Destruction of PFAS Using Electron Beams

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PFAS Sources and Contamination

Per and polyfluoroalkyl substances (PFAS) are a group of 1000s of different chemicals that have fluorine atoms attached to a carbon chain.

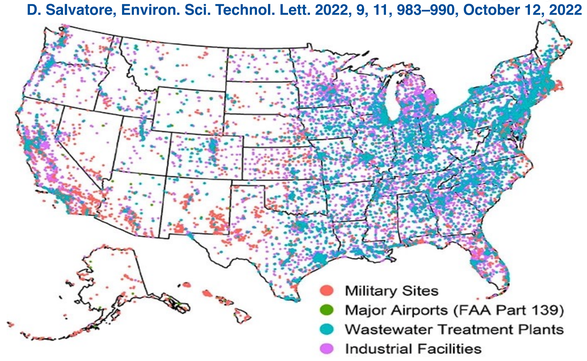
There are many PFAS of concern, but PFOA and PFOS have received special attention because of their persistent nature and because of health concerns when ingested in small quantities.

Sources for PFAS include:

Food packaging	*Fire Fighting Foams*
Surfactants	*Lubricants*
Paper and textile coatings	*Personal care products*
Paints	*Pesticides*



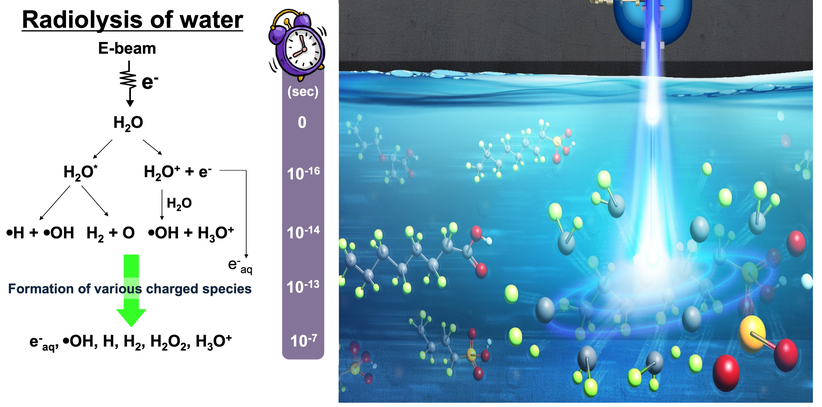

Presumptive Contamination Sites (n=57,412)
D. Salvatore, Environ. Sci. Technol. Lett. 2022, 9, 11, 983–990, October 12, 2022



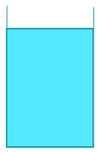
Problems with Conventional Treatment of PFAS

Attribute	E-Beam	Activated Carbon Filtration	Ion Exchange Resins	Membranes (RO)	Hydotherm/ Electrochem
Treat PFOA/PFOS	✓	✓	✓	✓	✓
Treats short-chain PFAS	✓	No	No	✓	In Development
Destroys PFAS on-site	✓	No	No	No	No ✓
Treats PFAS in mixed-streams	✓	No	No ✓	No	✓
Cost	High	✓	✓	✓ High	High

E-beam Destruction of PFAS

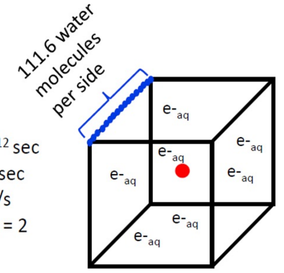


- In a process called water radiolysis the electron beam creates active species that break down PFAS.
- For high energy electrons (10 MeV), each electron will undergo roughly 100,000 interactions before coming to rest and each interaction has a good chance of producing the aqueous electrons needed for PFAS degradation.
- All the active species are created and dissipate on microsecond timescales.



In one liter of 20 ppm PFOA
2.9 E19 PFOA molecules
3.3 E25 Water molecules
1.7 E20 e_{-aq} per second
3.5 E22 e_{-aq} over 200 sec (200 kGy)

e_{-aq}:
Formation 10^{-12} sec
Longevity 10^{-6} sec
D = 5 10^{-5} cm^2/s
Reaction Radii = 2 angstroms

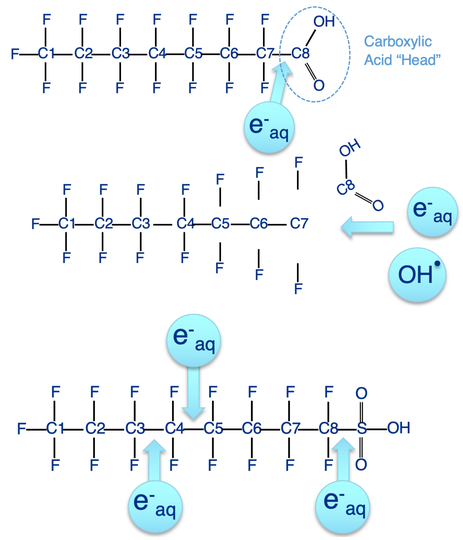


- **A lot of opportunities to improve energy efficiency**
- **Diffusion limited process can be improved when scaling up**

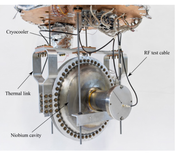
COST	300kW, 10 MeV IBA Rhodotron	Fermilab E-beam	GAC
Capital Cost	~3x cost of GAC	$7.8 M Ver1 ($15M) $5.5 M Ver 2 ($11M)	$3.3M
Operating Cost	$2.5k/kG PFAS ¢/gallon	$2-1.3k/kG PFAS ¢/gallon	$34k/kG PFAS ¢/1000 gallon

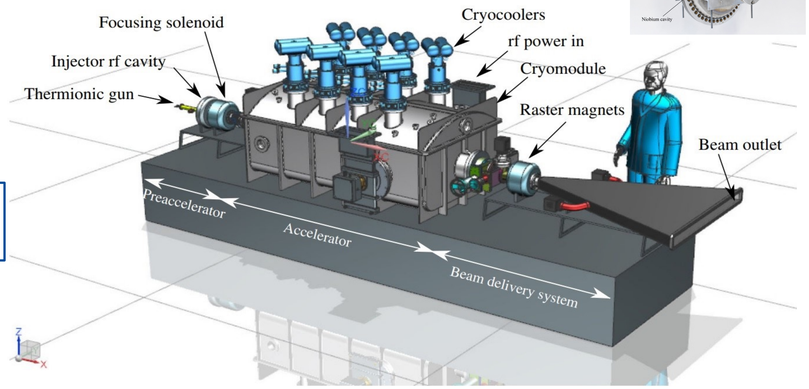
Degradation of PFAS

Destroys all PFAS proposed by the National Primary Drinking Water Regulation (NPDWR).



- Faster on branched chain
- Removes Carboxylic Acid Head Group (1.2 ps)
- Stepwise unzipping of PFAS chain
- C-F bond dissociation energy via aqueous electron is three times higher in PFOS when compared to PFOA(4ps)
- 100% Destruction of PFOA Homologs in a min, PFOS 2 min or less.
- Fluorine in the form of free fluoride.





- **Fermilab has designed a superconducting, radio frequency, linear accelerator for PFAS degradation.**
- **It is as much as 20% more energy efficient, and therefore cheaper to operate than accelerators on the market today.**

This poster does not contain any proprietary, confidential, or otherwise restricted information.

Fermi National Accelerator Laboratory

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