United States Environmental Protection Agency

Decontamination of Drinking Water Infrastructure

Homeland Security Research Program Webinar Series

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EPA's Homeland Security Research Program

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Why does the HSRP conduct decontamination research?

- Drinking water utilities need to know what contaminants are persistent on common drinking water infrastructure and what decontamination methods work
  - Chlordane in Pittsburgh, 1980
  - MCHM in West Virginia, 2014
  - Biological contamination of small water systems

- HSRP conducts research on decontamination so that data is available before a contamination event takes place

Presentation Overview

- Overview of current drinking water decontamination research projects at EPA
- Summary of Decontamination of Drinking Water Infrastructure: A Literature Review and Summary
- Future NHSRC decontamination research with the Water Security Test Bed
- Other decontamination projects of interest

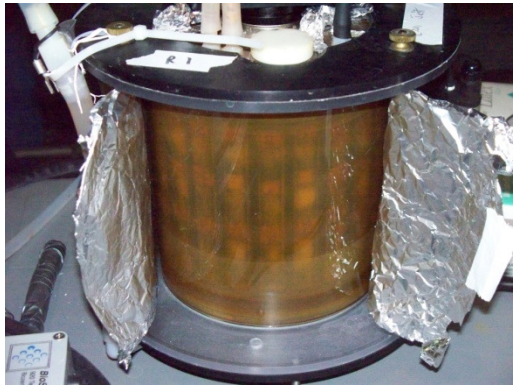
Drinking Water Systems

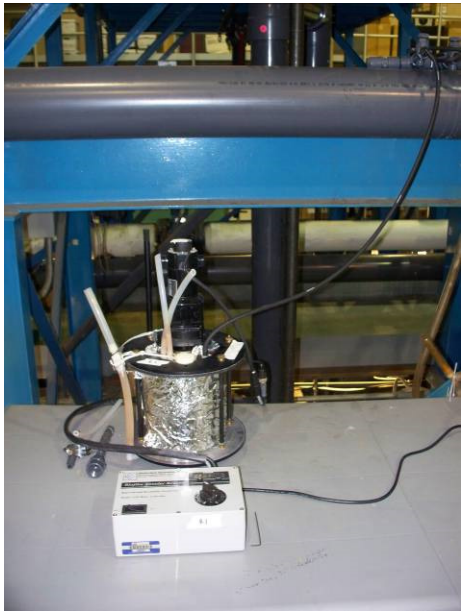
- Our focus is on the distribution system
  - Pipes, tanks, valves, fire hydrants
- These pipes can have corrosion and will likely have biofilm
  - Biofilm is composed of microorganisms and extracellular material
- Common water infrastructure materials are iron (corroded) and cement-mortar lined iron
- Home plumbing material such as PVC and copper are of interest

Bench Scale Experiments

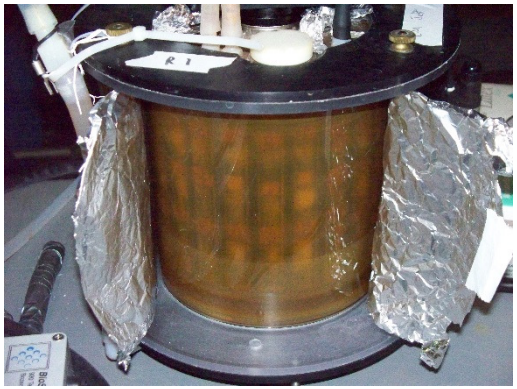
- Bench scale systems simulate a drinking water environment and allow small-scale decontamination experiments

- Biofilm annular reactors
  - Allow for variation of shear forces independent of flow
  - 20 sampling slides available
  - Minimizes the mass of contaminant
  - Use less water
  - Easier to clean between experiments and can be sterilized
  - Good for initial experiments when data does not exist on a contaminant





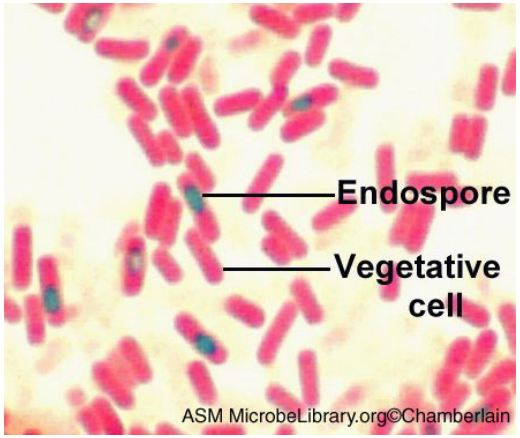
Experimental Methodology

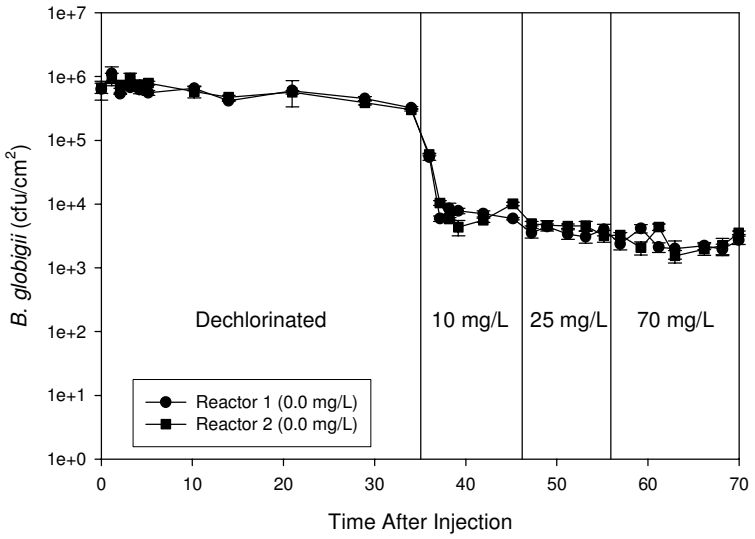


- Condition coupons in tap water
- Spike reactors with a contaminants
  - *Bacillus* spores, rad surrogates
- Harvest coupon and bulk phase samples over time
- Analyze by the appropriate method
- Persistence is monitored over time
- Decontamination
  - Simulate flushing by increasing the rotational speed of the drum
  - Spike the reactor with a decontaminating agent

Bench scale persistence and decontamination of *Bacillus* spores

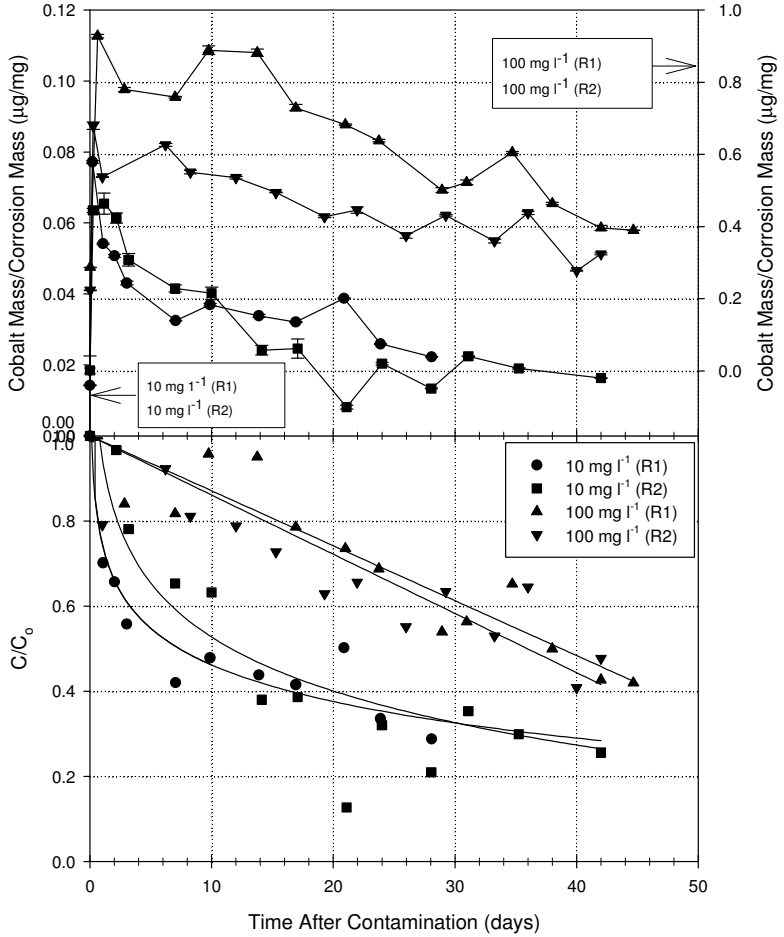
- Some biological agents are persistent on drinking water infrastructure with and without biofilm
- *Bacillus* spp. is particularly persistent since it forms spores
- Causative agent of anthrax
- It is difficult to decontaminate from water infrastructure
- Data from biofilm reactors show persistence up to 70 days.





Persistence of surrogate radionuclides

- Cobalt persisted for 42 days
  - Likely longer
- Soluble cobalt chloride formed a precipitate upon introduction to chlorinated water
- A black film formed on the coupons one day after injection



Confirming Radionuclide Surrogate Results

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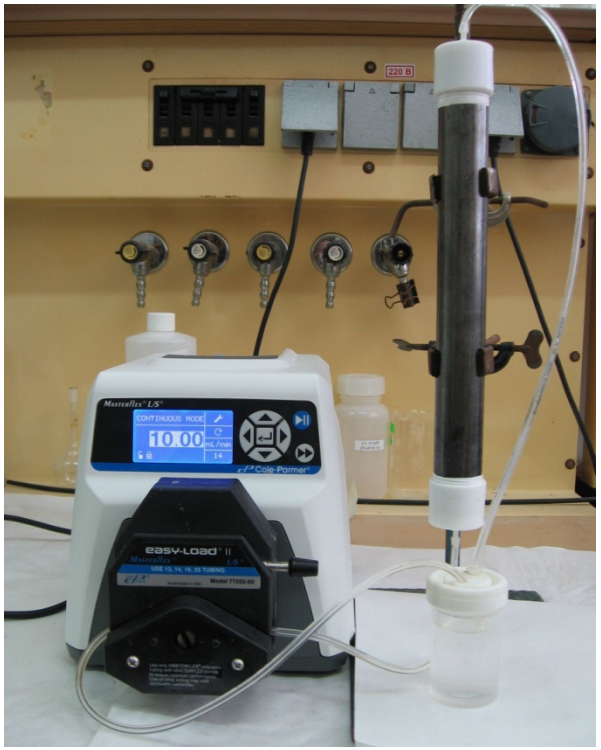
- Funded by the State Department
- ^{137}Cs, ^{85}Sr, and ^{60}Co sorption to iron (corroded), cement-mortar lined iron, copper and PVC pipe
- Cs, Sr and Co disappearance from solution measured using a gamma spectrometer
- Co sorbed to most pipe materials, Sr sorbed to iron and cement mortar, Cs sorbed to cement-mortar



- Flushing with clean water was ineffective at removing sorbed radionuclides
- Chelating agents (EDTA) removed sorbed Co, acidification (tartaric acid) was effective at removing Sr from iron, but not cement mortar. Cs and Sr were removed from cement mortar with solutions of KCl and ammonium acetate.

The Distribution System Simulator (DSS)

Located at the USEPA's Test and Evaluation facility

Coupons/Infrastructure Materials

- Coupons are meant to represent common drinking water infrastructure materials
- Coupons condition in tap water before contamination (>30 days)
  - Iron starts out uncorroded

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- Contaminant contacts coupons
- Coupons are harvested

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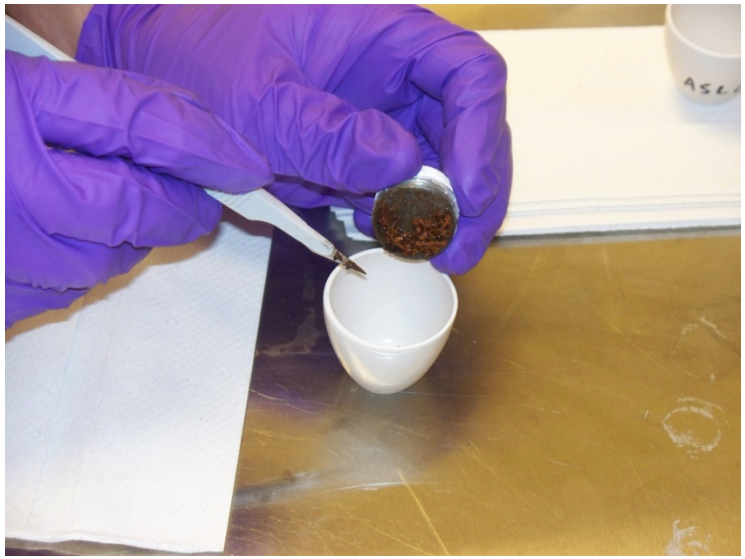
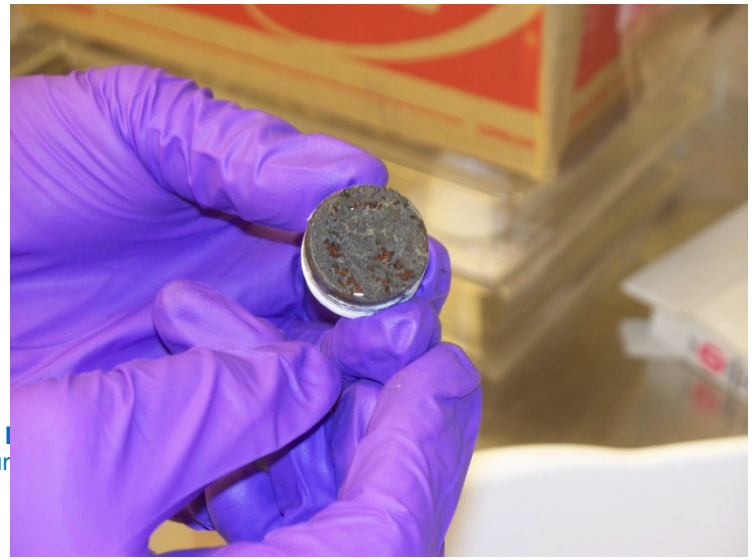
Sampling/Analysis

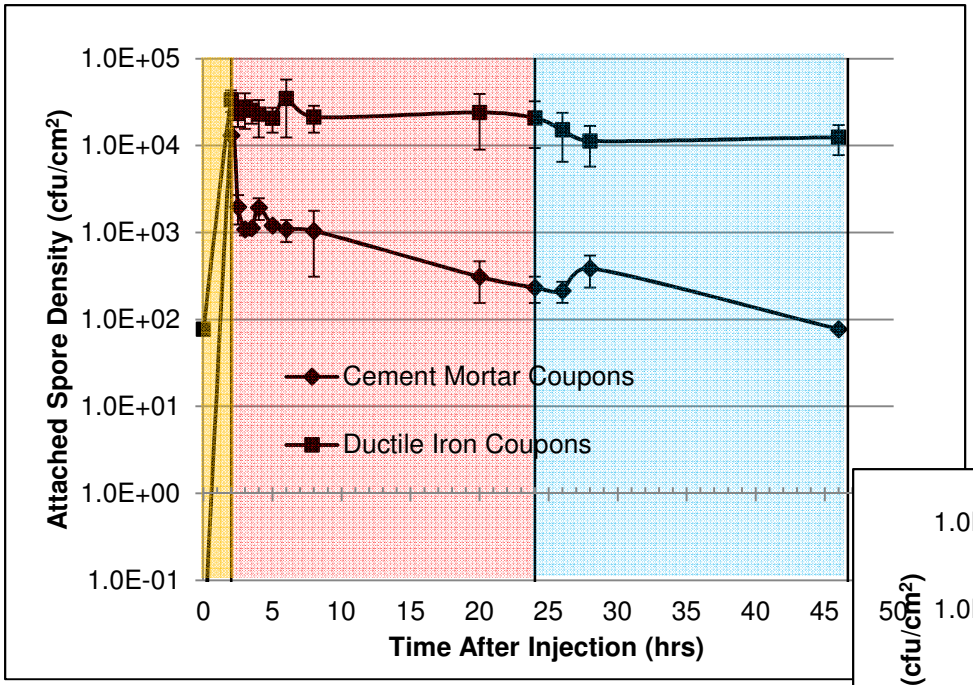
Coupons scraped in the lab

Scraped coupons rinsed. Ready for analysis or further sample prep.



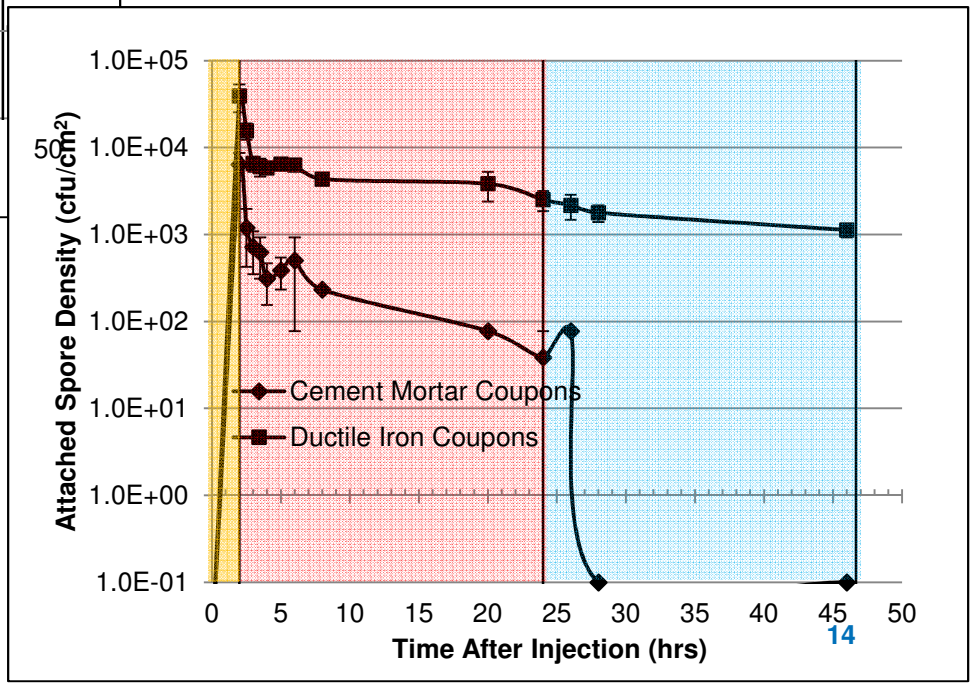


Decontamination with free chlorine



5 mg/L free chlorine

- 5 mg/L Ct: 5,800-7,200 mg/L-min
- 25 mg/L Ct: 32,900-26,600 mg/L-min



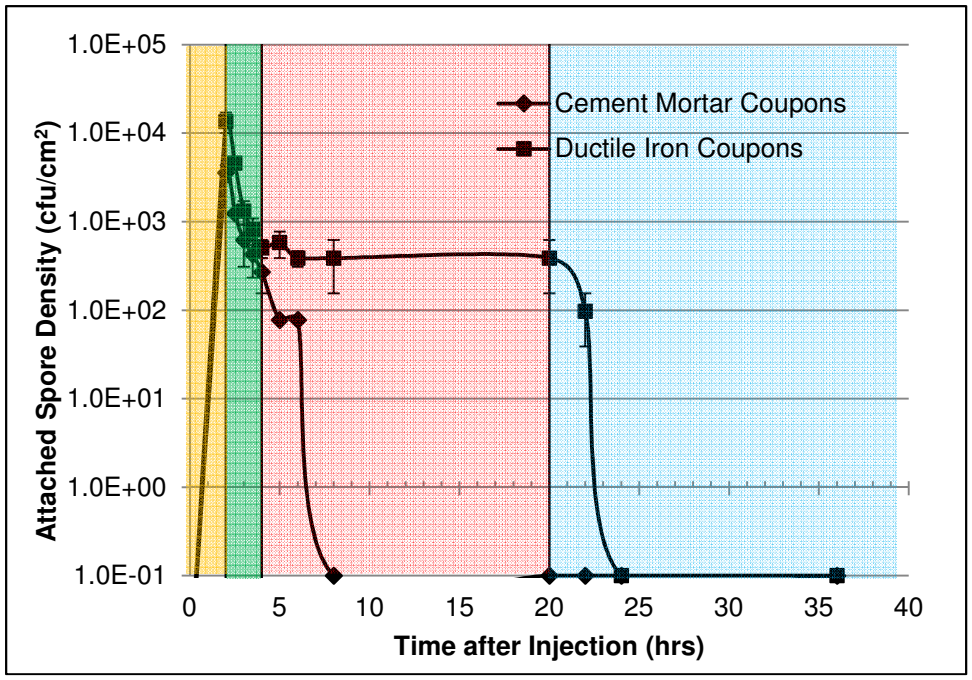
25 mg/L free chlorine

Orange = spore injection

Red = disinfection (5 or 25 mg/L free chlorine, no flow)

Blue = flushing (88 gpm, 1 ft/sec)

Decontamination with free chlorine and germinant



- 5 mg/L with germinant: Ct 1,300-1,700 mg/L-min
- Ductile iron: Germinant assisted flushing
- Cement-mortar: Germinant assisted chlorination

Orange = spore injection

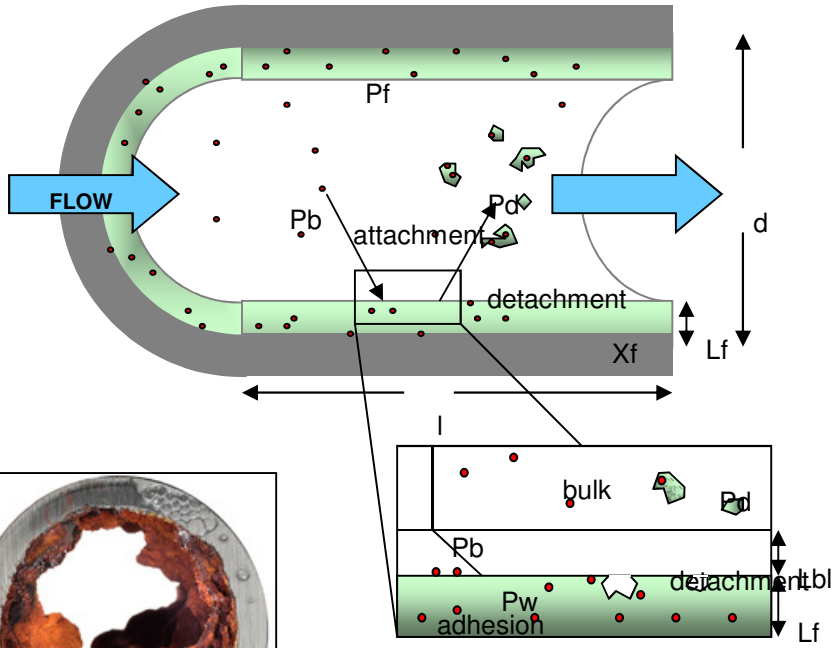
Green = germination (50% tryptic soy broth, 25 C, pH 7.3)

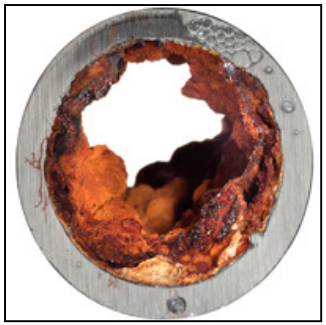
Red = disinfection (5 mg/L free chlorine, no flow)

Blue = flushing (88 pgm, 1 ft/sec)

Decontamination Literature Review and Summary Report

- Decontamination of Drinking Water Infrastructure: A Literature Review and Summary
- Publications from EPA represent the majority of research in some areas
- Provides data for decontamination resources
- Reference key to literature
- Gap analysis to guide research



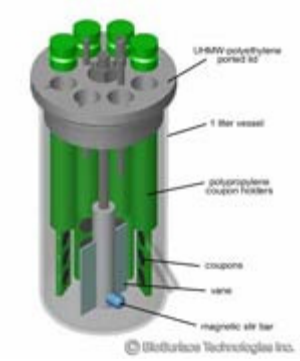


Report Considerations

- Chemical: inorganics (As, Hg), petroleum products, toxins, chemical warfare agents (CWA), pharmaceuticals, organics (chlordane, chloropyrifos, parathion, sodium fluoroacetate and p-dichlorobenzene)
- Biological: spore forming bacteria, vegetative bacteria, viruses
- Radionuclide: cesium, strontium, cobalt
- Infrastructure materials: unlined iron (corroded), cement-mortar lined iron, PVC (plastic), copper
  - Other materials were included if compelling data was identified
- Type of experimental system: how representative of reality is it?

Bench Scale Devices

- Flow cells
- CDC reactors
- Biofilm annual reactors
- Stagnant water pipe
- Homemade designs



Pilot Scale Water Infrastructure Testing

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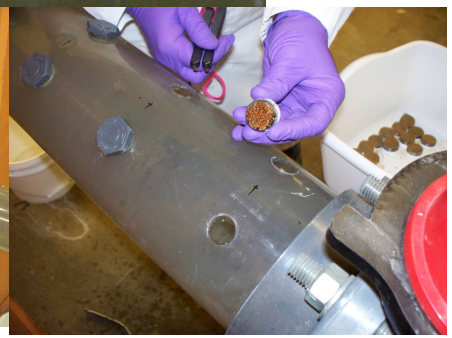


Report Results Summary

Chemical Agents	•Chemical agents are the broadest category with the least drinking water data •Data available for inorganics (Hg, As), organics (including chlordane) and gasoline •No useful data found on pharmaceuticals, toxins and CWA (no data found) •Validated chemical sampling methods from surfaces is needed
Biological Agents	•*Bacillus* spores are persistent, free chlorine effectiveness was limited, chlorine dioxide is promising. •Effective decon methods for spores could also be used for vegetative bacteria •Little data available for viruses •Specific disinfectants (chlorine dioxide, ozone, etc.) should be explored further
Radiological Agents	•Most data comes from bench scale experiments or the nuclear industry •Cs, Sr and Co persistence data on cement-mortar and PVC is needed •More research with real radionuclides is needed •Decontamination of Co with acidification was effective •Cs, Sr less persistent than Co, decon with low pH and competing ions proposed

The future of the decon scoping report

- The report identifies gaps in the current literature with respect to contaminant-infrastructure persistence data that is not available
- Suggestions for future decontamination work are presented in areas where persistence is observed
- The report will be updated and reissued periodically as new data is published
- EPA/NHSRC will perform research to fill those gaps
  - We hope others will too
- What kind of work will NHSRC focus on in the future?

The Water Security Test Bed

- Located at Idaho National Lab (INL)
  - Idaho Falls, Idaho (SE portion of state)
- Above ground drinking water pipe system with a 40,000 gallon lagoon, and high rate groundwater pump
- The WSTB can support drinking water, decontamination, cyber security, and wash/flush water related research
  - Decontamination will be the initial focus (Sept. 2014) with *Bacillus* spores and chlorine dioxide
- Located near BOTE building (connect?)
- CBR agents or simulants
- Collaboration with DOE, DOD, DHS, water industry and others being investigated

Where did the pipe come from?

- Drinking water pipe that was in service from the early 1970's until a few years ago
- The pipe was in good condition when it was excavated
- The pipe was partially filled with water, but no major leaks were found

Pipe material of construction

- Cement-mortar lined ductile iron
- Some pipes are corroded where the lining was worn or broken
- Four and eight-inch diameter pipes were excavated.

What will the WSTB look like?

- The pipe will be a straight run between fire hydrants (Phase I)
- Pipe will be constrained (braced)
- Service connections will installed
- Water will be pressurized (40-60 psi)
- Pipe will be elevated and leak containment will be installed
- Water will empty into a lagoon for collection, sampling, pre-treatment and disposal
- Water supply is chlorinated ground water
  - Groundwater pump will keep the WSTB pressurized

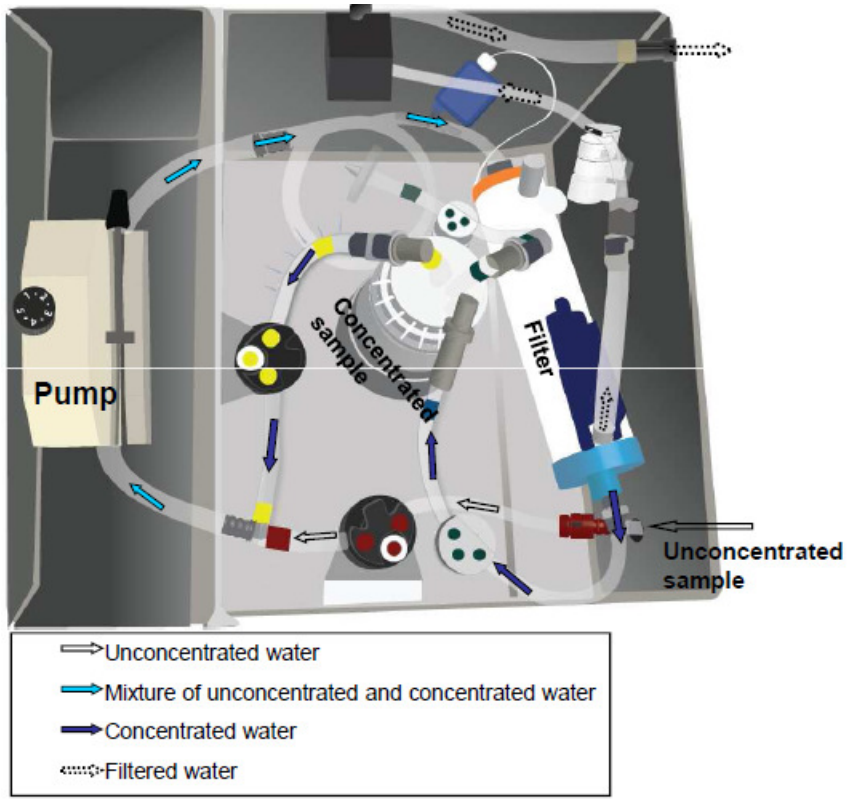
Sampling interior pipe surfaces

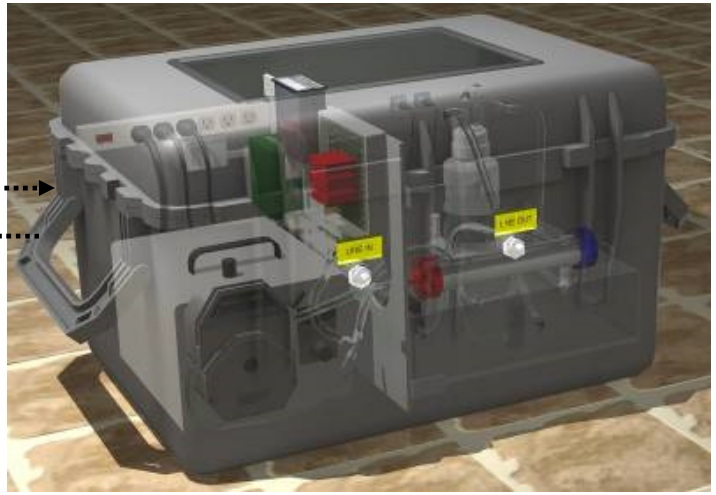
- Many of the samples from the WSTB will be water samples
- Interior pipe wall samples will also be available
- We may have coupon samples in multiple locations around the WSTB
- Coupon extraction procedure will be adapted from pilot scale decontamination studies at EPA

Water Sampling

- Water samples will be common during contamination/decontamination experiments

- For biological samples, we will use the water sample concentrator
  - Uses ultrafiltration to concentrate microorganisms
  - Field portable
  - Easy and cheap to use
  - Built at INL



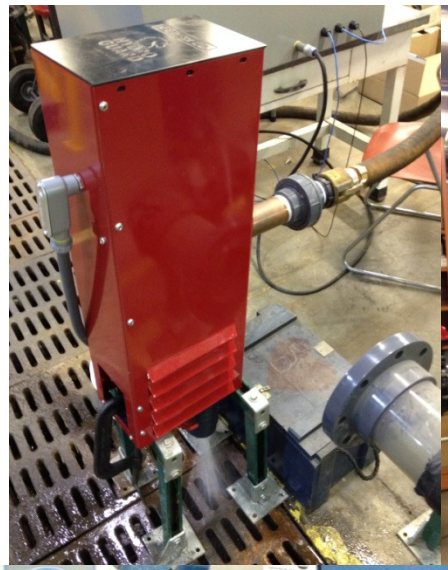


Flushing hydrants and sensors

- The WSTB will be equipped with two fire hydrants, one with automatic flushing

- Sensors will include:
  - Standard water quality sensors (chlorine, pH, turbidity)
  - Hydrant pressure sensors
  - Hydrant RFID tamper alarms
  - Flow meters (standard and specialized)

- Work in the WSTB will begin in September 2014



Contaminant Adherence to Sediments

- Investigating the adsorption of selected contaminants onto drinking water storage tank sediments
  - If contamination partitions into sediment, this could be another route of exposure which could impact human health
- Water utilities anonymously provided several sediment samples
- Sediment samples were analyzed with initial screening
  - Total organic carbon, organic matter, sand, silt, and clay content (grain size), pH, cation and anion exchange capacity
- Reviewed screening analysis results to select samples with varying characteristics

Sediment and Water Sampling

- Targeted tanks that have not been cleaned recently
  - Amount required: ~1 kg dry weight
  - Utility Service provided sampling services
- Drain tank, collect sediment in 125 mL and 4L plastic containers at five locations within tank
- Sterile sampling for biological measurements
- 4 L of water is collected from sampling port on tank (prior to draining) or from faucet using water from tank

Example Sediment Sample

- Collected several samples prior to procedure being finalized
- Sediment samples can vary greatly from tank to tank (% moisture, particle size, debris, etc.)

Technical Approach

- Contaminant Selection
  - Radiological (cesium), organic (lindane), and biological *(Bacillus globigii and Escherichia coli),* wall binding difficulties have caused change to *Bacillus anthracis Sterne*
  - *Legionella* may be examined in the future
- Drinking water (at pH 7.5 and 8.5) contaminated and placed in test tubes containing sediment
- Sediment to water ratio for adherence experiments likely 1 g sediment/50 mL drinking water
- Adherence experiments performed in triplicate with 6 or 18 hour sediment/ drinking water equilibration time
- Water concentrations used to determine adherence so controls without soil will control for container adsorption
- Uncontaminated controls to identify any background levels of target contaminant in sediment

Cesium Adherence Results pH 7.5

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Replicate	Description	Result (µg/L)	Avg.	SD	p-value	Sed Adh	% Adherence	
							Sediment	SD
A	Sediment and contaminated water	0.104	0.104	0.002	7.6E-09	68%	69%	0%
B	Sediment and contaminated water	0.105				68%		
C	Sediment and contaminated water	0.102				69%		
A	Sediment and contaminated water	0.100	0.095	0.005	8.4E-08	70%	71%	1%
B	Sediment and contaminated water	0.091				72%		
C	Sediment and contaminated water	0.093				72%		
A	Sediment and contaminated water	0.130	0.128	0.002	1.2E-08	61%	61%	0%
B	Sediment and contaminated water	0.128				61%		
C	Sediment and contaminated water	0.127				61%		
A	Control - contaminated water, no sediment	0.328	0.329	0.002		Average +/-SD	67% +/- 5%	
B	Control - contaminated water, no sediment	0.328						
C	Control - contaminated water, no sediment	0.332						
A	Blank - sediment and uncontaminated tank wat	ND	NA	NA				
B	Blank - sediment and uncontaminated tank wat	ND						
C	Blank - sediment and uncontaminated tank wat	ND						

- 67% +/- 5% adherence
- Adherence was determined in all three replicates

Aircraft Water Rule

- Promulgated in October 2009 to ensure that safe and reliable drinking water is provided to passengers and crew
  - Aircraft water systems are extensions of municipal water systems
- Provides protection against disease causing organisms that may be found in onboard tap water
- Requires:
  - Coliform and *E. coli* sampling
    - 2 samples each sampling period
    - 1 lavatory and 1 galley sample
    - Monthly to yearly sampling schedule
  - Disinfection and flushing
    - Up to 4 times per year
    - Required soon after positive coliform/*E. coli* sample

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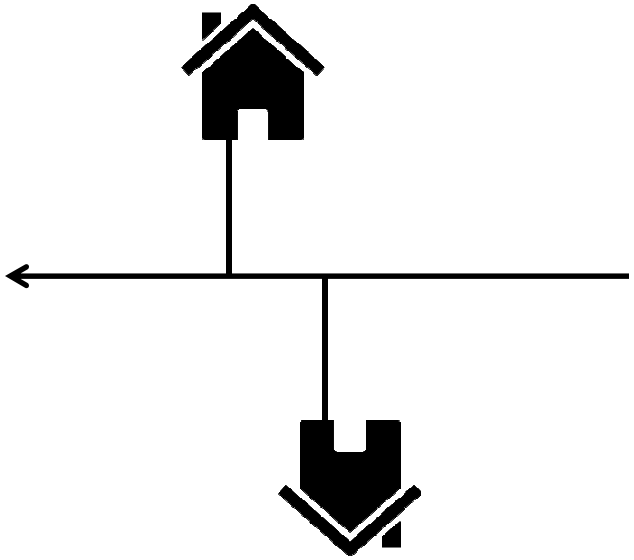
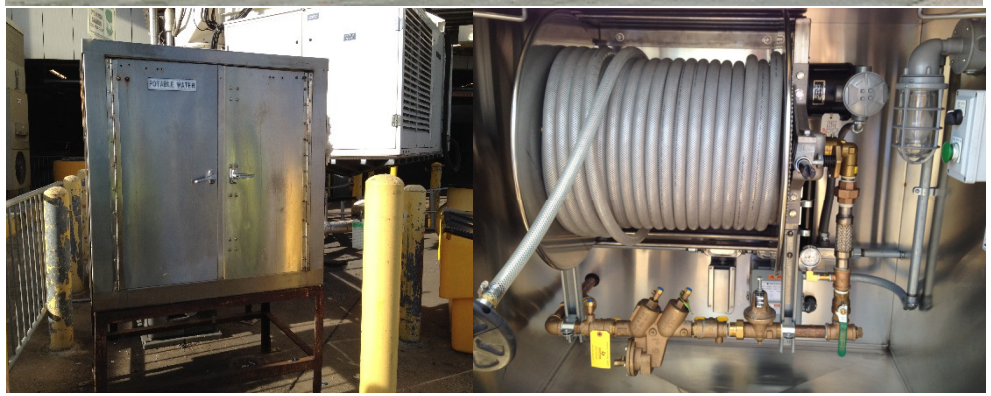
From the plant to the airport

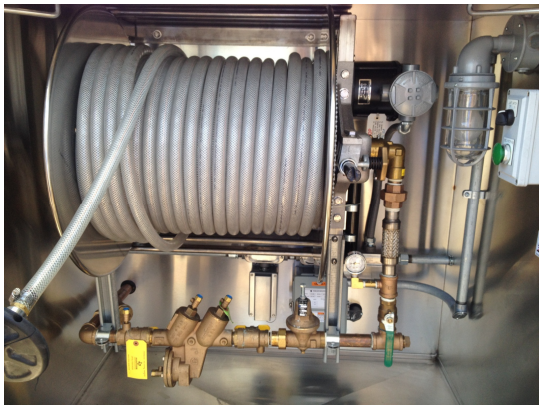


From the airport to the aircraft



Aircraft water quality can be affected by:

- Changes in water quality that occur in the airport
- Changes in water quality that occur in the water transfer facilities at the airport (hoses and water trucks or water closets)
- Changes in water quality that occur on the aircraft



RARE project description

- Regional Applied Research Effort (ORD and Region 6)
- Objective- Better understand how aircraft drinking water systems become contaminated and to investigate effectiveness of current disinfection and flushing procedures.
- Phase I - Isolation of bacteria
  - Water samples analyzed at contract labs
  - Positive coliform medium shipped overnight to EPA Cincinnati
  - Isolate coliform bacteria using MacConkey agar
  - Identify isolates using biochemical and molecular tests
- Phase II - Constructing mock water system in Cincinnati
- Phase III - Testing selected isolates for colonization of mock system
- Phase IV - Testing decontamination procedures for microbial and chemical contaminants

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Phase I: Results to date

- Participation by EPA Region 6 Air Carriers
  - We are working with three air carriers
  - Samples taken from the galley and lavatory
  - Six different aircraft represented, but most are Boeing 737
- 10 contract labs submitted samples
  - Colilert most common; also Colisure and Colitag
- 3 models yielded positive samples
  - 737 most common; also 757 and ERJ
- 36 total coliform water samples received from 35 planes
- All positive samples from lavatories, not galleys
  - *Enterobacter* and *Klebsiella* most common isolates
  - Also recovered *Citrobacter*, *Serratia*, *Hafnia*, *Kluyvera*, *Pseudomonas*, *Stenotrophomonas*, *Shigella*, *Myroides*

Phase II-IV: Mock Aircraft Water System

- It will be constructed at EPA's Test and Evaluation Facility in Cincinnati, OH
- Modeled after a Boeing 737 water system
- Water tank donated by Boeing; EPA is purchasing the remaining parts with RARE funds
  - Parts are on order with a 12 week lead time. Expected delivery is June 2014
- The mock system will be contaminated with the isolated coliforms and persistence/colonization observed
- Various decontamination techniques will be attempted
  - Purogene (chlorine dioxide) and ozone are candidates
  - NHSRC has experience with decontamination of biological agents from drinking water infrastructure

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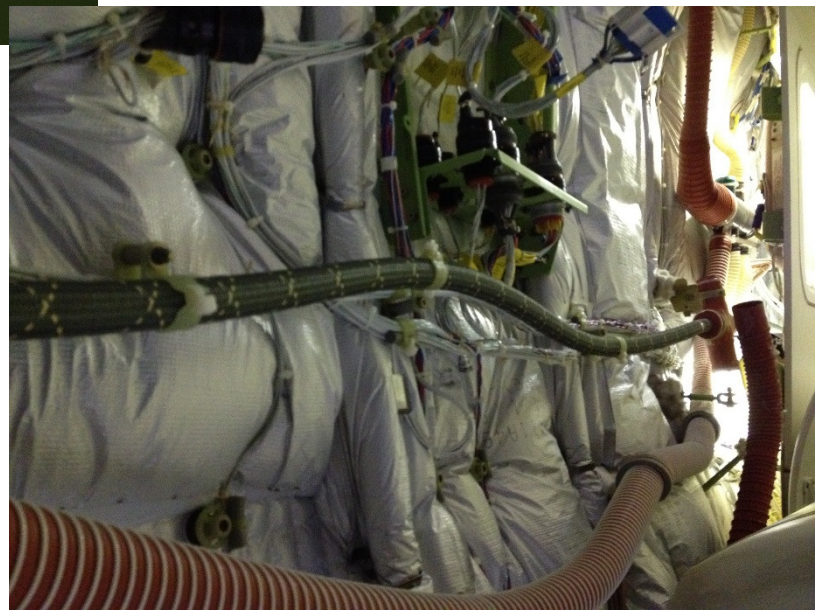
Boeing 737 Water Tank

Drinking Water Hoses in a 737



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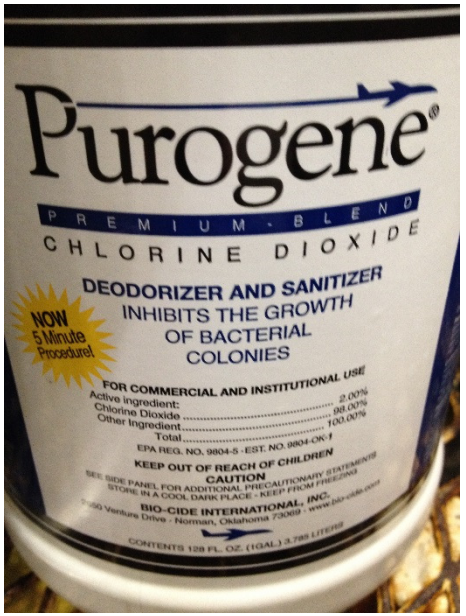
Decontamination



Summary

- In the coming years, the HSRP will continue using our bench and pilot scale tools to assess contaminant persistence and examine decontamination
- The decon scoping report will be updated periodically when new data is available
- In the near future, decontamination techniques will be demonstrated in the WSTB
- The sediments and aircraft projects will officially end in the coming years, but the protocols and pilot scale systems will be maintained.

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Questions?

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This presentation can be found at:

http://intranet.ord.epa.gov/nrp/hs/documents