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technical BRIEF
BUILDING A SCIENTIFIC FOUNDATION FOR SOUND ENVIRONMENTAL DECISIONS

Full-Scale Decontamination of *Bacillus* Spores from Drinking Water Infrastructure

Introduction

The drinking water distribution system is vulnerable to contamination, which presents challenges to maintaining good water quality and ensuring water availability. Decontamination of drinking water systems, following an intentional contamination incident or a natural disaster, is critical for the return of the system to operation and for restoring public confidence in the system's safety. The U.S. Environmental Protection Agency (EPA) is the lead federal agency responsible for working with water utilities to protect water distribution systems from contamination and to clean up systems that become contaminated. The effect of terrorist attacks using the causative agent of anthrax (*Bacillus anthracis* spores) against critical infrastructure, including the drinking water sector, has been an important research concern of the Agency. This technical brief describes EPA research to examine full-scale decontamination of *Bacillus* spores from drinking water infrastructure after a contamination event with *B. globigii*, a nonpathogenic surrogate for anthrax.

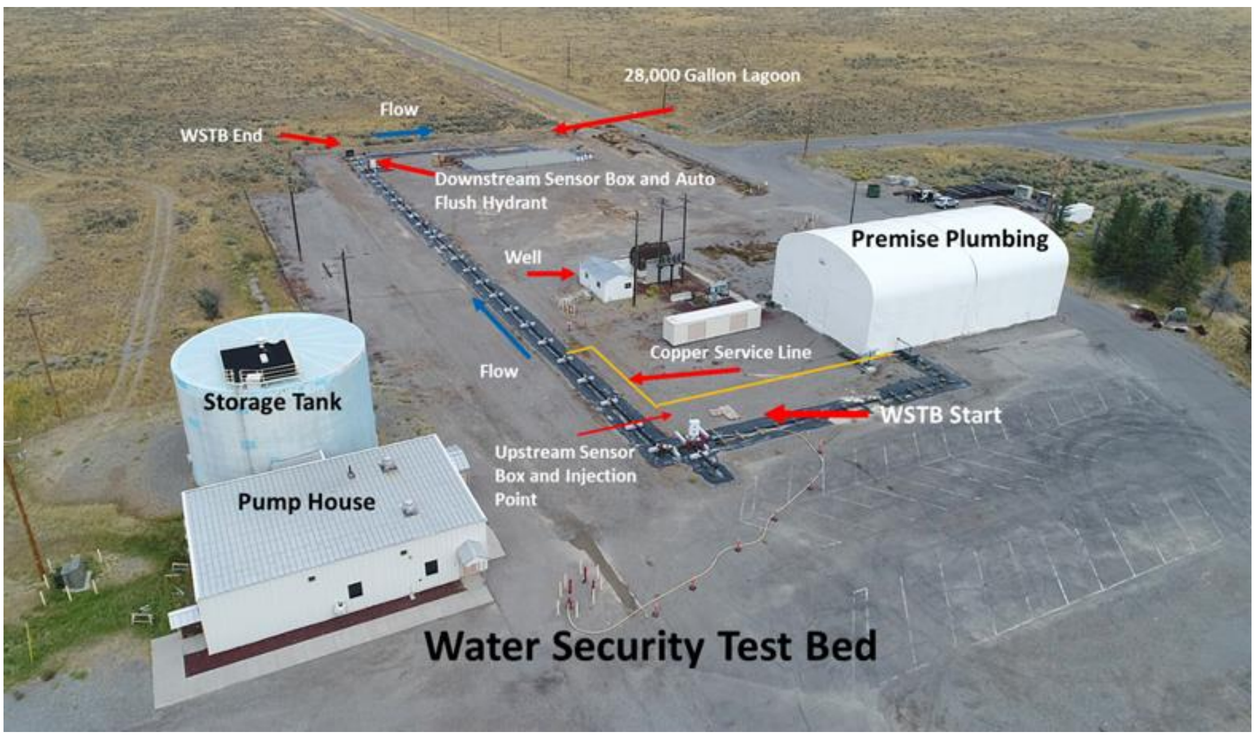

Figure 1: Overhead view of the Water Security Test Bed.

In collaboration with the U.S. Department of Energy's Idaho National Laboratory (INL), EPA began construction of the Water Security Test Bed (WSTB) facility in 2014 on the INL grounds

(Figure 1). The core of the WSTB facility was constructed with 450 ft of previously used 40-year-old 8-inch cement-mortar lined iron drinking water pipe (note that English units are used throughout this document as they are customary in the drinking water field). The pipe was excavated from the INL grounds and reassembled above ground. The pipe is pressurized and has chlorinated groundwater flowing through it in the same manner as a buried water distribution pipe. The white tented building in Figure 1 contains a full-scale household plumbing system with appliances that are connected to the main WSTB facility pipe through a 1-inch copper service connection.

Summary of decontamination experiments

The WSTB is a unique research facility that provides a venue for full-scale research on topics of interest to the drinking water community. The results presented here show that several infrastructure decontamination technologies are effective at killing spores and removing them from drinking water infrastructure when tested at a full scale. Key findings from the full-scale research on BG spore decontamination at the WSTB facility are as follows:

- Compared to smaller scale studies, the effectiveness of BG decontamination with chlorine dioxide in the WSTB pipe was decreased, possibly due to real world effects such as chlorine dioxide demand from the pipe, dead end/low flow sections, and temperature. As chlorine dioxide is a powerful disinfectant, it is unlikely that other disinfectants would perform better.

- Physical scouring, or pigging, with a nozzle effectively removed many of the BG spores from the pipe surface. Decontamination efficacy was enhanced when chlorine was added after pigging, but low numbers of spores were still detected on the pipe surface. Pigging with an ice slurry (ice pigging) was not an effective decontamination method for the WSTB pipe material.

- Pipe relining (after pigging) followed by chlorination is an effective way to eliminate detectable spores remaining on the inner pipe surface. However, in some experiments, small numbers of spores were still detected on the relined surface. This might have occurred from cross contamination during installation of the liner.

- Decontamination with chlorine and flushing removed most spores from the home plumbing pipes and appliances. However, after decontamination, spores were still detected in the water and on the infrastructure surfaces. Additional flushing, longer chlorination times or other decontamination methods may be needed for home plumbing.

The following sections describe how decontamination experiments were conducted and the results.

Decontamination of *Bacillus* spores from drinking water distribution system infrastructure

Decontamination using chlorine dioxide

Decontamination experiments were conducted by injecting a 40 L (10.6 gallon) suspension of *Bacillus globigii* (BG) spores into the eight-inch pipe. Figure 2 (left) shows the spore suspension divided into buckets. A small pump was used to overcome the pipe pressure and inject the spore suspension into the pipe. Once inside the pipe, the spores flowed with the water down the pipe and contacted the inner pipe surfaces, valves and fittings. A portion of the injected spores became stuck to the inner surfaces. As seen in Figure 3, removable coupons (excised sample materials) were inserted into the pipe, which allowed sampling of the inner pipe surface. In order to decontaminate the adhered spores, chlorine dioxide was injected and allowed to flow down the pipe (Figure 2, right). All effluent from this experiment flowed into the 28,000 gallon lagoon shown in Figure 1. More details about this experiment can be found in USEPA, 2016 and Szabo et al., 2017a.

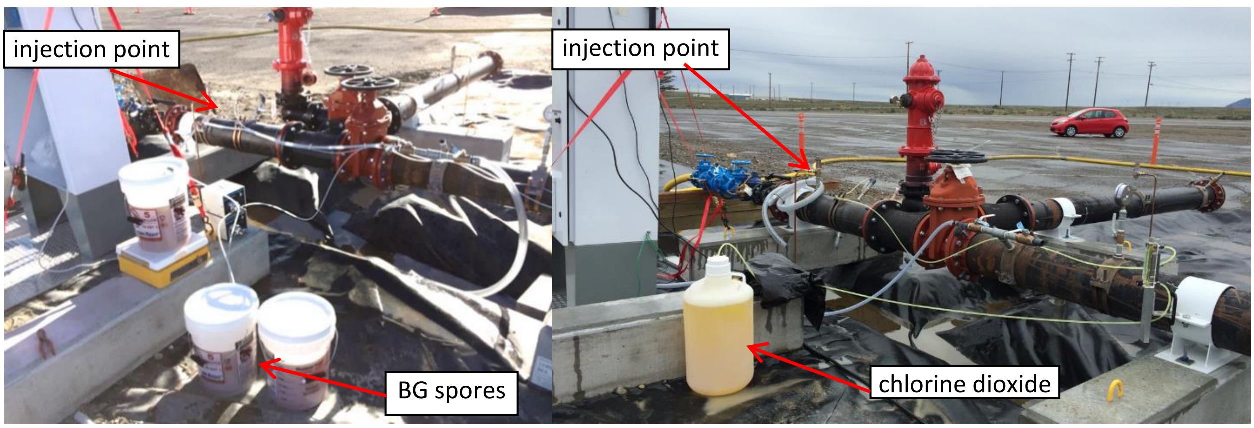

Figure 2: Injection of *Bacillus* (BG) spores (left) and chlorine dioxide (right) into the pipe.

Chlorine dioxide is a powerful disinfectant and is more effective at killing bacteria than commonly used water disinfectants like free chlorine and monochloramine. Sampling the WSTB pipe inner surface after contamination with the spores and again after decontamination with chlorine dioxide showed that about 99% (or 2-log) of the spores were removed with chlorine dioxide. However, similar but smaller pilot scale experiments conducted in previous years showed that decontamination with chlorine dioxide resulted in 99.998% (or 4.7 log) reduction of spores (Szabo et al, 2017). This difference between the full-scale and pilot scale results is significant because many spores were still left on the inner pipe surfaces after decontamination of the WSTB pipe with chlorine dioxide.

These results showed that the full-scale conditions in the WSTB pipe introduced challenges to the decontamination process that were not present during smaller pilot scale experiments. It could be that the disinfectant demand from the WSTB pipe and elevated temperatures destroyed the chlorine dioxide. It is also possible that the various dead ends and fire hydrant connections in the WSTB pipe system provided additional areas of low flow where spores survived and remained isolated from the chlorine dioxide solutions. In order to determine how to effectively decontaminate water pipes contaminated with spores, more aggressive decontamination methods would need to be tested.

Figure 3: Coupons used to sample the interior pipe surface.

Decontamination using pigging

Pigging, or pipe cleaning using a maintenance tool called a pig, is a process where the inner surface of a pipe is scoured and cleaned by forcing an object, a pig, down the pipe. The first pigging method used in the WSTB pipe was called ice pigging. In this method, an ice/water slurry similar to slush is mixed up in a truck and pumped from an upstream to a downstream fire hydrant after the pipe had been contaminated with spores (Figure 4). The pieces of ice in the slurry scour and clean the pipe. Unfortunately, ice pigging was not an effective decontamination method for BG on this type of pipe material (USEPA, 2018).

Figure 4: Ice pigging taking place by pumping an ice slurry down the Water Security Test Bed pipe.

Therefore, two additional pigging methods were tested at the WSTB facility using nozzles. Nozzles fit on the end of a hose and operate by pumping water at high flow (70 gallons per minute) and high pressure (2300 psi) through them. High pressure water was supplied by a combination truck (a truck tractor with vacuum and water jetting capabilities), which is shown in Figure 5 (left). The nozzle is inserted into a pipe, and the water flow through the hose pushes the nozzle up the pipe where it scours the internal pipe surface (Figure 5, right).

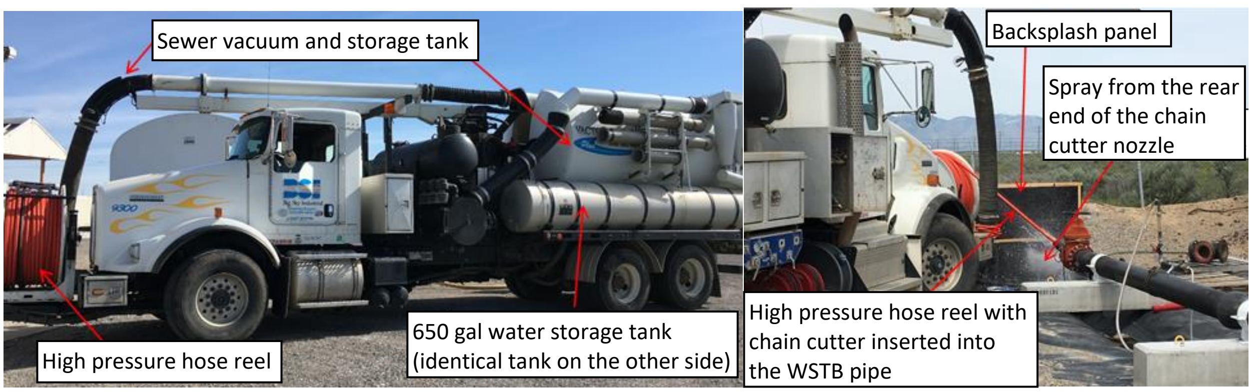

Figure 5: A combination truck (left), and a nozzle being inserted into the Water Security Test Bed pipe for decontamination (right).

The two nozzles that were used are shown in Figure 6. On the left is a chain cutter, which has bicycle chains that spin and scour the internal pipe surface when water is pumped through it. The other nozzle is called the Warthog® (StoneAge Inc., Durango, CO); it scours the pipe using a high-pressure water spray. Both nozzles were effective at decontaminating spores from the pipe. The chain cutter and Warthog removed 97% (1.5 log) and 99% (2 log) of the spores attached to the pipe surface, respectively. In separate experiments with a heavily corroded unlined iron pipe, chain cutter and Warthog removed 99.94% (3.2 log) and 99.9987% (4.9 log) of the spores attached to the pipe surface, respectively. Adding chlorine to the pipe after pigging with each nozzle and allowing it to sit in the pipe overnight further decreased the number of spores adhered to the pipes (usually by about 1-log). The spore removal performance of the nozzles (with chlorination) was substantially better than adding chlorine dioxide alone (USEPA, 2018; USEPA, 2019). However, since spores remained on the inside of the pipe after decontamination, it was decided the methods to encapsulate or reline the inner pipe surface should be investigated.

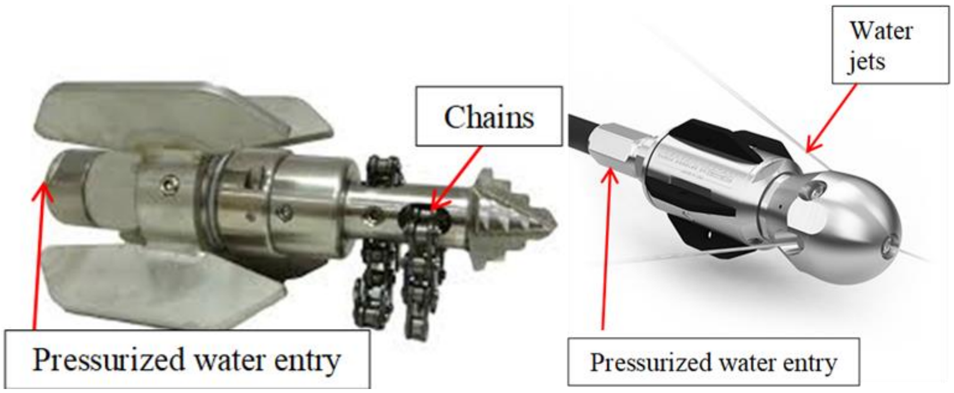

Figure 6: The chain cutter nozzle (left) and the Warthog water jet spray nozzle (right).

Pipe relining

Pipe relining is the process of installing a coating or an entirely new pipe inside of an existing pipe. Figure 7 shows the results of two pipe relining technologies. On the left is Oceanit® DragX™ (Oceanit Laboratories Inc., Honolulu, HI), which is a coating that is sprayed on with a device similar to a paint sprayer. The spray process deposits a very thin coating that is invisible to the naked eye (note that some of the spray pooled at the bottom of the pipe). On the right is a cured in place pipe (CIPP), where a cloth sock is soaked in a resin and pulled through the existing pipe, then hardened or cured with hot water. The result is a rigid pipe inside the original pipe that not only lines the pipe, but also provides structural integrity.

After relining, chlorine was added to the pipes and allowed to sit overnight. Detailed results are summarized in USEPA, 2019. Results showed that no spores were detected on the surface lined with Oceanit DragX. A few spores were detected on the CIPP relined surface, but these were likely due to cross contamination during liner installation. Overall, pipe relining appears to be an effective method for reducing exposure to spore contaminated surfaces in a drinking water pipe. However, the potential for cross contamination must be considered when attempting relining.

Figure 7: Pipes lined with Oceanit DragX (left) and CIPP (right).

Decontamination of *Bacillus* spores from home plumbing and appliances

In Figure 1, the white tented building contains a home plumbing and appliance setup that has been used for biological decontamination research. Figure 8 shows three images of that system. Water flows into the building through a one-inch diameter copper pipe. It passes through a residential water meter, and then through three pipe branches (Figure 8, left) containing removable sections of copper, PVC and PEX (cross-linked polyethylene), which are common home plumbing materials. The removable pipe sections, or coupons, can be sampled after contamination and decontamination to determine the effectiveness of a decontamination method.

From there, the water flows through a hot water heater (Figure 8, middle), refrigerator with water dispenser, washing machine, and a dishwasher (Figure 8, right), and then empties into a utility sink (not shown). BG spores were injected into the plumbing system at the same concentration as they were injected into the eight-inch diameter WSTB pipe and were allowed to contact all of the pipes and to flow through the appliances. Decontamination was accomplished by adding chlorine at 2,300 mg/L, then flushing the cold water lines for 20 minutes. The hot water heater was then drained and refilled, the hot water lines flushed for 75 minutes, and appliances run for one cycle.

Figure 8: Images of the home plumbing system.

Results of this study are summarized in Szabo et al., 2017a. In short, addition of chlorine and flushing killed off and removed more than 99.9999% (6 to 7 log) of the spores in the water. Approximately 99.5% to 99.99% (2.3 to 4.0 log) removal of spores was observed on the pipe surface coupons samples. These results are encouraging, but low numbers of spores were detected in the pipes and appliances after decontamination. Additional flushing and chlorination may be necessary.

References

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