ERDC/EL TR-19-9

Environmental Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

ERDC
ENGINEER RESEARCH & DEVELOPMENT CENTER

Environmental Quality/Installations (EQI) and
National Defense Center for Energy and the Environment (NDCEE)

Simulated Field Evaluation of the Decontamination Effluent Treatment System (DETS) for Wash Water from Mass Personnel Decontamination (MPD), Road Test, and Evaluation Treating Perfluorinated Alkyl Substances (PFAS)

Victor F. Medina, Scott A. Waisner, Jose Mattei-Sosa, Edith Martinez-Guerra, Christopher S. Griggs, Jacob M. Lalley, David L. Henderson, Lee C. Moores, and Brenda H. Prager

July 2019

Environmental Quality/Installations (EQI)
and National Defense Center for Energy and
the Environment (NDCEE)

ERDC/EL TR-19-9
July 2019

Simulated Field Evaluation of the Decontamination Effluent Treatment System (DETS) for Wash Water from Mass Personnel Decontamination (MPD), Road Test, and Evaluation Treating Perfluorinated Alkyl Substances (PFAS)

Victor F. Medina, Scott A. Waisner, Jose Mattei-Sosa,
Edith Martinez-Guerra, Christopher S. Griggs, Jacob M. Lalley,
David L. Henderson, and Lee C. Moores

U.S. Army Corps of Engineers
Environmental Laboratory (EL)
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Brenda H. Prager

Department of Chemical Engineering
University of Mississippi
140 Anderson Hall
University, MS 38677-1848

Final Report

Prepared for Headquarters, U.S. Army Corps of Engineers
Washington, DC 20314-1000

Under Environmental Quality/Installations Program under P2 455017, "Deployable Treatment of Decontamination Effluent."

Abstract

A previous ERDC report described the effectiveness of the Decontamination Effluent Treatment System (DETS) for the treatment of wash water generated from simulated CBRN decontamination. This study compliments that previous one in that it focused on the treatment of a simulant from Mass Personnel Decontamination (MPD). Treatment of both cesium 133 (used as a surrogate for radioactive cesium 137) and Malathion (as a surrogate for organophosphate chemical warfare agent) equaled or exceeded 99.95%. The conclusion was that the system proved to be highly effective at treating wash water from MPD, which would allow discharge or even potential reuse for more decontamination. The ERDC team conducted studies that confirmed that the DETS could be integrated into CERFP activities with minimal disruption. In addition, the DETS underwent a long road test in which it was driven for over 1000 miles from Vicksburg MS to St Robert MO (Fort Leonard Wood) and back. The conclusion is that the DETS could be moved around the United States as needed to respond to decontamination events. The DETS was also used to treat PFOS, a perfluorinated compound found in legacy firefighting foams, and the DETS processes achieved 99.97% removal of ~30 μg/L PFOS.

Contents

Figures and Tables

Figures

Tables

Preface

This study was conducted for Environmental Quality/Installations Program under P2 455017, “Deployable Treatment of Decontamination Effluent.” Dr. Elizabeth Ferguson, Senior Scientific Technical Leader (SSTL), is the director of the EQI program and the Technical Director for the project. Mr. John Ballard served as the program manager for the project.

The work was performed by the Environmental Engineering Branch (EPE) of the Environmental Processes Division (EP), U.S. Army Engineer Research and Development Center, Environmental Laboratory (ERDC-EL). At the time of publication, Dr. Andy Martin was Branch Chief, CEERD-EPE; Mr. Jared Johnson was Acting Division Chief, CEERD-EP. The Deputy Director of ERDC-EL was Dr. Jack E. Davis and the Director was Ilker R. Adiguzel.

COL Ivan P. Beckman was Commander of ERDC, and Dr. David W. Pittman was the Director.

Acronyms and Abbreviations

AFCEC	Air Force Civil Engineering Center
AFFF	Aqueous Firefighting Foam
CBRN(E)	Chemical, Biological, Radiological, Nuclear, (Explosive)
CERFP	CBRNE Enhanced Response Force Package
CONUS	within the Continental United States
CWA	chemical warfare agent
DETS	Decontamination Effluent Treatment System
cm	centimeter
EL	Environmental Laboratory
ERDC	Army Engineer Research and Development Center
EPE	Environmental Engineering Branch
EQI	Environmental Quality/Installations
Ft.	Fort
g	gram
GAC	Granular Activated Carbon
GC/NPD	Gas Chromatography/Nitrogen Phosphorus Detector
gpm	gallons per minute
IC	Ion Chromatography with UV/Visible Spectrophotometric detector
IDW	Investigative Derived Wastes.
JPEOCBD	Joint Program Executive Office Chem/Bio Defense
JPdM-CBRNE A&RS	Joint Product Manager -Chemical, Biological, Radiological, Nuclear, and Explosives (CBRNE) Analytics & Response Systems
JPM-P	Joint Program Manager-Protection
Kg	kilogram
km/hr	Kilometers per hour
kPa	Kilo Pascal(s)

L	liter(s)
LAS	Linear Alkylbenzene Sulfonate (a common surfactant form)
MCD	Mass Casualty Decontamination
mg	milligram
min	minute
MOPP	Mission Oriented Protective Posture
mph	miles per hour
MPD	Mass Personnel Decontamination
mL	milliliter(s)
MW	Molecular Weight
NAVFAC	Naval Facilities Command
NDCEE	National Defense Center for Energy and the Environment
NGB	National Guard Bureau
ng, ng/L	nanogram, nanogram per liter
NPDES	Non-point Discharge Elimination Discharge Elimination System
PFAS	Perfluorinated Alkyl Substance(s)
PFC	Perfluorinated Compound
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctanesulfonic acid
ppm	parts per million
ppb	parts per billion
ppt	parts per trillion
psi	pounds per square inch
RO	Reverse Osmosis
SLS	Sodium Laurel Sulfate
SM	Standard Methods
STB	Supertropical Bleach
SSTL	Senior Scientific Technical Leader
TSS	Total Suspended Solids

US	United States
UV	Ultraviolet
USACE	United States Army Corps of Engineers
USDoD	United States Department of Defense
USEPA	United States Environmental Protection Agency
WES	Waterways Experiment Station
WWTP(s)	Wastewater Treatment Plant(s)
µg	microgram
µS	microsiemens

1 Introduction

1.1 Background

A previous evaluation of the Decontamination Effluent Treatment System (DETS) was conducted on 27 June 2017, which focused on vehicle decontamination. Although the vehicular evaluation was very successful, many potential users became more interested in the application to wash water from Mass Personnel Decontamination (MPD). To address this, a second evaluation was conducted at the Engineer Research and Development Center (ERDC) facility in Vicksburg, MS on 24 May 2018, designed to demonstrate its effectiveness for MPD wash water. Subsequent tests were conducted to address several other key questions associated with the DETS, which are outlined in the objective.

1.1.1 The DETS

The DETS is an experimental water treatment system designed to treat contaminated water from decontamination (Figure 1). DETS contains the following series of unit processes: sand filtration to remove sediments and particulates, an ion exchange water softener to remove hardness, a granular activated carbon media filter to remove bleach, surfactants, oils and grease, and other organic compounds. The media filter processes are designed to be a pretreatment, removing constituents that could compromise the polishing and final processes, which is a six stage reverse osmosis system. The reverse osmosis (RO) system provides high rejection of organic and inorganic contaminants (Medina et al. 2012; Medina et al. 2015), including chemical warfare agents and radioisotopes. Detailed information on the DETS is provided in three previous publications (Dedeaux and Medina 2017; Medina et al. 2018a, 2018b; Medina 2019).

Figure 1. The Decontamination Effluent Treatment System (DETS).

1.1.2 Mass Personnel Decontamination (MPD)

Brame et al. (2016) discussed differences of decontamination in the battlefield (Green mission) vs. civilian decontamination (White mission), and between MPD and vehicle and equipment decontamination. MPD is the process of removing chemical, biological, radiological, and nuclear (explosive) (CBRNE) contaminants from large numbers of people. It could include events in which soldiers in appropriate MOPP (Mission Oriented Protective Posture) gear are exposed, but it also can include unprotected soldiers or civilians. The application of MPD to soldiers would likely occur on the battlefield. It is also conceivable that civilian MPD could be required either in battlefield operation affecting civilians or in a terrorist event within the United States. For an event affecting the civilian population in the United States, rapid application of MPD would be critical. A common approach is to suspend fire hoses between fire trucks and/or on ladders and set the nozzle to a mist to allow people to walk through and have contaminants washed off, which is sometimes referred to as gross decontamination (Figure 2).

MPD generally involves the application of large quantities of water to remove the CBRNE agent from the effected people. Studies have indicated that total removal of clothing greatly lessens the exposure. Mild soaps may frequently be used to improve removal of greasy agents. At the end, a wash water is generated that is contaminated with the removed CBRNE agents as well as with soaps, dirt, and organic material.

In addition, the U.S. Army Reserve and the National Guard maintains MPD capabilities, which are under groups that are referred to as CBRNE Enhanced Response Force Package (CERFP). CERFP units typically have mobile shower facilities in which CBRNE contaminants are removed from contaminated people (Figure 2). The water is collected and treated. MPD capability for combat applications is currently being reassessed by the Joint Program Manager – Protection (JPM-P).

Figure 2. MPD approaches. Left: a fire hose spray approach. Right: a shower system similar to those used by the National Guard and the Army Reserve.

1.1.3 Driver for MPD field evaluation

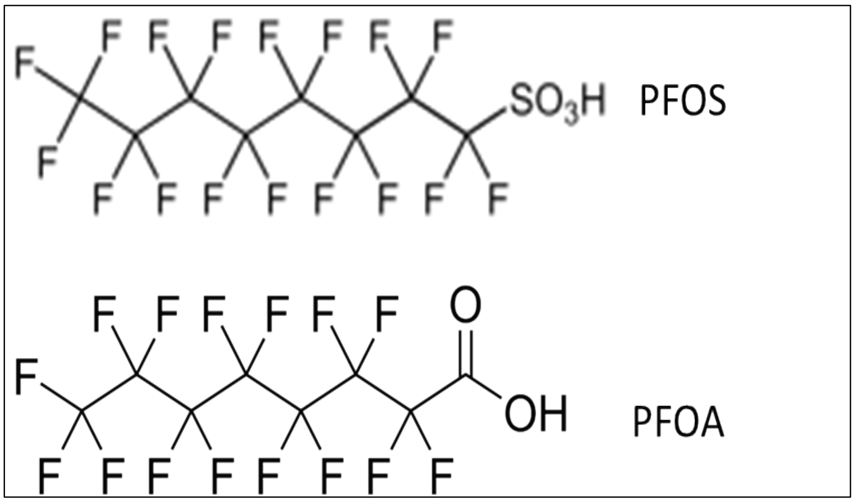
Previously (27 June 2017), ERDC evaluated the DETS for the treatment of wash water from vehicle decontamination (Medina et al. 2018). The demonstration was evaluated as very successful based on the removal of the target CBRN simulants and on the reliability of the system during the exercise (Medina et al. 2018). However, several potential users of the DETS indicated that application of the DETS to wash water from MPD would be a critical application.

1.2 Perfluorinated Alkyl Substances (PFAS)

Perfluorinated Alkyl Substances (PFAS) is the acronym used in general for Per-, Poly- fluorinated alkyl substances. These compounds have been shown to create chronic health issues (including kidney, liver and reproductive issues) and is a suspected carcinogen. Consequently, the United States Environmental Protection Agency (USEPA) developed a highly restrictive Drinking Water Health Advisory (0.070 mg/L PFAS. These compounds are commonly found in Aqueous Firefighting Foams (AFFF) as they are highly effective at suppressing fuel fires. As such, these compounds are commonly found at military sites containing military aviation. The U.S. Air Force has the most sites with PFAS contamination, however, all of the other services (Navy, Marine Corps, Army, and Coast Guard) also have contaminated sites.

There are hundreds, perhaps thousands of PFAS compounds. However, two in particular have been identified as problematic, these being Perfluorooctanesulfonic acid (PFOS) and Perfluorooctanoic acid (PFOA) (Figure 3).

Figure 3. Structures of PFOS and PFOA.



PFAS compounds are being found at many military installations and facilities. In addition to being found in increasing locations, they are also very challenging to degrade, particularly PFOS. For example, a study focusing on the use of advanced oxidation found that PFOA could be degraded by activated persulfate, but PFOS could not be (Park et al. 2016).

PFAS is a problematic contaminant for U.S. Military installations with firefighting training and maintenance areas. Our evaluation has indicated that there are sites and processes that have relatively small quantities (<250,000 gal) of PFAS. These include collection basins from firefighting training areas, equipment flushing/cleaning, and investigative derived waste (IDW). In these instances, a mobile treatment system, like the DETS, could be useful for addressing these small quantity sources.

1.3 Objectives

1.3.1 Objective 1. Demonstrate the DETS on simulated MPD water

The first objective was to document and analyze the testing of the DETS on a simulated wash water designed to mimic that from MPD, which is also referred to as Mass Casualty Decontamination (MCD). MPD will be the term used to describe this process in this report.

1.3.2 Objective 2. Integration of the DETS into existing CERFP practice

The second objective was to analyze how the DETS can be integrated into National Guard CBRNE Enhanced Response Force Package (CERFP) processes. This was accomplished by a field trip to a training exercise by the CERFP of Massachusetts Army National Guard and by a follow up integration exercise with the CERFP of the Louisiana Army National Guard on 11 January 2019.

1.3.3 Objective 3. Demonstrate transportability of the DETS System

The DETS is a trailer mounted system designed to be transportable to decontamination events throughout the U.S. Previously, the DETS had only been moved to different locations within the Waterways Experiment Station (WES) in Vicksburg, MS and it was necessary to show that the system could be moved long distances. Therefore, this report also discusses a test of the system to demonstrate its roadworthiness on a trip from Vicksburg, MS to Fort Leonard Wood, located just outside of St. Robert, MO, which was conducted from 24–26 July 2018.

1.3.4 Objective 4, Demonstrate efficacy of the DETS for treatment of PFOS

The DETS is designed for treatment of decontamination water. However, as an efficient, transportable, water treatment system, there has developed considerable interest in other possible applications, including water/wastewater treatment for deployed operations or disaster response (Waisner and Medina 2012; Medina et al. 2014), treatment of fracking water, or applications for remediation at military sites (Morrow et al. 2010). Therefore, a study was conducted to assess the DETS to treat PFOS, as a first step in assessing its effectiveness in addressing water contaminated by PFAS, which are highly problematic at military facilities throughout the U.S. and the world.

1.4 Approach

The DETS was set up at ERDC Vicksburg on 24 May 2018 (Figure 4). The MPD simulant was prepared in a 3,000 gallon blivet. Treatment progressed over a three day period in which 1500 gallons of the MPD simulant were treated.

1.5 Scope

The project scope consisted of series of pilot scale level studies performed using the DETS.

2 MPD Field Evaluation

2.1 Set-up

The DETS was set up at ERDC-Vicksburg on 24 May 2018 (Figure 4). The MPD simulant was prepared in a 3,000 gallon blivet. Treatment progressed over a three day period, in which 1,500 gallons of the MPD simulant were treated.

Figure 4. The DETS set up for the MPD Field Evaluation. Left: DETS set up. Right: Blivet used in the study as a source of simulant water.

2.2 Simulant MPD water

Grey water is wastewater generated from municipal type uses without latrine wastes (i.e., black water). Grey water includes showering, clothes washing, food preparation, and dish washing. A study conducted by Wang (2014) measured constituent concentrations of various grey water sources found at Forward Operating Bases and developed simulants for these sources. One of these simulants was for a source consisting of shower water only, and this was used as the general basis of the studies simulant. The team discussed the surfactant choice with the National Guard Bureau (NGB), and all mutually agreed that Dawn® Professional would work well for the exercise. Dawn Professional is a commercially available surfactant designed for industrial use, but it is also known to be mild (it is famously touted for its use to remove petroleum from wildlife). Malathion and cesium 133 (non-radioactive isotope) were chosen to simulate VX and cesium 137 respectively (see Brame et al. 2016, which establishes these as suitable simulants). Table 1 is the formulation used in this study to create 1,800 gallons (6,814 L) of contaminated water, and Figure 5 shows the constituents used.

Table 1. Formulation of MPD simulant based on 1,800 gallons (6,814 L).

Contaminant	Concentration (mg/L)
Malathion	10
Cesium (CsCl)	5
Surfactants	10
Sediment	5
Ash	6

Figure 5. Constituents used to spike the MPD simulant. From left to right: sediment, ash, Dawn soap, malathion, and cesium chloride.

2.3 Operation and sampling

The system treated the 1,800 gallons of simulant in about 2.5 hours of operational time over the four day period (from 24 – 27 May 2018). The operational flow rate was approximately 12 gallons/min (45.6 L/min). Samples were collected in triplicate near the end of the operational period. Samples were taken at the influent, effluent, and at an intermediate location in the system (between the granular activated carbon (GAC) filter and the RO system). This sample was collected so the performance of the pretreatment components (i.e., sediment filter, water softener, and GAC) could be compared to the RO system. The team did not sample the concentrate in this study, but it had been previously sampled in Medina et al. (2018). Malathion was analyzed using EPA method 8141A using Gas

Chromatograph with Nitrogen/Phosphorus Detector (GC/NPD). Cesium was measured using EPA method 6020A. Surfactants were measured following the method by Kloos (2015), which measures the surfactants as mg/L as linear alkylsulfonates (LAS).

2.3.1 Assessment of DETS integration into National Guard CERFP processes

The study included an assessment to determine how the DETS could fit into existing practices the CERFP's. This included the following three steps:

- Addressing questions from the NGB.
- A field visit to a CERFP exercise conducted by the Massachusetts Army National Guard.
- A field visit and DETS application exercise as part of a CERFP training exercise conducted by the Louisiana Army National Guard.

2.3.2 Road test

The roadworthiness test was conducted from 24 – 26 July 2018. The trailer mounted DETS was driven from Vicksburg, MS to Fort Leonard Wood in central Missouri (in close proximity of St. Robert). The total round-trip driving distance was approximately 1,100 miles (1,760 km). The trip included several areas of curving and mountainous roads, particularly in northeast Arkansas and just south of St. Robert. The DETS was also taken briefly on dirt roads at Fort Leonard Wood. In addition, the DETS was taken on a 300 mile trip from Vicksburg, MS to Baton Rouge, LA as part of the integration exercise with the Louisiana Army National Guard.

2.3.3 PFOS treatment

Professional knowledge indicated that processes on the DETS should be effective for treating PFAS. For example, the DETS has ion exchange and GAC processes, both used for control of PFAS (Ross et al. 2018). Furthermore, RO, which is perhaps the most effective water treatment process currently available, should be especially effective at large molecules like most PFAS.

To test this, a study was conducted on 02 November 2018 testing removal of 30 – 40 μg/L PFOS spiked water using the DETS (Figure 6). The first study focused on removal of PFAS using RO only. A second, studied removal by the pretreatment steps (sand bed, water softener, and GAC) and polishing with RO. Both studies were conducted at treatment rates of ~10 gpm for 30 minutes, treating ~300 gal per test. The studies were assisted by students of the University of Mississippi's Introduction to Chemical Engineering, taught by Dr. Brenda Prager (Assistant Professor, Chemical Engineering).

Analyses were conducted by the Environmental Chemistry Branch of the ERDC. Samples were analyzed by HPLC-MS/MS using a Vanquish LC and a QExactive Orbitrap mass spectrometer (ThermoFisher). The mobile phase was a gradient method of aqueous ammonium acetate and methanol. The mass spectrometer was operated in PRM mode allowing for detection of fragments of the parent compound.

Figure 6. Pictures of the 02 November 2018 testing of the DETS system for the treatment of PFAS.

3 Results

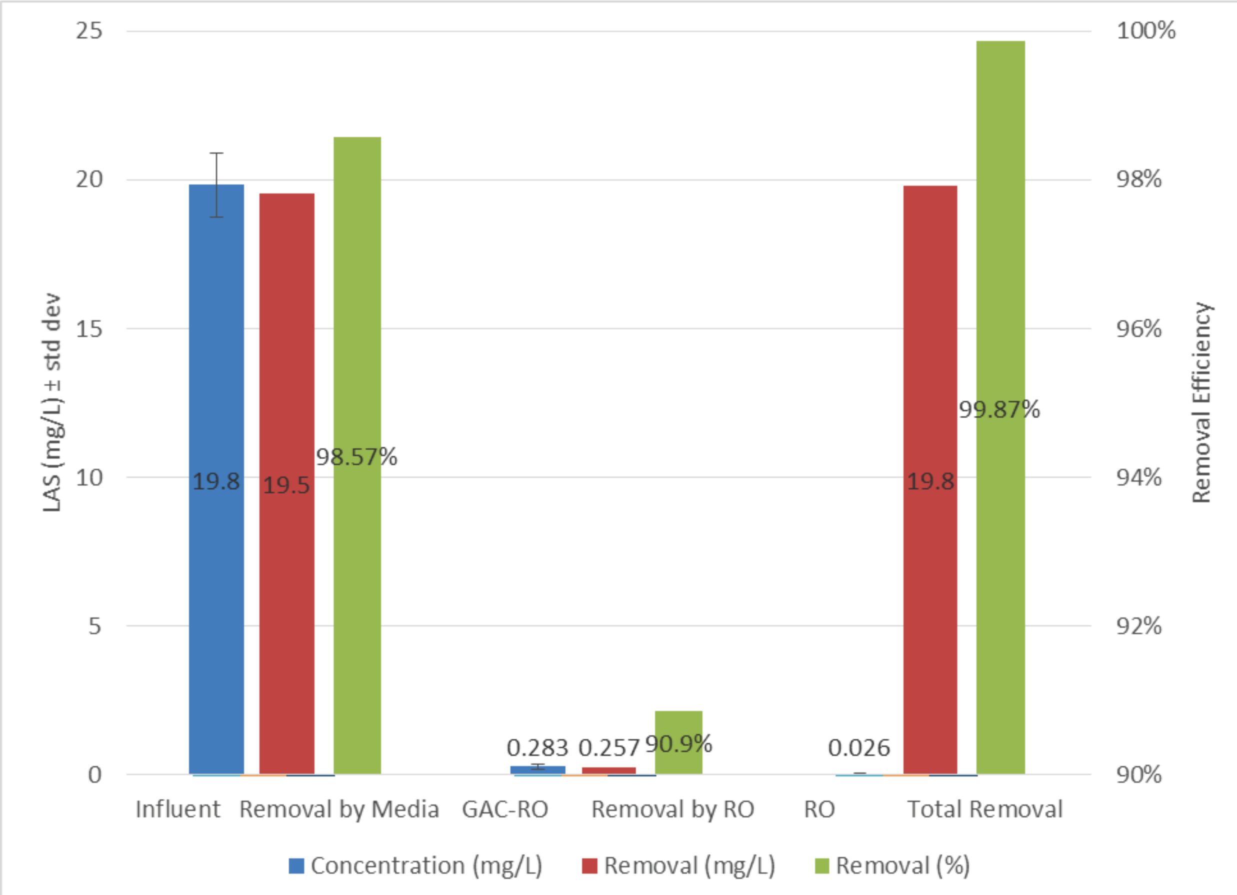
3.1 MPD demonstration

Figures 7–9 are designed to compare the removal of surfactants (Figure 7), cesium (Figure 8), and Malathion (Figure 9) by different portions of the treatment system, including the total treatment. The figures are divided into column sets showing the influent concentration, the amount removed by the processes being evaluated, and the percentage removal. The first set of columns show the initial concentration and the removal by the pretreatment processes. The second set of the columns focuses on the removal by the RO system based on the influent from the pretreatment steps. The last columns summarize the total treatment by the entire system.

3.2 Surfactant removal

Figure 7 gives the removal of surfactants during the MPD evaluation. The initial surfactant concentration was 19.8 mg/L as LAS. The pretreatment processes resulted in 98.57% removal, which left a residual concentration of 0.283 mg/L. The RO system removed 90.9% of the residual concentration, which resulted in a total removal of 99.87%.

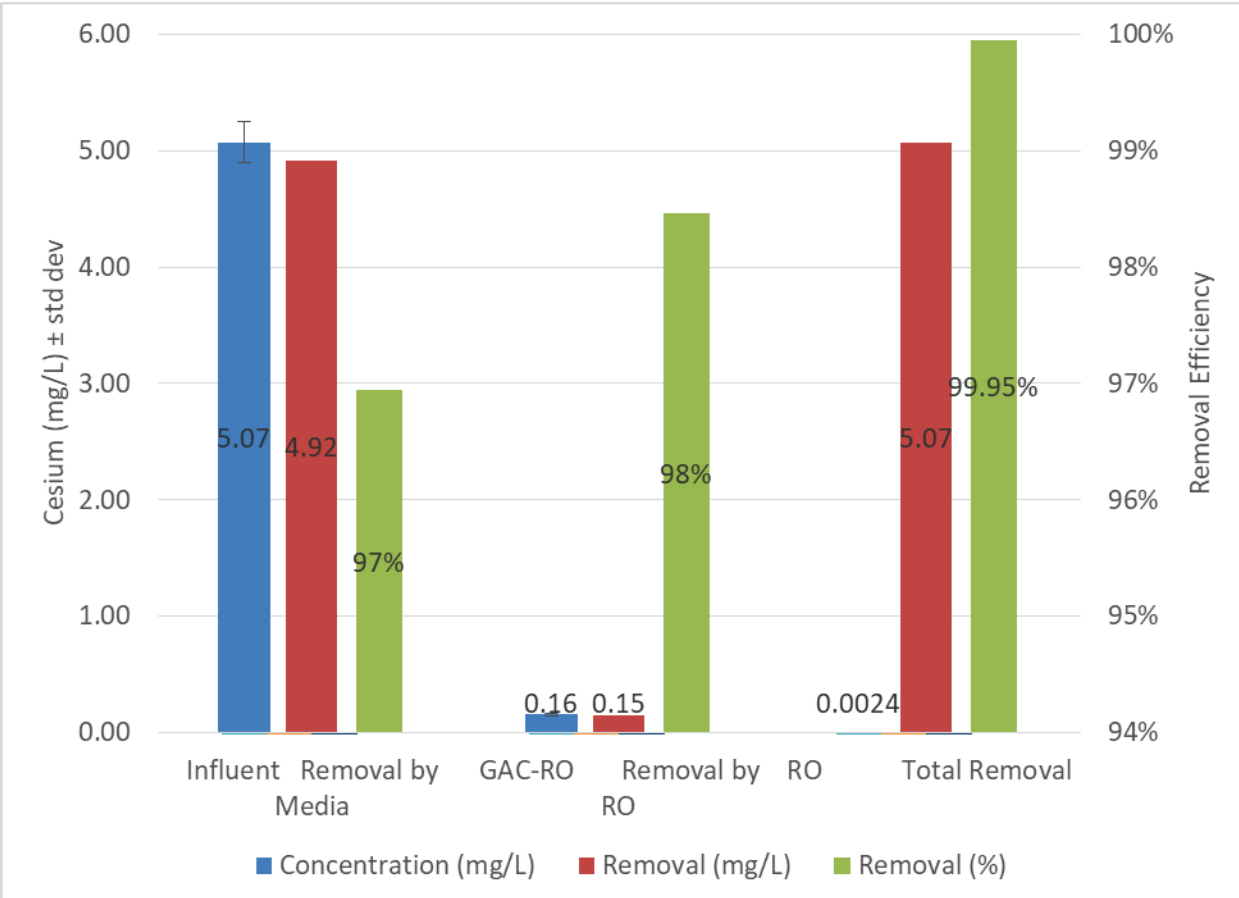
Figure 7. Removal of surfactant (as LAS) during the MPD evaluation.



3.2.1 Cesium removal

Figure 8 summarizes the removal of cesium during the experiment. The initial cesium concentration was 5.07 mg/L. The pretreatment steps removed 97% of the cesium, leaving a residual concentration of 0.16 mg/L. This entered the RO system, which removed 98% of the remaining cesium, leaving a concentration of 0.01 mg/L and resulting in a total removal of 99.95%.

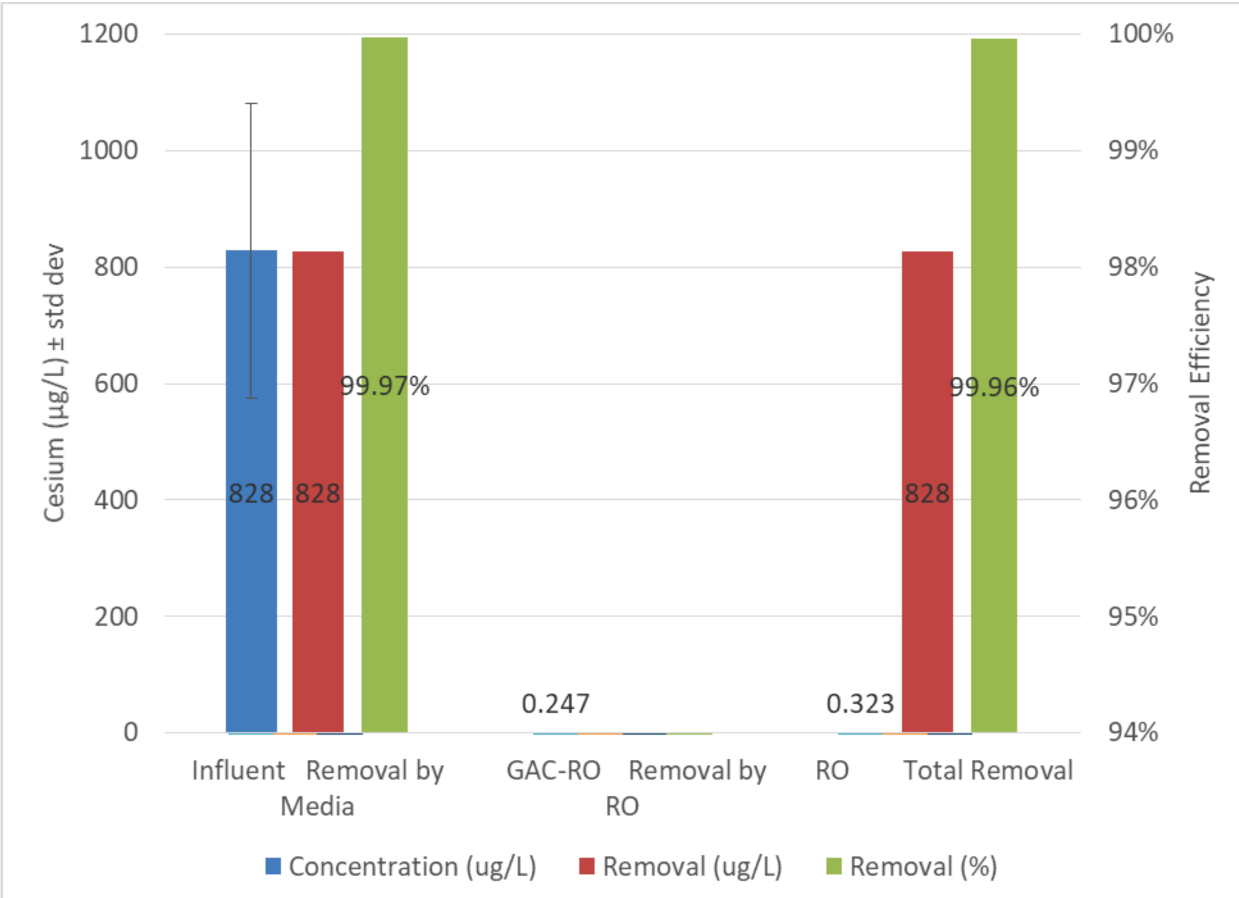
Figure 8. Removal of cesium during the MPD evaluation.



3.2.1 Malathion removal

Figure 9 summarizes the results of Malathion removal. The initial Malathion concentration was 828 µg/L. The pretreatment processes removed 99.97% of the contaminant, reducing the concentration 0.25 µg/L. The concentration after RO treatment was essentially the same, giving a total Malathion removal of 99.96%.

Figure 9. Removal of Malathion during the MPD evaluation.



3.3 Assessment of DETS integration to CERFP operation

3.3.1 Questions from the NGB

The NGB submitted several questions about the DETS. These were categorized into three categories – Operation; Maintenance, Deployability, and Safety; and Training. The NGB questions and the ERDC responses are provided in Table 2. Assessment of the questions and responses indicated that there are no unsurmountable obstacles to integrating the DETS with CERFP practices.

Table 2. NGB questions and answers.

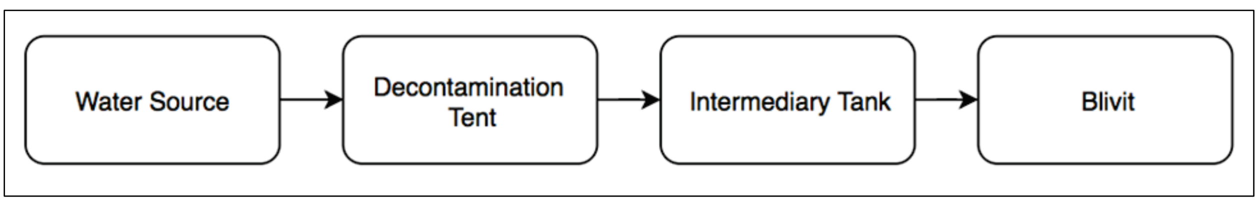
NGB Questions	ERDC Response
OPERATION	
After spiking, what is your process for ensuring Malathion is effectively removed from the training water storage blivet?	For this demonstration, we are taking samples and analyzing them in the laboratory. Malathion was analyzed using EPA method 8141A. Cesium is measured using EPA method 6020A.
Based on the Wet-Blub Globe Temperature (WBGT) what are the range of temperatures the DETS has been operated?	To date, the DETS has only operated in moderate temperature conditions, ranging from 70–95 °F. The treatment processes used by the DETS are chosen to be effective at a very wide range of temperatures. However, it is conceivable that freezing could occur in the system lines at very extreme cold.
How many personnel monitors are required to keep the DETS in operation?	As currently configured, one. We would like to use controls that can allow remote monitoring and operation. But we will not be able to get to that point for this funded project.
Has the DETS been tested during night time or other low light conditions?	No, not as of now. The operation of the unit should be possible at low light. The control panel is LCD and highly visible in darkness. However, hooking up hoses and prep work could be hampered by low light. This would be similar, however, to hooking up any hoses related to the shower/blivet system. The DETS has its own generator, and supplemental lighting could be easily accommodated.
How does the DETS alert personnel to a systematic/operations problem?	This is something we are working on. As of now, any serious problem will result in system stopping. We would like to develop it so it will buzz a device someone is wearing. We also would like to develop the concept of can actually be remotely monitored.
Does the DETS require a warm up period (minutes)?	When starting an empty DETS, the pump must fill up the media tanks and then pressure must then build to start the RO. This can take up to 5 minutes. If the DETS is filled with water, then it can be started within 1–2 minutes.
What is the DETS fuel requirement – diesel, gasoline, multi-fuel engine?	The generator in our current system is a diesel. It should be compatible with JP-8. However, the DETS is a test system, not a final product. So, it would be possible to specify exactly the fuel source desired in developing a final product. The DETS can also be directly plugged into 220V power.
MAINTENANCE – DEPLOYABILITY – SAFETY	
What is the heaviest component that must be replaced by a decontaminations team member?	The system can carry enough fuel for three days of operation. If needed to be manually replaced, the fuel could be heavy. RO cartridges weigh about 10 lbs. However, it is unlikely these would need to be replaced. The prefilter to the RO unit would probably need to be replaced if there is a lot of sediment. They weigh 1–2 lb.
After 1–2 hours of training/test run-time, is there a part of the DETS most likely to develop leakage?	The most vulnerable place for leaks would be the hose linkages. This would be similar in case for linkages already used for water collection into the blivets.
Does the DETS/trailer have any exterior light sources (e.g., control panel)?	The control screen is lit. Additional lighting could be added and easily operated using the generator.
Has the DETS/trailer been loaded onto a military aircraft?	No, not as of now. Its size and weight should be within airlift or air shipping requirements.
Will the CERFP have to provide generator support for the DETS?	The DETS does have its own generator as currently configured. This could be removed if generators are commonly available.

Are there any special or non-standard tools needed to maintain the DETS?	There is a filter wrench for the sediment filter mentioned above. It comes with the unit.
Is the DETS trailer certified for US highway/road travel?	Yes. It is a certified trailer.
TRAINING	
What is the estimated training time to operate the DETS (e.g., 8–24 hours)?	We are thinking a 4–8 hour class to cover set up, operation, shutdown, and basic problem solving.
How often should start-up and shutdown procedures be conducted for the DETS?	We recommend monthly inspection. The generator should be run every two months unless winterized. The generator battery should be maintained on a monthly basis.
What safety equipment is needed during training (e.g., eyewear, gloves)?	At a minimum, safety glasses and gloves. However, training should actually focus on simulating the protection needed for the CBRN agents.

3.3.2 Field evaluation of Massachusetts National Guard CERFP training

From 15 – 17 May 2018, an ERDC Team observed a CERFP training of the Massachusetts National Guard. The purpose of this visit was to familiarize the DETS team with practices of CERFP units and determine potential tie-in points for the DETS. Figure 10 is a simple schematic of the system used for MPD and collection of the contaminated wash water.

Figure 10. Schematic of water flow in current CERFP shower system.



The Massachusetts National Guard used a tent shower system, which is common throughout the CERFP units around the country (Figure 11). The shower systems contain a collection system that collects contaminated water and moves it to blivets for storage (Figure 11, right image).

Figure 11. Key elements in the shower system used by the Massachusetts National Guard. Left: the shower tent. Middle: collection tank. Right: blivet for collection of MPD wash water.

Two areas appeared interesting in terms of collecting water for DETS treatment. First, the collection tank, which collects discharge from separate shower facilities, appeared to be a potential location in which the DETS could be connected (Figure 10, middle image). However, the tank is small, and would not provide enough water for continuous operation of the DETS. A second location is the blivet, which is the final storage of the collected wash water. The blivet appears to be the best place to install the DETS. Some blivets have two valves, which would make DETS installation highly effective and very easy to accomplish.

3.3.3 Louisiana National Guard integration exercise

A two person ERDC team took the DETS to a Louisiana Army National Guard CERFP decontamination exercise on 10 and 11 January 2019. During the exercise, the DETS was successfully integrated into the decontamination element (Figure 12). Minor modifications to the hose fittings were required, changing the size of the fittings to fit their blivets (from 1 in. to 1.5 in.). Since the blivet fittings could vary from CERFP units, a series of connections should be carried.

Figure 12. Integration of DETS into the Louisiana National Guard CERFP 10–11 January 2019 exercise.

Darian Moore of the NGB attended the exercise and shared some questions from his notes. Team responses are in italics.

- Can the system have enhanced modularity? *Each system component stand-alone? Yes, if this is of interest, we can develop a modular system that would allow elements to be removed and/or added.*
- Can DETS by modified to run off of any generator? National Guard generators? *Certainly, the system runs off of 240V 40 Amp power. So, it can run off of any 240V 20 Amp source. If there is a desire to change the voltage (such as to 220V or 110V power), it should be possible by making some modifications to the water treatment units.*
- Can the size of the media columns be reduced while maintaining same capacity? *In order to maintain a capacity of operation for three days, the relative amounts of media must be maintained. Further, the media filtration process requires a portions of freeboard space above the surface of the media. However, the media configuration can be modified. For example, the media steps can be divided into a series of smaller vessels. This might allow for a different configuration.*
- Can DETS be mounted on a different trailer? *Yes, we could explore different kinds of trailers. One thought we have had was developing a trailer with an enclosure to provide additional protection on the road. Another thought could be to mount the DETS components on a skid if it would be easier to move it by flatbed truck.*

3.4 Road test

3.4.1 Preparation

To prepare for the trip, a tool and supply box was loaded to the trailer (Figure 13). Larger tools were strapped to the trailer floor for easy access. The pulse dampener, which could be prone to excessive vibration, was removed and also strapped to the trailer floor.

Figure 13. Supplies and modifications for the road test. Left: tool and supply box, Center: auxiliary jack strapped to trailer floor. Right: pulse dampener removed for the trip and strapped to trailer floor.

3.4.2 Evaluation of DETS on road test

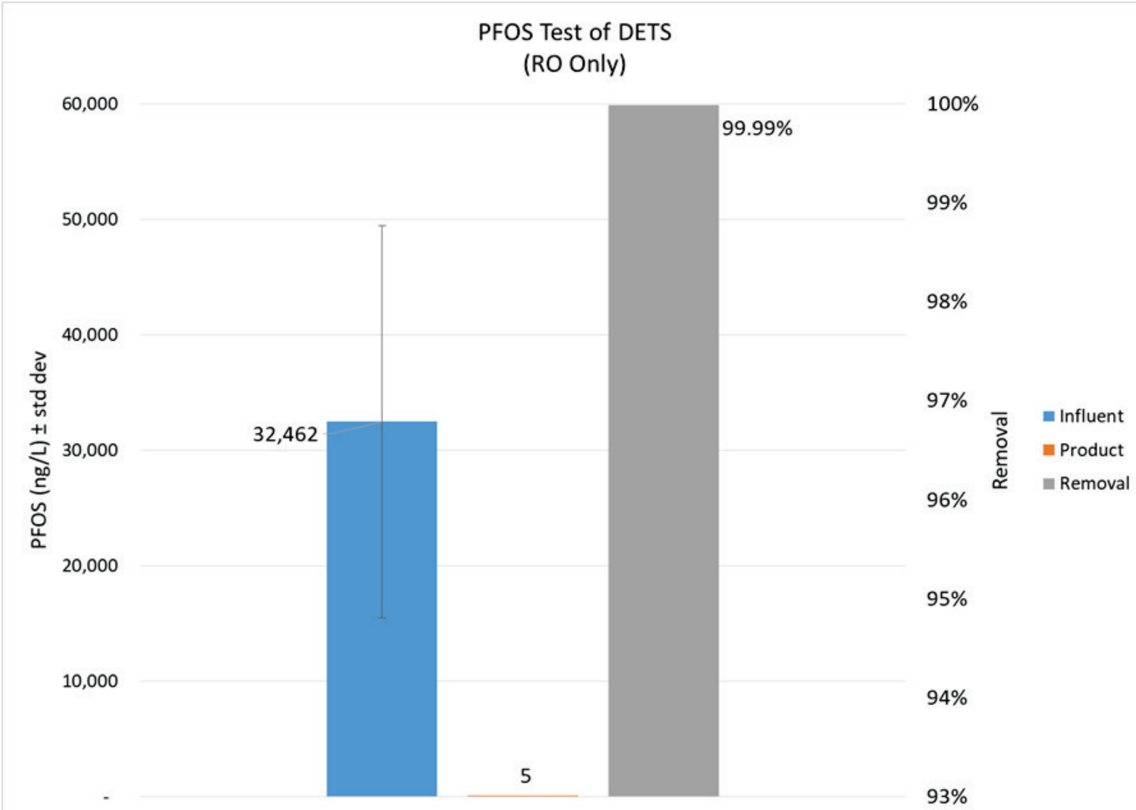
During the road trip there were no problems with the transportation of the DETS. The drivers were able to maintain speeds up to 70 mph (113 km/hr) without any fishtailing or other control problems. Caution was applied during winding mountain roads, but no problems were encountered. The DETS trailer had no problem being driven on dirt roads. One incident occurred early in the trip which the control panel housing became loosened. However, the driving team noticed this and were able to repair the loosened fittings. Once tightened, no further problems were encountered. It is likely that the bolts were not sufficiently tightened before the trip. With this issue addressed, DETS is deemed fully road worthy.

3.5 PFAS treatment

3.5.1 RO only

RO is very effective at removal of PFOS (Figure 14). The initial concentrations were over 32,000 ppt. The RO process reduced the concentration to 5 ppt, which is >99.99% removal. The removal was far below the 70 ppt EPA Drinking Water Health Advisory level and also below the minimum EPA reporting limit of 40 ppt.

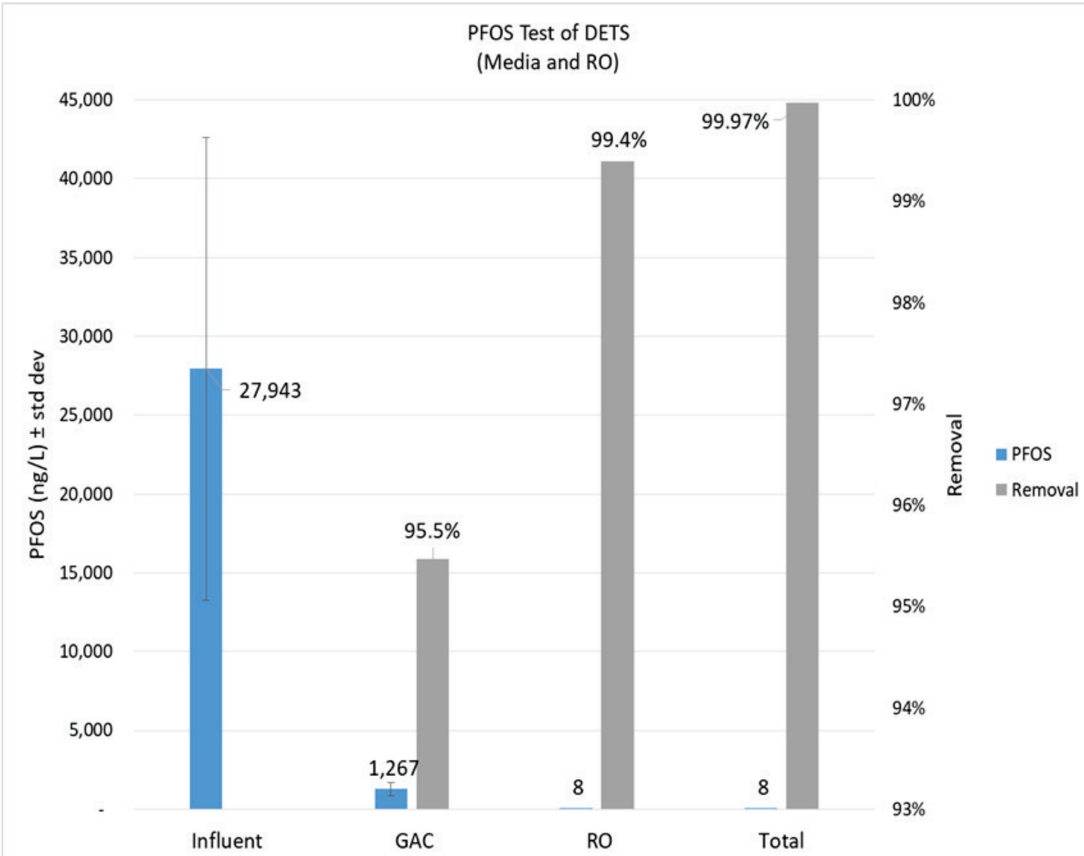
Figure 14. Results of PFAS removal by the DETS using the RO process only.



3.5.1 Pretreatment processes and RO

Figure 15 summarizes the result of the second test, which include the DETS pretreatment steps of sand filtration, ion exchange for water softening, and the GAC process. Sampling was conducted after the GAC process and the RO process. The results indicated that these media treatments also very effective at PFOS removal, reducing the initial concentration of 27,000 ppt to 1,200 ppt; a reduction of more than 95%.

Figure 15. Results of PFAS removal by the DETS using the pretreatment steps up to the GAC process and the RO process.



4 Discussion

4.1 Application of DETS to MPD

4.1.1 Treatment of the studied constituents

The study indicated that treatment of the target constituents (i.e., surfactants, cesium, Malathion) exceeded 99.8%. The residuals of cesium and Malathion were very small (2 µg/L and 0.323 µg/L, respectively). Analysis of the treatment system indicated that the pretreatment step was highly effective at reducing the contaminant concentration, removing most (97% or more) of the initial concentration. RO proved to be an effective polishing step for surfactant and cesium treatment. RO polishing was not as noticeable for Malathion removal, but this was likely due to the fact that the removal of the Malathion by the pretreatment steps was so high that the remaining concentration was difficult to resolve.

4.1.2 Relation of the study to people treated

Studies have indicated that a typical shower in the U.S. uses 17.2 gallons (65.4 L) in a shower lasting 8.2 minutes. At this rate, the 1,800 gallons (6,840 L) would account for the treatment of about 100 people. However, it is reasonable to assume that an MPD would have a faster showering rate, two minutes per shower would be reasonable. In this case, the volume would be equivalent to that of 400 people. Therefore, the demonstration represented a volume of wastewater representative to a small, but significant event.

The 1,800 gallons was treated in 2.5 hours, giving an average treatment rate of 12 gal/min (45.6 L/min) or 720 gal/hr (2,736 L/hr). Using these rates, a single DETS should be able to treat the wash water generated from 1280 people in eight hours of operation, and for 3,840 people in 24 hours of operation.

4.1.3 Application to National Guard CERFP processes

The assessments conducted as part of the study indicated that the DETS could be integrated with National Guard CERFP activities and hooked into the end blivets. It can also be transported easily over 1000 miles. Considering that future versions could be upgraded, it appears that the

DETS systems could be adapted to CERFP activities with minimal disruption to existing activities.

The DETS would add the benefit of allowing blivets to be safely cleared of water, allowing for no limits to the decontamination process. Furthermore, water reuse could be very useful in areas with limited water resources.

4.2 Treatment of PFOS and implication for PFAS sites

The PFAS testing indicated that the DETS is a very effective method for PFOS removal. Although the pretreatment steps (sand filtration, ion exchange, and GAC) removed over 95% of the PFOS, the water still had concentrations above that of the EPA Drinking Water Advisory. Also, this study did not evaluate the effectiveness of each of the pretreatment processes. The team expects the removal by the sand filter to be minimal. Ion exchange can be very effective for PFAS treatment, but the IX material in the DETS is designed for water softening, so it might not be highly effective. GAC is a widely used approach for PFAS contaminated water.

The RO process was very effective, both in conjunction with the pretreatment steps, and also by itself in reducing PFOS concentrations below the 70 ppt (ng/L) threshold. This is not surprising since RO is one of the highest quality treatment approaches available for water/wastewater treatment.

PFOS is just one of the many forms of PFAS, but it is one of the most important forms in terms of its toxicity and persistence. The team expects the processes to continue to be effective for other PFAS forms, although shorter chain PFAS types might be somewhat harder to remove either by adsorption or by RO. Nevertheless, it is expected that the DETS would be effective for all PFAS forms.

In addition, the processes of the DETS could be adjusted to optimize it for PFAS treatment. Since most PFAS collected water is not expected to have coarse particulates, the sand filter could be replaced or augmented with a cartridge filter, which are generally designed to remove very fine particulates. The water softening step could be removed, unless there is an unusually high hardness. The GAC filter could be kept to remove organic constituents like fuels, oils or solvents, which are sometimes found with PFAS as they were sometimes burned to simulate an aircraft fuel fire.

The water could then go straight into the RO process, which has been demonstrated to be highly effective for PFOS.

Alternatively, a bed ion exchange material that has a high affinity for PFAS could be applied, such as produced by Purolite, could be applied between the GAC and RO process. Purolite has a very high removal capacity for PFAS compounds, so it would then be the primary treatment process, with the RO serving as a safety process.

4.3 Concentrate associated with reverse osmosis

RO is a very effective treatment technology, but it has the disadvantage of generating a concentrate. The DETS has a high water recovery of 80 – 90% (Medina et al. 2018a, 2018b). Still, 20% of 100,000 gallons (378,000 L) treated would leave 20,000 gallons (>75,000 L) left as concentrated waste. However, as indicated in Medina et al. 2018b, concentrate generated from decontamination can be run back through the DETS system, potentially several times. Similarly, the concentrations of PFAS at most sites is on the order of 100 ppb or lower. The salt water membranes of the RO unit are designed to effectively treat much higher concentrations. So, it would be reasonable to expect that the concentrate could be treated, perhaps 2 or 3 times. Table 3 summarized expected concentrate residuals assuming 80% recovery for a 100,000 gallon waste stream. Three passes reduces this concentrate volume to just 160 gallons (645 L).

Table 3. Expected concentrate residuals after RO treatment of 10.000 gallons (37,800 L) assuming 80% recovery with concentrate treatment passes. This is then related to estimated cost savings assuming incineration at $3.80/gallon.

Number of concentrate treatment passes	Residual (gallons/liters)	Estimated cost reduction of PFAS contaminated water disposal (incineration).
0	20,000/75,600	$304,000
1	4000/15,120	$364,800
2	800/3042	$376,960
3	160/645	$379,392

Offsite disposal of water contaminated with CWA or with PFAS would likely involve incineration. A cost of $3.80 per gallon incinerated has been cited to ERDC in discussions with NAVFAC (Naval Facilities Command) and AFCEC (Air Force Civil Engineering Center), two organizations that manage multiple sites with PFAS contamination. This cost is the same even if the contaminant is diluted or concentrated. Therefore, using the RO process to concentrate the contaminants can greatly reduce disposal costs. Table 3 summarizes the cost reduction assuming the DETS treats 100,000 gallons and achieves 80% recovery, and how it increases with concentrate treatment passes.

5 Conclusions

Based on this study, the following conclusions can be derived:

- The DETS was highly effective treating the MPD effluent and would allow discharge, or potentially reuse, for further decontamination.
- The DETS can be easily applied to collection blivets at the end of the MPD process used by most CERFP's.
- The DETS proved to be road worthy in two, long trips, the longest over 1000 miles.
- The DETS was effective at treating PFOS in a limited study, both with the RO process only, and with the pretreatment processes and RO.

References

Brame, J., V. F. Medina, I. Smith, and L. Procell. 2016. *Composition of CBRN Decontamination Effluent and Development of Surrogate Mixtures for Testing Effluent Treatment Technologies*. ERDC-SR-16-2. Vicksburg, MS: U.S. Army Engineer Research and Development Center (USACE). http://acwc.sdp.sirsi.net/client/en_US/search/asset/1050948.

Carluccio, T. 2019. PFAS — A national problem with personal costs. *Water Online*. Accessed on 14 March 2019. https://www.wateronline.com/doc/pfas-a-national-problem-with-personal-costs-0001

Dedeaux, R., and V. F. Medina 2017. New technology recycles water for DECON operations. *Army Public Works Digest* 29(4):21.

Kloos, R. 2015. *Measuring "LAS" based surfactants with hach barcode cuvette testing TNTPlus 874*. Application Note. Loveland, CO: Hach Company.

Medina, V. F., S. A. Waisner, S. Cosper, G. Rodriguez, D. Gilbert, R. Tucker, I. MacAllister, R. Scholze, J. Burken, and J. Wang. 2014. *Assessment of Anaerobic Digestion for Contingency Base Waste*. ERDC/EL TR-14-3. Vicksburg, MS: U.S. Army Engineer Research and Development Center (USACE). http://acwc.sdp.sirsi.net/client/search/asset/1034690.

Medina, V. F., S. A. Waisner, J. L. Johnson, R. Wade, J. Mattei-Sosa and R. Brown. 2012. *Laboratory Study for Evaluating Performance of Unit Processes to Treat the Electrodialysis Reversal (EDR) Reject Stream for the Proposed Fort Irwin Water Treatment Plant*. ERDC/EL TR-12-30. Vicksburg, MS: U.S. Army Engineer Research and Development Center (USACE). http://acwc.sdp.sirsi.net/client/search/asset/1013680.

Medina, V. F., J. L. Johnson, S. A. Waisner, R. Wade, and J. Mattei-Sosa. 2015. Development of a treatment process for electrodialysis reversal reject with intermediate softening and secondary reverse osmosis. *Journal of Environmental Engineering* 141(7). doi: 10.1061/(ASCE)EE.1943-7870.0000929.

Medina, V. F., S .A Waisner, E. Martinez-Guerra, and J. Johnson. 2018a. Developing and testing the decontamination effluent treatment system. *Army Chemical Review*. PB 3-18-1.

Medina, V. F., S. A. Waisner, E. Martinez-Guerra, J. Johnson, J. Brame, E. Gao, and M. Page. 2018b. *Simulated Vehicle Decontamination and Field Evaluation of the Decontamination Effluent Treatment System (DETS) and Associated Background Studies*. ERDC TR-18-19. Vicksburg, MS: U.S. Army Engineer Research and Development Center (USACE).

Medina, V. F. 2019. DETS proves versatile and effective. *The Corps Environment*. 20:27.

Morrow, A. B., V. F. Medina, and B. Extine. 2010. *Biodegradation of Perchlorate in Laboratory Reactors under Different Environmental Conditions*. ERDC/EL TR-10-14. Vicksburg, MS: U.S. Army Engineer Research and Development Center (USACE). http://el.erdc.usace.army.mil/elpubs/pdf/trel10-14.pdf

Park, S., L. S. Lee, V. F. Medina, A. Zull, and S. A. Waisner. 2016. Heat-activated persulfate oxidation of PFOA, 6:2 fluorotelomer sulfonate, and PFOS under conditions suitable for in-situ groundwater remediation. *Chemosphere*. 145:376–383. https://doi.org/10.1016/j.chemosphere.2015.11.097.

Ross, I, J. McDonough, J. Miles, P. Storch, P. T. Kochunarayanan, E. Kalve, J. Husrt, S. S. Dasgupta, and J. Burdick. 2018. A review of emerging technologies for remediation of PFASs. *Remediation*. 28:101–126.

Waisner, S. A. and V. F. Medina. 2012. Wastewater treatment for deployed military forces and disaster response. 2011 *McGraw Hill Yearbook of Science and Technology*. McGraw Hill Publishers. ISBN 978-007-177403-1. p. 303-305.

Wang, H. 2014. *Membrane Bioreactor/Ultra Low Energy Reverse Osmosis Membrane Process for Forward Operating Base Wastewater Reuse*. SERDP Project ER-2238. Alexandria, VA: Strategic Environmental Research and Development Program (SERDP).

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
July 2019	Final Report	

4. TITLE AND SUBTITLE
Simulated Field Evaluation of the Decontamination Effluent Treatment System (DETS) for Wash Water from Mass Personnel Decontamination (MPD), Road Test, and Evaluation Treating Perfluorinated Alkyl Substances (PFAS)

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT

6. AUTHOR(S)
Victor F. Medina, Scott A. Waisner, Jose Mattei-Sosa,
Edith Martinez-Guerra, Christopher S. Griggs, Jacob M. Lalley,
David L. Henderson, Lee C. Moores, and Brenda H. Prager

5d. PROJECT NUMBER
611102AH68

5e. TASK NUMBER

5f. WORK UNIT NUMBER
P2 455017

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Corps of Engineers
Environmental Laboratory (EL)
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Department of Chemical Engineering
University of Mississippi
140 Anderson Hall
University, MS 38677-1848

8. PERFORMING ORGANIZATION REPORT NUMBER
ERDC/EL TR-19-9

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Headquarters, U.S. Army Corps of Engineers
Washington, DC 20314-1000

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
A previous ERDC report described the effectiveness of the Decontamination Effluent Treatment System (DETS) for the treatment of wash water generated from simulated CBRN decontamination. This study compliments that previous one in that it focused on the treatment of a simulant from Mass Personnel Decontamination (MPD). Treatment of both cesium 133 (used as a surrogate for radioactive cesium 137) and Malathion (as a surrogate for organophosphate chemical warfare agent) equaled or exceeded 99.95%. The conclusion was that the system proved to be highly effective at treating wash water from MPD, which would allow discharge or even potential reuse for more decontamination. The ERDC team conducted studies that confirmed that the DETS could be integrated into CERFP activities with minimal disruption. In addition, the DETS underwent a long road test in which it was driven for over 1000 miles from Vicksburg MS to St Robert MO (Fort Leonard Wood) and back. The conclusion is that the DETS could be moved around the United States as needed to respond to decontamination events. The DETS was also used to treat PFOS, a perfluorinated compound found in legacy firefighting foams, and the DETS processes achieved 99.97% removal of ~30 µg /L PFOS.

15. SUBJECT TERMS
Biological decontamination, Radioactive decontamination, Decontamination (from gases, chemicals, etc.), Sewage--Purification

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (include area code)
Unclassified	Unclassified	Unclassified	SAR	40	