Underground Transport Restoration Research

From laboratory sampling and decontamination studies to a full scale operational technology demonstration

Lukas Oudejans
U. S. EPA
National Homeland Security Research Center

Homeland Security Research Program Webinar
January 23, 2018

Outline of Webinar

- Objectives of Underground Transport Restoration (UTR)
- Why focus on subway system?
- UTR Participation
- Major UTR projects
- EPA Research under UTR
  - Laboratory studies
  - Operational Technology Demonstration (OTD)

Gap and Objectives

- Subway systems present a special challenge as to (quickly) recover and restore service following a biological incident (such as a *Bacillus anthracis* release)

- Shut down of subway system causes a significant negative impact on local, regional or national economy

- Objectives of the UTR
  - Improve capability and shorten timeline for subway systems to recover
  - Identify AND field tests methods, decision-support tools, and protocols
    - Rapid characterization (sampling, modeling)
    - Clean-up (decontamination, waste management)
    - Clearance of physical infrastructure and rolling stock
  - Create guidance to transit systems, local, state and federal stakeholders

Challenges for Subway Remediation / Recovery

- Size and Complexity
  - Stations, tunnels, tubes, rolling stock, interconnections
  - Large surface areas and volumes
  - Presence of electronic equipment with no readily available replacements
  - Connections to above-ground
- Environmental Conditions
  - Harsh, dirty, unsafe, lots of concrete
- Contamination spread underground and above ground due to piston effect of trains
- Time and Cost
  - High economic impact

UTR Participants (2012-2017)

EPA United States Environmental Protection Agency

Homeland Security Science and Technology

CDC

Commonwealth Of Virginia

Sandia National Laboratories

Lawrence Livermore National Laboratory

Pacific Northwest NATIONAL LABORATORY

Argonne NATIONAL LABORATORY

BROOKHAVEN NATIONAL LABORATORY

LINCOLN LABORATORY MASSACHUSETTS INSTITUTE OF TECHNOLOGY

- EPA: Regions, OLEM/OEM/CMAD, OLEM/OEM/ORCR, and ORD/NHSRC

Major UTR Projects

- Subway Car Remediation
  - Methyl bromide fumigation July 2015

Livermore, CA

- Subway Biological Threat Phenomenology
  - Simulant Releases in NYC Subway May 2016

New York City

- Development of UTR Guidance / Decision Framework
  - Generic framework with specific elements for NYCT and BART
- EPA Laboratory Sampling and Decon Studies
- Operational Technology Demonstration

Fort A.P. Hill

EPA Research Contributions to UTR

Decontamination

- Fogging — Lab Study
- Fumigation — Lab Study
- Available Equipment for Subway Decontamination — Lab & Field Study

Sampling

- Emerging Composite Sampling — Lab & Field Study

Operational Technology Demonstration

Field Study

Decontamination Options

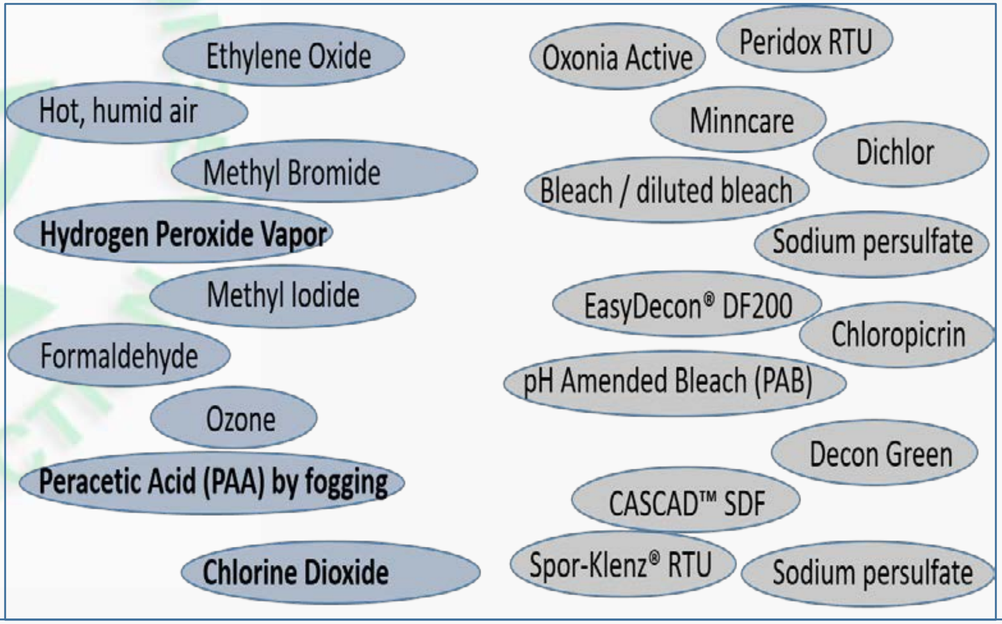
- Very limited number of FIFRA registered products exist for *Bacillus anthracis* decontamination
  - One registered for porous materials (chlorine dioxide fumigation)

- Impact of realistic (subway) conditions on decontamination efficacies is unknown

- EPA's Homeland Security Research Program has filled many gaps over the past years

- Examples of remaining gaps relate to:
  - Clean versus dirty surfaces
  - Environmental Conditions
  - Capacity and logistics to deliver decontaminants

- **No universal decontamination solution exists**



Fumigation / Volumetric Decon | Surface Decon

EPA Research Contributions to UTR

Fogging

Fumigation

Available Equipment for Subway Decontamination

Decontamination

Emerging Composite Sampling

Sampling

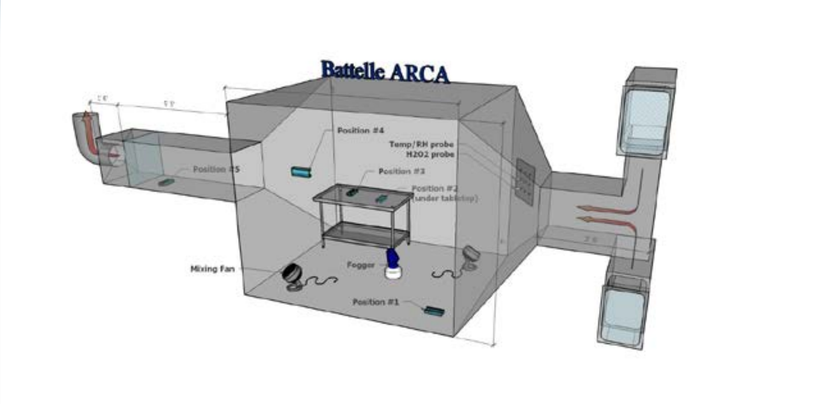
Operational Technology Demonstration

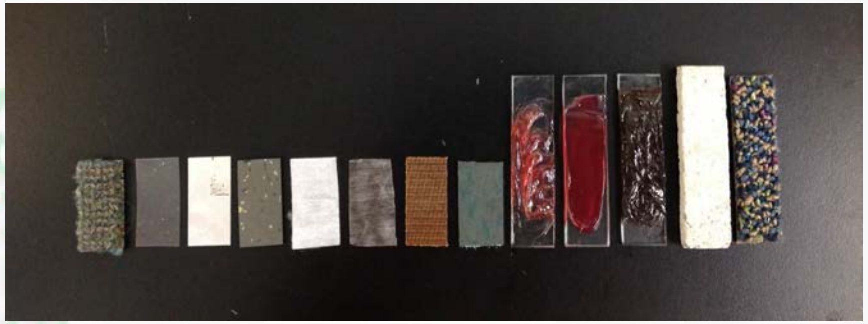
Decontamination of Subway Railcar and Related Materials Contaminated with *Bacillus anthracis* Spores Via the Fogging of Peracetic Acid or Aqueous Hydrogen Peroxide

POC: Joseph Wood, ORD/NHSRC

Test Variables

- Tests in pilot-scale chamber using *B. anthracis* Ames and *Bacillus atrophaeus* aka *Bacillus globigii (Bg)*
- 13 railcar and/or tunnel materials
- Two foggers
- Two air temperatures: 10 °C (representative of tunnel) and 20 °C
- Two sporicidal liquids: PAA (4.5% PAA, 22% H_2O_2) and H_2O_2 (8, 22, and 35%)





Railcar Carpet, Mylar Window Covering, Aluminum Seat Back, Rubber Flooring, New Cabin Air Filter, Used Filter, Fiberglass Siding, Seat Upholstery, New Grease (spores encapsulated), New Grease (spores on top), Used Grease SOT, Unpainted Concrete, Industrial Carpet

Main Findings

- Efficacious* conditions (at least one test producing ≥ 6 log reduction [LR]) were found for every material except concrete and grease (with spores encapsulated)
- *Bg* is a suitable surrogate for *B. anthracis* Ames for fogging PAA and H_2O_2
- The inexpensive fogger, with larger average droplet size distribution, was as effective as the high tech expensive one
- Fog was well distributed and there was minimal difference in average efficacy by location with test chamber
- Efficacy was diminished somewhat at lower temperatures
- 35% H_2O_2 fog produced similar results as PAA fog; 22% H_2O_2 somewhat less effective

Material	Number of Tests	Average *B.a.* LR ± SD	Average *B.g.* LR ± SD
Mylar	8	7.83 ± 0.17	7.10 ± 0.17
Aluminum	4	7.81 ± 0.29	7.30 ± 0.25
Upholstery	4	7.79 ± 0.45	6.96 ± 0.57
Rubber	8	7.76 ± 0.35	6.92 ± 0.46
Used Air Filter	11	7.10 ± 1.70	6.41 ± 1.30
New Air Filter	3	6.77 ± 1.10	6.54 ± 0.14
Fiberglass Interior Siding	16	5.82 ± 1.15	5.65 ± 1.06
Used Grease SOT	12	5.00 ± 2.29	5.34 ± 1.58
New Grease SOT	8	4.45 ± 2.62	4.70 ± 1.90
New Industrial Carpet	1	4.32	4.81
Used railcar Carpet	20	2.43 ± 1.64	1.91 ± 1.20
Unpainted Concrete	13	1.62 ± 0.60	1.36 ± 0.65
Encapsulated New Grease	13	1.59 ± 0.85	2.24 ± 1.02

*: Efficacious defined as better than 6 log reduction in viable spores
EPA report EPA/600/R-16/321 and
Journal of Environmental Management Vol. 206, 15 Jan 2018, Pages 800-806
POC: Joseph Wood

EPA Research Contributions to UTR

Decontamination

- Fogging
- Fumigation
- Available Equipment for Subway Decontamination

Sampling

- Emerging Composite Sampling

Operational Technology Demonstration

Chlorine Dioxide Fumigation in a Subway Environment: Impact of Dirt, Grime, Relative Humidity, Temperature

POC: Lukas Oudejans, ORD/NHSRC

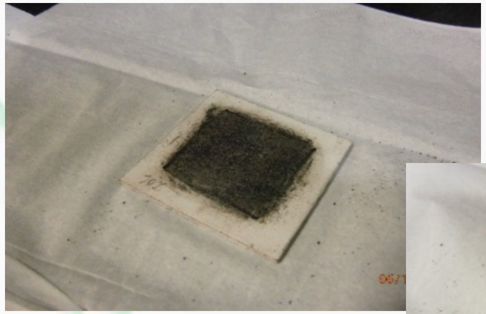
Decontamination of Subway Infrastructure Materials Contaminated with Biological Spores Using Methyl Bromide

POC: Shannon Serre, OLEM/OEM/CMAD

Experimental ClO_2 (Bench Scale) Studies

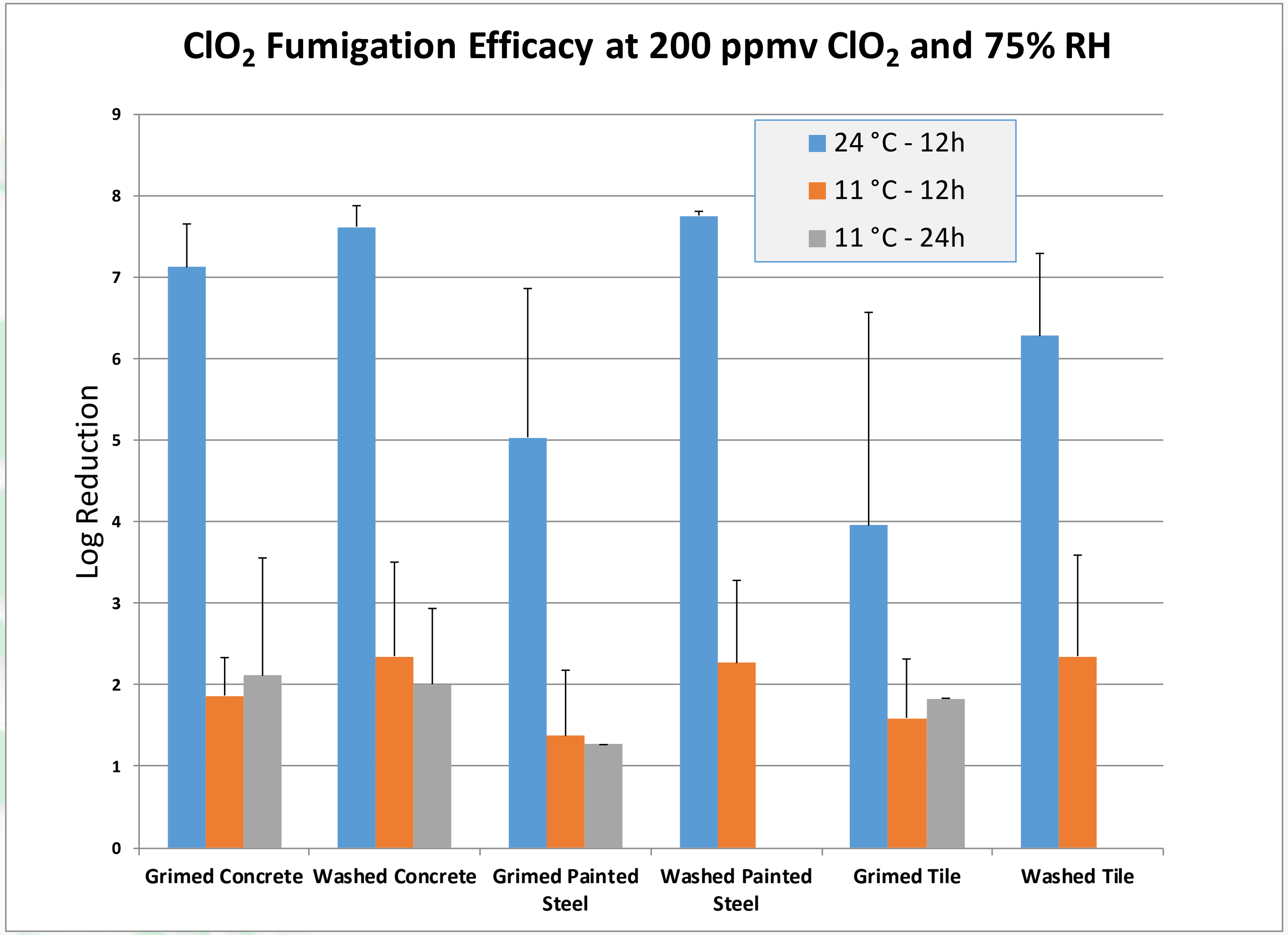
Objective

- Conduct experimental studies to fill knowledge gaps between use of “ideal” lab studies and actual subway system conditions
  - Apply subway dirt and grime to materials
  - Focus on subway building materials
  - Investigate impact of lower (50 °F) temperatures (w. 75% RH)



Significant Results

- Substantial lower efficacies observed at 50 °F (11 °C) compared to 75 °F (24 °C)
- Occurred for 100, 200 and 3000 ppmv ClO_2 concentrations
  - Increase in air and/or surface temperature (TBD) may overcome this limitation
- Impact of dirt and grime was less noticeable and dependent on material



Ungrimed ("washed") painted steel and washed tile were not included in test at 11 C/24h

EPA report EPA/600/R-16/038 ; POC: Lukas Oudejans

Decontamination of Subway Infrastructure Materials Contaminated with Biological Spores Using Methyl Bromide

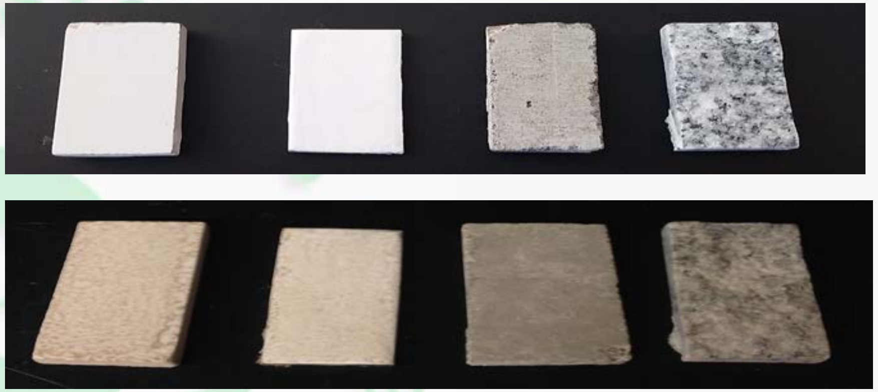
POC: Shannon Serre, OLEM/OEM/CMAD

Objective

- Evaluate efficacy of MB against *Bacillus anthracis (Ba)* on Subway Materials
- Evaluate with and without presence of grime
- Evaluate effect of temperature and RH on efficacy
- Comparison between *Ba* Ames and *Ba* Sterne

Materials & Conditions

Ceramic Tile Painted Steel Concrete Granite



As Received

With Grime

- MB (0.5% chloropicrin) at 212 mg/l
- 10^8 CFU/Coupon of *Ba* Ames or *Ba* Sterne
- Temperature: 40 or 50 °F; RH: 50 or 75%
- Fumigation time: 2-9 days

Main Findings: Tests with >6 LR on all Materials

- Temperature, RH, and time affected the efficacy
- 4 days (ungrimed) and 5 days (grimed) at 212 mg/l MeBr concentration required for effective decon (>6 LR) at 50 °F for all materials
- Presence of grime increased time required to achieve 6 LR
- Confirmed that *Ba* Sterne is a suitable surrogate for *Ba* Ames (for MeBr fumigation)
- No impacts to subway materials (concrete, painted steel, ceramic tile, granite)
- Added chloropicrin results in corrosion; not the MeBr itself

MB Concentration (mg/L)	Grimed	Temperature (° F)	RH (%)	Time (days) Required to Achieve ≥6 LR on All Materials
				B.a. Ames
212	No	50	75	4
212	Yes	50	75	5
212	Yes	40	75	7

EPA report EPA/600/R-17/187 ; POC: Shannon Serrre

EPA Research Contributions to UTR

Fogging

Fumigation

Available Equipment for Subway Decontamination

Decontamination

Emerging Composite Sampling

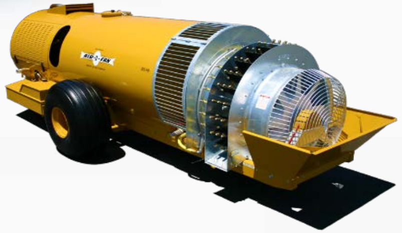
Sampling

Operational Technology Demonstration

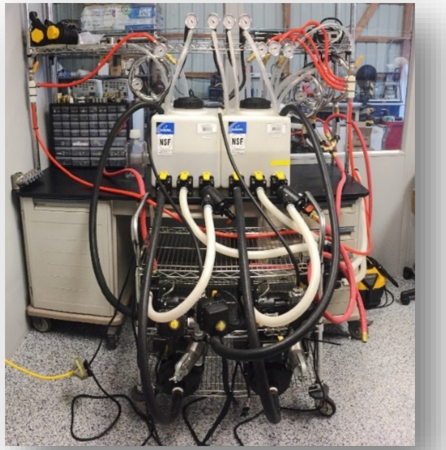
Survey and Evaluation of Commercially-Available Equipment for Subway Decontamination

POC: M. Worth Calfee, ORD/NHSRC

Research Objectives



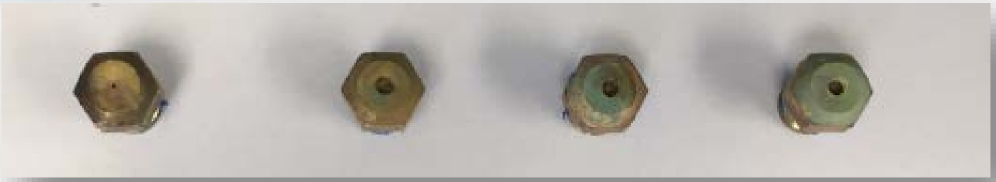
- Identify commercially-available equipment applicable for subway decontamination
  - Ranked according to 3 metrics:
    - Commercial readiness/availability
    - Ease of deployment
    - Decontamination application rate
- Durability
  - Bench-scale tests
  - Operated with sporicidal liquid [pH amended bleach (pAB)] for ≥100 hours
- Decontamination Testing
- Equipment Demonstration: Video




Orchard sprayer video in subway tunnel

Main Findings

- 100-hour Compatibility Tests
  - Nozzle and pump diaphragm failures
  - Most failures preventable by altering part materials
    - i.e., use stainless nozzles rather than brass
- Decontamination Tests
  - Achieved high efficacy (>6LR) on tile (horizontal and vertical)
  - Concrete more difficult to decon
  - Repeated applications on concrete increased efficacy
    - 1 application - ~1 LR
    - 2 applications - ~3 LR
    - 3 application - ~4 LR
- Demonstration
  - Commercial equipment sprayed test venue <u>400X faster than fogging or manual spraying</u>



EPA report EPA/600/R-17/156 ; POC: Worth Calfee

EPA contributions to UTR

Decontamination

- Fogging
- Fumigation
- Available Equipment for Subway Decontamination

Sampling

- Emerging Composite Sampling

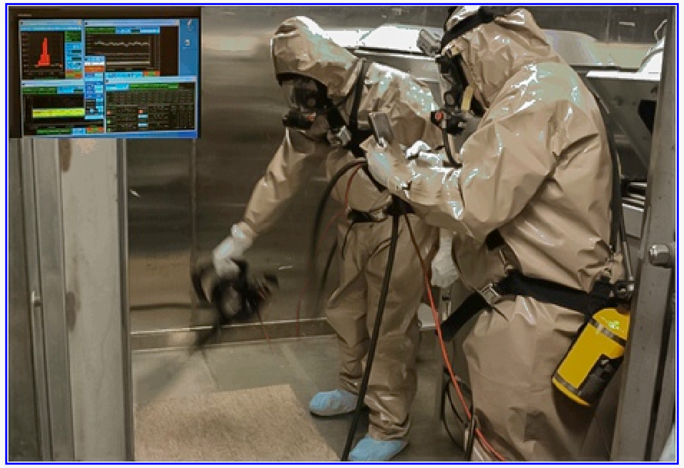
Operational Technology Demonstration

Underground Transport Restoration Emerging Composite Sampling

POC: Sang Don Lee, ORD/NHSRC

Research Summary

- Objective: To assess the applicability of composite sampling methods for anthrax contaminated underground transportation system
- Tested sampling methods:
  - Aggressive Air Sampling (AAS)
  - Robotic Floor Cleaners (RFC)
  - Wet Vacuum
- Bench scale and field tests (mock subway) were conducted
- Specific challenges were
  - Large area
  - Dusty concrete surfaces,
  - Ballast surfaces, and
  - Inclusion of contaminated hotspots



EPA report EPA/600/R-17/212 ; POC: Sang Don Lee

EPA contributions to UTR

Decontamination
- Fogging
- Fumigation
- Available Equipment for Subway Decontamination

Sampling
- Emerging Composite Sampling

Operational Technology Demonstration

UTR Operational Technology Demonstration
Fort A. P. Hill, VA, Sep/Oct 2016

Objectives

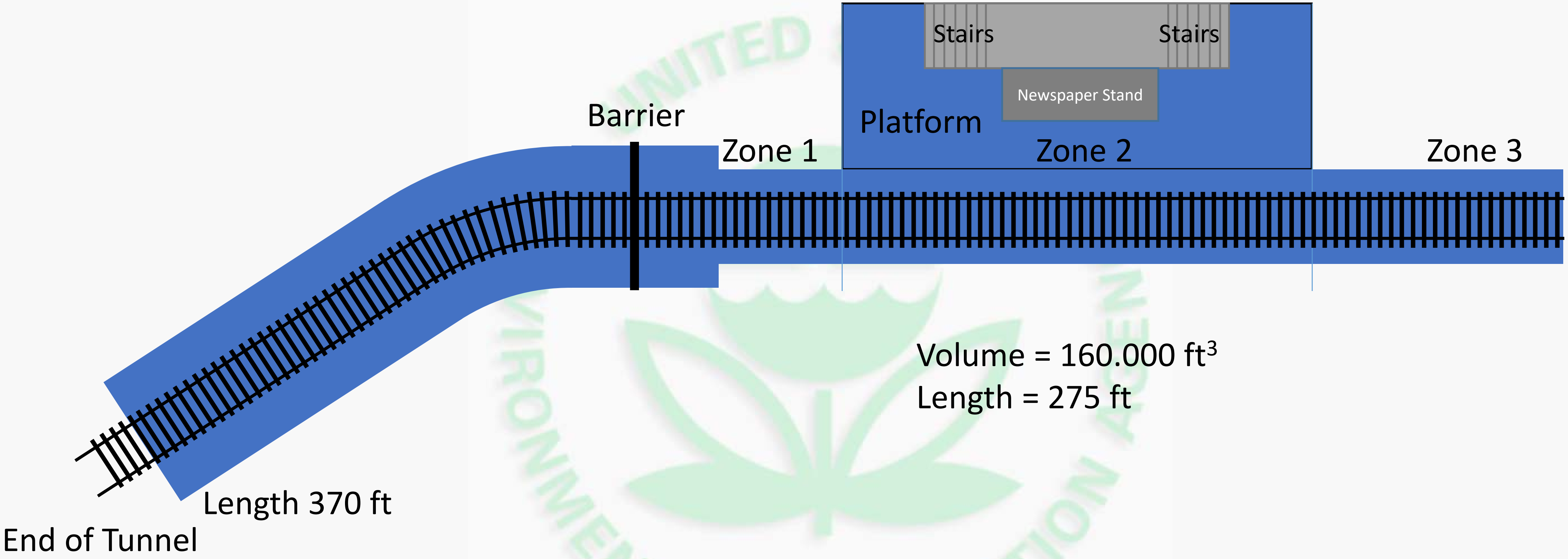
- Test and evaluate two options for decon of a subway platform and tunnel
  - Sampling (pre-decon and post-decon)
  - Effect of grime/organic burden on decontamination
- Evaluate/Capture
  - Efficacy
  - Operational aspects
  - Time and personnel required
  - Cost of each application
  - Material and waste management requirements

Collaborative Effort

5 Week Effort - Over 250 Personnel Participated

- US EPA
  - OEM/CMAD
  - ORD/NHSRC
  - Regions 3, 6, 7, 9
  - OLEM/ORCR
  - OSRTI/ERT
- DHS
- Commonwealth of Virginia
- Sandia National Laboratory
- MIT – Lincoln Laboratory
- Lawrence Livermore National Lab
- Pacific Northwest National Lab
- Department of Defense
  - Asymmetric Warfare Group
  - Fort A.P. Hill
  - Civil Support Teams
- US Coast Guard
  - Atlantic Strike Team
- CDC/Laboratory Response Network

Location / Site



Additions to the Study Area

Intercom

Card Reader

Commercial Kiosk

Additional grimed and non-grimed subway materials

Agent Dispersion in Tunnel/Station

Agent

Biological – *Bacillus atrophaeous, aka Bg*

- Biosafety Level 01 (lowest level) organism; not infectious to healthy humans/ animals

- Same level of deposition in each round

Round 1 Spore Dispersion on 9/18/16 and Round 2 Spore Dispersion on 9/29/16

- Target spore deposition concentration: $1x10^6$ cfu/ft^2

- 800 mg spore release

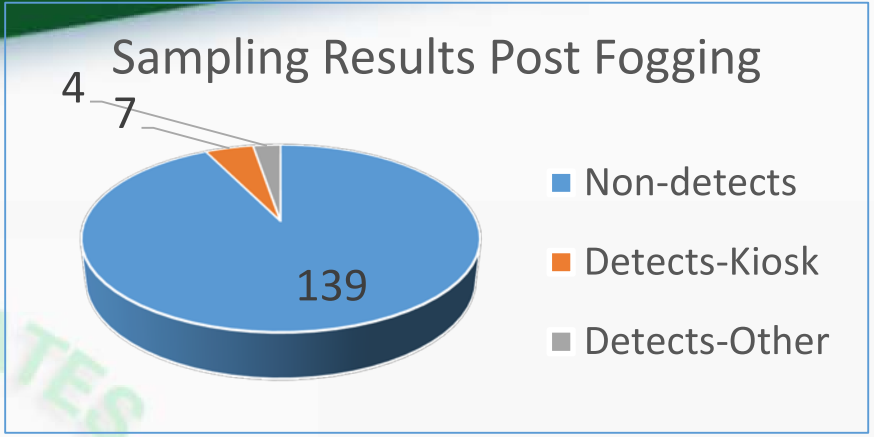
Decontamination

- **Round 1:** Fogging (automated system)
  - Diluted Bleach (4:1)
  - 4 units with 100 gallons diluted bleach
- **Round 2:** Spraying surfaces with low-pressure sprayers
  - pH amended bleach (bleach + vinegar + water)
  - Powered sprayer with 4 take-offs
  - 575 gallons were applied

Fogging Video Clip

Round 1: Fogging

- Pre-decon $1.3 \times 10^5 \pm 5.4 \times 10^5$ CFU/ft²
- 150 samples taken
- Eleven post-decon positives. Of these, seven were Kiosk-associated surfaces
- All grimed and non-grimed coupons were zero except for one painted steel coupon (3 CFU)

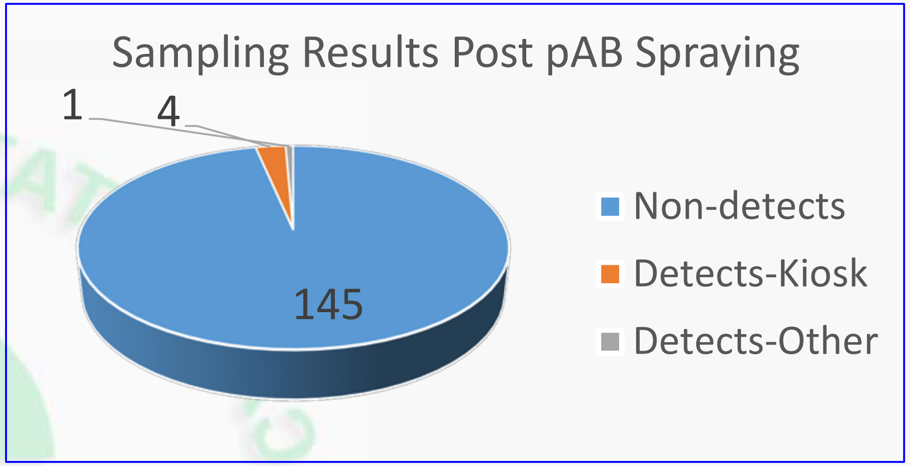


Zone	Sample Type	Remarks	Recovery (CFU)	Recovery (CFU / ft²)
Zone 6 (kiosk)	Grab/Extract	Kiosk tee shirt, 4 shirts	2395	n/a
Zone 6 (kiosk)	Grab/Extract	Hot dog buns	600	n/a
Zone 6 (kiosk)	Grab/Extract	Kiosk wax paper	20	n/a
Zone 6 (kiosk)	Sponge Wipe	Newspapers	60	86
Zone 6 (kiosk)	Sponge Wipe	Under register	12	17
Zone 6 (kiosk)	Sponge Wipe	Food kiosk	240	346
Zone 6 (kiosk)	Sponge Wipe	Plexiglass poster case outside	36	52
Zone 2	Sponge Wipe	Track wall	3	4
Zone 2	Micro-Vac	Platform	11	4
Zone 2	Micro-Vac	Platform	5.5	6
Zone 2	Micro-Vac	Platform	5.5	6

Spraying Video Clip

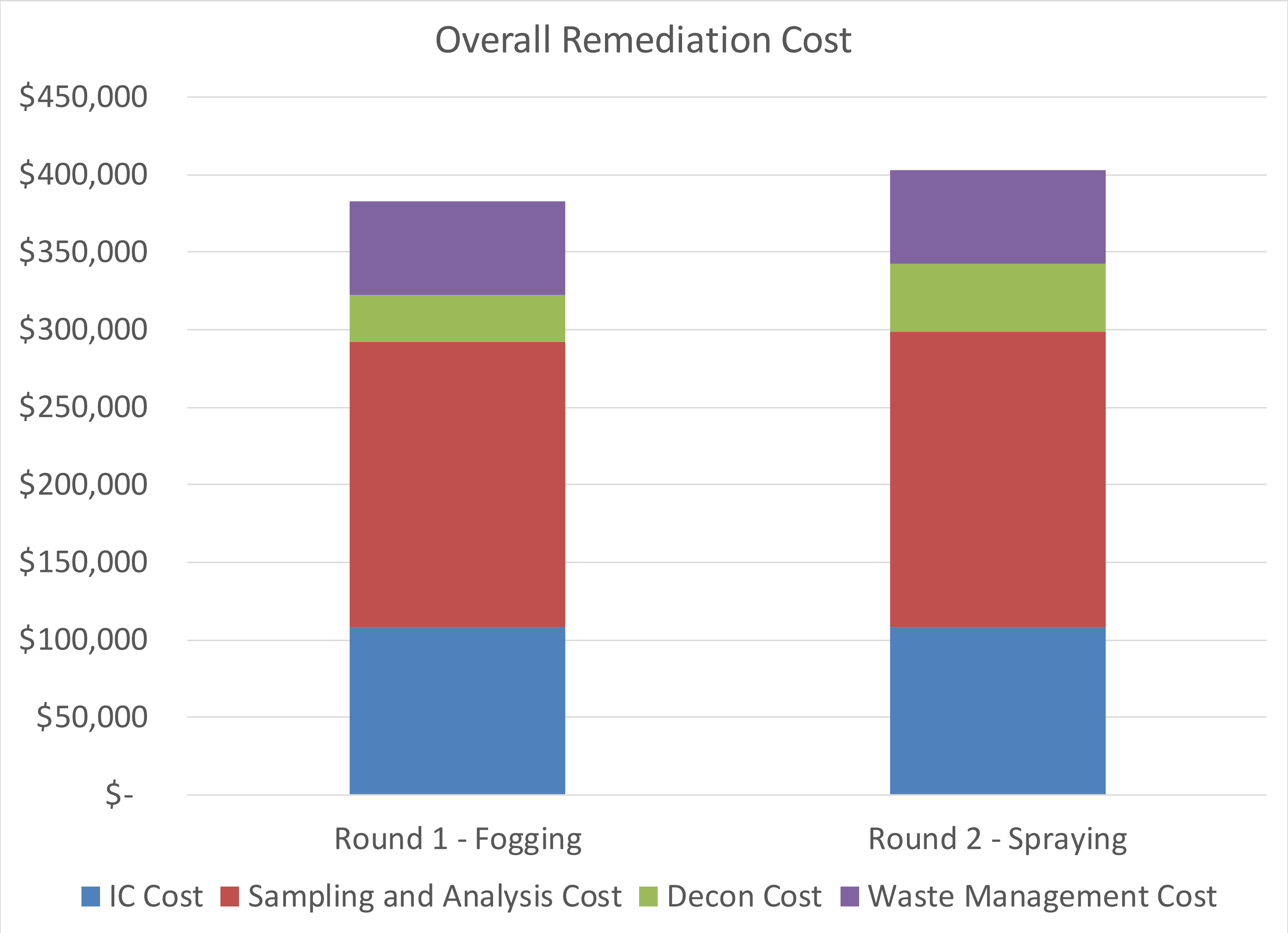
Round 2: pAB Spraying

- Pre-decon sampling: $5.4 \times 10^4 \pm 5.0 \times 10^4$ CFU/ft^2
- 150 samples taken
- Five post-decon positives. Of these, four were Kiosk-associated surfaces
- All grimed and non-grimed coupons were zero except for one ceramic tile coupon (3 CFU)



Zone	Sample Method	Remarks	Recovery (CFU)	Recovery (CFU / ft^2)
Zone 6 (kiosk)	Grab/Extract	Newspaper - Cash	10	n/a
Zone 6 (kiosk)	Grab/Extract	Food - Hot Dogs	50	n/a
Zone 6 (kiosk)	Grab/Extract	Newspaper - T-shirts	500	n/a
Zone 6 (kiosk)	Grab/Extract	Newspaper	5	n/a
Zone 4	Micro-Vac	Platform	6	6

Overall Cost Fogging vs Spraying



Main OTD Findings

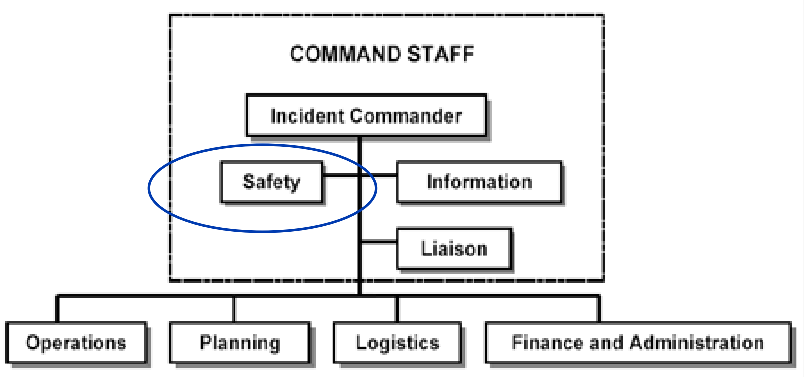
- From Science point of view:
  - Successfully fogged /sprayed mock subway station and tunnel
  - In both rounds, minimal number of spores detected post-decon based on used sampling techniques (sponge stick /37 mm cassette vacuum) and sampling strategy
  - No practical difference in decon efficacy (fogging vs spraying)
  - No adverse impacts to FAPH facility, little more oxidation on rails
  - Waste management:
    - Removal of porous materials for *ex situ* waste treatment is a more effective approach

Lessons Learned – Response Perspective:

- Improved response readiness for mitigating the effects of a release of a biological organism in an underground transportation facility
- EPA staff gained cross-regional training and bio-sampling experience
- Fostered collaboration across other federal agencies
- Gained real-world experience with inactivation of a biological organism

Other OTD activities (1)

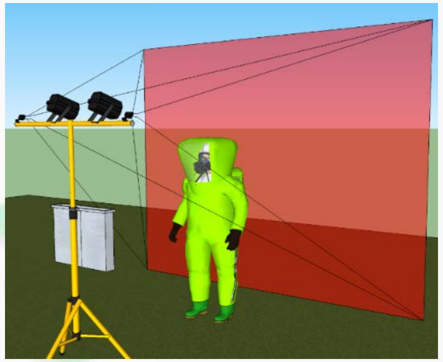
- OTD Health & Safety group
  - Site safety during the exercise
  - Prevention of accidents, injuries, occupational exposures or accidental releases to the environment
  - HASP, Waste Management Plan and Risk Assessment
  - NEPA Approval
- Ensure PPE is adequate for the activity
  - Characterization and Clearance – Level C w/ PAPR
  - Decon (Fogging and Spraying) – Level A
- Personal exposure monitoring
  - Chlorine, *Bg* spores

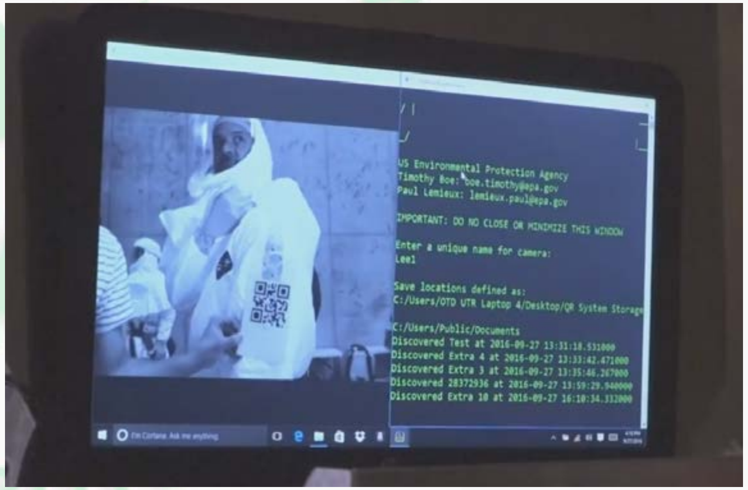


POC: John Archer, EPA/ORD/NHSRC

Other OTD activities (2)

- Use of QR codes to support timekeeping efforts during OTD
- Python based script developed to recognize and record data and time associated with QR codes using web cameras
- System can be used to track movements of personnel within contaminated area
- Records and communicates occupancy duration





POC: Timothy Boe, ORD/NHSRC

Reports:

https://www.epa.gov/homeland-security-research

Remediation Following Natural or Man-Made Disasters

- Contaminant Fate and Transport
- Decontamination of Indoor and Outdoor Areas
- Underground Transportation Restoration Project
- Wide Area Radiological Technology Demonstration

Disclaimers

The U.S. Environmental Protection Agency (EPA) through its Office of Research and Development (ORD) managed the research described. It has been subjected to the Agency's review and has been approved for publication and distribution. Note that approval does not signify that the contents necessarily reflect the views of the Agency. Mention of trade names, products, or services does not convey official EPA approval, endorsement, or recommendation.

This work was funded under an Interagency Agreement (HSHQPM-14-X-00178) with the Homeland Security Advanced Research Projects Agency of the Department of Homeland Security, Science and Technology Directorate. The contents are the sole responsibility of the authors and do not necessarily represent the official views of S&T, DHS, or the United States Government.

Homeland Security

Science and Technology

Acknowledgments

... and many more !

UTR Video

https://www.youtube.com/watch?v=5QlZBW8N02Y&feature=youtu.be

Underground Transport Restoration Research

From laboratory sampling and decontamination studies to full scale technology demonstration

Lukas Oudejans

Oudejans.Lukas@epa.gov

or

Romy Campisano

Campisano.Romy@epa.gov

U. S. EPA

National Homeland Security Research Center

Individual Points of Contact

- Fogging: Joseph Wood, Wood.Joe@epa.gov
- Fumigation: Lukas Oudejans, Oudejans.Lukas@epa.gov (ClO_2)
  Shannon Serre, Serre.Shannon@epa.gov (MeBr)
- Equipment: M. Worth Calfee, Calfee.Worth@epa.gov
- Sampling: Sang Don Lee, Lee.Sangdon@epa.gov

- OTD: Shannon Serre and Lukas Oudejans
- Subway Car Fumigation: Shannon Serre
- Other studies Lukas Oudejans