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Application of electron beam technology to decompose persistent emerging drinking water contaminants: poly- and perfluoroalkyl substances (PFAS) and 1,4 dioxane.

**Cooperative Research and Development Agreement
Final Report**

CRADA Number: FRA-2019-0030

Fermilab Technical Contact: Charles Cooper

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In accordance with Requirements set forth in Article X of the CRADA document, this document is the final CRADA report, including a list of Subject Inventions, to be forwarded to the Office of Science and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

CRADA number: FRA-2019-0030

CRADA Title: Application of electron beam technology to decompose persistent emerging drinking water contaminants: poly- and perfluoroalkyl substances (PFAS) and 1,4 dioxane

Parties to the Agreement: Stony Brook University and Fermi Research Alliance, LLC

Sponsoring DOE Program Office(s): Office of Science

DOE Funding Commitment Table:

| <i>(a)</i> | <i>(b)</i> |
|--------------|-------------|
| | Year 1 Cost |
| Grand Totals | \$47,000 |

Abstract of CRADA work:

Fermi Research Alliance, LLC (FRA) operates Fermilab under contract with the U.S. Department of Energy and has patents on technologies and applications of a novel mobile electron beam accelerator. A high-power version of this mobile accelerator based on FRA-developed SRF technology is under development at Illinois Accelerator Research Center (IARC) and can enable several new applications that have significant commercial potential. One such application is the e-beam treatment of persistent emerging contaminants in drinking water. The contaminants of concern are poly- and perfluoroalkyl substances (PFAS) and 1,4-dioxine. Both PFAS and 1,4-D are highly resistant to degradation and are not effectively removed by conventional drinking water treatment systems. Existing technologies, such as granular activated carbon (GAC) filters and reverse osmosis (RO) systems do not decompose. The Center for Clean Water Technology (CCWT) at Stony Brook University (SBU) is in the process of identifying and testing effective technologies to remove PFAS and/or 1,4-D from drinking waters. se PFAS, but rather concentrate them either by adsorption (GAC) or membrane rejection (RO). The Center for Clean Water Technology (CCWT) at Stony Brook University (SBU) is in the process of identifying and testing effective technologies to remove PFAS and/or 1,4-D from drinking waters to demonstrate the full-scale application of novel water treatment technologies.

and is experienced in conducting research to understand treatment performance with a particular focus on 1,4-D and PFAS contamination

Summary of Research Results:

Results from this study showed that e-beam is effective in treating both 1,4-dioxane and PFAS. Complete degradation of 1,4-dioxane was observed at a dose of 5 kGy for an initial concentration of up to 1 ppm without the need for any sample modification. The electrical energy per order (EEo) for treatment of 1,4-dioxane ranged from 0.46 to 0.72 kWh/m³/order and was comparable and even lower, in some cases, than other AOP technologies. Alkaline conditions (pH 13) and low dissolved oxygen concentration (2 mg/L) highly favored the treatment of PFAS by e-beam. Greater than 90% removal of PFOA and PFOS from an initial concentration of 100 to 500 ppb was achieved at a dose of 250 kGy and 500 kGy, respectively, under optimized conditions. The degradation efficiency was not significantly changed when treating other PFAS of perfluorinated carbon chain length of 5 to 7 individually at 250 kGy with a removal ranging from 85–99% for different compounds. Short chain PFAS (perfluorobutanoate: PFBA and perfluorobutane sulfonate: PFBS) did not degrade under the same conditions at 250 kGy, but 70 to 99% degradation was observed at a higher dose of 1000 kGy.

Short chain PFAS (perfluorohexanoate: PFHxA and perfluoroheptanoate: PFHpA) were detected after treatment of PFOA, but not after PFOS treatment. Inability to close the mass balance through targeted analysis suggests the presence of other intermediates not detectable by available analytical methods. When treating PFAS mixture containing ten compounds at equimolar concentration of 0.05 µM each, preferential degradation of polyfluorinated compound (6:2 fluorotelomer sulfonate or 6:2 FTS) followed by C8 and C7 compounds was observed as a function of increasing e-beam dose. About 30% degradation of ΣPFAS was observed at 250 kGy and no further removal was observed up to a dose of 1000 kGy. C4 to C6 PFASs showed no degradation, while C3 PFAS (PFBS) showed an increase in concentration by 34% at 1000 kGy due to formation from the breakdown of other long chain PFAS. These results suggested that (a) the reaction kinetics is likely different for different PFAS based on chain length, functional group, and the degree of fluorination of the carbon chain, and (b) there may be intermediates generated from the degradation of 6:2 FTS and C7/C8 compounds that can potentially scavenge hydrated electrons needed for reaction with the untreated PFAS molecules. Calculated EEo for PFAS ranged from as low as ~48 to 1081 kWh/m³/order depending on the type of PFAS treated. These values are comparable and even lower, in some cases, than other destructive technologies employed for PFAS treatment such as ultrasound, plasma, and photochemical treatment.

Related Reports, Publications, and Presentations:

Final Report DOE: Application of electron beam technology to decompose persistent emerging drinking water contaminants: poly- and perfluoroalkyl substances (PFAS) and 1,4-Dioxane

Publications: Energy Evaluation of Electron Beam Treatment of Perfluoroalkyl Substances in

Water: A Critical Review

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<https://doi.org/10.1021/acsestengg.0c00222>

Presentations/Posters:

Application of electron beam for the degradation of 1,4-dioxane and perfluoroalkyl substances in drinking water – Strategic Environmental Research and Development Program (SERDP) Symposium 2020

Optimization and energy evaluation of electron beam treatment of PFAS – Great Lakes PFAS Summit, December 2021

Subject Inventions listing:

Electron beam destruction of 1,4 dioxane

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