Innovations Deserving
Exploratory Analysis Programs

Transit IDEA Program

Chemical and Biological Decontamination System for Rail Transit Facilities

Final Report for
Transit IDEA Project 45

Prepared by:
Christos Athanassiu and
Jeremiah Rathbun
Foster-Miller, Inc.
Waltham, MA

January 2007

Innovations Deserving Exploratory Analysis (IDEA) Programs Managed by the Transportation Research Board

This Transit IDEA project was funded by the Transit IDEA Program, which fosters development and testing of innovative concepts and methods for advancing transit practice. The Transit IDEA Program is funded by the Federal Transit Administration (FTA) as part of the Transit Cooperative Research Program (TCRP), a cooperative effort of the FTA, the Transportation Research Board (TRB) and the Transit Development Corporation, a nonprofit educational and research organization of the American Public Transportation Association (APTA).

The Transit IDEA Program is one of four IDEA programs managed by TRB. The other IDEA programs are listed below.

- NCHRP Highway IDEA Program, which focuses on advances in the design, construction, safety, and maintenance of highway systems, is part of the National Cooperative Highway Research Program.
- High-Speed Rail IDEA Program, which focuses on innovative methods and technology in support of the Federal Railroad Administration's (FRA) next-generation high-speed rail technology development program.
- Safety IDEA Program, which focuses on innovative approaches for improving railroad safety and intercity bus and truck safety. The Safety IDEA program is funded by the Federal Motor Carrier Safety Administration and the FRA.

Management of the four IDEA programs is coordinated to promote the development and testing of innovative concepts, methods, and technologies.

For information on the IDEA programs, look on the Internet at www.trb.org/idea or contact the IDEA programs office by telephone at (202) 334-3310 or by fax at (202) 334-3471.

IDEA Programs
Transportation Research Board
500 Fifth Street, NW
Washington, DC 20001

CHEMICAL AND BIOLOGICAL DECONTAMINATION SYSTEM FOR RAIL TRANSIT FACILITES

Final Report

Transit IDEA Project 45

Prepared for

Transit IDEA Program

Transportation Research Board

National Research Council

Prepared by

Christos Athanassiu

Jeremiah Rathbun

Foster-Miller, Inc.

Waltham, MA

January 2007

ACKNOWLEDGEMENTS

The following people generously donated their time and expertise to review draft versions of this report and earlier reports associated with this Transit IDEA project:

Tina M. Carlsen, Ph.D.
Environmental Chemistry and Biology Group Leader
Environmental Restoration Division
Lawrence Livermore National Laboratory

Joan LeLacheur
Manager, Environmental Services
Office of Engineering & Technical Support
Washington Metropolitan Area Transit Authority

Vladimir Gilman, Ph.D.
Senior Engineer
Infoscitex Corporation

Karl Liebenberg
Supervisor, Hazardous Waste
Environmental Services
Office of the Chief Engineer of Facilities
Washington Metropolitan Area Transit Authority

Anthony T. Zimmer, Ph.D., PE, CIH
Commander, USPHS
Engineer, National Decontamination Team
Environmental Protection Agency

Jeff Kempter
Senior Advisor
Antimicrobials Division
Office of Pesticide Programs
Environmental Protection Agency

Charles E. Fitzsimmons, CHMM
On-Scene Coordinator for National Capital Region
Environmental Protection Agency, Region III

Harvey Berlin
Transit IDEA Program
Transportation Research Board

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figure **Page**

LIST OF TABLES

Table **Page**

LIST OF SUPPLEMENTS

Supplement **Document Number**

ACRONYMS AND ABBREVIATIONS

ACST	Air Compressor with Storage Tank
BW	Biological Warfare
CW	Chemical Warfare
CFM	Cubic Feet per Minute
DAADV	Difficult Access Area Decontamination Vehicle
DC	Direct Current
ECADS	Electrostatically Charged Aerosolized Decontamination System
ECBC	Edgewood Chemical Biological Center
EFST	Engine Fuel Storage Tank
EPA	Environment Protection Agency
EPG	Electric Power Generator
HPT	Hydraulic Pump and Tank
NDA	Nozzle Delivery Arm
OCV	Operation Controls Vehicle
PLC	Programmable Logic Controller
PPE	Personnel Protection Ensemble
PSIG	Pounds per Square Inch Gage
PTZ	Pan Tilt Zoom
ROTV	Remotely Operated Transport Vehicle
RST	Reagent Storage Tank
RWST	Rinse Water Storage Tank
SBIR	Small Business Innovative Research
SCFM	Standard Cubic Feet per Minute
SDD	System Design Description
SOV	Solenoid Operated Valve
SOP	Standard Operating Procedure
TBD	To Be Determined
WMATA	Washington Metropolitan Area Transit Authority

1. EXECUTIVE SUMMARY

CONCEPT AND INNOVATION

The purpose of this Transit IDEA project was to investigate the potential use and effectiveness of a remotely operated Electrostatically Charged Aerosol Decontamination (ECAD) process for decontaminating a rail transit station after a chemical or biological release. The ECAD process produces an aerosol fog of electrically charged droplets of a liquid decontamination reagent. These droplets repel one another and are attracted to surfaces and airborne particles in any orientation. Thus, ECAD is a reagent delivery system that minimizes the amount of reagent used, thus potentially minimizing damage to materials and equipment (depending on the reagent used), while still achieving complete coverage of the area to be decontaminated.

SUMMARY OF PROJECT ACCOMPLISHMENTS AND RESULTS

This project was segmented into three stages, with each stage further divided into two or three tasks. The following is a summary of the tasks accomplished and results within each stage of this project:

- <u>Stage I – Requirements Development and State-of-the-Art Assessment</u>
  - *Task 1, Requirements Development* – Foster-Miller worked with the staff at the Washington Metropolitan Area Transit Authority (WMATA) to define the problem by exploring the layout of five major transit stations in their Metrorail rail rapid transit system.

    From this project, a system requirements document (System Design Description or SDD) was generated that served as a specification for the conceptual design of the ECAD system. The SDD was reviewed by WMATA personnel and decontamination experts.
  - *Task 2, Literature Search* – Foster-Miller used an advanced search technology to find information on other programs and technologies performing similar work. The goal was, first, not to duplicate any efforts previously undertaken elsewhere and, second, to learn from and build on the benefits and limitations of existing technologies.

    The ultimate objective was to define a decontamination system which approximates as closely as possible the following ideal set of characteristics:

    - Achieves complete coverage of the exposed area.
    - Effective against any chemical or biological agent.
    - Does not damage materials and equipment in the exposed area.
    - Requires no post-application cleanup.

    The results of the extensive literature search confirmed that some relevant commercial and government products do exist. However, no system currently exists which has all the characteristics above. None of the delivery systems had been designed for transit stations.

    Foster-Miller recognizes that achieving the objective of defining the most effective reagent(s) extends beyond the scope of this project. Once the reagent(s) are defined, they can be fully evaluated with the ECAD system.
  - *Task 3, Decontamination Reagent Investigation (In-Kind Effort)* – Foster-Miller conducted an extensive review of available liquid, gaseous, and solid phase reagents for chemical and biological decontamination. The goal was to identify various reagents which show promise as potentially ECAD-compatible, relatively easy to clean up after ECAD application, and effective against as wide an array of chemical/biological agents as possible.

The investigation suggests that a need exists for a reagent or a mixture of reagents capable of decontaminating both chemical and biological threats, while being non-reacting with treated materials. The promise of hydrogen peroxide based formulations (e.g., Decon Green) should be noted. If the reactivity towards the treated materials is not of importance, bleach (or in general, active chlorine formulations) could be equally effective against chemical and biological agents.

For the subway cleaning applications using ECAD, liquid hydrogen peroxide based formulations appear to be the most promising class of reagents due to their effectiveness against biological agents and minimal clean-up requirements. This kind of reagent of course, might not be very effective against chemical agents, and is thus only a partial solution.

No liquid reagents have been shown to be effective against biological agents on porous surfaces (such as concrete, ubiquitous in a transit environment).

- <u>Stage II – Conceptual System Design</u>
  - *Task 4, Conceptual Design* – Based on the preliminary SDD, Foster-Miller developed a conceptual design of the rail transit decontamination system. The goals were to first, complete the conceptual design drawings along with critical analyses of flow rates and delivery requirements to meet the needs defined in this project, and second, design and fabricate the required hardware for the Stage III static testing.

    The complete conceptual design included all major components depicted in the preliminary SDD. Initial sizing of equipment was completed and an approach to the boom extension was chosen.

    The critical analysis of flow rates and delivery requirements was performed to meet the needs defined in stage I of this project. The ECADS nozzle flow rate increased with supply air pressure. Extrapolations from prior work conducted by Foster-Miller indicated that the ECADS nozzles had to be positioned within 20 feet from a targeted surface while operating between 60 and 80 PSIG air pressure.

    The Stage III demonstration hardware was designed and fabricated.
  - *Task 5, Analysis of Aerosol Effectiveness in Transit Environment (In-Kind Effort)* – Foster-Miller referenced past work to address the impact of the transit environment on aerosol delivery. Foster-Miller further investigated reagents identified in Stage I of this project to develop an opinion on reagent compatibility with the ECADS system which addressed the impact of aerosolization on reagent efficacy.

    Air currents within a transit station must be significantly minimized to reduce the impact on ECADS operations.

    A maximum electrical current of 33 mA (at 1500 VDC) was suggested as an upper limit for ECADS operations to avoid any impact of aerosolization on certain reagent efficacy due to vulnerability potentials of some ingredients included in a reagent. Electrical currents above this limit may lead to a chemical breakdown of the active ingredients within these vulnerable reagents, rendering them less effective.

- <u>Stage III – Demonstration Test and Final Report</u>
  - *Task 6, Demonstration Test* – This test was successfully conducted on August 16, 2006 by Foster-Miller in WMATA's Judiciary Square Metrorail station with the consultation and participation of the WMATA staff. Wetting properties and ventilations effects were observed.

    Each of the three test locations within the station demonstrated surface wetting with a minimal amount of droplets settling to the floor. No clean-up efforts, associated with the nozzle spray, were required after the test. No noticeable ventilation disturbances were observed, however, cycling the ventilation power during the test may have illustrated some minor disturbances.

During actual decontamination if an attack occurred, the area would first be isolated, which should minimize noticeable air movement disturbances.

- *Task 7, Project Final Report* – This report summarizes the work performed and results obtained during each stage of this project.

  In general, the ECADS technology is a viable reagent delivery system. Concrete porosity and hidden cavities (i.e. areas covered by perforated panels) within transit stations are known obstacles for the success of any liquid decontamination effort, including this program. Upon selection of the appropriate reagent(s), lab testing should occur to determine the efficacy of the reagent(s) against the intended biological and/or chemical contaminants on the intended target surfaces together with the ECADS technology.

2. INTRODUCTION

In March of 2005, the Transit IDEA project contract was awarded to Foster-Miller for the TRANSIT-45 contract titled *Chemical and Biological Decontamination System for Rail Transit Facilities*. The second and third stages of this contract were authorized thereafter. This report documents the work performed and the results obtained in each of the three stages of this Transit IDEA Project 45.

2.1 BACKGROUND

Foster-Miller has been developing charged aerosol spraying systems for several years, originally for use in hard rock mines for dust control systems. The concept for use of the technology was conceived several years ago and was successfully demonstrated by Foster-Miller. Funding was then provided by the Washington Demilitarization Group to develop a system to assist in the decontamination effort underway at Johnston Atoll Chemical Agent Disposal System (JACADS). A system was designed, developed, and fabricated to decontaminate Munitions Demilitarization Machines (MDMs). In the spring of 2001, a successful simulation test was conducted on the system at the Chemical Demilitarization Training Facility (CDTF) in Edgewood, MD on the MDM used for training plant operators. The test demonstrated the distribution effectiveness of ECAD for decontamination of large demilitarization equipment as discussed in a Foster-Miller report dated April 2001 titled *Electrostatically Charged Aerosol Decontamination System Qualification at the CDTF in Edgewood, MD*. Due to schedule issues, the equipment was never deployed at JACADS for use in decontaminating the two MDMs. In September of 2001, however, the Washington Demilitarization Group invited Foster-Miller to use the equipment to support live agent tests under the Assembled Chemical Weapons Assessment (ACWA) program. The initial testing with mustard (HD) was successfully conducted, using bleach as a reagent, in the fall of 2001 in the main chemical test chamber at Aberdeen Proving Ground in Edgewood, MD.

2.2 ECAD SYSTEM DESCRIPTION

The ECAD system is a Foster-Miller proprietary technology that takes any electrically conductive liquid, atomizes it by combining with a stream of compressed air, and processes the mixture through a high electric field as the mixture is sprayed into the atmosphere. The cloud of droplets charged to the same polarity are rapidly self-repelled moving about equally horizontally, upward and downward since the electric forces on the droplets dominate over gravity. Both, top and bottom surfaces of the target are coated with spray droplets.

3. IDEA PRODUCT

The envisioned product of this project is a conceptual automated decontamination system which could be deployed to completely and quickly decontaminate a rail transit station after a biological or chemical release. The system will robotically deploy a suitable reagent, from a remote location, using an Electrostatically Charged Aerosol Decontamination (ECAD) process. The ECAD process produces an aerosol fog of electrically charged droplets of a liquid decontamination reagent and has the potential to achieve complete decontamination of complex profile surfaces without needing to flood the transit station with liquid or foam reagent. Remote deployment will protect first responders and other personnel from accidental exposure to harmful agents and/or cleaning reagents.

4. CONCEPT AND INNOVATION

The purpose of this Transit IDEA project was to investigate the potential use and effectiveness of an ECAD process for decontaminating a rail transit station after a chemical or biological release. The ECAD process produces an aerosol fog of electrically charged droplets of a liquid decontamination reagent. These droplets repel one another and are attracted to surfaces and airborne particles in any orientation. The ECAD is a reagent delivery system that minimizes the amount of reagent used, thus potentially minimizing damage to materials and equipment (depending on the reagent used), while still achieving complete coverage of the area and volume to be decontaminated.

Some conventional decontamination systems require the extensive use of liquid or foam reagents to effect decontamination. This tends to create an even larger clean-up problem as well as damaging materials and equipment. Other conventional decontamination technologies involve gaseous fumigation using chlorine dioxide or other gasses which, while often effective against biological agents, are less so against chemical agents. Techniques in the research stage effective against both BW and CW agents include the use of different gaseous reagents or plasmas. Plasmas, for example, have been shown to be quite effective and non-damaging, but have coverage limitations that may limit their utility in large area decontamination.

The ultimate objective, based on the literature search, was to define a decontamination system which approximates as closely as possible the following ideal set of characteristics:

- Achieves complete coverage of the exposed area.
- Effective against any chemical or biological agent.
- Does not damage materials and equipment in the exposed area.
- Requires no post-application cleanup.

No system currently exists which meets all of these characteristics, and it was not Foster-Miller's contention that the output of this project would be such a system. However, Foster-Miller believes that the ECAD delivery system, coupled with the right reagent, could come close to this goal.

5. INVESTIGATION

This Transit IDEA investigation proceeded in three stages. The first stage consisted of the requirements development, a literature search, and decontamination reagent investigation. The second stage included a conceptual design, and an analysis of aerosol effectiveness in a transit environment. Lastly, the third stage entailed a validation demonstration test, and this final report.

5.1 STAGE I

5.1.1 Task 1 – Requirements Development

The goal of Task 1 was to define the requirements for a transit station decontamination system. This involved visiting various WMATA stations to understand their layout, look at existing surfaces, materials, and obstacles, as well as discussing various system alternatives with knowledgeable transit personnel. It also involved creating and approving a preliminary System Design Description (SDD) describing how the system might work and what characteristics it might have.

This task resulted in a Field Survey Trip Report and an SDD. A summary of the Field Survey Trip Report is included in this report and the SDD is a separate supplement 1. The Stage I Report, dated September 2005, includes the complete Field Survey Trip Report.

5.1.1.1 Field Survey Trip Report

On May 23, 2005, Foster-Miller personnel attended a meeting with the Washington Metropolitan Area Transit Authority (WMATA) at the WMATA Headquarters building in Washington, D.C. The purpose of this trip was to introduce Foster-Miller's concept for subway remediation to WMATA personnel and exchange ideas with regards to producing a good working preliminary SDD.

The following are some highlights of the meeting:

- Foster-Miller presented the scope of study along with a description of the proposed ECADS based remediation system.
- Foster-Miller explained to WMATA personnel the required ancillary equipment to support the ECADS. For discussion purposes, an outline of the system configuration, required system components and controls were also covered.
- All exchanged ideas regarding the degree of system automation versus system reliability and cost.
- Discussions occurred regarding pros and cons for having a manual system operation, with a system operator dressed in level A Personal Protective Equipment (PPE) ensemble versus a remotely operated system including a means for getting the equipment to a location, on demand.
- Foster-Miller personnel, accompanied by Lt. Leslie Campbell of the Metro Transit Police, visited five subway stations to evaluate the physical layouts and commonalities. This also presented an opportunity to determine the best approach to providing complete coverage of all surfaces within each station. A summary of Metrorail subway station findings and commonalities are included in Table 1 (all dimensions are approximate).

TABLE 1 Summary of WMATA subway station findings and commonalities (all dimensions are approximate)

Station Name	Union Station	Judiciary Square	Gallery Place	Metro Center	L'Enfant Plaza
No. of WMATA Lines thru Station	1	1	3	3	4
Multi-Level Station	No	No	Yes	Yes	Yes
Distance from Rail to Highest Accessible Point (feet)	~35	~35	~35	~35	~35
Distance Station Width (feet)	~40	~40	~40	~40	~60
Station Length (feet)	~200	~250	~300 x 300 ~200 Lower Level	~300 x 300 ~200 Lower Level	~300 x 350 ~200 Lower Level
Mezzanine	Yes	Yes	Yes	Yes	Yes
Narrow Teardrop Shaped Access Holes to Mezzanine (from Rail)	No	No	No	Yes	Yes

- Lastly, Foster-Miller personnel visited a Metrorail maintenance facility to look at self contained rail guided de-icing and subway station washing systems used by WMATA. These systems may provide a baseline for Foster-Miller's concept.

5.1.1.2 General Observations

- All stations were constructed of porous concrete formed slabs. These porous surfaces will pose a significant challenge to liquid bio-decon chemicals.
- There were vents in the formed slab walls of each station.
- There were perforated ceiling tiles in lower rail levels and mezzanines. These surfaces will also pose a challenge for a liquid-based system due to their porosity.
- The width of the handicap access opening through the turnstiles is 28 in.

In conclusion, this trip was very informative for both Foster-Miller and WMATA. We exchanged some good ideas and established a good working relationship. Foster-Miller is confident that a rail guided ECAD based remediation system in conjunction with a conventional ECAD would be a viable solution to WMATA's needs, at least from a reagent delivery or coverage standpoint. Though a rail guided ECAD would provide a great percentage of station coverage, a conventional ECAD would still be required for coverage from the point of egress to the turnstiles, due to limited access through the turnstiles and increased distances from the turnstiles to the point of egress. This solution would provide complete station coverage. One key issue will be the decontamination reagent used, and whether it can provide effective decontamination on porous surfaces.

5.1.2 Task 2 – Literature Search

The goal of Task 2 was twofold: To ensure that this effort did not duplicate any work previously done in this area, and to draw comparisons with other approaches investigated for other applications from which lessons might be drawn. Task 3 was also a literature search of a sort: It was more focused specifically on decontamination reagents and especially on those that might be compatible with an ECAD delivery system and useful for transit decontamination.

5.1.2.1 Search Parameters and Methodology

Foster-Miller used a literature search methodology in collaboration with HAB Technologies. For this search, Foster-Miller found the methodology more effective than Lexis-Nexis, NERAC, Dialog, and other database-driven systems because they use human researchers to penetrate the 'deep internet.'

Utilizing teams of professional research editors, HAB scours the surface web as well as the deep web (99 percent of the Internet's content, not indexed by search engines) to find highly relevant information on every conceivable facet of this industry. HAB's editors coordinate this information within a secure collaborative taxonomy solution (XtremeShare™). Foster-Miller's personnel were able to use XtremeShare to monitor search results and guide the search agenda.

5.1.2.2 Search Results

A summary of the significant search results follows. The results fall into two main categories.

First, a variety of other decontamination technologies and equipment packages were found either fully developed or still in the early stages. None had been specifically adapted for transit applications, but it was still instructive to see other general decontamination approaches and compare them with ECAD. In this section, the focus was on the delivery system, not the reagent used. The comparison was between the ECAD delivery system, using a charged aerosol spray, and other liquid reagent delivery systems, such as foams or un-charged aerosols.

Second, a few other government programs were supporting efforts to develop plans for response and remediation in the event of a chemical/biological release. These programs are discussed in later subsections of Section 5.1.2.2. It was instructive to see the focus of their programs and their results, and to see where the results of the current project might fit along with those programs. As of the summer of 2005, the Department of Homeland Security had apparently not pursued a rail transit station specific decontamination *demonstration* program.

5.1.2.2.1 Foam Cleaners

There are a variety of portable manual units for industrial and institutional cleaning on the market. This is the most conventional method of biological or chemical remediation. These systems are typically human-deployed (exceptions being talked about in the next section). A variety of reagents are available depending on the application. The disadvantages of foam are clear: highly damaging to equipment, materials, and documents as well as posing a cleanup problem.

Foam cleaning systems are available from a variety of vendors including: Innovative Cleaning Equipment, Inc., OWR AG, Modec Decon Solutions, Inc., Andax Environmental, Inc., Life Safety Systems (a distributor/agent for a variety of OEMs), and others.

5.1.2.2.2 Various Decontamination Trailers with Booms

Most of these have been designed for general use, rather than specifically for a transit environment. They typically use foams as the decontamination reagent. They are available from many of the same OEMs and distributors as listed above.

5.1.2.2.3 Very Fine Mist Foggers

There are a variety of conventional, uncharged, foggers which use high atomizing air pressures and liquid flow rates to produce fogs with very fine aerosol particles (under 10µ). None have been developed specifically for transit applications, but are general purpose. There may be a reason to combine ECAD with a very fine mist, to minimize wetting if the equipment being decontaminated is so sensitive that wetting must be kept to an absolute minimum.

5.1.2.2.4 Intecon/Titan's 'Binary Ionization Technology'

This system looks a great deal like an ECAD system, but in general it provides smaller area coverage and is not as versatile as ECAD, being dependent on only one reagent: hydrogen peroxide. It often seems to be used in glove box-style applications and in small areas. It is offered in a joint venture by Titan Corporation of San Diego and Intecon Systems.

The 'BIT' technology produces a plasma-activated species of hydrogen peroxide mist by shooting an atomized spray of a hydrogen peroxide solution through a field of atmospheric plasma. The resulting mist is then effective against both biological and chemical agents. The system works with small amounts of hydrogen peroxide and leaves little damaging residue since the species rapidly recombine or combine with atmospheric atoms to form stable molecules. Since the 'activated' hydrogen peroxide does recombine so quickly, it makes effective large area coverage difficult.

The Edgewood Chemical Biological Center (ECBC) is funding Titan to perform work on sensitive equipment decontamination using this technology. Titan and Boeing are looking for possible TSWG funding for a retrofit sprinkler system for building, transportation system, and transit terminal biological/chemical release mitigation.

5.1.2.2.5 Clean Earth Technologies' 'Electrostatic Decontamination System'

Clean Earth Technologies' Electrostatic Decontamination System (EDS) sounds in principle much like Foster-Miller's ECAD system. Clean Earth has focused much of their development efforts on the combination of their EDS delivery system with a UV-activated reagent they claim is effective against both chemical and biological agents.

The potential benefit of the UV-activation is twofold: First, the activity of the reagent is greatly enhanced and the decontamination times reduced; second, the reagent after UV treatment may become chemically inert and thus there are greatly reduced cleanup requirements and little danger of corrosion or equipment degradation. The drawback of the UV-activation process is, of course, the line-of-sight limitation which becomes a serious problem with complex geometries and large areas.

They have received general development funding from TSWG and the DoD, but none specifically for transit station remediation.

5.1.2.2.6 Atmospheric Glow Technologies' 'Atmospheric Plasma Decontamination'

This decontamination system produces a stream of atmospheric molecules in their ionic ('plasma') state or an excited ('activated') state. In either state, the molecules are highly reactive and generally antimicrobial. The main benefit of this system is its ability to decontaminate highly sensitive materials and equipment with little to no risk of any damage. In general, the technology's range is limited, making it potentially unsuitable in the short term for large area decontamination. It is unclear what its effectiveness against chemical agents would be due to lack of data.

5.1.2.2.7 PROTECT Program (Program for Response Options and Technology Enhancements for Chemical/Biological Terrorism in Subways)

This is a Department of Energy sponsored program, co-sponsored by the Department of Homeland Security, tasked with making plans and improvements to every stage of responding to a transit station attack. It deals with detection systems, emergency responder coordination, mitigation during the attack, as well as cleanup and decontamination after the attack. So far, the parts of the program dealing with post-attack mitigation rely on fairly conventional technologies such as various foams and reagents.

Part of that program is to create a general restoration plan for WMATA. No automated system for large-scale decontamination seems currently envisioned. However, the results of the current project should be reported to the PROTECT program and the Livermore Group for integration into that larger overall effort, and integration into the restoration plan, if successful.

5.1.2.2.8 U.S. Army Soldier and Biological Chemical Command (SBCCOM), Edgewood Chemical Biological Center (ECBC)

The development of a number of technologies, including the Binary Ionization Technology (BIT) mentioned in subsection 3.2.4, are funded by SBCCOM and tested at the ECBC. Much of the research focuses on better liquid reagents, with the goal being the creation of a 'universal' reagent which would be effective against the greatest number of possible chemical and biological threats. These liquid reagents could be deployed using conventional foam systems, but many could also be deployed using an ECAD type system.

ECBC is also actively investigating activated gaseous reagents for use in buildings and airplanes that would be effective on chemical and biological agents. They have focused on vaporous hydrogen peroxide as a promising candidate.

5.1.2.2.9 Technical Support Working Group (TSWG), Chemical, Biological, Radiological, and Nuclear Countermeasures (CBRNC) Subgroup

TSWG has a yearly budget for funding the development of a variety of technologies for detection, protection, decontamination, and information sharing in the area of chemical/biological mitigation. They have funded the development of a variety of mitigation technologies including several of those listed above.

5.1.3 Task 3 – Decontamination Reagent Investigation (In-Kind Effort)

The goal of Task 3 was to research possible reagents for use with ECAD for the purpose of subway decontamination.

Any reagent for use in biological decontamination with ECAD or any other delivery system will require EPA approval or a FIFRA crisis exemption. EPA receives its authority to register pesticides (which a biological decontaminant would be considered) under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). Section 18 of FIFRA authorizes EPA to allow States to use a pesticide for an unregistered use for a limited time if EPA determines that emergency conditions exist. It will be critical as this project continues to make sure that any promising reagent will be able to get a FIFRA crisis exemption if it is not already EPA approved.

5.1.3.1 General Outline

Reagents can be categorized and compared in many ways. For the purposes of the Stage I Report, the goal was to categorize them in such a way as to reveal which might be potentially best suited for transit station decontamination using the ECAD process as a reagent delivery system. Only reagents available commercially, or close to being available commercially, were included in that survey.

First, reagents can be classified by their physical state during use as a decontaminant: liquid, solid, or gas. Since the ECAD work done to date has involved only liquid-state reagents, these were the main focus of the Stage I Report. It may be possible, if there is enough promise in a given gaseous or solid reagent, to create a charged gaseous or aerosolized solid particle spray, but this has not been done to date.

The second criterion applied in the Stage I Report was the distinction between those liquid-phase reagents which require post-application cleanup and those which do not. Clearly the latter would be preferable in the context of transit station decontamination. Of those requiring post-application cleanup, they can be further categorized according to the severity of the cleanup requirements. For example, some reagents may create products which are themselves hazardous, thus requiring cleanup personnel to wear hazmat suits and take extensive precautions, while others may be cleaned by ordinary means. As another example, some highly corrosive reagents may require immediate removal, while other less corrosive materials may be allowed some time before cleanup without ill effect.

Once these two criteria are applied, each reagent is described in the Stage I Report according to:

1. Efficacy Against Biological and Chemical Agents.
2. Basic Technology Description.
3. Cleanup Description.
4. Toxicity and Environmental Concerns.

5.1.3.2 Summary of Decontamination Reagents Researched

This section presents a summary of the decontamination reagents researched, categorized by the physical-chemical state during application. The Stage I Report, dated September 2005, includes more detailed descriptions of these reagents.

- <u>Liquid Phase Reagents</u>
  - Liquid Phase Reagents Requiring No Post-Application Cleanup
    - Aqueous Hydrogen Peroxide
    - Aqueous Chlorine Dioxide
  - Liquid Phase Reagents Requiring Post-Application Cleanup
    - L-GEL
    - CASCAD
    - Sandia Foams
    - TechXtract®
    - Decon Green
    - GD-5; GD-6

- <u>Gaseous Phase Reagents</u>
  - Methyl Bromide
  - Chlorine Dioxide Gas
  - Hydrogen Peroxide Vapor
- <u>Solid Phase Reagents</u>
  - Solid Phase Decon, FAST-ACT™
  - Paraformaldehyde

The following results were obtained from the decontamination reagent research:

- The investigation suggests that a need exists for a reagent or a mixture of reagents capable of decontaminating both chemical and biological threats, while being non-reacting with treated materials. The promise of hydrogen peroxide based formulations (e.g., Decon Green) should be noted. If the reactivity towards the treated materials is not of importance, bleach (or in general, active chlorine formulations) could be equally effective against chemical and biological agents.
- For the subway cleaning applications using ECAD, liquid hydrogen peroxide based formulations appear to be the most promising class of reagents due to their effectiveness against biological agents and minimal clean-up requirements. This reagent, of course, might not be very effective against chemical agents, and would thus be only a partial solution.
- No liquid reagents have been shown to be effective against biological agents on porous surfaces (such as concrete, ubiquitous in a transit environment).

5.2 STAGE II

5.2.1 Task 4 – Conceptual Design

The goal of Task 4 was to create a conceptual design of a rail transit station decontamination system based on the findings of Stage I and Stage II. This conceptual design includes all of the major equipment identified in the SDD (supplement 1).

This task resulted in three deliverables:

- The three-dimensional conceptual design drawings and descriptions
- Critical analyses of flow rates and delivery requirements to meet the needs defined in Stage I of this project
- Sketches, pictures and a test plan for the Stage III demonstration hardware

5.2.1.1 Conceptual Design Drawings and Descriptions

Foster-Miller generated three-dimensional conceptual design drawings of the rail transit decontamination system (see Figures 1 and 2). Standard commercial items were included where possible for the system. These drawings were accompanied by conceptual design descriptions, in the Stage II Report, to further illustrate the details.

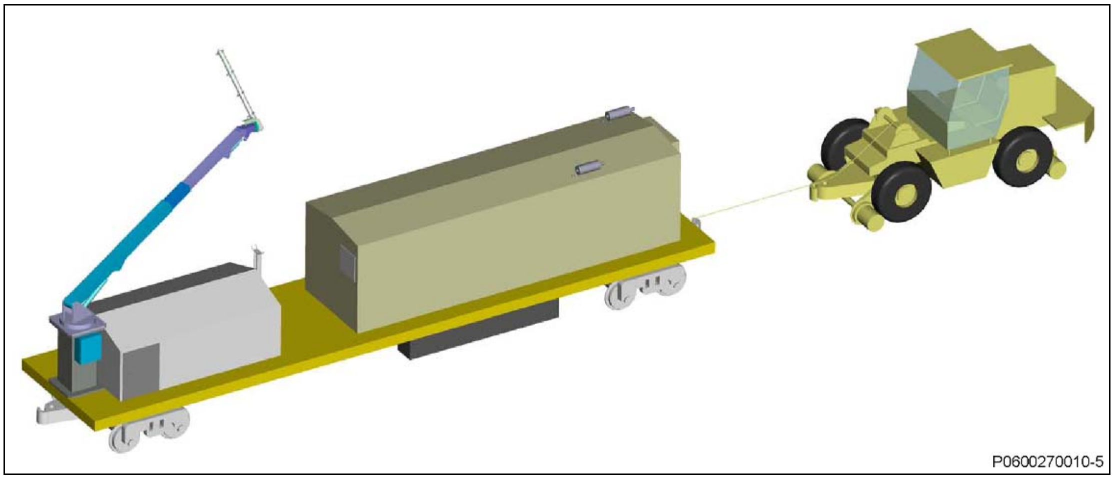

FIGURE 1 Transit station decontamination concept

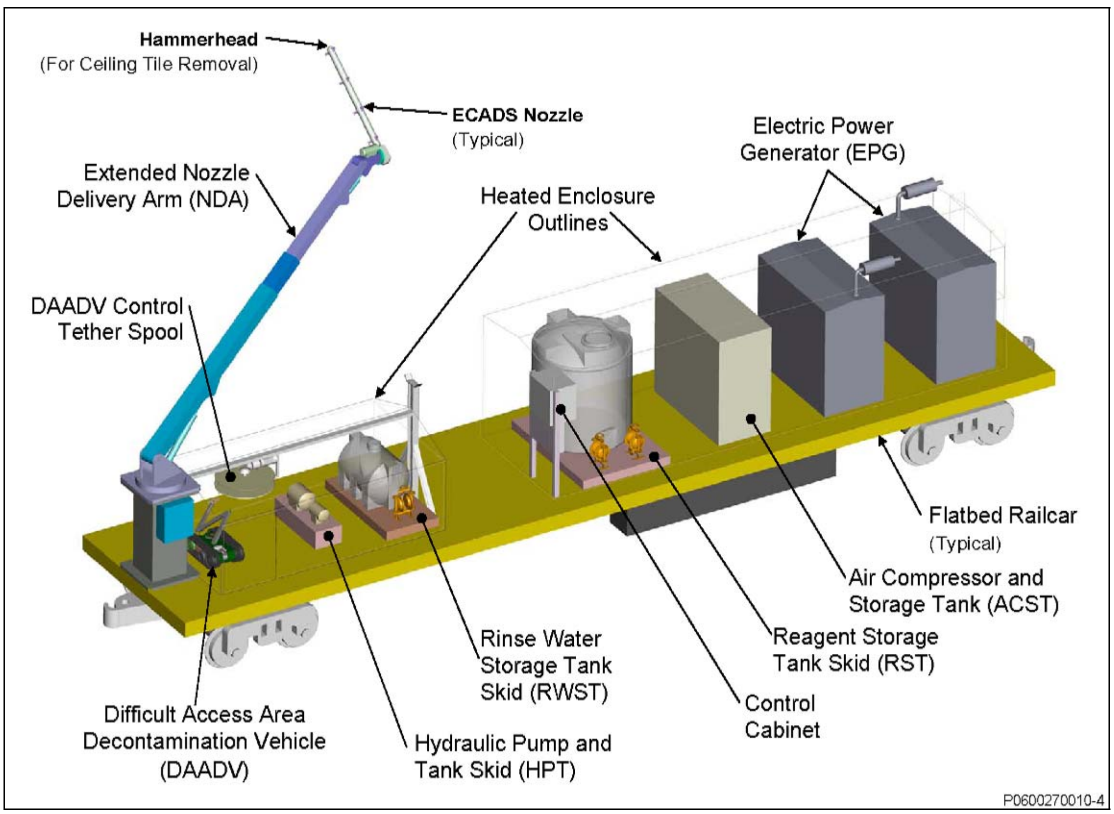

FIGURE 2 Conceptual design - Remote Operated Transport Vehicle (ROTV) - detailed view

5.2.1.2 Critical Analysis of Flow Rates and Delivery Requirements

There are a total of eight nozzles attached to the NDA. The airflow vs. air pressure characteristics for the selected commercially available nozzle is shown in Figure 3.

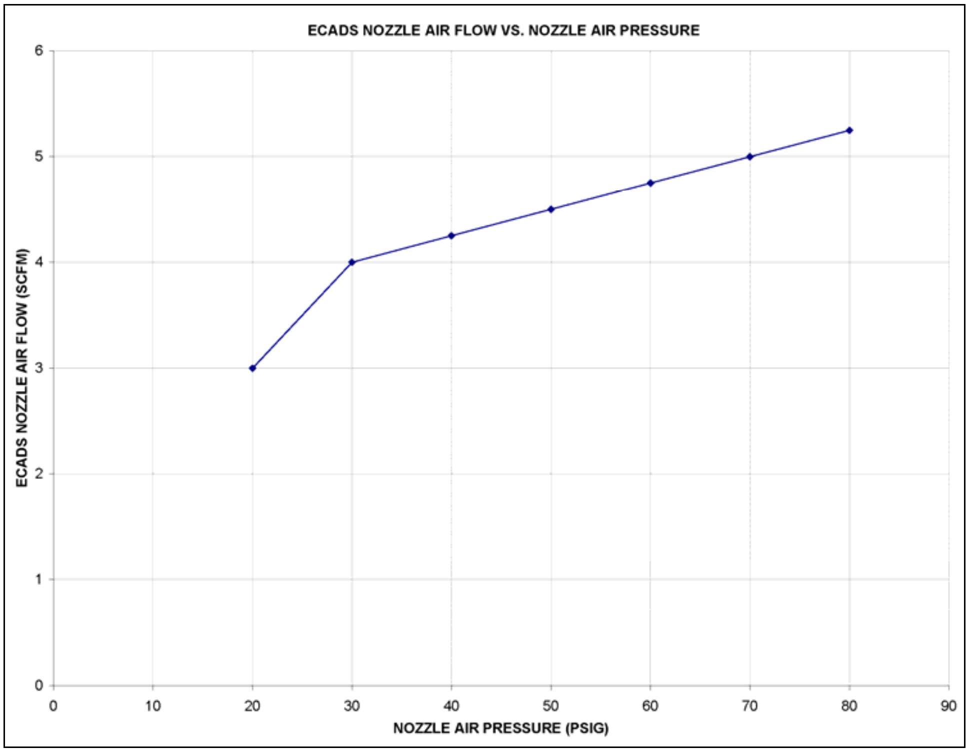

FIGURE 3 ECADS nozzle flow vs. nozzle pressure chart

In cold weather, below 40° F, there is a freezing potential for the reagent upon aerosolization. This is not a concern for the underground subway stations of WMATA's Metrorail system. This may be a concern in some other cities with colder environments, and further testing may be warranted for application in there cities to evaluate the magnitude of this potential issue, and methods to alleviate it, if necessary.

5.2.1.3 Stage III Validation Hardware

The proposed ECAD delivery system was demonstrated for use in rail transit facilities using the Stage III test apparatus. A sketch, as well as a picture of the actual hardware, is shown in Figure 4. The two primary components of this apparatus are the control unit and an ECADS nozzle mounted to the top of a telescoping pole.

The control unit includes an electronics module, a reagent reservoir and an air compressor. The electronics module increases the voltage by a factor of 10. The reagent reservoir stores sufficient reagent for the validation. And finally, the air compressor provides compressed air for reagent supply and aerosolization.

The telescoping pole has an operating range up to 15 feet above ground level. The pole is to be manipulated by a technician to rotate about the base and move the base along a path fulfilling the test requirements stated in the Stage III Validation Demonstration Test Plan (supplement 2).

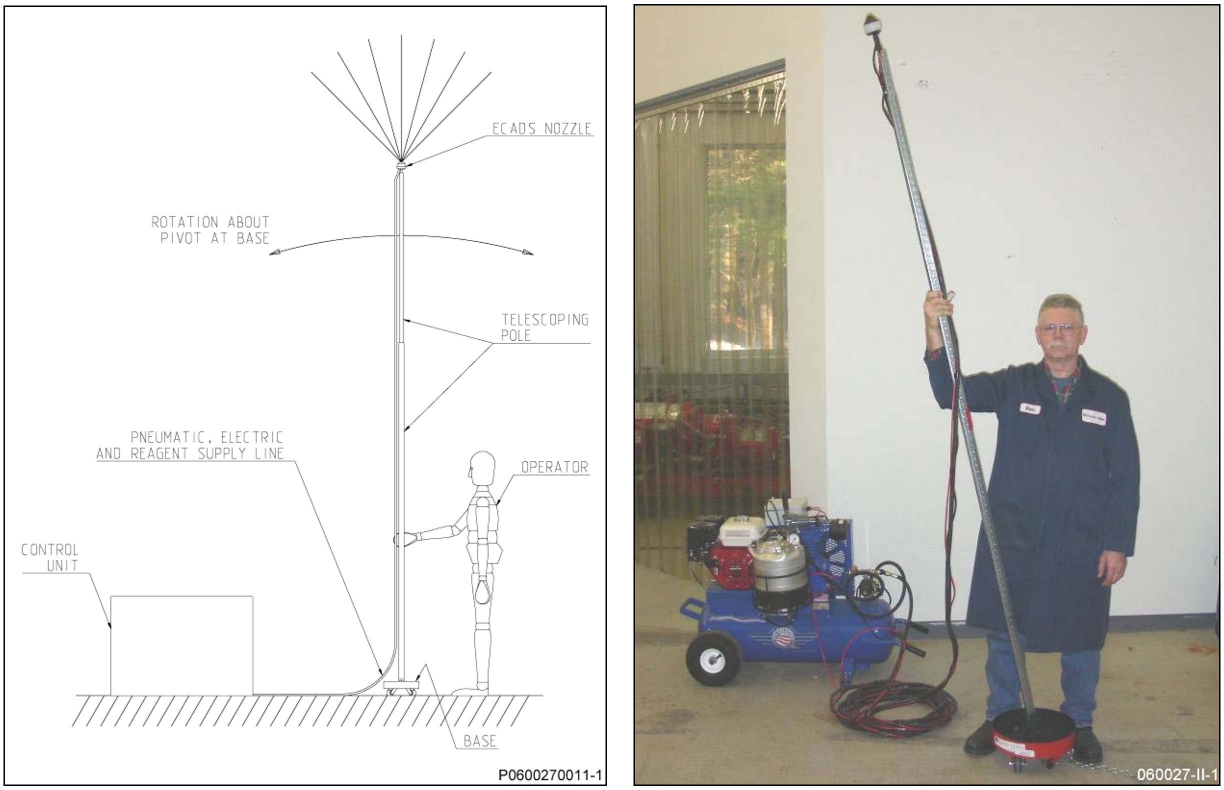

FIGURE 4 Stage III test apparatus sketch and picture

5.2.2 Task 5 – Analysis of Aerosol Effectiveness in Transit Environment

The goal of Task 5 was to address the two issues related to the use of an aerosol for chemical or biological reagent delivery in the open environment of a transit station or tunnel. Specifically,

- Impact of transit environment on aerosol delivery
- Impact of aerosolization on reagent efficacy

5.2.2.1 Impact of Transit Environment on Aerosol Delivery

Subway stations are subject to air currents generated from ventilation shafts, fans, and tunnel currents. These conditions can affect the distribution of ECADS produced droplets, typically in the order of 30 to 50 microns, and influence the deposition, or coverage, across subway surfaces.

With regards to air ducts and fans we recommend that all be turned off and isolated, as soon as an event is detected in order to prevent/minimize the spread of contamination, and achieve optimal deposition of reagent(s).

Preliminary tests, specifically deposition studies, conducted by Foster-Miller during an EPA SBIR, contract #: 68-D-02-083, ECADS for Small Building Decontamination, and Air Force SBIR contract #: FA8650-04-M-6523, ECADS for Aircraft Cargo Space Decontamination showed that it was possible to decontaminate ducts using ECADS equipment. Operation of the equipment would require turning the ECADS power supply ON-OFF at approximately 30 seconds intervals to allow uncharged droplets to be transported upstream without saturating the duct entry. Here again, additional tests are needed to define the exact sequence and means of transporting the aerosol inside the ducts, characterize air pressure/flow and apply metrics to effectiveness in large scale ducts with perhaps many turns and twists as the ones that may be found in a subway. In addition, the duct exits (exhaust points) should be temporarily redirected inside the subway station using temporary plastic ducts for re-circulating the air, or carbon bed filters should be installed to trap any airborne agent present. The tests conducted within the EPA SBIR scope were for small office environments and extrapolations may not accurately represent transit environments.

As for the tunnel effect currents, if strong (greater than 3 mph) air currents exist, Foster-Miller recommends that at least one side of the tunnel be sealed off using an inflatable balloon (bladder). Test results from the EPA SBIR show that it is possible to optimize the ECADS design and operating parameters to accommodate light air currents. Additional tests, however, are needed to confirm the extrapolations and observations. The proposed design is based on data and observations from the EPA SBIR study taking into account light air currents that may exists within a subway. Extrapolations indicate that the NDA must position the ECADS nozzles within 20 feet from a targeted surface while operating between 60 and 80 PSIG air pressure. The nozzle pressure can be further adjusted to optimize the aerosol delivery and distribution.

5.2.2.2 Impact of Aerosolization on Reagent Efficacy

The material provided below describes the author's opinion on compatibility of reagents outlined in the Stage I report with the electrostatic potential created by the ECAD system.

The issues of influence of the shear stress, and ECAD material compatibility are not discussed. However, it has to be noted, that certain reagents (particularly peroxide based) may need careful selection of the storage materials contacting them in order to avoid decomposition of active ingredients, or loss of efficacy.

Currently, the information about stability of aerosolized organics exposed to the electrostatic fields is available within studies of decontamination of organic pollutants in gas–liquid gliding arc (glidarc) discharge reactors [1,2]. This information is used further in the text.

In order to observe breakdown of organic molecules exposed to high electrostatic potential, the voltage that averages 0.5-10 kV for currents from 0.1 to 5 A per discharge need to be created (or 50 to 50000 VA energy loads); therefore, a gliding arc discharge in a flowing gas at atmospheric pressure is formed [3]. Under the conditions of the low temperature plasma the oxygen atoms form peroxy radicals and ozone. These reactive oxygen species are very unstable and oxidize the organics. When additional sources of free radical are present in the liquid (e.g. nitrites) some other radicals ($NO^{\cdot}$) will participate in oxidation of organic molecules.

Some reagents outlined in the Stage I report of this project may have components that the ECADS could render vulnerable to chemical breakdown and less effective when exposed to reactive oxidizing species (radicals). These compounds, and the respective reagents incorporating them, are presented in Table 1. All other reagents presented in Stage I report seem to be compatible with the ECADS system.

TABLE 2 Ingredient compounds and reagents rendered potentially vulnerable

Compound	Active/Assisting Component	Reagent
Fichlor (sodium dichloroisocyanurate)	Active	CASCAD®
Surfactants	Inert	Sandia National Laboratories Foams (EasyDECON™)
Organic Acids	Active	TechXtract
Propylene carbonate Triton X-100	Inert	Decon Green
Aminoalcholates	Active	GD-5; GD-6

In the above table, each compound is described as either active, or inert. An active compound causes or contributes to the efficacy of the product. An inert compound serves a non efficacy function (e.g. stabilizer, emulsifier, etc.).

With the 1,200-1,500 VDC proposed for the ECADS system, the intensity of the current should not exceed 33 mA in order to avoid chemical changes in some ingredients of reagents listed in Table 1.

It should be noted that the predictions are based on data available in the literature for volatile organic solvents. The data on susceptibility of the reagent ingredients are not currently available. Additional testing is required to better understand the interaction between selected reagents and the ECADS system.

In previous tests we have observed the current to be better than 100 mA with similar operating parameters as the ones proposed for this system. It is the author's belief that the reason for the high current is external leakage, however we do not have any data at this time to characterize and confirm the exact current path. This is another area where additional testing is needed in order to first understand and define the current intensity, then assess selected reagents.

5.3 STAGE III

5.3.1 Task 6 – Demonstration Test

The demonstration test was successfully performed on August 16, 2006 in WMATA's Judiciary Square Metrorail station. This task was performed in accordance with the Stage III Validation Demonstration Test Plan (supplement 2) using the equipment illustrated above in Figure 4.

Three test locations were selected within the Judiciary Square station. The first location was the mezzanine "teardrop" positioned between the inside of the escalator and the mezzanine as shown in Figure 5.

FIGURE 5 Stage III demonstration, location #1

The second location was at the end of the mezzanine with an escalator to one side and no other obstructions on the other side as shown in Figure 6 (right). The third location was towards the middle of the station where there were no obstructions from the station floor to the ceiling.

Each of the three test locations within the station demonstrated surface wetting on the concrete ceiling. Due to rapid evaporation and possible absorption into the dry concrete ceiling slabs, the surface remained wet for approximately two minutes. The distance from the nozzle to the ceiling ranged from 4 to 14 feet during the demonstration; closer distances provided surface wetting in less time than longer distances. A target distance of 20 feet from the nozzle to the station ceiling was not achievable due to the height limitations of Judiciary Square. Figure 6 below (right) shows the stream of charged aerosol droplets emitting from the nozzle towards the ceiling.

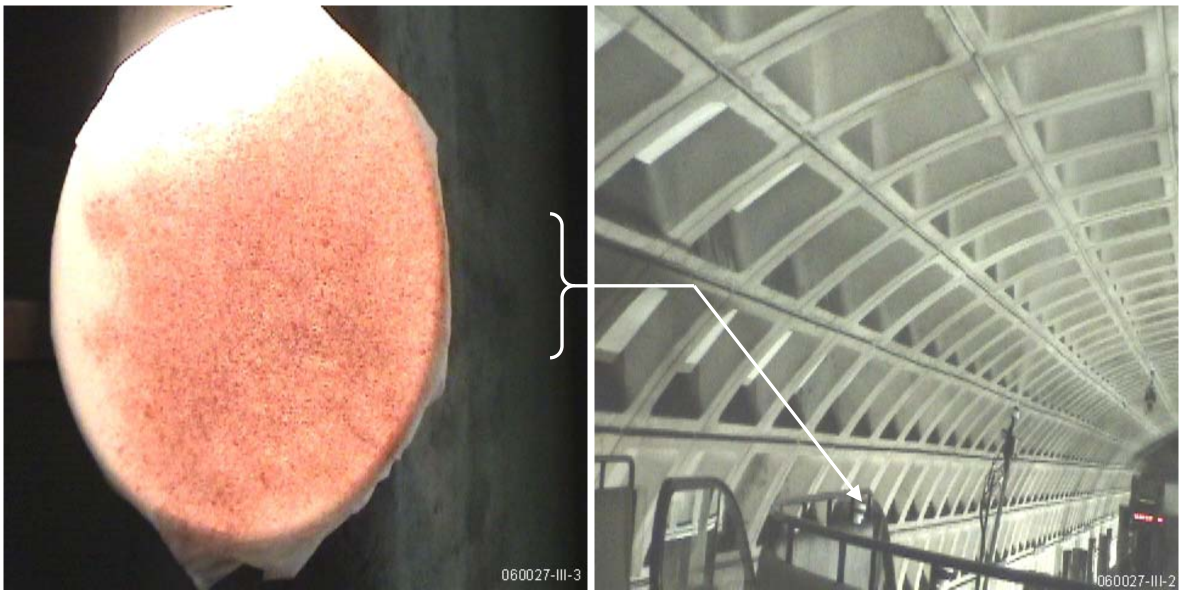

FIGURE 6 Stage III demonstration hygroscopic test coupon and droplet stream, location #2

The amount of charged droplets settling to the floor was minimal, as long as wand movement continued, which represented encouraging ECAD efficacy. A qualitative measurement of these charged droplets was captured using the hygroscopic test coupons which were attached to the hand rails on the mezzanine as shown in Figure 6 (left - dark red specs). As an observation, if the wand was held in-place long enough for the targeted area to become saturated with charged droplets, more droplets would settle to the hygroscopic test coupon and floor. Holding the wand in-place is not within the Standard Operating Procedure.

No clean-up efforts, associated with the nozzle spray, were required after the test. The small amount of charged droplets that had settled to the floor was not noticeable. Between tests, some water drained out of the hose, through the nozzle, onto the floor. This was the result of laying the wand horizontal onto the floor while setting up for the next test location. This created puddles of water which did require clean-up. If the wand were held vertical during this time, the water would have drained back to the supply tank.

This decontamination system has been demonstrated in the WMATA Metrorail system. The application of this technology to other subway systems with different station architecture and materials may require adaptations or refinements to ensure optimal results.

6. PLANS FOR IMPLEMENTATION

The results summarized in this report could be incorporated subsequent work as a follow-on after this project. Many of the results obtained during this project may be used to bring the conceptual design of the reagent delivery system down the path towards a final design. Proper reagent(s) selection, by those qualified, is essential for this program to evolve into an effective chemical and biological decontamination system for rail transit facilities. Upon reagent(s) selection, sufficient testing can occur to provide hard data which can be used to properly address many of the valid concerns raised during this project.

The following should be pursued during follow-on efforts after this project, to address the unknowns identified:

- The proper selection of reagent(s) by a qualified organization (including reagent candidate selection, development of an EPA approved test protocol, and successful laboratory testing).
- The effectiveness of selected liquid reagent(s) on porous surfaces like concrete.
- The temperature affects on selected aerosolized reagent(s) for systems in colder climates.
- The compatibility of selected reagent(s) with the conceptual rail transit decontamination system.

7. CONCLUSIONS

The results of this investigation expand the knowledge base of the transit community regarding decontamination of a rail transit station. Highlights of each stage of this project are discussed below.

In Stage I, the requirements development defined the problem and need for this concept and allowed Foster-Miller to understand the particulars of five WMATA Metrorail transit stations. These efforts led to the development of a System Design Description which provides a baseline document of how Foster-Miller envisions the operation of this concept.

The literature search, as part of Stage I, evaluated emerging and existing technologies to recognize benefits and limitations to be built upon while ensuring that this effort did not duplicate work done previously. This literature search identified several commercially developed delivery systems for foams or uncharged aerosols, however none had been designed for transit applications. This literature search also identified a few studies to research response and remediation in the event of a chemical or biological release.

The decontamination reagent investigation suggests that a need exists for a reagent or mixture of reagents capable of effectively decontaminating both chemical and biological threats. Currently, the hydrogen peroxide based formulations appear to be the most promising class of reagents and should therefore be noted. Finally, the effectiveness of liquid reagents on porous surfaces (such as concrete) has not yet been demonstrated.

In Stage II, a conceptual design of the reagent delivery system was developed. This design included all of the major components depicted in the System Design Description. Initial sizing of the equipment, including an approach to the boom extension, was also performed.

The critical analysis of flow rates and delivery requirements was performed. This indicated that the ECADS nozzles must be positioned within 20 feet of the targeted surface(s) while operating between 60 and 80 PSIG air pressure.

Lastly, in Stage III, the demonstration test was successfully performed in a rail transit station environment to verify the operating parameters above of the delivery system using water as a simulated reagent. Due to station height constraints, the test did demonstrate successful operation of the equipment and the proposed reagent delivery system design up to 14 feet away from the targeted surface. Though a maximum standoff distance of 20 feet can be achieved, it was observed that shorter distances provided more rapid coverage. No noticeable ventilation disturbances were observed, however, cycling the ventilation power during the test may have illustrated some minor disturbances.

In closing, Foster-Miller believes that major strides have been made in the area of a reagent delivery system. A System Design Description and preliminary design of the entire system were generated. A delivery system validation test was successfully conducted and demonstrated that the ECADS operated without any apparent problems during the application of water spray, which was achieved between 4 and 14 feet from the ceiling, with a minimal amount of droplets settling to the station platform. In general, the ECADS technology is a viable reagent delivery system.

There are unknowns which remain to be pursued in follow-on efforts toward implementation, such as the effectiveness of liquid reagents on porous surfaces like concrete, the temperature effects on aerosolized reagent in colder climates, and others identified in the ‘Plans for Implementation’. Foster-Miller recognizes that proper reagent(s) selection, by those qualified, is essential for this program to evolve into an effective chemical and biological decontamination system for rail transit facilities. Upon reagent(s) selection, lab testing should occur to provide hard data which can be used to properly address many of the valid concerns regarding reagents raised during this project.

8. INVESTIGATOR PROFILE

Principal Investigator:	Christos Athanassiu, Senior Engineer
Research Agency or Firm:	Foster-Miller, Inc. 350 Second Ave. Waltham, MA 02451
Contact Information:	phone: 781-684-4439 Fax: 781-890-8515 email: cathanassiu@foster-miller.com

Key Investigator:	Jeremiah Rathbun, Project Engineer
Research Agency or Firm:	Foster-Miller, Inc. 350 Second Ave. Waltham, MA 02451
Contact Information:	phone: 781-684-4039 Fax: 781-890-8515 email: jrathbun@foster-miller.com

9. REFERENCES

1. Yan, Jian-hua., Du, Chang-ming., Li, Xiao-dong., Sun, Xiao-dan, Ni, Ming-jiang, Cen, Ke-fa, Cheron, Bruno. 2005. Plasma chemical degradation of phenol in solution by gas–liquid gliding arc discharge. Plasma Sources Sci. Technol. 14 637-644
2. Moussa1, D., Abdelmalek, F., Benstaali1, B., Addou, A. Hnatiuc E. Brisset J.-L. 2005. Acidity control of the gliding arc treatments of aqueous solutions: application to pollutant abatement and biodecontamination. Eur. Phys. J. Appl. Phys. 29, 189-199
3. Czernichowski, A. Ranaivosoloarimanana. 1996. Zapping VOCs with a discontinuous electric arc. A. CHEMTECH 26(4), 45—49.