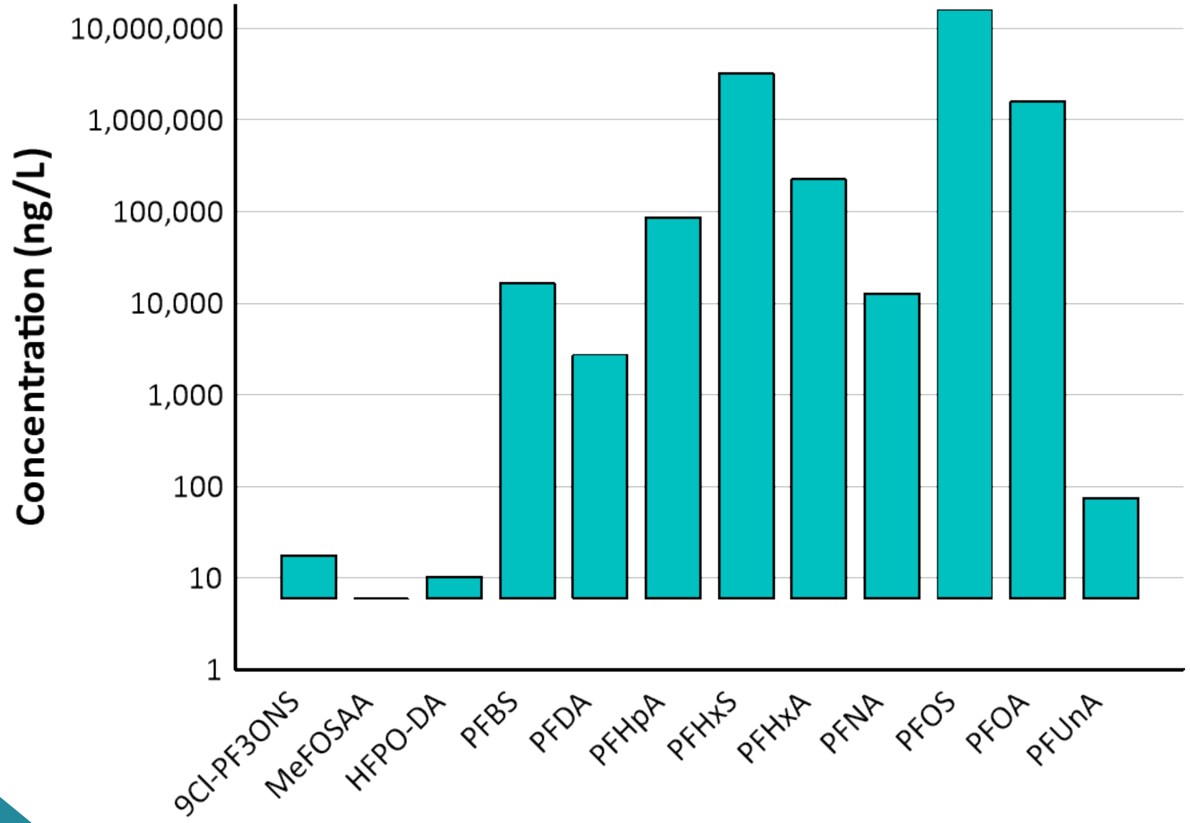
# Treatment of waste concentrate: in situ foam fractionation

- Foamate sample produced from an in situ foam fraction groundwater remediation system from a DoD site
  - Tens of ppm level of PFAS
  - PFOS and 6:2 FTS dominant
  - Low level of TOC and nitrate/nitrite
- Sample was diluted with tap water for the destruction due to limited amount of field sample
- A 30-gallon batch liquid waste (diluted still bottom) was treated in pilot system
- Pre-oxidation is intended to convert precursor to terminal compounds



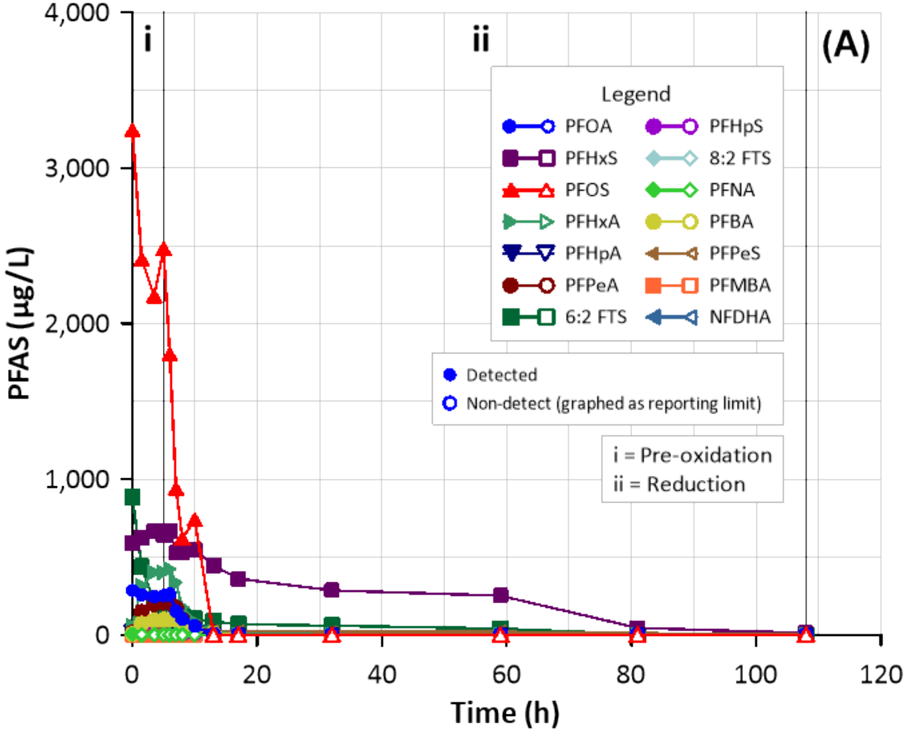
PFAS concentrate produced from an in situ foam fractionation system for groundwater remediation (Source: Nelson 2022)

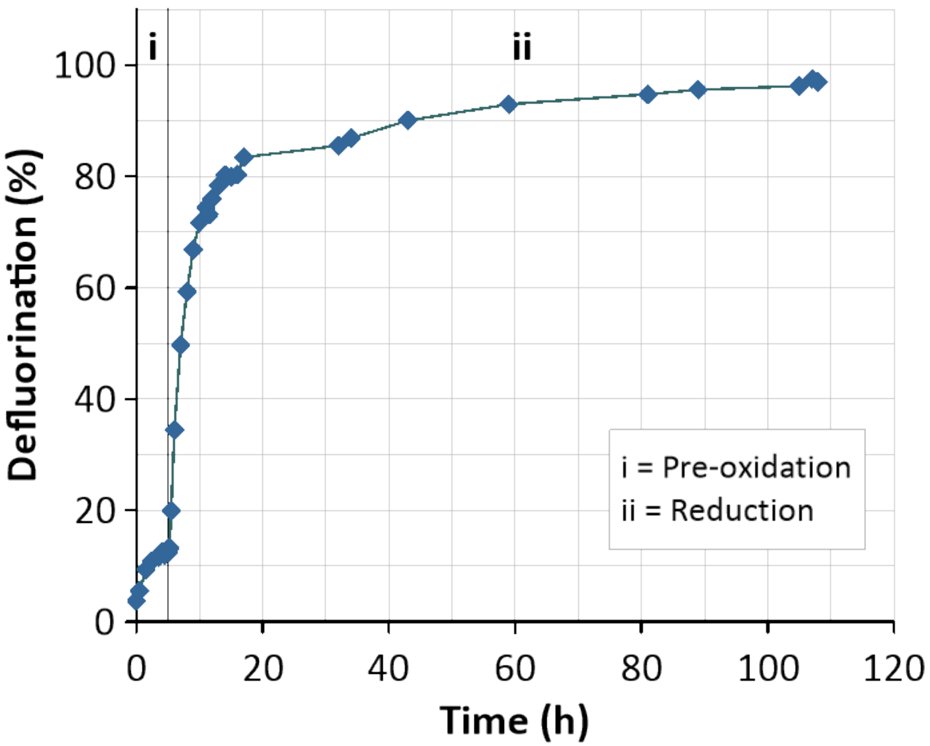
# Constituents of the foam fractionate




| Parameter | Concentration | Unit |
|---|---|---|
| Alkalinity | 28.4 | mg $CaCO_3$/L |
| Total Dissolved Solids | 92 | mg/L |
| Nitrogen, Nitrite | ND | mg/L |
| Nitrogen, Nitrate | ND | mg/L |
| Total Organic Carbon | 16 | mg/L |
| Sulfate | 34.3 | mg/L |

# Results: foam fractionation




**i** = Pre-oxidation

**ii** = Reduction

- >95% defluorination was achieved
- >99.9% destruction of PFOS, PFOA
- Technology is effective in PFAS destruction in foam fractionate
- Most of PFAS are destroyed within 20 hrs

# Potential applications of **EradiFluor™**

- Residue from foam fractionation, ion exchange regeneration, activated carbon regeneration, reverse osmosis/nanofiltration reject
- Industrial wastewater from PFAS manufacturers
- AFFF delivery vehicle cleaning solution
- Soil washing residue.

- **Not** designed to treat low concentration PFAS in groundwater and drinking water

# Comparison with other destructive technologies

- **Strength**
  - Do not need special parts
  - Low capital cost
  - Operate under ambient pressure and temperature (and high pH)
  - Low energy use and cost
  - Safer operation
  - High uptime (rarely shut down)
  - Performance not affected by salt

- **Limitation**
  - Long reaction time (to be applied along with concentration technologies)
  - Color of liquid waste affects performance (pretreatment is required)

# Summary

- Existing technologies produce concentrated PFAS waste
- Growing need for destruction technologies
- Hydrated electrons are effective to destroy various classes of PFAS
- **EradiFluor™** tests showed that near complete PFAS destruction based on fluorine mass balance was achieved
- Next step: move the technology to the field; two field demonstrations are planned for 2024

# Questions?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## Take-home messages

- Existing technologies produce concentrated PFAS waste
- **EradiFluor™** is effective in destroying various PFAS classes
- **EradiFluor™** provides a low cost and reliable option for PFAS destruction



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