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THE WIDE-AREA DECONTAMINATION TOOL

by
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DISCLAIMER

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FOREWORD

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The Center for Environmental Solutions and Emergency Response (CESER) within the Office of Research and Development (ORD) conducts applied, stakeholder-driven research and provides responsive technical support to help solve the Nation’s environmental challenges. The Center’s research focuses on innovative approaches to address environmental challenges associated with the built environment. We develop technologies and decision-support tools to help safeguard public water systems and groundwater, guide sustainable materials management, remediate sites from traditional contamination sources and emerging environmental stressors, and address potential threats from terrorism and natural disasters. CESER collaborates with both public and private sector partners to foster technologies that improve the effectiveness and reduce the cost of compliance, while anticipating emerging problems. We provide technical support to EPA regions and programs, states, tribal nations, and federal partners, and serve as the interagency liaison for EPA in homeland security research and technology. The Center is a leader in providing scientific solutions to protect human health and the environment.

This report describes the methodology developed for the Wide-Area Decontamination Tool, a tool developed to characterize the cost and time associated with a remediation effort following a biological incident impacting indoor, outdoor, and underground areas. This report details the development of this tool, which began with a detailed review of existing remediation tools, a literature review, and an in-depth statistical analysis of data on different decontamination methods. It also includes detailed calculations which are performed within the tool, as well as a proposed model improvement plan for future work on the tool.

Gregory Sayles, Director

Center for Environmental Solutions and Emergency Response

The Wide-Area Decontamination Tool

for

THE WIDE-AREA DECONTAMINATION TOOL

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ACRONYMS AND ABBREVIATIONS

AIC	Akaike Information Criterion
BOTE	Bio-response Operational Testing and Evaluation
CBR	Chemical, Biological, and Radiological
CBRN	Chemical, Biological, Radiological and Nuclear
CDC	Centers for Disease Control and Prevention
CFU	Colony Forming Units
CS	Characterization Sampling
DC	Decontamination
DHS	(US) Department of Homeland Security
EPA	(US) Environmental Protection Agency
GIS	Geographic Information System
HSRP	Homeland Security Research Program (EPA)
IC	Incident Command
LR	Log Reduction
MLE	Maximum Likelihood Estimation
NEIC	National Enforcement Investigations Center
OTD	Operational Technology Demonstration
PPE	Personal Protective Equipment
RTP	Research Triangle Park, NC
S&T	Science and Technology Directorate (DHS)
SR	Source Reduction
TOTS	Trade Off Tool for Sampling
UTR	Underground Transport Restoration
WADE	Wide-Area CBR Decontamination Incident Estimator
WADT	Wide-Area Decontamination Tool
WEST	Waste Estimation Support Tool
WS	Waste Sampling

EXECUTIVE SUMMARY

Large-scale biological incidents throughout indoor, outdoor, and underground areas have the potential to extensively contaminate these sites, presenting risks to human health and requiring extensive time, money, and resources to successfully decontaminate and allow these areas to be utilized again. Contaminated sites must be sampled to characterize the level of contaminant initially present; waste materials may be removed from the site to reduce the cost associated with decontamination of materials that are not worth decontaminating; the site may need to be treated with a decontamination agent; finally, after decontamination, surfaces may need to be sampled again to ensure the level of contaminant has been adequately reduced or completely eliminated. The ability to estimate the cost of decontaminating affected areas following such an incident, as well as the time and resources required to do so, is critical to planning and preparedness for a wide-area decontamination effort.

This report details the development of a probabilistic model, the Wide-Area Decontamination Tool (WADT), which simulates the overall cost, time, and resource demand associated with the decontamination of a wide-area indoor, outdoor, and underground biological incident. This effort included three elements: 1) a review of existing models to identify important aspects of the decontamination process and calculations that should be considered during the development of the tool, 2) a review of studies on the mock decontamination of indoor and underground transportation sites to determine how similar the three decontamination area types (i.e., indoor, outdoor, and underground) were and to identify relevant data that could be used to facilitate the probabilistic nature of the tool (note that no such outdoor study existed at the time of development), and 3) an analysis of EPA's biodecon compendium to develop models for the effectiveness of decontamination treatment types on various surface materials utilized in the tool.

A desktop application was developed to run the probabilistic model estimating cost, time, and resource demands for a wide-area biological incident. Excel workbooks containing the baseline parameters for these models were also developed, allowing users to easily modify any data within the application. A series of equations was defined to characterize each step of the decontamination process, including the sampling of surfaces to define initial contaminant levels, removal of waste from the site area, and the decontamination of surfaces. Driving the decontamination of surfaces is a series of equations and distributions developed to estimate the effectiveness, or efficacy, of a particular decontamination treatment method on a given surface material. This analysis provided a method for estimating efficacy although it should be noted that a more rigorous multivariate analysis may be beneficial to constructing the best possible efficacy model from the available data for future versions of the tool. While the developed application includes most of the desired functionality decided upon at the start of the effort, a model improvement plan was also included to suggest enhancements for future iterations of the tool.

1 INTRODUCTION

1.1 Goals of Preliminary Modeling Efforts

There are many types of emergencies and disasters that threaten the stability of society. Among the most serious are incidents involving a persistent biological agent (e.g., *Bacillus anthracis*, the causative agent for anthrax), for which government agencies have a specific interest in developing mitigation strategies. For example, the 2001 Amerithrax incident, where letters laced with *Bacillus anthracis* were mailed via the U.S. Postal Service, killed five Americans and injured 17 others and was considered the worst biological attack in U.S. history[1]. The first incident of its kind, this event highlighted the importance of recovery planning in reducing the disruption caused by the accidental or intentional release of a persistent biological agent.

Following a biological incident, it is critical that contamination within affected site areas is contained and the impacted areas decontaminated to ensure the biological agent does not spread and that the risk of exposure is reduced. However, remediation efforts for such an incident are costly. In fact, the cost of decontamination after the Amerithrax incident was estimated to be between \$290 and \$350 million[2]. Additionally, these large-scale efforts are time consuming and place a high demand on several specific resources, requiring months to years to fully resolve in the case of the Amerithrax incident. Thus, it is important for government agencies to estimate the demands associated with a wide-area biological incident in order to better prepare for future incidents.

Preliminary research efforts into the issue of wide-area decontamination defined the context and scope of modeling such an event as 1) conducting a meticulous analysis of various existing models, literature, and datasets, 2) identifying the decontamination steps that will be considered in modeling efforts, 3) identifying potential models that are capable of estimating the many costs and resource demands associated with a wide-area incident, and 4) developing and implementing a final model. The initial review of the existing decontamination models identified the need for a modeling tool that could characterize wide-area indoor, outdoor, and underground biological incidents and estimate the cost, time, and resources associated with the decontamination of these areas while implementing a methodology for estimating efficacy, or the effectiveness of a given decontamination treatment at reducing the contaminant present on a surface. This efficacy model, which no existing tool currently implements, would simulate decontamination in a more realistic way: surfaces possibly requiring multiple treatments to be fully decontaminated.

The final developed model estimates the cost of each step of the decontamination process as well as the overall cost of the remediation effort for the incident. It also estimates the overall time spent decontaminating and the various resources needed for the process, such as personal protective equipment (PPE), decontamination agent, and associated delivery systems. This application includes highly detailed cost and resource parameters that have not yet been fully implemented in other existing tools, as well as a model for estimating efficacy which is unique to this tool.

1.2 Desirable Model Criteria

In order to model wide-area decontamination following a biological incident, it was important to consider the aspects of the model being selected. The following set of criteria was established to describe the optimal model:

- The modeling tool should quantify the resource demands (e.g., cost, time, and materials) of decontaminating a wide-area indoor, outdoor, and underground area following a biological incident.

- The modeling tool should determine the resource demands of such an incident, including, but not limited to, personnel requirements, PPE usage, decontaminants, equipment acquisition and/or rentals, and sampling materials, as well as the costs associated with sample collection, processing, analysis, and waste.

- The modeling tool should include traditional sampling types, such as sponge sticks and 37 mm vacuum filter surface sampling types, for the characterization of the amount of contaminant present in the site area.

- The modeling tool should characterize a decontamination treatment by its efficacy, or its effectiveness at reducing contaminant levels present on a given surface.

- The modeling tool should include methodology to estimate the efficacy of decontamination treatment methods based on any environmental or surface composition factors which have been identified as relevant to the estimation of efficacy.

- The modeling tool should calculate waste quantities generated as a result of the remediation effort but should not include any cost estimates based on these quantities. These cost estimates will be calculated by an outside tool, e.g., the Waste Estimation Support Tool (WEST) application. The modeling tool should generate waste quantities in a format that can be accepted by this outside tool. This outside tool will then calculate costs associated with these quantities.

2 LITERATURE REVIEW

The development of the Wide-Area Decontamination Tool began with an in-depth review of various existing models, literature, and data. These resources facilitated the effort by providing valuable information and calculations that were used to fully define a wide-area decontamination scenario. The following sections summarize the reviewed resources and detail the information identified as relevant to the effort.

2.1 Existing Models

At the start of this effort, four existing models were reviewed, each of which were related to the decontamination process in some way: 1) The Wide-Area Chemical, Biological, and Radiological (CBR) Decontamination Incident Estimator (WADE)[3], 2) The WEST application[5],

3) the Trade Off Tool for Sampling (TOTS)[6], and 4) the Decontamination Spreadsheet. Each of these tools were reviewed and analyzed to identify methodologies which were crucial to modeling a decontamination event, as well as the parameters which were important to consider as they applied to those methodologies. This analysis also helped identify areas where these tools may have been missing key functionality or processes that were important to include in the Wide-Area Decontamination Tool. The following sections summarize these models, detail the relevant information identified within each, and highlight any areas in which gaps were found within each model.

2.1.1 WADE Model Analysis

EPA's WADE tool was designed to help on-scene coordinators determine the cost associated with the decontamination of indoor scenarios. The Microsoft Excel-based tool estimates the total cost of decontamination by considering individual costs associated with each step, or element, of the remediation process[3]. The elements considered in the WADE tool are each listed and defined below:

- **Incident Command:** The oversight and management of all personnel and all decontamination processes. This process is ongoing throughout the entire decontamination event.
- **Characterization Sampling:** The sampling of all surfaces to define the level of contaminant initially present at the site area.
- **Site Containment:** The process of containing site contamination to ensure that CBR hazards do not spread to uncontaminated areas and to prevent potential recontamination from other sites after decontamination.
- **Source Reduction:** The removal of contaminated waste materials from a site area before any decontamination has begun.
- **Decontamination:** The treatment of contaminated surfaces with any agent which may reduce the level of contaminant present on those surfaces.
- **Waste Sampling:** The sampling of waste materials removed from the site area to define the level of contaminant present and determine how hazardous the waste is.
- **Waste Management:** The treatment/disposal of waste removed from a contamination site area.
- **Clearance Sampling:** The sampling of surfaces after decontamination has been performed to determine if the level of contaminant meets clearance standards and the site can be deemed safe.

The WADE tool also included historical data gathered from several references which influenced cost estimates. These data ranged from hourly wages for various personnel types which may be present onsite during a decontamination event to the numerous costs associated with a specific decontamination treatment, such as fumigation[3].

Analysis of the WADE tool and the historical data included within it helped identify the key components necessary to fully define a decontamination scenario. Six primary elements of the decontamination process were identified within this tool as relevant to the current effort: 1) Incident Command (IC), 2) Characterization Sampling (CS), 3) Source Reduction (SR), 4) Decontamination (DC), 5) Clearance Sampling (CL), and 6) Waste Sampling (WS).

Although WADE was developed for indoor scenarios only, many of the cost equations for the four primary elements were deemed relevant for indoor *and* underground scenarios and were utilized in the model development. Additionally, the historical data informing these elements within WADE were included in the development of the initial workbook driving the model, Individual Data for Parameters.xlsx. Each data point identified as relevant can be found in Table 1.

Table 1: Relevant Data Found in the WADE Tool[3]

Relevant Data	Description
Personnel Required	Breakdown of personnel required for each team (includes different personnel types)
Number of Teams Required	Number of teams required for each element of remediation; teams nominally consist of three people.
Number of Entries	Number of times teams enter the site area
Respirator Quantity	Number of respirators for each person (either zero or one)
Surface Area per Sponge Stick	Surface area that can be sampled with one sponge stick
Surface Area per 37 mm Cassette	Surface area that can be sampled with one 37 mm cassette
Sponge Sticks Used	Number of sampling sponge sticks used per hour per sampling team
37 mm Cassettes Used	Number of 37 mm cassettes used per hour per sampling team
Waste Mass Removed per Hour per Team	Mass of waste removed from the site area per hour per team before decontamination
Personnel Hourly Rates	Hourly wages for each personnel type
Per Diem	Daily allowance for personnel expenses
Respirator Cost	Cost per one respirator
Cost of Decontamination Agent	Cost of decontamination agent by volume
Cost per Sample Shipped	Cost to ship each sample to an external lab
Cost of Analysis per Sample	Cost associated with the analysis of one sample at an external laboratory
Cost per Sponge Stick	Cost to purchase one sampling sponge stick
Cost per 37 mm Cassette	Cost to purchase on sampling 37 mm cassette
Vacuum for 37 mm Cassette Rental Cost	Rental cost per day for one 37 mm vacuum
IC Rentals per Day	Cost of any rentals required for Incident Command per day
Plane Ticket Cost	Cost of one roundtrip ticket

Values for each of these data points were included in the initial workbook. Values from other sources were also added, as described in Section 2.2.1 and Section 2.2.2. Due to the high amount of uncertainty associated with decontamination events given the plethora of potentially contaminated surfaces, the number of decontamination methodologies and options, the various other influencing factors that may change for decontamination scenarios (e.g., environmental factors influencing efficacy, overall extent of contamination), and the sparsity of available data covering these wide-ranging scenarios, distributions were fit to the final set of data points using a Python script. These statistical models best quantified the vast number of parameters for any potential scenario with the uncertainty associated with the available data captured by the statistical bounds.

Each parameter which had only one data point reported was fit with a constant distribution. Each parameter which had between 2 and 5 data points was fit with a uniform distribution. All other parameters which had 6 or more data points were fit with the following distributions:

- Beta PERT
- Truncated Exponential
- Lognormal
- Truncated Normal
- Uniform
- Weibull Minimum
- Weibull Maximum

Each distribution was fit to the data using the built-in SciPy stats .fit method in Python. The .fit method estimates the parameters of a given distribution by using Maximum Likelihood Estimation (MLE) or maximizing a log-likelihood function[4].

An Akaike Information Criterion (AIC) estimator was then calculated using the formula in Equation 1 in order to determine which distribution was the best fit using the log-likelihood (LL) and the number of distribution parameters (K).

$$AIC = -2LL + 2K \tag{1}$$

The distribution corresponding to the lowest AIC was subsequently fit to the data. Once distributions had been fit to each parameter, a second worksheet, ModifyParameters.xlsx, was generated as the baseline workbook driving the distributions from which values would be drawn in the model. Additional information on these baseline values is provided in Section 2.4.

While WADE was found to be a valuable resource in informing the IC, CS, SR, DC, and WS elements, the tool did not include any efficacy or probabilistic information, nor was it found relevant to outdoor scenarios. The lack of efficacy modeling capabilities was noted as a particular disadvantage of the tool as a number of parameters influence efficacy and the accurate estimation of efficacy based on surface composition and decontamination treatment methods can have a large impact on the cost resulting from remediation efforts. As such, the efficacy modeling capabilities desired for the Wide-Area Decontamination Tool were considered a crucial piece of the tool.

2.1.2 WEST Application Model Analysis

EPA's WEST application was designed to estimate waste quantities based on contamination, decontamination, and geographic information system (GIS) datasets. WEST is a Microsoft Access planning tool which aids decision making by generating and characterizing a first order estimate of waste quantities following a radiological incident. It allows users to investigate different decontamination and demolition approaches and assess how these different approaches affect waste generation. Included in the tool are three elements which were previously defined in WADE: 1) Waste Sampling, 2) Waste Management, and 3) Clearance Sampling[5].

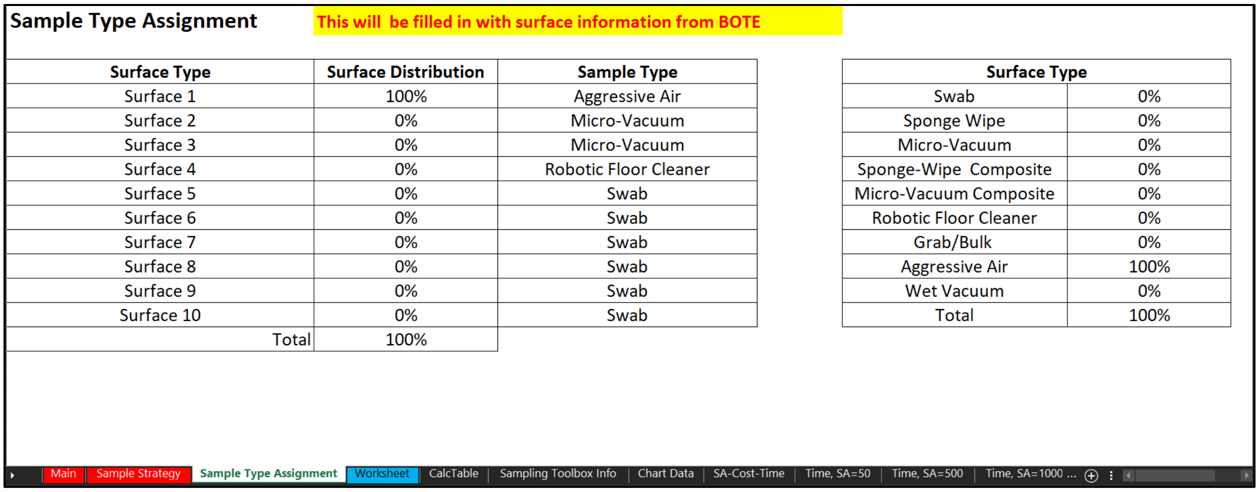
Although Waste Management functionality was not a desired component of the wide-area decontamination model, this application helped identify a structure for the model outputs to serve as inputs to the WEST application. For instance, the WEST application accepts waste quantities as model inputs to simulate waste sampling and management. As such, it was determined that these quantities would be calculated within the wide-area model and the resulting outputs would be compatible with the WEST application to facilitate further analysis.

As the WEST application focuses on the estimation of costs associated with waste sampling and waste management, the tool did not include modeling which simulated the actual decontamination of surfaces following a contamination incident or the estimation of the resource demand associated with the remediation efforts of such an incident. However, such functionality was considered the keystone of the Wide-Area Decontamination Tool.

2.1.3 TOTS Model Analysis

TOTS is a GIS-based Excel tool designed to estimate the resource demand associated with large-scale sampling efforts. Following a CBRN incident, surfaces must be sampled to determine the level of contaminant present in the affected area. EPA's Homeland Security Research Program (HSRP) developed this tool to leverage geospatial data to estimate how sampling decisions affect cost and resource demands[6].

TOTS provided a useful framework for the scenario definition data required. For instance, the TOTS tool allows users to define a breakdown of surface types and their overall percentage contribution to the site area to inform the sampling scenario. This can be seen in a screenshot of the tool in Figure 1. This same surface breakdown was utilized in the Wide-Area Decontamination Tool.



Sample Type Assignment

This will be filled in with surface information from BOTE

Surface Type	Surface Distribution	Sample Type
Surface 1	100%	Aggressive Air
Surface 2	0%	Micro-Vacuum
Surface 3	0%	Micro-Vacuum
Surface 4	0%	Robotic Floor Cleaner
Surface 5	0%	Swab
Surface 6	0%	Swab
Surface 7	0%	Swab
Surface 8	0%	Swab
Surface 9	0%	Swab
Surface 10	0%	Swab
Total	100%	

Surface Type	
Swab	0%
Sponge Wipe	0%
Micro-Vacuum	0%
Sponge-Wipe Composite	0%
Micro-Vacuum Composite	0%
Robotic Floor Cleaner	0%
Grab/Bulk	0%
Aggressive Air	100%
Wet Vacuum	0%
Total	100%

Main | Sample Strategy | Sample Type Assignment | Worksheet | CalcTable | Sampling Toolbox Info | Chart Data | SA-Cost-Time | Time, SA=50 | Time, SA=500 | Time, SA=1000 ...

Figure 1: TOTS Spreadsheet Tool Screenshot

The cost and time estimates provided within TOTS for various sampling techniques on different surfaces were used to inform the traditional sampling types of interest (e.g., sponge sticks and 37 mm vacuums) as well as nontraditional sampling types (e.g., robotic household vacuum cleaner-type sampling and wet vac).

TOTS also provided a blueprint for the type of geospatial data required for defining an outdoor incident. While geospatial data were not included in the first iteration of the Wide-Area Decontamination Tool, these data will be useful for future iterations and improvements.

The TOTS spreadsheet focuses only on costs associated with sampling. As such, this tool did not consider other elements of the decontamination process from which additional costs are generated. Similar to the WEST application, this tool alone did not provide a detailed estimation of the cost and resource demand associated with the remediation of a wide-area incident. It also did not include any efficacy modeling capabilities, all of which was desired functionality of the Wide-Area Decontamination Tool.

2.1.4 Decontamination Spreadsheet Model Analysis

The Decontamination Spreadsheet, an internal research effort at the EPA, simulates a contamination incident in the Manhattan borough in New York City, New York. The spreadsheet includes a breakdown of indoor, outdoor, and underground surfaces within the affected area as well as detailed population, square footage, vegetation, and vehicle data for the affected area. A screenshot of the tool is shown in Figure 2.

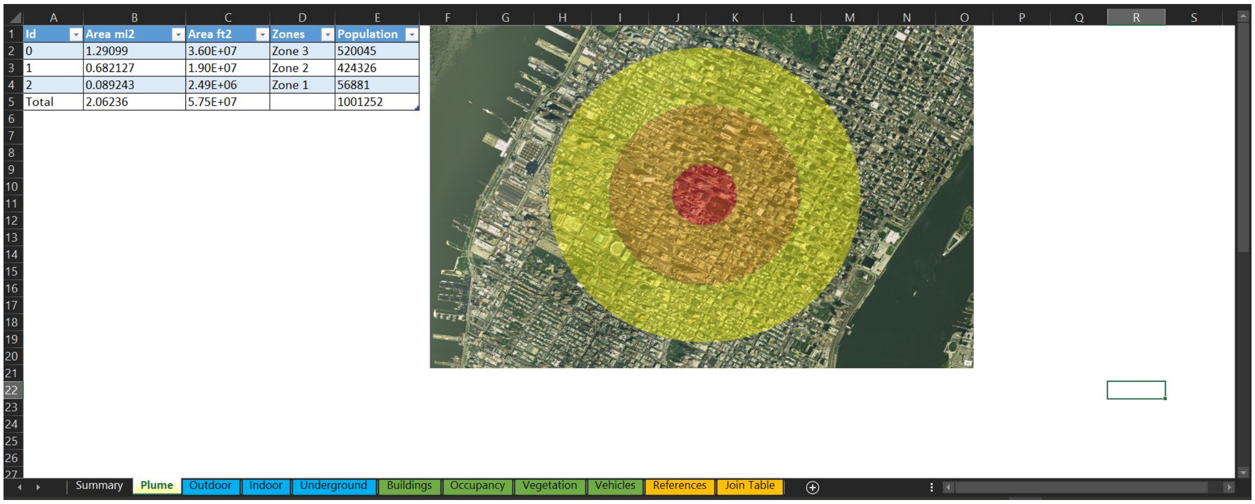


Figure 2: Decontamination Spreadsheet Tool Screenshot

The breakdown of surfaces for indoor, outdoor, and underground spaces found in the tool was used similarly in the Wide-Area Decontamination Tool. Additionally, the building types listed on the "Occupancy" tab of the tool helped identify important building types to include within the definition of indoor scenarios.

The Decontamination Spreadsheet did not include any estimation of costs or resources resulting in the decontamination of a wide-area incident. Similar to the other tools analyzed, this spreadsheet also did not include any efficacy modeling capabilities. Again, this tool alone is not able to provide enough detail for use as an adequate recovery planning tool and does not include key functionality that was desired for the Wide-Area Decontamination Tool.

2.2 Field Studies

In addition to the three existing models that were reviewed, two primary references were used as a source of data to fill in the model and to inform model assumptions: the Bio-response Operational Testing and Evaluation (BOTE) Project report[7] and the Underground Transport Restoration (UTR) Operational Technology Demonstration (OTD) report[8]. Each report summarizes an in-depth investigation into the decontamination of different facilities and provides a detailed cost analysis for the study. The following sections summarize both reports and detail the relevant information identified within them.

2.2.1 BOTE Report

The BOTE Project report details a comprehensive investigation into the decontamination of a biological agent in an indoor scenario, a joint effort between EPA, the Department of Homeland Security Science and Technology Directorate (DHS S&T), and the Centers for Disease Control and Prevention (CDC). In this mock decontamination scenario, a surrogate (*Bacillus atrophaeus*, subspecies *globigii*) for the biological agent *Bacillus anthracis* was disseminated in a facility modified to replicate an office and residential building. Surfaces were sampled with cellulose sponge-stick wipes, swabs, and vacuum socks to determine the initial level of contaminant present. Waste material was subsequently removed from the site area and disposed of. The building was then decontaminated using three different treatment methods: 1) fumigation with hydrogen peroxide vapor, 2) surface decontamination using pH-adjusted bleach, and 3) fumigation with chlorine dioxide gas[7].

The objectives of the BOTE project were to employ three different decontamination methods in a large building scenario to assess the efficacy of each and to characterize and analyze the costs associated with the remediation process. Costs were broken down for each decontamination method and included personnel entering and exiting the site area, materials, supplies, and rentals, and waste management costs, as well as general costs which remained fixed between decontamination methods, such as sampling costs and safety management oversight costs[7].

The BOTE report included a myriad of data which was found to be relevant to both indoor *and* underground scenarios. Each data point identified as relevant can be found in Table 2.

Table 2: Relevant Data found in the BOTE report[7]

Relevant Data	Description
Personnel Required	Breakdown of personnel required for each team (includes different personnel types)
Hours per Entry	Amount of time needed to for teams to enter the site area
Number of Entries	Number of times teams enter the contaminated area
Respirator Quantity	Number of respirators for each person (either zero or one)
Personnel Overhead Days	Number of setup and teardown days at the start and end of each element
Waste Mass per Surface Area	Mass of waste present at the site area per surface area
Sponge Sticks Used	Number of sampling sponge sticks used per hour per sampling team
37 mm Cassettes Used	Number of sampling 37 mm cassettes used per hour per sampling team
Solid Waste Mass Generated per Surface Area	Mass of solid waste generated after decontamination per surface area
Aqueous Waste Mass Generated per Surface Area	Mass of aqueous waste generated after decontamination per surface area
Personnel Hourly Rates	Hourly wages for each personnel type
Per Diem	Daily allowance for personnel expenses
Rental Car Cost	Cost of the rental car per day
Cost of Analysis per Sample	Cost associated with the analysis of one sample at an external laboratory
Decontamination Materials Cost	Total cost of decontamination materials based on the decontamination treatment method

These data were included in the initial workbook developed for the Wide-Area Decontamination Tool and used to develop distributions for the baseline parameters found in

ModifyParameters.xlsx. For more detail regarding the generation of this baseline workbook, refer back to Section 2.1.1.

2.2.2 UTR OTD Report

The Underground Transport Restoration (UTR) Operational Technology Demonstration (OTD) report by EPA summarizes the decontamination of a mock subway system contaminated with a surrogate (*Bacillus atrophaeus*, subspecies *globigii*) for the biological agent *Bacillus anthracis*. The UTR OTD project was similar to the BOTE project in that the *Bacillus anthracis* surrogate was disseminated in a mock facility and surfaces were sampled using sponge sticks, vacuum cassettes, and a wash/extract method to assess the present contaminant level in ballast. However, this scenario did not include the removal of all waste materials prior to decontamination as some were decontaminated with the surrounding site area. Additionally, only two methods of decontamination were utilized in this study: 1) fogging with diluted bleach, and 2) liquid spraying of pH-adjusted bleach[8].

A cost analysis similar to that found in the BOTE report was also included in the UTR OTD report. Data from this analysis were used to inform both the indoor and underground scenarios and was included in the initial workbook developed for the Wide-Area Decontamination Tool to develop distributions for the baseline parameters needed in the model calculations. Each data point identified as relevant can be found in Table 3.

Table 3: Relevant Data Found in the UTR OTD Report[8]

Relevant Data	Description
Personnel Required	Breakdown of personnel required for each team (includes different personnel types)
Personnel Overhead Days	Number of setup and teardown days at the start and end of each element
Number of External Labs	Number of external labs to which samples are sent for analysis
Lab Distance from Site Area	Distance from the contamination site to each external lab
Surface Area to be Sampled	Surface area which will be sampled for spore loading
Days Required for Decontamination	Days required to fully apply a decontamination treatment method
Number of Teams Required	Number of teams required for each element of decontamination
Hours per Entry	Amount of time needed to for teams to enter the site area
Number of Entries	Number of times teams enter the site area
Solid Waste Mass Generated per Surface Area	Mass of solid waste generated after decontamination per surface area
Liquid Waste Mass Generated per Surface Area	Mass of liquid waste generated after decontamination per surface area
Volume of Decontamination Agent Applied	Volume of decontamination agent needed for treatment
Personnel per Rental Car	Number of people using one rental car
Personnel Hourly Rates	Hourly wages for each personnel type
Per Diem	Daily allowance for personnel expenses
Decontamination Materials Cost	Total cost of decontamination materials based on the decontamination treatment method
PPE Unit Costs	Cost per one unit of PPE for each PPE level
Cost of Decontamination Agent	Cost of decontamination agent by volume
IC Supplies Cost	Cost of supplies for the Incident Command element

These data were included in the initial workbook developed for the Wide-Area Decontamination Tool and was used to develop distributions for the baseline parameters found in ModifyParameters.xlsx. For more detail regarding the generation of this baseline workbook, refer to Section 2.1.1.

2.3 The BioDecontamination Compendium

In addition to the existing models and literature used to inform this effort, an extensive dataset consisting of information obtained from a vast literature search regarding the efficacy of various decontamination methods on a variety of surface materials was also reviewed. This dataset, the BioDecontamination Compendium, was found to provide relevant data for all three scenario types (i.e., indoor, outdoor, and underground).

The BioDecontamination Compendium combines data from over 150 peer-reviewed sources investigating various methods of decontaminating *Bacillus anthracis*, from aerosolized sporicidal solutions to UV irradiation. The processed compendium is made up of 8,555 records and includes 71 columns of both numerical and nonnumerical data, all pertaining to the efficacy of a specific decontamination application method on a specific surface[10].

The BioDecontamination Compendium provided useful categorizations for which efficacy could be investigated. For instance, the compendium included an extensive list of decontamination treatment application methods which varied in their effectiveness. These methods are listed in Table 4.

Table 4: Application Methods Found in the BioDecontamination Compendium[9]

Application Methods	Description
Aerosol	Aerosolized sporicidal agent sprayed onto a surface
Aqueous Suspension	Mixture of sporicidal solution with spore-laden suspension
Foam Ambiguous	Surface decontamination foam applied ambiguously to a surface
Foam Spray	Surface decontamination foam applied using a liquid sprayer
Fogging	Fogging device used to disperse an aerosol
Fumigation	Release of a gas or vapor in an enclosed environment
Fumigation/Liquid	Both fumigation and liquid application methods
Gel	Sporicidal gel applied to a surface
Immersion	Spore-laden surface immersed on a liquid solution containing decon agent
Liquid	Sporicidal liquid applied to a surface in various ways
Liquid Dropper	Small amount of sporicidal liquid applied to a surface using a dropper
Liquid Immersion	Spore-laden surface immersed in a liquid solution containing decontamination agent
Liquid-Soaked Gauze Covering	Surface is covered in gauze soaked in sporicidal solution
Liquid-Soaked Gauze Wipe	Surface is covered in gauze wipe soaked in sporicidal solution
Liquid Spray	Liquid solution is applied to a surface by spraying
Liquid Suspension	Contaminated liquid suspended in sporicidal solution
Liquid Wipe	Cleaning wipes wetted with decontaminant solution
Physical	Decontamination of surfaces using methods such as ultraviolet treatment, UV-excimer laser irradiation, microwave, infrared, filtration, pasteurization
Solid Powder	Sporicidal powder applied to a surface
Suspension	Spore-containing liquid media is added to or spiked with a solution of liquid decontamination agent to produce a treated media

Note that some of these application methods have vague or similar descriptions. This list of methods was reviewed, and some methods were found to be surrogates for others or irrelevant entirely. The methods that were maintained for use in the tool are listed in Section 3.5.2.

The compendium also included an extensive list of surface materials which these methods were applied[9]. These materials can be found in Appendix A. The application methods and surface materials combined created a classification system for efficacy and allowed estimates of efficacy to be assigned to each combination. This classification was used extensively throughout the Wide-Area Decontamination Tool. Other numerical data was also investigated to determine which environmental factors (e.g., temperature and relative humidity), agent factors (e.g., sporicidal agent used, concentration of agent used), or application factors (e.g., contact time) were relevant to efficacy and could be used to estimate a value for each of these classifications. A rigorous analysis of these factors and their influence on efficacy was performed for each classification and used to develop an Efficacy Model to determine the effectiveness of the decontamination treatments performed within the tool. For a more detailed explanation of this analysis, refer to Section 3.5.

2.4 Conclusion

Generally, the existing tools reviewed informed the methodologies within the Wide-Area Decontamination Tool and identified the key modeling aspects desired in one standalone tool in order to accurately and fully estimate the cost and resource demand associated with decontamination. The field studies that were reviewed helped identify relevant operational data that could be used as the underlying data within the tool to drive the calculations. Finally, the BioDecontamination Compendium provided valuable efficacy modeling data which was identified as unique to the Wide-Area Decontamination Tool. For a full list of data collected from these sources, refer to Appendix B.

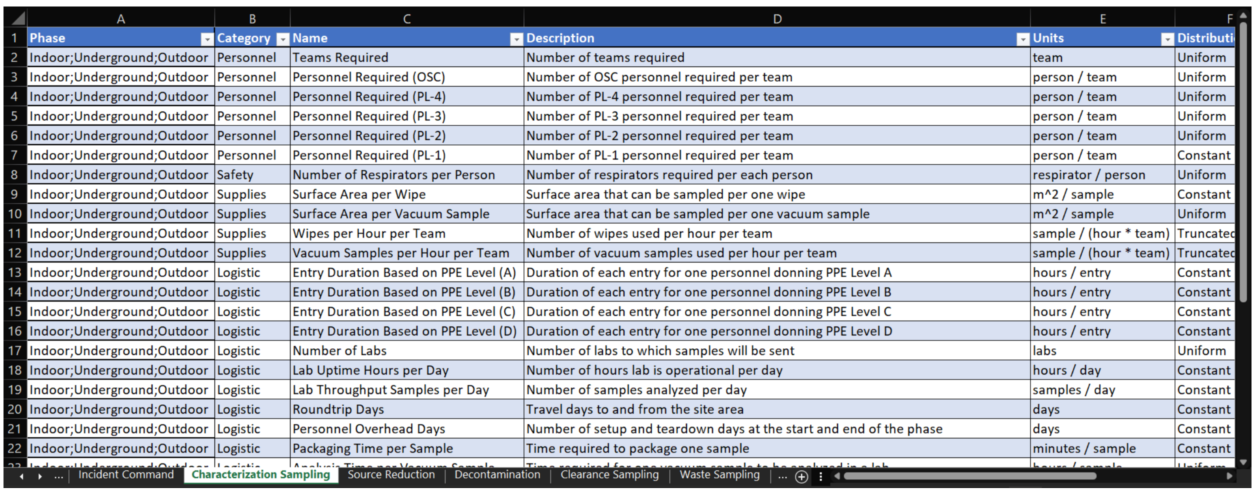
3 METHODOLOGY

3.1 Model Methodology Overview

The Wide-Area Decontamination Tool is a probabilistic model that estimates the efficacy of decontamination treatments applied to various surfaces in realistic indoor, outdoor, and underground scenarios in order to identify the cost and resource demand of a remediation effort following a biological incident. The user defines the scenario type (i.e., indoor, outdoor, and underground) and the necessary parameters. The scenario is then run, and the results are calculated and output to the user. This flow is illustrated in Figure 3.

Figure 3: Wide Area Decontamination Model Flow

The tool is an ASP.NET Core application with a VueJS frontend and is compatible with any Windows system without additional dependencies. The ModifyParameters.xlsx Excel worksheet drives the baseline parameters in the tool, allowing users to easily change underlying data to fit their needs. A screenshot of this worksheet is shown in Figure 4.



	A	B	C	D	E	F
1	Phase	Category	Name	Description	Units	Distributi
2	Indoor;Underground;Outdoor	Personnel	Teams Required	Number of teams required	team	Uniform
3	Indoor;Underground;Outdoor	Personnel	Personnel Required (OSC)	Number of OSC personnel required per team	person / team	Uniform
4	Indoor;Underground;Outdoor	Personnel	Personnel Required (PL-4)	Number of PL-4 personnel required per team	person / team	Uniform
5	Indoor;Underground;Outdoor	Personnel	Personnel Required (PL-3)	Number of PL-3 personnel required per team	person / team	Uniform
6	Indoor;Underground;Outdoor	Personnel	Personnel Required (PL-2)	Number of PL-2 personnel required per team	person / team	Uniform
7	Indoor;Underground;Outdoor	Personnel	Personnel Required (PL-1)	Number of PL-1 personnel required per team	person / team	Constant
8	Indoor;Underground;Outdoor	Safety	Number of Respirators per Person	Number of respirators required per each person	respirator / person	Uniform
9	Indoor;Underground;Outdoor	Supplies	Surface Area per Wipe	Surface area that can be sampled per one wipe	m^2 / sample	Constant
10	Indoor;Underground;Outdoor	Supplies	Surface Area per Vacuum Sample	Surface area that can be sampled per one vacuum sample	m^2 / sample	Uniform
11	Indoor;Underground;Outdoor	Supplies	Wipes per Hour per Team	Number of wipes used per hour per team	sample / (hour * team)	Truncatec
12	Indoor;Underground;Outdoor	Supplies	Vacuum Samples per Hour per Team	Number of vacuum samples used per hour per team	sample / (hour * team)	Truncatec
13	Indoor;Underground;Outdoor	Logistic	Entry Duration Based on PPE Level (A)	Duration of each entry for one personnel donning PPE Level A	hours / entry	Constant
14	Indoor;Underground;Outdoor	Logistic	Entry Duration Based on PPE Level (B)	Duration of each entry for one personnel donning PPE Level B	hours / entry	Constant
15	Indoor;Underground;Outdoor	Logistic	Entry Duration Based on PPE Level (C)	Duration of each entry for one personnel donning PPE Level C	hours / entry	Constant
16	Indoor;Underground;Outdoor	Logistic	Entry Duration Based on PPE Level (D)	Duration of each entry for one personnel donning PPE Level D	hours / entry	Constant
17	Indoor;Underground;Outdoor	Logistic	Number of Labs	Number of labs to which samples will be sent	labs	Uniform
18	Indoor;Underground;Outdoor	Logistic	Lab Uptime Hours per Day	Number of hours lab is operational per day	hours / day	Constant
19	Indoor;Underground;Outdoor	Logistic	Lab Throughput Samples per Day	Number of samples analyzed per day	samples / day	Constant
20	Indoor;Underground;Outdoor	Logistic	Roundtrip Days	Travel days to and from the site area	days	Constant
21	Indoor;Underground;Outdoor	Logistic	Personnel Overhead Days	Number of setup and teardown days at the start and end of the phase	days	Constant
22	Indoor;Underground;Outdoor	Logistic	Packaging Time per Sample	Time required to package one sample	minutes / sample	Constant

Figure 4: ModifyParameters.xlsx Screenshot

A separate Excel worksheet, the DefineScenario.xlsx worksheet, lists all of the user-inputs that can be defined and edited directly in the tool. A screenshot of this worksheet is shown in Figure 5.

	A	B	C	D	E	F	G	
1	Phase	Category	Name	Description	Units	Distribution Typ	Parameter 1	Parar
2	Outdoor	Outdoor	Area Contaminated	The total outdoor surface area contaminated	m^2	Constant		
3	Outdoor	Outdoor	Loading	The severity of contamination on outdoor surfaces	log(cfu / m^2)	Constant		
4	Indoor	Indoor	Area Contaminated	The total indoor surface area contaminated	m^2	Constant		
5	Indoor	Indoor	Loading	The severity of contamination on indoor surfaces	log(cfu / m^2)	Constant		
6	Underground	Underground	Area Contaminated	The total underground surface area contaminated	m^2	Constant		
7	Underground	Underground	Loading	The severity of contamination on underground surfac	log(cfu / m^2)	Constant		
8	Indoor	Residential	Indoor Contamination Breakout	The fraction of interior contaminated surface area wh	unitless	Constant	0	
9	Indoor	Commercial	Indoor Contamination Breakout	The fraction of interior contaminated surface area wh	unitless	Constant	0.5	
10	Indoor	Industrial	Indoor Contamination Breakout	The fraction of interior contaminated surface area wh	unitless	Constant	0.5	
11	Indoor	Agricultural	Indoor Contamination Breakout	The fraction of interior contaminated surface area wh	unitless	Constant	0	
12	Indoor	Religious	Indoor Contamination Breakout	The fraction of interior contaminated surface area wh	unitless	Constant	0	
13	Indoor	Government	Indoor Contamination Breakout	The fraction of interior contaminated surface area wh	unitless	Constant	0	
14	Indoor	Educational	Indoor Contamination Breakout	The fraction of interior contaminated surface area wh	unitless	Constant	0	
15	Outdoor	Outdoor Exterior	Outdoor Surface Type Breakout	The fraction of surface outdoors which is building ext	unitless	Constant	0.1	
16	Outdoor	Pavement	Outdoor Surface Type Breakout	The fraction of surface outdoors which is pavement	unitless	Constant	0.3	
17	Outdoor	Roofing	Outdoor Surface Type Breakout	The fraction of surface outdoors which is roofing	unitless	Constant	0.1	
18	Outdoor	Water	Outdoor Surface Type Breakout	The fraction of surface outdoors which is water	unitless	Constant	0.05	
19	Outdoor	Soil	Outdoor Surface Type Breakout	The fraction of surface outdoors which is soil	unitless	Constant	0.3	
20	Outdoor	Outdoor Miscellaneous	Outdoor Surface Type Breakout	The fraction of surface outdoors which is miscellaneo	unitless	Constant	0.15	
21	Underground	Underground Walls	Underground Surface Type Breakou	The fraction of surface underground which is walls	unitless	Constant	0.1	
22	Underground	Underground Ceilings	Underground Surface Type Breakou	The fraction of surface underground which is ceilings	unitless	Constant	0.3	
23	Underground	Underground Carpet	Underground Surface Type Breakou	The fraction of surface underground which is carpet	unitless	Constant	0.1	

Internal - File Info | Internal - Data Validation | Extent of Contamination | Residential Characteristics | Commercial Characteristic ...

Figure 5: DefineScenario.xlsx Screenshot

Utilities were developed to convert both of these Excel worksheets to a usable format in the tool for ease of user-editing and calculation purposes. Figure 6 below depicts a flowchart of resources informing these worksheets which then inform the Wide-Area Decontamination Tool.

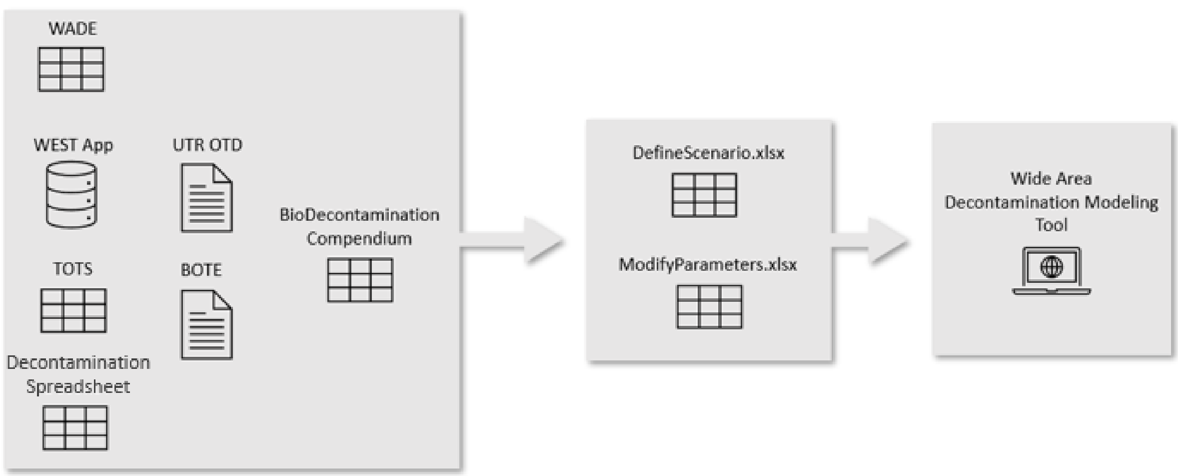


Figure 6: Flowchart of Resources into the Wide-Area Decontamination Tool

The following sections detail the calculations performed within each element of the tool (e.g., incident command, characterization sampling) in order to estimate the cost and time associated with a wide area decontamination incident. For a full guide on how to use the tool, refer to Appendix C.

The model calculations are broken down by element: 1) Incident Command; 2) Characterization Sampling; 3) Source Reduction; 4) Decontamination; 5) Clearance Sampling; 6) Waste Sampling; and 7) Travel. The costs and times associated with each element are then summed to estimate the total resource demand of remediation for the incident. The following sections describe the calculations performed for each of these elements of decontamination.

3.2 Incident Command

The IC element oversees the entire decontamination effort and is active during every model step. It is important to note that the resulting IC costs do not change throughout the different elements. The following sections list the parameters relevant to the IC model as well as the calculations performed to characterize the cost and resource demands of this element.

3.2.1 Incident Command Parameters

The IC model parameters are listed in Table 5 below. Note that this table only includes user-input and baseline parameters. All calculated quantities are explained in detail in the subsequent section.

Table 5: IC Model Parameters

Parameter	Name	Description	Units
$\overrightarrow{P_Q}$	Personnel Required	Number of personnel of each type required for one team (OSC, PL-1, PL-2, PL-3, PL-4)	personnel
P_{DO}	Personnel Overhead Days	Number of setup and teardown days at the start and end of the element	days
P_{DRT}	Personnel Roundtrip Days	Number of travel days both to and from site	days
$\overrightarrow{C_P}$	Personnel Hourly Rate	Hourly wage of each personnel type (OSC, PL-1, PL-2, PL-3, PL-4)	$ / hour
C_{E_D}	Equipment Rental Cost Per Day	Cost of Incident Command equipment rentals per day	$ / day
C_{S_D}	Supplies Cost Per Day	Cost of Incident Command supplies per day	$ / day

3.2.2 Incident Command Model

The overall cost of IC is broken down into two primary costs of equal weight: 1) cost of labor (C_L), and 2) cost of supplies (C_S). The cost of labor for IC is calculated using Equation 2 below.

$$C_L = P_H * \left(\overrightarrow{P_Q} \cdot \overrightarrow{C_P}\right) * T_Q \quad \textbf{(2)}$$

Where:

- P_H = Total IC labor hours
- $\overrightarrow{P_Q}$ = Number of personnel required per team by personnel type

- $\overrightarrow{C_P}$ = Personnel hourly rate by personnel type
- T_Q = Number of teams required for IC

The parameter P_H is a calculated quantity for the total number of labor hours for IC. This parameter is calculated using Equation 3 below. Note that 12-hour workdays were assumed in keeping with what was found in the BOTE and UTR OTD project reports.

$$P_H = 12 * P_D \quad \textbf{(3)}$$

Personnel onsite, or P_D, is calculated using Equation 4.

$$P_D = P_{D_{CS}} + P_{D_{SR}} + P_{D_{DC}} + P_{D_{WS}} + P_{D_O} \quad \textbf{(4)}$$

Where:

- $P_{D_{CS}}$ = Personnel onsite days for CS
- $P_{D_{SR}}$ = Personnel onsite days for SR
- $P_{D_{DC}}$ = Personnel onsite days for DC
- $P_{D_{WS}}$ = Personnel onsite days for WS
- P_{D_O} = Personnel overhead days

Note that $P_{D_{CS}}$, $P_{D_{SR}}$, $P_{D_{DC}}$, and $+ P_{D_{WS}}$ are each calculated within their respective model portion.

The cost of supplies for IC is calculated using Equation 5 below.

$$C_S = P_W * (C_{E_D} + C_{S_D}) \quad \textbf{(5)}$$

Where:

- P_W = IC workdays
- C_{E_D} = Equipment rental cost per day
- C_{S_D} = Supplies cost per day

The parameter P_W is calculated using Equation 6 below.

$$P_W = P_D - P_{D_O} \quad \textbf{(6)}$$

C_L and C_S combine to give the overall cost of IC (C_{IC}), as illustrated by Equation 7 below.

$$C_{IC} = C_L + C_S \quad \textbf{(7)}$$

3.3 Characterization Sampling

CS is required to determine the level of contamination which is present at the contaminated area. This information is then used to determine which decontamination methods will be used and how many applications will be needed. The following sections list the parameters relevant to the CS model as well as the calculations performed to characterize the cost and resource demands of this element.

3.3.1 Characterization Sampling Parameters

The CS model parameters are listed in Table 6 below. Note that this table only includes user-input and baseline parameters. All calculated quantities are explained in detail in the subsequent section.

Table 6: CS Model Parameters

Parameter	Name	Description	Units
A_T	Total Surface Area	Total surface area of the site	m^2
A_S	Fraction of Surface Area to be Sampled	Fraction of the total surface area that will be sampled	unitless
W_A	Surface Area Per Sponge Stick	Surface area which can be sampled by one sponge stick	m^2/ sample
H_A	Surface Area Per 37 mm Cassette	Surface area which can be sampled by one 37 mm cassette	m^2/ sample
W_H	Quantity of Sponge Sticks Used Per Hour Per Team	Number of sponge sticks used for sampling per hour per team	samples / hour * team
H_H	Quantity of 37 mm Cassettes Used Per Hour Per Team	Number of 37 mm cassettes used for sampling per hour per team	samples / hour * team
$\overrightarrow{E_D}$	Entry Duration	Entry durations based on PPE levels	hours / entry * team
E_P	Entry Preparation Time	Time required for preparation into the contaminated site area	hours / entry * team
E_{DC}	Decontamination Line Time	Time required for decontamination of personnel upon exiting the contaminated site area	hours / entry * team

Parameter	Name	Description	Units
E_R	Post-Entry Rest Period	Time required for rest period upon exiting the contaminated site area	hours / entry * team
R_P	Number of Respirators Per Person	Number of respirators per one person	respirators / person
T_Q	Number of Teams	Number of teams required for element	teams
$\overrightarrow{P_Q}$	Personnel Required	Number of personnel of each type required for one team (OSC, PL-1, PL-2, PL-3, PL-4)	personnel
P_{DO}	Personnel Overhead Days	Number of setup and teardown days at the start and end of the element	days
$\overrightarrow{E_{PPETEAM}}$	PPE Fraction Per Team	Fraction of total PPE that is each level for one team (Level A, Level B, Level C, Level D)	unitless
Lab_Q	Number of Analysis Labs	Number of external labs to which samples are sent for analysis	labs
$\overrightarrow{L_D}$	Distance from Contamination Site	Distance of external lab from contamination site	km
$\overrightarrow{L_T}$	Lab Throughput Per Day	Number of samples analyzed per day	samples / day
T_R	Time for Result Transmission to IC	Time for sampling analysis results to be sent from external labs to Incident Command	hours
T_{PS}	Time for One Sample to be Packaged	Time for one sample to be packaged for shipment to an external analysis lab	minutes / sample
C_{EP}	Entry Preparation Cost	Cost associated with preparation before entering the site area	$ / entry * team
C_{EDC}	Decontamination Line Cost	Cost associated with the personnel decon line	$ / entry * team
C_{WA}	Costs Per Sponge Stick Sample	Analysis costs per one sponge stick sample	$ / sample
C_{HA}	Costs Per 37 mm Sample	Analysis costs per one 37 mm cassette sample	$ / sample
C_R	Cost Per Respirator	Cost per one respirator	$ / respirator
$\overrightarrow{C_{EPPE}}$	Cost Per Individual PPE	Cost per one unit of PPE of each level	$ / PPE level
C_W	Cost Per Sponge Stick	Cost to purchase one sponge stick	$ / sample
C_H	Cost Per 37 mm Cassette	Cost to purchase one 37 mm cassette	$ / sample
C_{HD}	37 mm Vacuum Rental Cost Per Day	Cost of 37 mm vacuum rental per day	$ / day
$\overrightarrow{C_P}$	Personnel Hourly Rate	Hourly wage of each personnel type (OSC, PL-1, PL-2, PL-3, PL-4)	$ / hour

3.3.2 Characterization Sampling Model

Characterization Sampling is performed once before decontamination is performed in order to characterize the amount of contaminant present on each surface. The overall cost of CS is broken down into four primary costs of equal weight: 1) cost of labor (C_L), 2) cost of supplies and rentals (C_S), 3) cost associated with entering and exiting the contamination area (C_E), and 4) cost of sample analysis, including shipping and packaging (C_A). The cost of labor for CS is calculated using Equation 8 below.

$$C_L = P_H * (\overrightarrow{P_Q} \cdot \overrightarrow{C_P}) * T_Q \quad \textbf{(8)}$$

Where:

- P_H = Total CS labor hours
- $\overrightarrow{P_Q}$ = Number of personnel required per team by personnel type
- $\overrightarrow{C_P}$ = Personnel hourly rate by personnel type
- T_Q = Number of teams required for CS

The parameter P_H is calculated using Equation 9 below.

$$P_H = 12 * P_{D_{CS}} \quad \textbf{(9)}$$

Where the personnel onsite days, or $P_{D_{CS}}$, is calculated using Equation 10.

$$P_{D_{CS}} = P_{D_W} + P_{D_O} \quad \textbf{(10)}$$

Where:

- P_{D_W} = Total workdays
- P_{D_O} = Personnel overhead days

The parameter P_{D_W} is calculated using Equation 11 below.

$$P_{D_W} = P_{D_L} + T_{E_P} + T_{E_{DC}} + T_{E_R} \quad \textbf{(11)}$$

Where:

- P_{D_L} = Personnel labor days
- T_{E_P} = Total entry prep time

- $T_{E_{DC}}$ = Total personnel decon line time
- T_{E_R} = Total entry rest time

The parameter P_{D_L} is calculated using Equation 12 below.

$$P_{D_L} = \frac{W_{HR}}{12} + \frac{H_{HR}}{12} \tag{12}$$

Where:

- W_{HR}, H_{HR} = Number of hours spent sampling with sponge sticks or 37 mm vacuum, respectively

These quantities are calculated using Equation 13 and Equation 14, respectively.

$$W_{HR} = \frac{W_Q}{W_H * T_Q} \tag{13}$$

$$H_{HR} = \frac{H_Q}{H_H * T_Q} \tag{14}$$

Where:

- W_Q, H_Q = Total quantity of sponge sticks or 37 mm cassettes used for sampling, respectively
- W_H, H_H = Quantity of sponge sticks or 37 mm cassettes used per hour per team, respectively

The parameters W_Q and H_Q are calculated using Equation 15 and Equation 16, respectively.

$$W_Q = \frac{A_S * A_T * 0.5}{W_A} \tag{15}$$

$$H_Q = \frac{A_S * A_T * 0.5}{H_A} \tag{16}$$

Where:

- A_S = Fraction of the surface area of the contamination site to be sampled
- A_T = Surface area of the contamination site
- W_A, H_A = Surface area covered by one sponge stick or 37-mm cassette, respectively

Note that the total surface area sampled is evenly split between the sponge stick and 37-mm cassette sampling types.

The parameter T_{E_P} is calculated using Equation 17 below.

$$T_{E_P} = E_T * E_P \quad \textbf{(17)}$$

Where:

- E_T = Total number of entries
- E_P = Prep time required per entrance

The parameter E_T is calculated using Equation 18 below.

$$E_T = \sum \frac{\frac{P_{D_L} * 12}{PPE\ Levels}}{E_{D_i}} \quad \textbf{(18)}$$

Where:

- PPE Levels = The number of unique PPE levels required for the team (note that if a specific level of PPE is not required, the default contribution to the total number of entries for that level is 0)
- E_{D_i} = The entrance duration based on the PPE level i

The parameter $T_{E_{DC}}$ is calculated using Equation 19 below.

$$T_{E_{DC}} = E_T * E_{DC} \quad \textbf{(19)}$$

Where:

- E_{DC} = Time required for personnel decon line operations after each entrance

The parameter T_{E_R} is calculated using Equation 20 below.

$$T_{E_R} = E_T * E_R \tag{20}$$

Where:

- E_R = Time required for rest after each entrance

The cost of supplies for CS is calculated using Equation 21 below.

$$C_S = (W_Q * C_W) + (H_Q * C_H) + (H_D * C_{H_D}) \tag{21}$$

Where:

- C_W, C_H = Cost per one sponge stick or 37 mm cassette, respectively
- H_D = Total 37 mm vacuum rental days
- C_{H_D} = 37 mm vacuum rental cost per day

The parameter H_D is calculated using Equation 22 below.

$$H_D = \frac{H_{HR}}{12} \tag{22}$$

A lag time due to time spent analyzing samples at external labs (T_{LAG}) is also calculated for the CS element. T_{LAG} is calculated using Equation 23 below.

$$T_{LAG} = T_P + \max(T_{L_i}) + T_R \tag{23}$$

Where:

- T_P = Total packaging time for all samples
- T_{L_i} = Total time samples spent at lab for each external lab i
- T_R = Time for completed sample result to be transmitted to IC

The parameter T_P is calculated using Equation 24 below.

$$T_P = \frac{T_{P_S} * (W_Q + H_Q)}{60\ min * 12\ h} \tag{24}$$

Where:

- T_{P_S} = Time for one sample to be packaged (minutes per sample)

Note that this equation includes a conversion from minutes to days as it was necessary to convert the packaging time per sample given in minutes to a total packaging time for all samples in days.

The parameter T_{L_i} is calculated using Equation 25 below.

$$T_{L_i} = T_{S_i} + T_{A_i} \tag{25}$$

Where:

- T_{S_i} = Total shipping time to each external lab i which is assumed to be 12 hours as samples are overnighted to their destination
- T_{A_i} = Total sample analysis time per each external lab i

The parameter T_{A_i} is calculated using Equation 26 below.

$$T_{A_i} = \frac{\frac{W_Q}{Lab_Q} + \frac{H_Q}{Lab_Q}}{L_{T_i}} \tag{26}$$

Where:

- Lab_Q = Number of external labs to which samples are sent for analysis
- L_{T_i} = Lab throughput for each external lab i

Note that an equal number of sponge stick and 37-mm cassette samples are sent to each external lab for analysis.

The cost associated with entering and exiting the contamination site for CS is calculated using Equation 27 below.

$$C_E = C_{E_L} + \left(R_Q * C_R\right) + \left(\overrightarrow{E_{PPE}} \cdot \overrightarrow{C_{E_{PPE}}}\right) \quad \textbf{(27)}$$

Where:

- C_{E_L} = Entrance/exit labor cost
- R_Q = Total number of respirators
- C_R = Cost per respirator
- $\overrightarrow{E_{PPE}}$ = Total PPE quantity for all CS teams by PPE level
- $\overrightarrow{C_{E_{PPE}}}$ = Cost per one PPE unit by PPE level

The parameter C_{E_L} is calculated using Equation 28 below.

$$C_{E_L} = [P_H * \left(\overrightarrow{P_Q} \cdot \overrightarrow{C_P}\right) * T_Q] + C_{T_P} + C_{T_{DC}} \quad \textbf{(28)}$$

Where:

- C_{T_P} = Total cost of entry prep
- $C_{T_{DC}}$ = Total cost of personnel decon line operations

The parameter C_{T_P} is calculated using Equation 29 below.

$$C_{T_P} = E_T * C_{E_P} \quad \textbf{(29)}$$

Where:

- C_{E_P} = The cost of entry prep per entrance

The parameter $C_{T_{DC}}$ is calculated using Equation 30 below.

$$C_{T_{DC}} = E_T * C_{E_{DC}} \quad \textbf{(30)}$$

- $C_{E_{DC}}$ = The cost of personnel decon line operations per entrance

The parameter R_Q is calculated using Equation 31 below.

$$R_Q = P_Q * T_Q * R_P \quad \textbf{(31)}$$

Where:

- R_P = Number of respirators per person (typically either 0 or 1)

The parameter $\overrightarrow{E_{PPE}}$ is calculated using Equation 32 below.

$$\overrightarrow{E_{PPE}} = \overrightarrow{E_{PPE_{TEAM}}} * E_{Q_T} * \sum \overrightarrow{P_Q} \quad \textbf{(32)}$$

Where:

- $\overrightarrow{E_{PPE_{TEAM}}}$ = Fraction of total PPE that is each level, per one team

$$C_A = (W_Q * C_{W_A}) + (H_Q * C_{H_A}) \quad \textbf{(33)}$$

Where:

- C_{W_A}, C_{H_A} = Cost of one sponge stick sample or 37 mm sample for analysis, respectively

C_L, C_S, C_E, and C_A combine to give the overall cost of CS (C_{CS}), as illustrated by Equation 34 below.

$$C_{CS} = C_L + C_S + C_E + C_A \quad \textbf{(34)}$$

3.4 Source Reduction

SR is the process of removing contaminated material to save the cost of decontaminating these contaminated materials. SR is used to reduce the potential material demands associated with different decontamination methods; material demand issues can significantly impact the amount of decontamination chemicals required to decontaminate a given area. The cost and time savings associated with SR being removed from the site is heavily dependent upon the decontamination method that would have been used as well as the amount of material packaged and removed from the site area. For example, if all roofing material is removed and hauled away from the site as waste it will not be required to be decontaminated. However, the tool does not implicitly adjust the amount of material removed based on the decontamination method chosen as the specific details of what the SR consists of (e.g., roofing, vehicles, vegetation) are user defined and amounts and associated costs would be highly variable and difficult to automate. As such, realistic differences in SR results between different decontamination methods are only seen if the user adjusts the amount of material removed based on the decontamination methods they selected.

The following sections list the parameters relevant to the SR model as well as the calculations performed to characterize the cost and resource demands of this element.

3.4.1 Source Reduction Parameters

The SR model parameters are listed in Table 7 below. Note that this table only includes user-input and baseline parameters. All calculated quantities are explained in detail in the subsequent section.

Table 7: SR Model Parameters

Parameter	Name	Description	Units
A_T	Total Surface Area	Total surface area of the contamination site	m^2
A_{MASS}	Fraction of Mass to be Source Reduced	Fraction of the total waste mass to be removed	unitless
$MASS_A$	Mass Per Surface Area	Mass of waste per surface area of site	kg / m^2
$MASS_H$	Mass Removed Per Hour Per Team	Mass of waste removed per hour per team	kg / hour * team
$\overrightarrow{E_D}$	Entry Duration	Entry durations based on PPE levels	hours / entry * team
E_P	Entry Preparation Time	Time required for preparation into the contaminated site area	hours / entry * team
E_{DC}	Decontamination Line Time	Time required for decontamination of personnel upon exiting the contaminated site area	hours / entry * team
E_R	Post-Entry Rest Period	Time required for rest period upon exiting the contaminated site area	hours / entry * team
R_P	Number of Respirators Per Person	Number of respirators per one person	respirators / person
T_Q	Number of Teams	Number of teams required for element	teams
$\overrightarrow{P_Q}$	Personnel Required	Number of personnel of each type required for one team (OSC, PL-1, PL-2, PL-3, PL-4)	personnel
P_{D_O}	Personnel Overhead Days	Number of setup and teardown days at the start and end of the element	days
$\overrightarrow{E_{PPE_{TEAM}}}$	PPE Fraction Per Team	Fraction of total PPE that is each level for one team (Level A, Level B, Level C, Level D)	unitless
C_R	Cost Per Respirator	Cost per one respirator	$ / respirator
$\overrightarrow{C_{E_{PPE}}}$	Cost Per Individual PPE	Cost per one unit of PPE of each level	$ / PPE level
C_{MASS}	Cost Per Mass of Material Removed	Cost per mass of waste materials removed from site	$ / kg
C_{E_P}	Entry Preparation Cost	Cost associated with preparation before entering the site area	$ / entry * team
$C_{E_{DC}}$	Decontamination Line Cost	Cost associated with the personnel decon line	$ / entry * team
$\overrightarrow{C_P}$	Personnel Hourly Rate	Hourly wage of each personnel type (OSC, PL-1, PL-2, PL-3, PL-4)	$ / hour

3.4.2 Source Reduction Model

The overall cost of SR is broken down into two primary costs of equal weight: 1) cost of labor (C_L) and 2) cost associated with entering and exiting the contaminated area (C_E). The cost of labor for SR is calculated using Equation 35 below.

$$C_L = \left[P_H * T_Q * \left(\overrightarrow{P_Q} \cdot \overrightarrow{C_P}\right)\right] + \left(MASS_Q * C_{MASS}\right) \quad \textbf{(35)}$$

Where:

- P_H = Total SR labor hours
- T_Q = Number of teams required for SR
- $\overrightarrow{P_Q}$ = Number of personnel required per team by personnel type
- $\overrightarrow{C_P}$ = Personnel hourly rate by personnel type
- $MASS_Q$ = Mass of waste removed from contamination site
- C_{MASS} = Cost per mass of waste material removed from contamination site

The parameter P_H is calculated using Equation 36 below.

$$P_H = 12 * P_{D_{SR}} \quad \textbf{(36)}$$

Where the personnel onsite days, or $P_{D_{SR}}$, is calculated using Equation 37.

$$P_{D_{SR}} = P_W + P_{D_O} \quad \textbf{(37)}$$

Where:

- P_W = Total workdays
- P_{D_O} = Personnel overhead days

The total number of workdays for SR is calculated using the same equation as is used in the calculation of total workdays for CS. See Equation 11 for the appropriate calculation.

The parameter P_{D_L} is calculated using Equation 38 below.

$$P_{D_L} = \frac{MASS_Q}{12 * MASS_H * T_Q} \quad \textbf{(38)}$$

Where:

- $MASS_H$ = Mass of material removed from contamination site per hour per team

The parameter $MASS_Q$ is calculated using Equation 39 below.

$$MASS_Q = A_T * A_{MASS} * MASS_A \quad \textbf{(39)}$$

Where:

- A_T = Total surface area of the contamination site
- A_{MASS} = Fraction of the total waste mass to be source reduced
- $MASS_A$ = Mass of waste per surface area of contamination site

The cost associated with entering and exiting the contamination site for SR is calculated using the same equations as are used in the calculation of entrance and exit cost for CS. See Equations 27-33 for the appropriate calculations.

C_L, and C_E combine to give the overall cost of SR (C_{SR}), as illustrated by Equation 40 below.

$$C_{SR} = C_L + C_E \quad \textbf{(40)}$$

3.5 Efficacy

At the heart of the decontamination model is the Efficacy Model, which estimates the efficacy of a given decontamination application method on a specific surface type. The development of the Efficacy Model began with a detailed review of the BioDecontamination Compendium in order to identify and utilize relevant data[9].

The BioDecontamination Compendium consisted of 8,555 records of data from a myriad of literature investigating the efficaciousness of different decontamination application methods on various surface materials. This compendium contained valuable data pertaining to decontamination which were used to develop a model estimating the efficaciousness of the application methods found in the compendium on various indoor, underground, and outdoor surface types. However, this compendium contained naming inconsistencies for various parameters. It also contained ambiguous and supplemental data that were either unquantifiable or unnecessary. As such, the compendium underwent a rigorous review before any analysis on the efficacy parameters was performed. The following sections describe not only this review and the subsequent analysis of the cleaned data, but the resulting efficacy model as well.

3.5.1 BioDecontamination Compendium Review

The BioDecontamination Compendium review consisted of the following five steps:

1. Identification of relevant columns
2. Resolution of ambiguous values and removal of incomplete values
3. Removal of unnecessary records
4. Conversion of data
5. Additional calculations

Each of the steps is described in detail in the following sections.

3.5.1.1 Identification of Relevant Columns

It was important to first identify columns that were deemed relevant to developing an efficacy model based on decontamination application type and surface material in order to reduce the scope of the compendium. The BioDecontamination Compendium contained 71 columns, not all of which were deemed necessary for modeling efficacy. Table 8 lists only the 27 columns within the compendium that were kept.

Table 8: Compendium Columns Deemed Relevant to the Efficacy Model

Column Name	Description
Ref	Reference where data given in the corresponding record can be found
AppMeth	Decontamination application method applied to surface
LoadingNum	Target number of spored the surface is initially contaminated with pre-decontamination treatment
LoadingUn	Units of the pre-treatment spore loading
LposRec	Log of the spores recovered from the positive control coupon
CoupArea	Area of the test coupon
CoupAreaUn	Units of the area of the test coupon
ConcDoseNum	Concentration of the active decontamination agent in the treatment
ConcDoseUn	Units of the concentration of active agent
VolApp	Volume of decontamination agent applied
VolAppUn	Units of the volume of agent applied
TempNum	Temperature of environment where decontamination was performed (in Celsius)
RHNum	Relative humidity of environment where decontamination was performed (in %)
ContTimeNumMin	Amount of time that a surface is exposed to a treatment method (in minutes)
EffMeas	Measure that the efficacy value is given in
Eff	Effectiveness of treatment in reducing spores on a given surface
ReApp	Number of times a decontamination method is reapplied
DeconAgent	Active decontamination agent
Rinsate	Number of spores rinsed off material after decontamination
RinsateUn	Units of the rinsate
EffVar	Value of efficacy variability statistic
EffVarStat	Variability statistic
Positives	Number of samples out of N positive for growth after treatment
ClO2(ppm)	Chlorine dioxide concentration applied
MB(mg/L)	Methyl bromide concentration applied
H2O2(ppm)	Hydrogen peroxide concentration applied
N	Number of replicates of test condition

Certain columns within the BioDecontamination Compendium were deemed redundant as equivalent data could be found in another column. These columns were thus removed from the compendium. A list of the columns that were removed on this basis can be found in Appendix D.

Finally, some columns within the BioDecontamination Compendium were deemed not relevant for the purposes of efficacy model development. A list of the columns that were removed on this basis can be found in Appendix E.

3.5.1.2 Resolution of Ambiguous Values and Removal of Incomplete Values

Data input into the compendium was not always in the right format (e.g., strings within numerical columns). In order to enable further processing of these data, unwanted values were removed, and ambiguous values were resolved, as follows:

- Strings that implied no value was given (i.e., “ambiguous”, “undefined”, “not reported”) were removed from the numerical columns and given a null value.

- Strings that could not be converted to any specific value (i.e., “trigger pulls of spray”, “as needed to keep wetted”, “until wetted”) were removed from numerical columns and given a null value.

- Values that were given with a “>” or “<” symbol were replaced with the numerical value without the symbol.

- Values input as ranges were removed and replaced with the lower value in the given range.

- Inconsistent naming was addressed within text columns to standardize naming conventions. For instance, within the AppMethod column, “liquid (ambiguous)” was changed to “liquid ambiguous”, the latter of which was the naming convention that occurred most throughout the column.

- All studies where the efficacy value was recorded as “Lrsurf” were changed to list “LR” as the EffMeas. This was done because in the three studies for which “Lrsurf” was recorded, efficacy values were reported as a log reduction (LR) and the term “Lrsurf” was never defined.

- For the ContTime column, most contact times found in the compendium were estimated based on plot images using the WebPlotDigitizer tool. This tool extracts numerical data from charts and graphs[12]. However, these data extraction is only an estimation of the actual plotted data. As such, certain contact times were extracted and input into the compendium as negative values. To ensure physical validity of the values utilized, any negative times were set to zero.

- The list of application methods found in the compendium were narrowed down by determining which methods could be surrogates of others. “Foam Ambiguous” was deemed a sufficient surrogate for “Foam Spray”. “Fumigation/Liquid” was found to include only data that was applicable to the “Liquid” method and was thus replaced with this naming convention. “Immersion” was found to be equivalent to “Liquid Immersion”. Finally, “Liquid”, “Liquid Ambiguous”, and “Liquid Dropper” were all found to be equivalent to “Liquid Spray”.

3.5.1.3 Removal of Unnecessary Records

Some of the data in the compendium were removed as certain records could not be used in the development of the efficacy model. The records removed along with the justification for removal are as follows:

- All records that did not list a decontamination treatment application method (AppMethod) were removed as these records could not be classified based on their application method and therefore did not help define any specific treatment. Four records were removed on this basis.

- The efficacy measure QualPos describes the number of test replicates that tested positive for growth after decontamination treatment. Likewise, QualNeg describes the number that tested negative for growth. These efficacy measures could not be used to calculate a number of spores recovered from the test coupon after treatment and thus an investigation into these studies was performed to determine if more detailed data could be gathered. Through this investigation, it was found that one of two things occurred within the studies with these efficacy measures: 1) for shorter studies, better data could not be collected as the records in the compendium already contained all of the data found in the study, and 2) for studies that provided more data regarding their findings, data were typically presented in a more usable way (log reductions, number of spores recovered from the test coupon after treatment) and these data was also input into the compendium when available. However, these studies may have also included QualPos/QualNeg data for various bio test strips which acted as supplemental data. For these reasons, QualPos and QualNeg records were removed. Five hundred and thirteen records were removed on this basis.

- Loading values were given in a variety of units. However, for standardization purposes, all Loadings were converted to a value of CFU per area, mass, or volume of the test coupon. Thus, a coupon area, mass, or volume was required for all Loadings given in CFU. All records that gave LoadingUn in CFU but did not provide a coupon area, mass, or volume were removed. Four hundred and thirty-nine records were removed on this basis.

3.5.1.4 Conversion of Data

Data given in the compendium came in a variety of units, even within the same columns. In order to compare data within and between columns, it was necessary to convert numerical columns to standard units.

The following coupon area units (CoupAreaUn) shown in Table 9 were converted to standard units. Note that some of the coupon surfaces were liquids and thus a volume was provided for the area column. Additionally, some of the coupon surfaces were foods or irregular shapes and thus a mass was provided for the area column.

Table 9: Converted Coupon Area Units

Original Units	Converted Units
mm^2	cm^2
cm^2	
m^2	
in^2	
ft^2	
uL	cm^3
mL	
L	
cm^3	
m^3	
kg	g
g	

The following units for the volume of decontamination agent applied to the surface (VolAppUn) shown in Table 10 were converted to standard units. Note that some of the volumes were given per area of the surface they were applied to. This was maintained as it was the desired unit, and all other values were divided by their corresponding coupon area for consistency. Additionally, the application methods "Foam Spray" and "Liquid Spray" gave a volume in mass.

Table 10: Converted Volume of Agent Applied Units

Original Units	Converted Units
uL	mL/cm^2 or mL/cm^3
L	
L/m^2	mL/cm^2
mL/m^3	mL/cm^3
g	g/cm^2 or g/cm^3

The following units for the initial coupon loading (LoadingUn) shown in Table 11 were converted to standard units. Each value was then divided by the area of the coupon for those that were not already in terms of area, volume, or mass. These same conversions were also performed on the corresponding LposRec values as this column was assumed to have the same units.

Table 11: Converted Loading Units

Original Units	Converted Units
CFU/mL	CFU/cm^3
CFU/L	CFU/cm^3
CFU	CFU/cm^2 or CFU/cm^3 or CFU/g
$\log(CFU)$	
CFU/g	CFU/g
CFU/cm^2	CFU/cm^2
$CFU/100cm^2$	CFU/cm^2

A total of 31 unique units were provided for the concentration of decontamination agent applied (ConcDoseUn). These were converted to standard units where possible, as illustrated by Table 12.

Table 12: Converted Concentration Dose Units

Original Units	Converted Units
kJ	J
$FAC\ ppm\ (FAC\ mg/L)$	g/mL
mg/L	g/mL
W/m^2	W/cm^2
kW/m^2	W/cm^2
$wt\%$	g/mL
uW/cm^2	W/cm^2
g/L	g/mL
$mg\ tablet/L$	g/mL
ppm	g/mL
J/cm^2	J/cm^2
$\%\ wt/vol$	g/mL
$ppmv$	g/mL
mW/cm^2	W/cm^2
$wt\%\ NaOCl$	g/mL
mJ/cm^2	J/cm^2
mg/mL	g/mL
$wt\%\ (liquid\ applied)$	g/mL
J/m^2	J/cm^2
$maximum\ ppm$	g/mL
g/m^3	g/mL
$wt\%\ in\ wetting\ liquid$	g/mL

While there were still quite a few disparate units found in ConcDose even after conversions were performed, g/mL were the most common. The remaining units were dependent upon the application method. Table 13 lists the application methods and the respective unique ConcDose units that applied to each.

Table 13: Unique Concentration Dose Units

Application Method	Unique ConcDose Units
Foam Spray	g/mL
Aqueous Suspension	
Liquid-Soaked Gauze Wipe	
Liquid-Soaked Gauze Covering	
Aerosol	
Liquid Wipe	
Physical	J/cm^2
	$Mrad$
	Gy
	W/cm^2
	$discharges\ (40A\ for\ 200nS)$
	W
	W/cm^3
	bar
Fumigation	J
	g/mL
Fogging	g/mL
	mL
Liquid Suspension	g/mL
	M
	$vol\%$
	$\%\ available\ iodine$
Liquid Spray	g/mL
	M
	$vol\%$
Liquid Immersion	g/mL
	M
Gel	$vol\%$

Note that the Physical application method included a wide range of physical treatments, including radiation and treatment with UV radiation. As such, this method accounted for most of the disparate units. Also note that while J does not seem an appropriate unit for the Fumigation application method, this unit was given in the compendium where the decontamination agent applied was listed as plasma.

3.5.1.5 Additional Calculations

Certain calculations were deemed necessary in order to create a full set of usable data for the development of the efficacy model. Various columns were added to hold these new values, as listed in Table 14.

Table 14: Columns Added to the BioDecontamination Compendium

Column Name	Description
RepSurface	Representative surface based on the surface found in the compendium. These representative surfaces are listed in Appendix A.
IndoorWalls	Holds a zero or one based on whether the representative surface in the RepSurface column was a material used for interior walls for the indoor scenario. Surfaces were classified using the lookup tables in Appendix F.
IndoorCarpet	Holds a zero or one based on whether the representative surface in the RepSurface column was a material used for carpeted flooring for the indoor scenario. Surfaces were classified using the lookup tables in Appendix F.
IndoorNonCarpet	Holds a zero or one based on whether the representative surface in the RepSurface column was a material used for non-carpeted flooring for the indoor scenario. Surfaces were classified using the lookup tables in Appendix F.
IndoorCeiling	Holds a zero or one based on whether the representative surface in the RepSurface column was a material used for ceilings for the indoor scenario. Surfaces were classified using the lookup tables in Appendix F.
IndoorHVAC	Holds a zero or one based on whether the representative surface in the RepSurface column was a material used for HVAC and duct work for the indoor scenario. Surfaces were classified using the lookup tables in Appendix F.
IndoorMisc	Holds a zero or one based on whether the representative surface in the RepSurface column was a material found indoors but not already included in the other categories for the indoor scenario. Surfaces were classified using the lookup tables in Appendix F.
OutdoorExterior	Holds a zero or one based on whether the representative surface in the RepSurface column was a material found in exterior walls for the outdoor scenario. Surfaces were classified using the lookup tables in Appendix G.
Roofing	Holds a zero or one based on whether the representative surface in the RepSurface column was a material found in roofing for the outdoor scenario. Surfaces were classified using the lookup tables in Appendix G.
Pavement	Holds a zero or one based on whether the representative surface in the RepSurface column was a material found in outdoor flooring or pavement for the outdoor scenario. Surfaces were classified using the lookup tables in Appendix G.
Water	Holds a zero or one based on whether the representative surface in the RepSurface column describes a body of water for the outdoor scenario. Surfaces were classified using the lookup tables in Appendix G.
Soil	Holds a zero or one based on whether the representative surface in the RepSurface column topsoil or vegetation for the outdoor scenario. Surfaces were classified using the lookup tables in Appendix G.

Column Name	Description
OutdoorMisc	Holds a zero or one based on whether the representative surface in the RepSurface column was a material found outdoors but not already included in the other categories for the outdoor scenario. Surfaces were classified using the lookup tables in Appendix G.
UndergroundWalls	Holds a zero or one based on whether the representative surface in the RepSurface column was a material used for interior walls for the underground scenario. Surfaces were classified using the lookup tables in Appendix H.
UndergroundCarpet	Holds a zero or one based on whether the representative surface in the RepSurface column was a material used for underground carpeted flooring for the underground scenario. Surfaces were classified using the lookup tables in Appendix H.
UndergroundNonCarpet	Holds a zero or one based on whether the representative surface in the RepSurface column was a material used for underground non-carpeted flooring for the underground scenario. Surfaces were classified using the lookup tables in Appendix H.
UndergroundCeiling	Holds a zero or one based on whether the representative surface in the RepSurface column was a material used for ceilings for the underground scenario. Surfaces were classified using the lookup tables in Appendix H.
UndergroundHVAC	Holds a zero or one based on whether the representative surface in the RepSurface column was a material used for HVAC and duct work for the underground scenario. Surfaces were classified using the lookup tables in Appendix H.
UndergroundMisc	Holds a zero or one based on whether the representative surface in the RepSurface column was a material found outdoors but not already included in the other categories for the underground scenario. Surfaces were classified using the lookup tables in Appendix H.
TotalApp	Total number of decontamination treatment applications. This column was already calculated in the compendium; however, for some numerical values within ReApp, the calculated TotalApp was NA which should not be the case. Note that blank values and NA values within ReApp were replaced with zeroes. This was done based on the assumption that at least one treatment must be applied in order to decontaminate a surface with a given decon method. If multiple treatments were not indicated, it was assumed that at least one treatment was applied.
Nt	Number of spores recovered from the test coupon after treatment with a decontamination agent. Values in this column were calculated differently depending on the efficacy measure given.

Note that the Nt column calculation varied given the efficacy measure. The calculations used for each efficacy measure are provided in Table 15.

Table 15: Nt Calculations Based on EffMeas

EffMeas	Description	Equation
LR	Log reduction	$Eff(LR)$ = LposRec −log(Nt)
Lsurv	Log of the spore survival count	$Eff(LSurv)$ = log(Nt)
LsurvFrac	Log of the spore survival fraction	$Eff(LSurvFrac)$ = log(Nt/Loading)
%Surv	Percent of spores that survive treatment	$Eff(\%Surv)$ = (Nt/Loading) ∗100
%Kill	Percent of spores killed in treatment	$Eff(\%Kill)$ = ((Loading −Nt)/Loading) ∗100
SurvFrac	Spore survival fraction	$Eff(SurvFrac)$ = Nt/Loading

Finally, the efficacy measure SurvFrac describes the fraction of spores that are recovered from the test coupon after decontamination given the initial loading of spores. Intuitively, this number should be between zero and one. However, certain records provided values for SurvFrac that were found to be unreasonably high. As such, all values greater than one were divided by 100 under the assumption that the value was given within the reference as a percentage rather than a fraction.

3.5.2 Application Method Review

Upon completion of the BioDecontamination Compendium review, the application methods found within the compendium were reviewed for their relevance to wide area scenarios as well as the three scenario types to be considered within the model (i.e., indoor, outdoor, and underground) based on subject matter expert (SME) determination. The following application methods were deemed relevant to these scenarios and, thus, were included in the tool:

- Aerosol
- Foam Spray
- Fogging
- Fumigation
- Gel
- Liquid Immersion
- Liquid Spray
- Liquid Suspension
- Liquid Wipe
- Physical

3.5.3 Application Method and Surface Type Combinations Review

The application method and surface type combinations included in the tool were also reviewed by SMEs to identify which were valid for the three scenario types. Figure 7 lists all application method and surface type combinations color-coded by their inclusion status. Green highlighted cells indicate combinations that were found to be valid and were thus included in the tool. Black highlighted cells indicate combinations that were included in the tool only for waste materials. Red highlighted cells indicate combinations that had no underlying data in the compendium and, thus, were not included in the tool. Finally, blue highlighted cells indicate combinations that were deemed irrelevant and, thus, were not included in the tool.

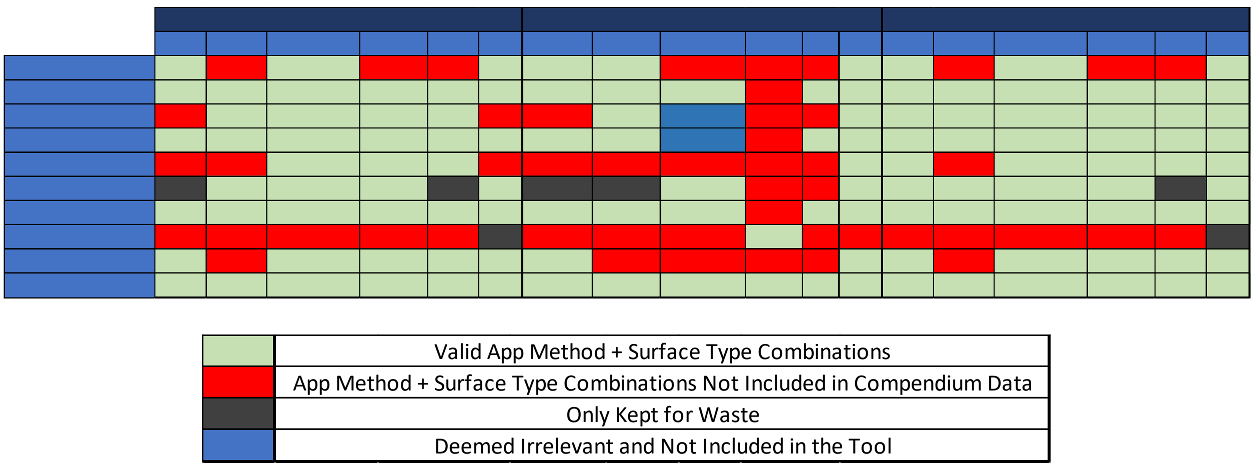


Figure 7: Reviewed Application Method and Surface Type Combinations

3.5.4 Bivariate Relationship Analysis

The development of the efficacy model began with an analysis of the bivariate relationships within the BioDecontamination Compendium. Bivariate relationships are connections between two parameters and an analysis of the connections that were present between efficacy and other numerical factors was performed in order to identify those factors which had the greatest influence on efficacy. This analysis facilitated the development of a guideline for predicting efficacy based on the identified related factors. By determining the relationship between efficacy and a given numerical parameter, the estimation of that parameter and application of the appropriate relationship results in an estimated efficacy value. This analysis helped capture the high amount of uncertainty associated with efficacy due to the sparsity of available data, the myriad of factors that may change for decontamination and impact efficacy (e.g., temperature, relative humidity), and the numerous decontamination application treatment methodologies. It should be noted that for future iterations of the tool, a more rigorous multivariate analysis may be beneficial to constructing the best possible efficacy model from the available data.

Three categorizations of Biodecon Compendium data were investigated: 1) application method, 2) surface type, and 3) application method and surface type. For each subset of data, Python scripts were used to calculate a Pearson correlation coefficient r describing the strength of the linear relationship between efficacy in log reductions and each of the numerical columns found in Table 16.

Table 16: Numerical Columns Included in the Bivariate Relationship Analysis

Numerical Columns Used for Analysis		
Loading	H2O2	ContTime
ConcDose	VolApp	Rinsate
ClO2	Temp	TotalApp
MB	RH	

A p-value (p) indicating the probability that an uncorrelated dataset would produce a correlation coefficient at least as extreme as the corresponding coefficient was also calculated for each subset of data to describe the strength of the correlation coefficient.

Guidance on the breakdown of correlation coefficients and corresponding relationship strengths was obtained from Statology.org[12] as well as a paper by Diana Mindrila and Phoebe Balentyne on scatterplots and correlations[13] and is summarized in Table 17 below.

Table 17: Relationship Strength of Correlation Coefficients

Absolute Value of r[12]	Absolute Value of r[13]	Relationship Strength
r < 0.25	r < 0.30	No Relationship
0.25 < r < 0.50	0.30 < r < 0.50	Weak Relationship
0.50 < r < 0.75	0.50 < r < 0.70	Moderate Relationship
r > 0.75	r > 0.70	Strong Relationship

Despite discrepancies in the threshold between the moderate and strong relationship, the threshold between the moderate and weak relationship was consistent. Based on this guidance, the following threshold for r was defined in Equation 41 to include both moderate and strong relationships:

$$|r| \geq 0.50 \quad \textbf{(41)}$$

A threshold for p was also determined, as illustrated by Equation 42. Guidance for this threshold came from the Corporate Finance Institute stating that a p-value less than 0.01 is considered highly statistically significant [14].

$$p \leq 0.01 \quad \textbf{(42)}$$

The combination of both thresholds ensured that only correlations which were moderate to strong and statistically significant to 99% were considered when determining bivariate relationships between efficacy and other numerical parameters within the compendium. The following datasets (application method *or* surface type) and subsets (application method *and* surface type) listed in Table 18 were found to meet these thresholds.

Table 18: Compendium Datasets and Subsets Which Met r and p-value Thresholds

Application Method	Surface Type
Foam Spray	-
Liquid Suspension	-
Liquid Wipe	-
Foam Spray	IndoorWalls
	IndoorHVAC
	UndergroundHVAC
	OutdoorExterior
	Pavement
	Roofing
Fumigation	IndoorHVAC
	UndergroundHVAC
	UndergroundNonCarpet
	Roofing
	IndoorNonCarpet
Physical	IndoorMisc
Liquid Immersion	IndoorCeilings
	IndoorCarpet
	IndoorMisc
	OutdoorMisc
	UndergroundCeilings
	UndergroundCarpet

Table 19 below shows the datasets and subsets for which a strong correlation was found with Loading, along with the sampled size of the set and the p-value corresponding to the correlation coefficient.

Table 19: Subsets with Strong Correlations with Loading

Dataset or Subset	r - Loading	Data Points	p-Value
Liquid Immersion and UndergroundCeilings	0.99	8	3.34E-06
Liquid Immersion and OutdoorMisc	0.50	62	3.16E-05
Foam Spray and Pavement	-0.97	5	5.41E-03
Foam Spray and Roofing	-0.97	5	5.41E-03
Foam Spray and OutdoorExterior	-0.90	11	1.70E-04
Liquid Immersion and IndoorMisc	0.53	30	2.68E-03
Liquid Immersion and IndoorCeilings	0.99	8	3.34E-06
Foam Spray and IndoorWalls	-0.90	11	1.70E-04

Table 20 below shows the datasets and subsets for which a strong correlation was found with ConcDose, along with the sampled size of the set and the p-value corresponding to the correlation coefficient.

Table 20: Subsets with Strong Correlations with ConcDose

Dataset or Subset	r - ConcDose	Data Points	p-Value
Foam Spray	0.87	55	9.31E-18
Liquid Immersion and IndoorMisc	0.64	30	1.29E-04
Fumigation and IndoorHVAC	-0.54	270	1.81E-21
Fumigation and UndergroundHVAC	-0.54	270	1.81E-21

Table 21 below shows the datasets and subsets for which a strong correlation was found with H2O2, along with the sampled size of the set and the p-value corresponding to the correlation coefficient.

Table 21: Subsets with Strong Correlations with H2O2

Dataset or Subset	r – H2O2	Data Points	p-Value
Fumigation and UndergroundNonCarpet	0.55	26	3.53E-03
Fumigation and Roofing	-0.88	12	1.81E-04
Fumigation and IndoorHVAC	0.78	22	2.03E-05
Fumigation and UndergroundHVAC	0.78	22	2.03E-05
Fumigation and IndoorNonCarpet	0.55	26	3.53E-03

Table 22 below shows the datasets and subsets for which a strong correlation was found with Temp, along with the sampled size of the set and the p-value corresponding to the correlation coefficient.

Table 22: Subsets with Strong Correlations with Temp

Dataset or Subset	r – Temp	Data Points	p-Value
Foam Spray	0.66	52	1.08E-07
Liquid Suspension	0.54	1,402	1.22E-106
Liquid Immersion and UndergroundCarpet	-0.76	48	3.11E-10
Foam Spray and Pavement	0.97	5	5.41E-03
Foam Spray and Roofing	0.97	5	5.41E-03
Foam Spray and OutdoorExterior	0.89	11	2.47E-04
Foam Spray and IndoorHVAC	-0.99	5	1.37E-03
Foam Spray and UndergroundHVAC	-0.99	5	1.37E-03
Liquid Immersion and IndoorCarpet	-0.76	48	3.11E-10
Foam Spray and IndoorWalls	0.89	11	2.47E-04

Table 23 below shows the datasets and subsets for which a strong correlation was found with RH, along with the sampled size of the set and the p-value corresponding to the correlation coefficient.

Table 23: Subsets with Strong Correlations with RH

Dataset or Subset	r – RH	Data Points	p-Value
Foam Spray and OutdoorExterior	0.86	11	7.04E-04
Foam Spray and IndoorWalls	0.86	11	7.04E-04

Table 24 below shows the datasets and subsets for which a strong correlation was found with ContTime, along with the sampled size of the set and the p-value corresponding to the correlation coefficient.

Table 24: Subsets with Strong Correlations with ContTime

Dataset or Subset	r – ContTime	Data Points	p-Value
Liquid Wipe	-0.60	26	1.31E-03
Liquid Immersion and UndergroundCeilings	0.73	58	9.39E-11
Physical and IndoorMisc	0.71	17	1.51E-03
Liquid Immersion and IndoorCeilings	0.73	58	9.39E-11

A scatter plot was generated for each correlation of efficacy vs the given parameter. Each scatter plot was then fit with a uniform x-dependent distribution. A uniform x-dependent distribution is a uniform distribution generated from a maximum y-value and minimum y-value at a given x-value. In order to fit this distribution to each scatter plot, the point with the highest corresponding y-value and the point with the lowest corresponding y-value were chosen at each distinct x-value on every plot. The red dotted line segments in Figure 8 indicate the maximum and minimum boundary on the y-axis for each x-value. Note that the resulting minimum and maximum line segments are monotonic, meaning each either increases or decreases but not both. Points for the segments were chosen with this caveat.

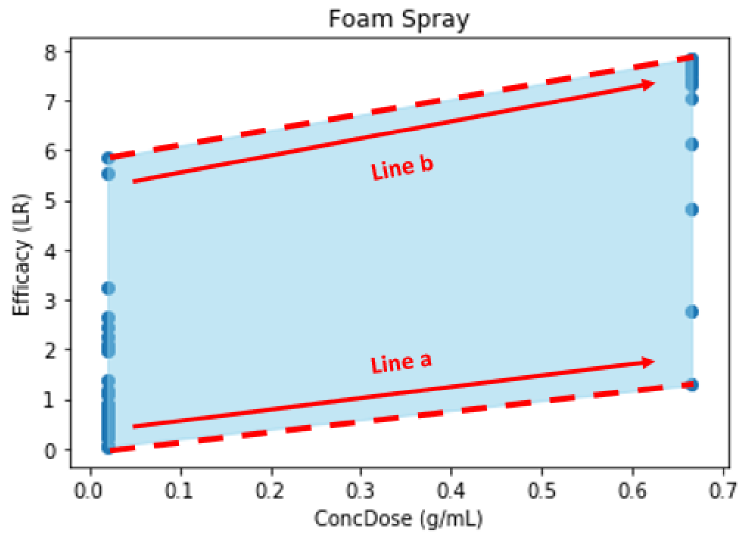


Figure 8: Uniform X-Dependent Distribution for ConcDose and Efficacy for Foam Spray

For every x-value on the plot, a uniform distribution was created using the corresponding y-value from the bottom-most line segment as the lower limit of the range (a), and the top-most line segment as the upper limit of the range (b). This is demonstrated in Figure 9 below.

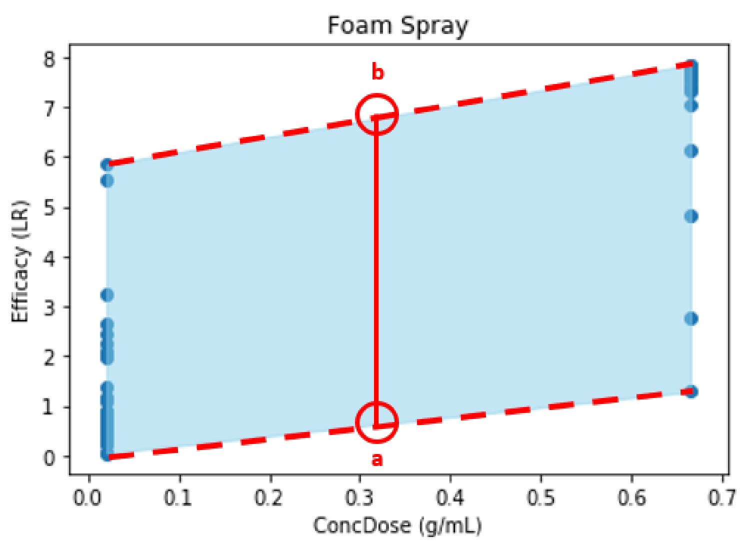


Figure 9: Drawn a and b Values for Each X-Value

The a and b values drawn from the scatter plot were then used to calculate the uniform distribution using the following piecewise formula shown in Equation 43.

$$f(x) = \frac{1}{b-a} \quad for\ a \leq x \leq b$$
$$f(x) = 0 \quad for\ x < a\ or\ x > b \tag{43}$$

As previously stated, scatter plots were generated for all datasets and subsets for which strong correlations were found between efficacy and another numerical parameter. These plots can be found in Appendix I.

3.5.5 Single Dimensional Uncertainty Analysis

Where there was a weak or no relationship between efficacy and other numerical parameters, single dimensional uncertainty analysis (i.e., fitting a distribution to a histogram of efficacy for different categorizations) was utilized to determine an adequate distribution to model efficacy at a lower resolution. Since the efficacy model was parameterized by both application method and surface type, histograms were first generated for efficacy in log reductions for each application method. Based on the behavior of the histograms, further categorization was performed when appropriate. For instance, when application method histograms indicated bimodality (two means), additional histograms were generated for the application method and surface type in an effort to produce a unimodal (one mean) histogram.

All histograms which indicated unimodality were fit with the following distributions:

- Beta
- Truncated Exponential
- Lognormal
- Truncated Normal
- Uniform
- Weibull Minimum
- Weibull Maximum

Each distribution was fit to the data using the built-in SciPy stats .fit method in Python and then the distribution corresponding to the lowest AIC was subsequently fit to the data, as described in Section 2.1.1. Additionally, all histograms which indicated bimodality were fit with bimodal truncated normal distributions.

The Physical dataset, excluding IndoorMisc as this subset was already accounted for in the bivariate relationship analysis, was fit with a lognormal distribution as shown in Figure 10.

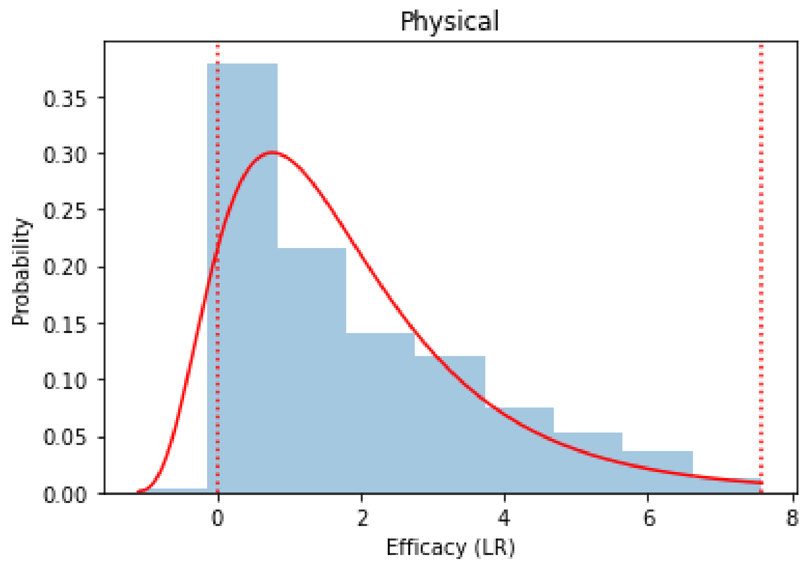


Figure 10: Histogram of Efficacy for Physical

The Fumigation histogram shown in Figure 11 indicated bimodality. As such, an investigation into the cause of this behavior indicated that various surface types combined with Fumigation produced subsets possibly explaining the bimodality.

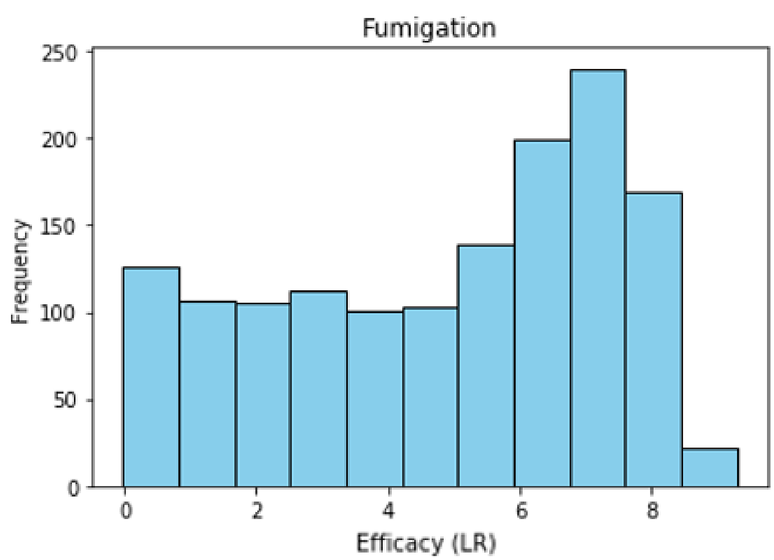


Figure 11: Bimodal Fumigation Efficacy Histogram

All Fumigation and surface type subsets that indicated unimodality were fit with appropriate unimodal distributions and the data from these subsets was removed from the Fumigation dataset.

The Fumigation and IndoorCarpet subset was found to be unimodal and was fit with a beta distribution as shown in Figure 12.

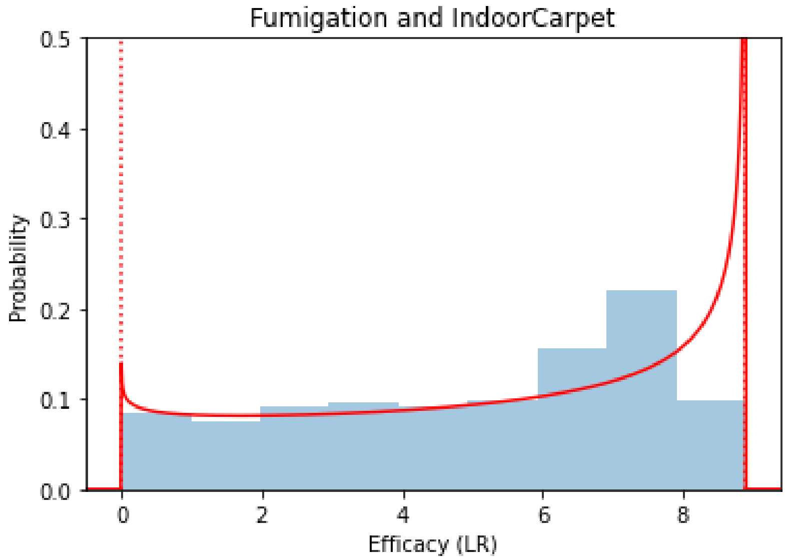


Figure 12: Histogram of Efficacy for Fumigation and IndoorCarpet

The Fumigation and IndoorCeilings subset was found to be unimodal and was fit with a beta distribution as shown in Figure 13.

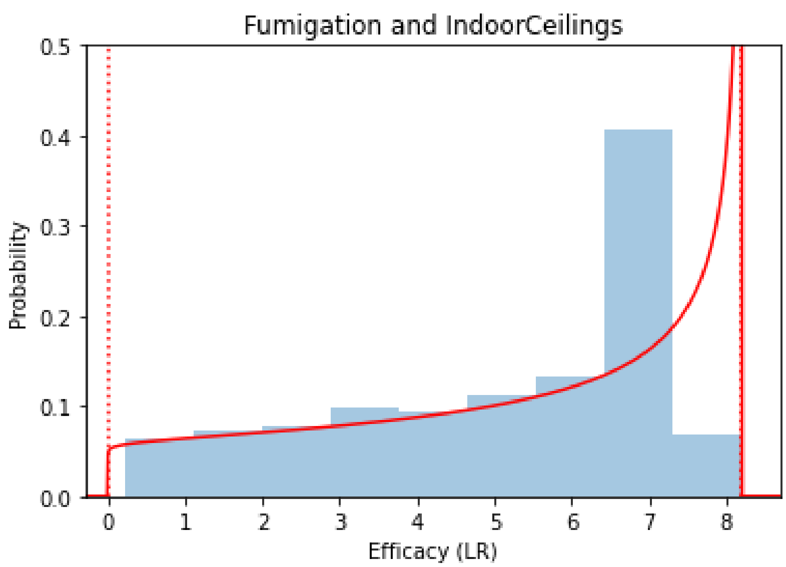


Figure 13: Histogram of Efficacy for Fumigation and IndoorCeilings

The Fumigation and IndoorMisc subset was found to be unimodal and was fit with a beta distribution as shown in Figure 14.

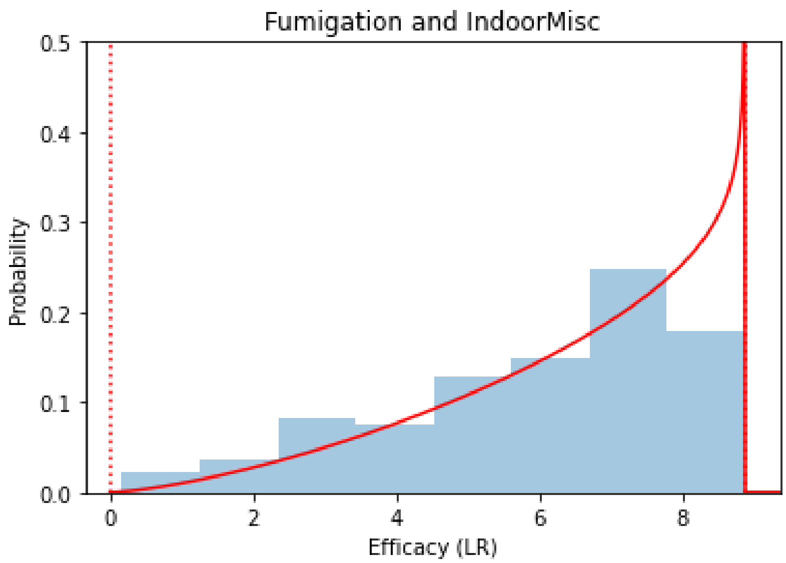


Figure 14: Histogram of Efficacy for Fumigation and IndoorMisc

The Fumigation and UndergroundCarpet subset was found to be unimodal and was fit with a beta distribution as shown in Figure 15.

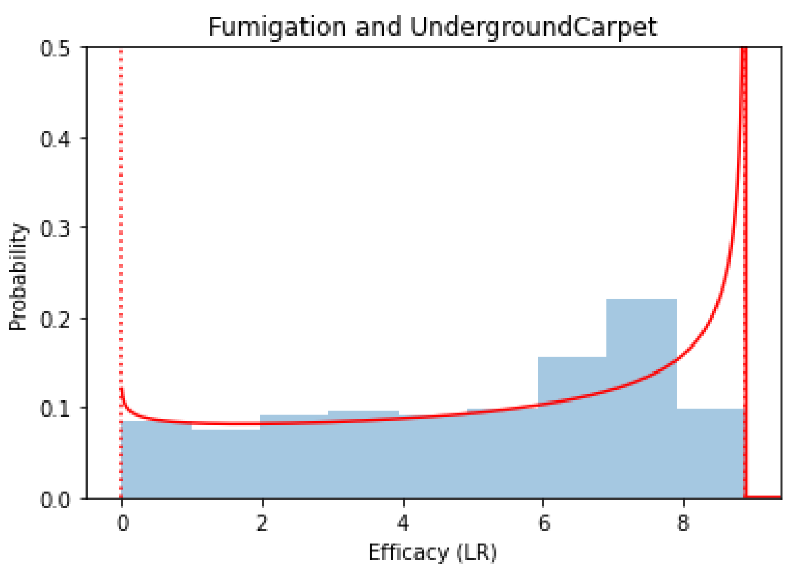


Figure 15: Histogram of Efficacy for Fumigation and UndergroundCarpet

The Fumigation and UndergroundCeilings subset was found to be unimodal and was fit with a beta distribution as shown in Figure 16.

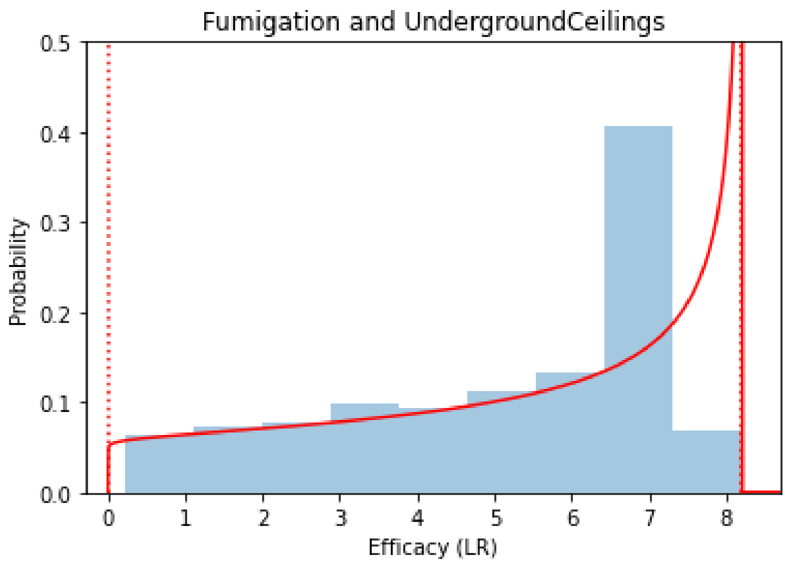


Figure 16: Histogram of Efficacy for Fumigation and UndergroundCeilings

The subsets shown in Figure 12, Figure 13, Figure 14, Figure 15, and Figure 16 were removed from the Fumigation dataset. The resulting dataset was still found to be bimodal and was fit with a bimodal truncated normal distribution as shown in Figure 17.

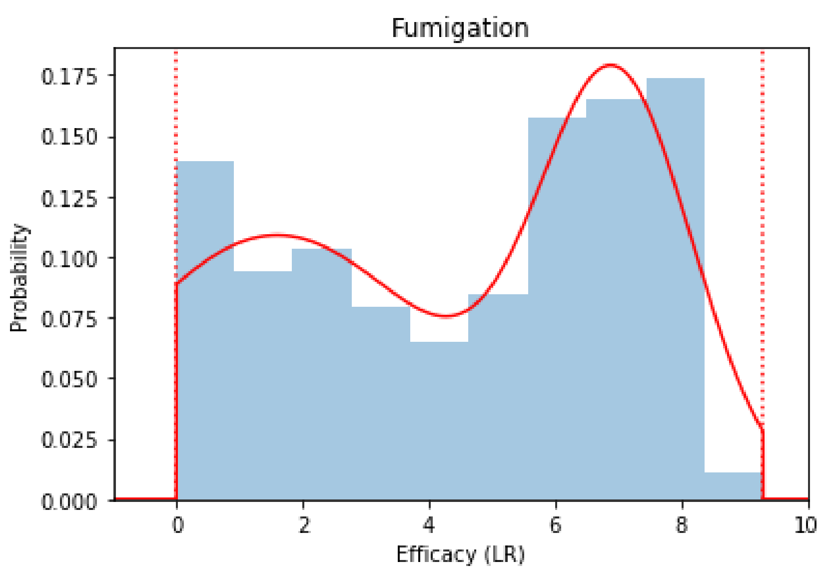


Figure 17: Histogram of Efficacy for Fumigation

The Liquid Spray histogram shown in Figure 18 indicated bimodality. As such, an investigation into the cause of this behavior indicated that various surface types combined with Liquid Spray produced subsets possibly explaining the bimodality.

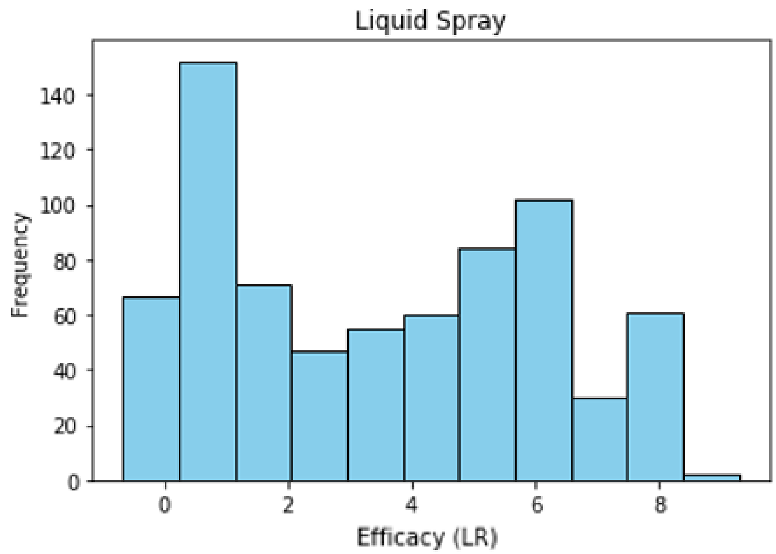


Figure 18: Bimodal Liquid Spray Efficacy Histogram

The Liquid Spray and Roofing subset was found to be unimodal and was fit with a beta distribution as shown in Figure 19.

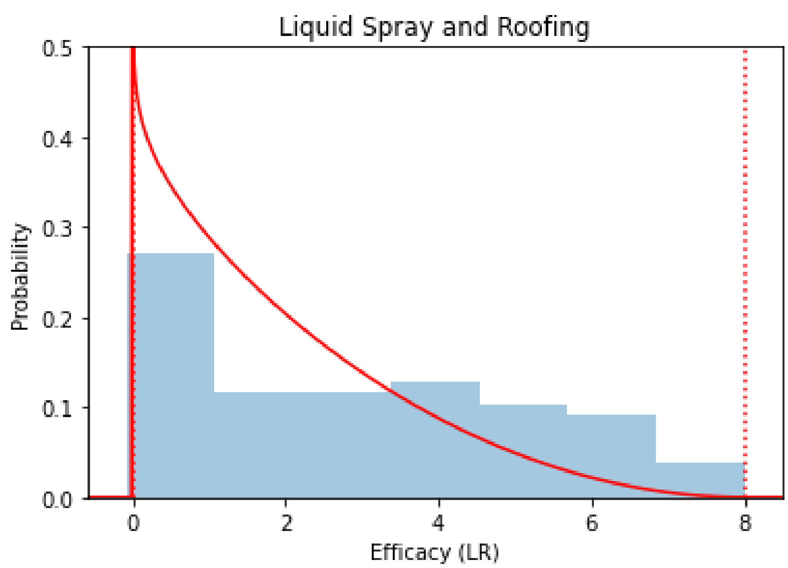


Figure 19: Histogram of Efficacy for Liquid Spray and Roofing

The subset shown in Figure 19 was removed from the Liquid Spray dataset. The resulting dataset was still found to be bimodal and was fit with a bimodal truncated normal distribution as shown in Figure 20.

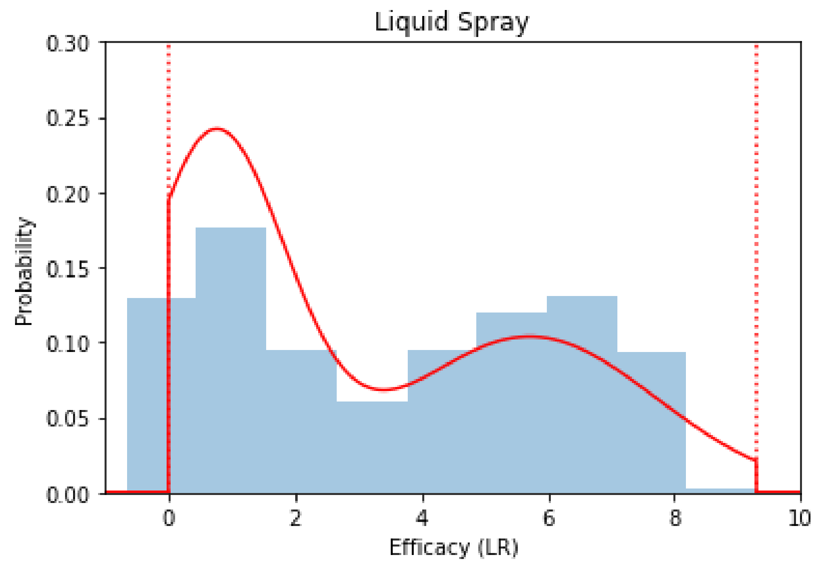


Figure 20: Histogram of Efficacy for Liquid Spray

The Liquid Immersion histogram indicated bimodality. As such, an investigation into the cause of this behavior indicated that the bimodality was not caused by any one factor but rather may be the consequence of multiple confounding factors within the data. Therefore, this dataset was left as-is and was fit with a bimodal truncated normal distribution as shown in Figure 21.

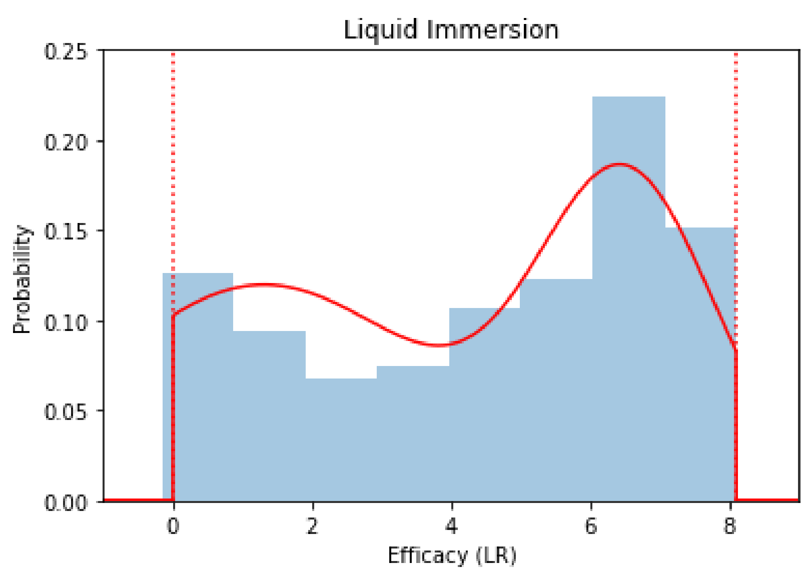


Figure 21: Histogram of Efficacy for Liquid Immersion

The Gel dataset was fit with a Weibull minimum distribution as shown in Figure 22.

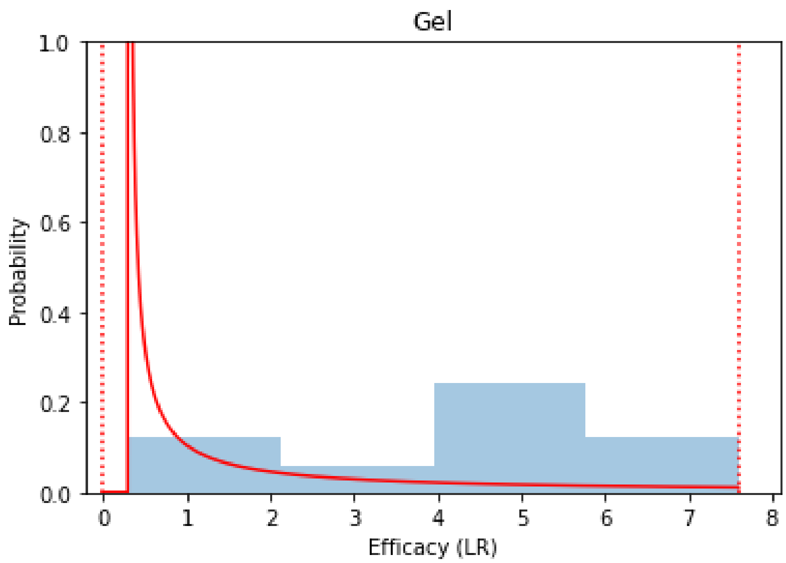


Figure 22: Histogram of Efficacy for Gel

The Aerosol dataset was fit with a beta distribution as shown in Figure 23.

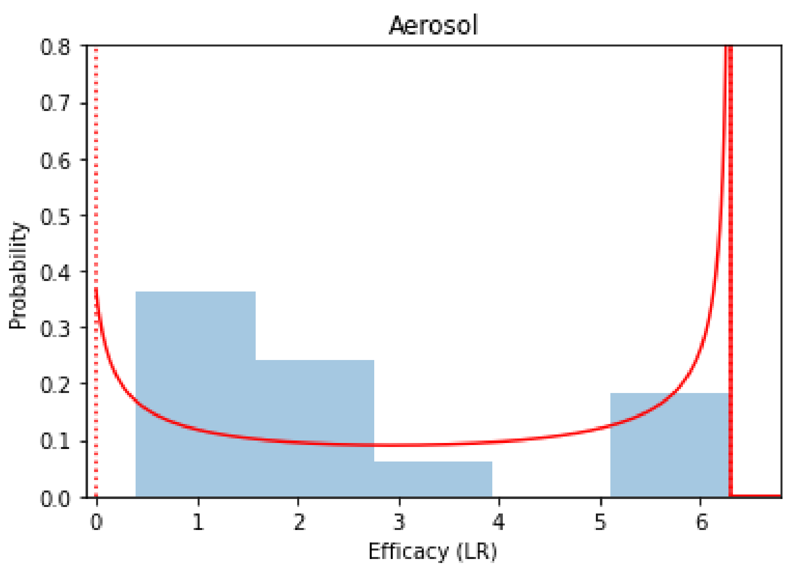


Figure 23: Histogram of Efficacy for Aerosol

The Fogging dataset was fit with a beta distribution as shown in Figure 24.

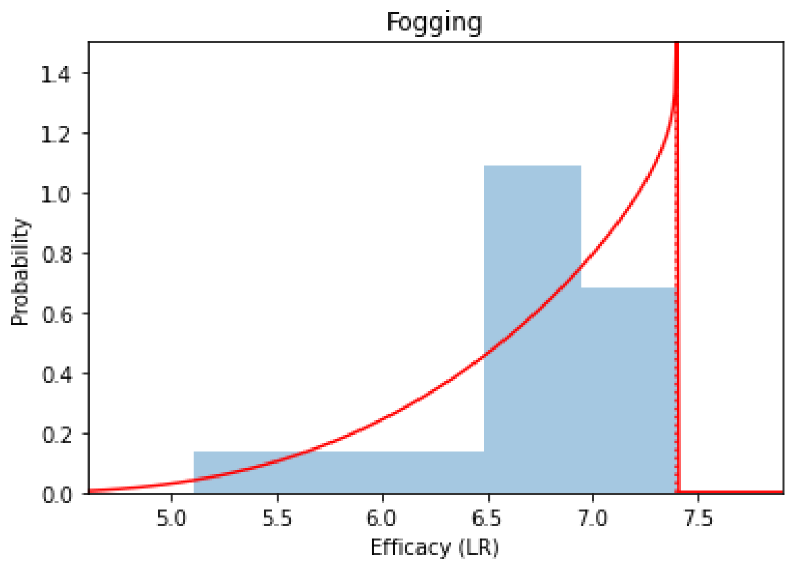


Figure 24: Histogram of Efficacy for Fogging

3.5.6 Creating a Single Model

The Efficacy model calculates a specific value for efficacy based on the application method and surface type combination that the user chooses and the corresponding distribution that has been applied to that subset. The grid in Figure 25 shows the possible combinations of application method and surface type which the user can choose. The cells highlighted orange represent the combinations for which efficacy is determined based on the bivariate relationship defined. The cells highlighted green represent the combinations for which efficacy is drawn from a distribution fit to the corresponding application method dataset. Finally, the cells highlighted blue represent the combinations for which efficacy is drawn from a distribution fit to the corresponding application method and surface type subset.

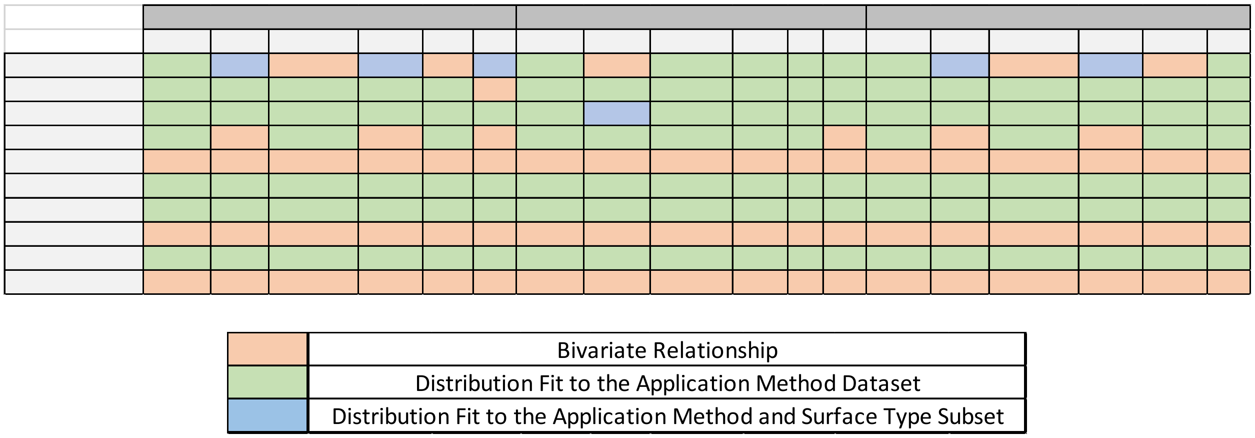


Figure 25: Efficacy Model Categorizations Grid

3.5.7 Efficacy Model Parameters

The Efficacy model includes various parameters which help fully define the treatment of surfaces for the DC model. These parameters are listed in Table 25.

Table 25: Efficacy Model Parameters

Parameter	Name	Description	Units
$\boldsymbol{PreL_{ST_i}}$	Previous Spore Loading	Spore loading on each surface type after any number of decontamination treatments	CFU
$\boldsymbol{AM_{ST_i}}$	Application Method for Surface Type	The application method required to decontaminate each corresponding surface type	application method
$\boldsymbol{DC_{D_{AM}}}$	Decontamination Days for Application Method	Number of days required to fully treat a given surface(s) with one application method, including drying days, for each application method	days

3.5.8 Efficacy Model

When an efficacy value (Eff_{ST_i}) is drawn from the appropriate distribution based on the application method and surface type, Equation 44 is used to determine the remaining spore loading on each surface based on that reduction in spores.

$$PostL_{ST_i} = PreL_{ST_i} - Eff_{ST_i} \tag{44}$$

Where:

- $PreL_{ST_i}$ = Previous spore loading on each surface type i

The number of treatments of each application method i (T_{Q_i}) is determined by the number of times Equation 44 is needed in order to reduce the spore count present on each surface type to the desired spore threshold on each surface type i.

The parameter P_{D_W} is calculated in the Efficacy Model using Equation 45 below.

$$P_{D_W} = \sum P_{D_{AM}} \quad \textbf{(45)}$$

Where the workdays per application method, or $P_{D_{AM}}$, is calculated using Equation 46.

$$P_{D_{AM}} = max\left(T_{Q_i}\right) * DC_{D_{AM}} \quad \textbf{(46)}$$

Where:

- $max\left(T_{Q_i}\right)$ = the max number of treatments for a given application method

$DC_{D_{AM}} =$ Number of days required for one treatment by application method (including drying days)

3.6 Decontamination

DC is the process of reducing any contaminants to a safe level. The methods of removal and threshold for safety are dependent on the input scenario parameters. The decontamination element relies on the Efficacy Model to predict how effective a specific decontamination application method will be when applied to a given surface. The following sections list the parameters relevant to the DC model as well as the calculations performed to characterize the cost and resource demands of this element. Note that certain Efficacy Model parameters are used in the following DC calculations to fully define the costs associated with the DC element.

3.6.1 Decontamination Parameters

The DC model parameters are listed in Table 26 below. Note that this table only includes user-input and baseline parameters. All calculated quantities are explained in detail in the subsequent section.

Table 26: DC Model Parameters

Parameter	Name	Description	Units
DC_{AM}	Number of Days for One Treatment of Application Method	Days required to apply one treatment of each application method (includes drying days)	days
T_Q	Number of Teams	Number of teams required for element	teams
$\overrightarrow{P_Q}$	Personnel Required	Number of personnel of each type required for one team (OSC, PL-1, PL-2, PL-3, PL-4)	personnel
P_{DO}	Personnel Overhead Days	Number of setup and teardown days at the start and end of the element	days
R_P	Number of Respirators Per Person	Number of respirators per one person	respirators / person
$\overrightarrow{E_{PPETEAM}}$	PPE Fraction Per Team	Fraction of total PPE that is each level for one team (Level A, Level B, Level C, Level D)	unitless
$\overrightarrow{E_D}$	Entry Duration	Entry durations based on PPE levels	hours / entry * team
E_P	Entry Preparation Time	Time required for preparation into the contaminated site area	hours / entry * team
E_{DC}	Decontamination Line Time	Time required for decontamination of personnel upon exiting the contaminated site area	hours / entry * team
E_R	Post-Entry Rest Period	Time required for rest period upon exiting the contaminated site area	hours / entry * team
R_V	Volume of Room	Volume of contamination site area or room	m^3
SA_S	Room Surface Area	Surface area of the contamination site or room	m^2
V_F	Volume of Agent (Fogging/Fumigation)	Volume of decontamination agent needed for Fogging or Fumigation for one cubic meter of contamination site area	$mL\ /\ m^3$
$\overrightarrow{V_{AM}}$	Volume of Agent (Other)	Volume of decontamination agent needed for all other application methods for one square meter of each surface	$mL\ /\ m^2$
C_{DA}	Cost of Decontamination Agent	Cost per volume of decontamination agent	$ / mL
C_R	Cost Per Respirator	Cost per one respirator	$ / respirator
$\overrightarrow{C_{EPPE}}$	Cost Per Individual PPE	Cost per one unit of PPE of each level	$ / PPE level
C_{EP}	Entry Preparation Cost	Cost associated with preparation before entering the site area	$ / entry * team
C_{EDC}	Decontamination Line Cost	Cost associated with the personnel decon line	$ / entry * team
C_{SQ}	Cost of Decontamination Materials	Cost of decontamination supplies and equipment per surface area of contamination site	$ / m^2
$\overrightarrow{C_P}$	Personnel Hourly Rate	Hourly wage of each personnel type (OSC, PL-1, PL-2, PL-3, PL-4)	$ / hour

3.6.2 Decontamination Model

The overall cost of DC is broken down into three primary costs of equal weight: 1) cost of labor (C_L), 2) cost associated with entering and exiting the contaminated area (C_E), and 3) cost of supplies and rentals (C_S). The cost of labor for DC is calculated using Equation 47 below.

$$C_L = P_H * T_Q * \left(\overrightarrow{P_Q} \cdot \overrightarrow{C_P}\right) \tag{47}$$

Where:

- P_H = Total DC labor hours
- T_Q = Number of teams required for DC
- $\overrightarrow{P_Q}$ = Number of personnel required per team by personnel type
- $\overrightarrow{C_P}$ = Personnel hourly rate by personnel type

The parameter P_H is calculated using Equation 48 below.

$$P_H = 12 * P_D \tag{48}$$

Where the personnel onsite days, or $P_{D_{DC}}$, is calculated using Equation 49.

$$P_{D_{DC}} = P_W + P_{D_O} \tag{49}$$

Where:

- P_W = Total workdays (calculated in the Efficacy Model)
- P_{D_O} = Personnel overhead days

The cost associated with entering and exiting the contamination site for DC is calculated using the same equations as are used in the calculation of entrance and exit cost for CS. See Equations 23-26 for the appropriate calculations. However, note that no entrances are made for the fogging or fumigation decontamination methods and the total time used within the entrance and exit cost calculation is adjusted to include only non-fogging and non-fumigation treatment methods.

The cost of supplies for DC is calculated using Equation 50 below.

$$C_S = \left(C_{S_Q} * SA_S\right) + \left(DA_{Q_F} + DA_{Q_{AM}}\right) C_{DA} \qquad \textbf{(50)}$$

Where:

- C_{S_Q} = Cost of DC materials (supplies and equipment), per surface area of contamination site
- SA_S = Site or room surface area
- DA_{Q_F} = Volume of decon agent needed per room for fogging or fumigation for one treatment
- $DA_{Q_{AM}}$ = Volume of decon agent needed per room for one application method for one treatment (excluding fogging and fumigation)
- C_{DA} = Cost of decontamination agent per gallon

The parameter DA_{Q_F} is calculated using Equation 51 below.

$$DA_{Q_F} = R_V * V_F \qquad \textbf{(51)}$$

Where:

- R_V = Volume of room
- V_F = Volume of decon agent applied for fogging or fumigation for one treatment per cubic meter of room

Note that DA_{Q_F} may be zero if fogging or fumigation *were not* performed.

The parameter $DA_{Q_{AM}}$ is calculated using Equation 52 below.

$$DA_{Q_{AM}} = \sum \overrightarrow{R_{ST_i}} * \overrightarrow{V_{AM_i}} * A_T \qquad \textbf{(52)}$$

Where:

- $\overrightarrow{R_{ST}}$ = Percentage breakdown of room by surface type (only for the surfaces that do not require fogging or fumigation)

- $\overrightarrow{V_{AM}}$ = Volume of decon agent applied for one application method for each surface type (excluding fogging and fumigation) for one treatment per square foot of surface
- A_T = Total surface area of the contamination site

Note that $DA_{Q_{AM}}$ may be zero if *only* fogging or fumigation were performed.

C_L, C_E, and C_S combine to give the overall cost of DC (C_{DC}), as illustrated by Equation 53 below.

$$C_{DC} = C_L + C_E + C_S \tag{53}$$

3.7 Clearance Sampling

CL is required to determine the level of contamination which is present at the contamination site following each round of decontamination. This information is then used to determine additional decontamination applications are necessary. The following sections list the parameters relevant to the CL model as well as the calculations performed to characterize the cost and resource demands of this element.

3.7.1 Clearance Sampling Parameters

The CL model parameters are listed in Table 27 below. Note that this table only includes user-input and baseline parameters. All calculated quantities are explained in detail in the subsequent section.

Table 27: CL Model Parameters

Parameter	Name	Description	Units
A_T	Total Surface Area	Total surface area of the site	m^2
A_S	Fraction of Surface Area to be Sampled	Fraction of the total surface area that will be sampled	unitless
W_A	Surface Area Per Sponge stick	Surface area which can be sampled by one sponge stick	m^2/ sample
H_A	Surface Area Per 37 mm Cassette	Surface area which can be sampled by one 37 mm cassette	m^2/ sample
W_H	Quantity of Sponge Sticks Used Per Hour Per Team	Number of sponge sticks used for sampling per hour per team	samples / hour * team
H_H	Quantity of 37 mm Cassettes Used Per Hour Per Team	Number of 37 mm cassettes used for sampling per hour per team	samples / hour * team
$\overrightarrow{E_D}$	Entry Duration	Entry durations based on PPE levels	hours / entry * team
E_P	Entry Preparation Time	Time required for preparation into the contaminated site area	hours / entry * team

Parameter	Name	Description	Units
E_{DC}	Decontamination Line Time	Time required for decontamination of personnel upon exiting the contaminated site area	hours / entry * team
E_R	Post-Entry Rest Period	Time required for rest period upon exiting the contaminated site area	hours / entry * team
R_P	Number of Respirators Per Person	Number of respirators per one person	respirators / person
T_Q	Number of Teams	Number of teams required for element	teams
$\overrightarrow{P_Q}$	Personnel Required	Number of personnel of each type required for one team (OSC, PL-1, PL-2, PL-3, PL-4)	personnel
P_{D_O}	Personnel Overhead Days	Number of setup and teardown days at the start and end of the element	days
$\overrightarrow{E_{PPE_{TEAM}}}$	PPE Fraction Per Team	Fraction of total PPE that is each level for one team (Level A, Level B, Level C, Level D)	unitless
Lab_Q	Number of Analysis Labs	Number of external labs to which samples are sent for analysis	labs
$\overrightarrow{L_D}$	Distance from Contamination Site	Distance of external lab from contamination site	km
$\overrightarrow{L_T}$	Lab Throughput Per Day	Number of samples analyzed per day	samples / day
T_R	Time for Result Transmission to IC	Time for sampling analysis results to be sent from external labs to Incident Command	hours
T_{P_S}	Time for One Sample to be Packaged	Time for one sample to be packaged for shipment to an external analysis lab	minutes / sample
C_{E_P}	Entry Preparation Cost	Cost associated with preparation before entering the site area	$ / entry * team
$C_{E_{DC}}$	Decontamination Line Cost	Cost associated with the personnel decon line	$ / entry * team
C_{W_A}	Costs Per Sponge Stick Sample	Analysis costs per one sponge stick sample	$ / sample
C_{H_A}	Costs Per 37 mm Sample	Analysis costs per one 37 mm cassette sample	$ / sample
C_R	Cost Per Respirator	Cost per one respirator	$ / respirator
$\overrightarrow{C_{E_{PPE}}}$	Cost Per Individual PPE	Cost per one unit of PPE of each level	$ / PPE level
C_W	Cost Per Sponge Stick	Cost to purchase one sponge stick	$ / sample
C_H	Cost Per 37 mm Cassette	Cost to purchase one 37 mm cassette	$ / sample
C_{H_D}	37 mm Vacuum Rental Cost Per Day	Cost of 37 mm vacuum rental per day	$ / day
$\overrightarrow{C_P}$	Personnel Hourly Rate	Hourly wage of each personnel type (OSC, PL-1, PL-2, PL-3, PL-4)	$ / hour

3.7.2 Clearance Sampling Model

Clearance Sampling is performed after each round of decontamination is performed in order to characterize the amount of contaminant present on surfaces and to determine if additional rounds of decontamination are required. The Wide-Area Decontamination Tool calculated cost and time results for Clearance Sampling using the same model used to calculate the cost and time of Characterization Sampling. For these calculations, refer to Section 3.3.2.

3.8 Waste Sampling

WS is required to determine the level of contamination which is present in the waste that will be removed from the contamination site and disposed of. This information is used to determine whether waste acceptance criteria (usually established by the state decision makers and the receiving treatment/disposal facility) have been met, as certain safety precautions are necessary in order to dispose of biohazardous waste. The following sections list the parameters relevant to the WS model as well as the calculations performed to characterize the cost and resource demands of this element.

3.8.1 Waste Sampling Parameters

The WS model parameters are listed in Table 28 below. Note that this table only includes user-input and baseline parameters. All calculated quantities are explained in detail in the subsequent section.

Table 28: WS Model Parameters

Parameter	Name	Description	Units
A_T	Total Surface Area	Total surface area of the site	m^2
A_W	Fraction of Waste to be Sampled	Fraction of the total waste that will be sampled	unitless
S_A	Mass Per Solid Waste Sample	Mass of waste which can be sampled by one solid waste sample	m^2/ sample
L_A	Volume Per Liquid Waste Sample	Volume of waste which can be sampled by one liquid waste sample	m^2/ sample
W_H	Quantity of Waste Samples Used Per Hour Per Team	Number of waste samples used for sampling per hour per team	samples / hour * team
W_S	Solid Waste Per Surface Area	Total solid waste produced per surface area of site	kg / m^2
W_L	Liquid Waste Per Surface Area	Total liquid waste produced per surface area of site	L / m^2
$\overrightarrow{E_D}$	Entry Duration	Entry durations based on PPE levels	hours / entry * team
E_P	Entry Preparation Time	Time required for preparation into the contaminated site area	hours / entry * team
E_{DC}	Decontamination Line Time	Time required for decontamination of personnel upon exiting the contaminated site area	hours / entry * team
E_R	Post-Entry Rest Period	Time required for rest period upon exiting the contaminated site area	hours / entry * team
R_P	Number of Respirators Per Person	Number of respirators per one person	respirators / person

Parameter	Name	Description	Units
T_Q	Number of Teams	Number of teams required for element	teams
$\overrightarrow{P_Q}$	Personnel Required	Number of personnel of each type required for one team (OSC, PL-1, PL-2, PL-3, PL-4)	personnel
P_{DO}	Personnel Overhead Days	Number of setup and teardown days at the start and end of the element	days
$\overrightarrow{E_{PPETEAM}}$	PPE Fraction Per Team	Fraction of total PPE that is each level for one team (Level A, Level B, Level C, Level D)	unitless
Lab_Q	Number of Analysis Labs	Number of external labs to which samples are sent for analysis	labs
$\overrightarrow{L_D}$	Distance from Contamination Site	Distance of external lab from contamination site	km
$\overrightarrow{L_T}$	Lab Throughput Per Day	Number of samples analyzed per day	samples / day
T_R	Time for Result Transmission to IC	Time for sampling analysis results to be sent from external labs to Incident Command	hours
T_{PS}	Time for One Sample to be Packaged	Time for one sample to be packaged for shipment to an external analysis lab	minutes / sample
C_{EP}	Entry Preparation Cost	Cost associated with preparation before entering the site area	$ / entry * team
C_{EDC}	Decontamination Line Cost	Cost associated with the personnel decon line	$ / entry * team
C_{SA}	Costs Per Solid Waste Sample	Analysis costs per one solid waste sample	$ / sample
C_{LA}	Costs Per Liquid Waste Sample	Analysis costs per one liquid waste sample	$ / sample
C_R	Cost Per Respirator	Cost per one respirator	$ / respirator
$\overrightarrow{C_{EPPE}}$	Cost Per Individual PPE	Cost per one unit of PPE of each level	$ / PPE level
C_W	Cost Per Waste Sample	Cost to purchase one waste sample	$ / sample
$\overrightarrow{C_P}$	Personnel Hourly Rate	Hourly wage of each personnel type (OSC, PL-1, PL-2, PL-3, PL-4)	$ / hour

3.8.2 Waste Sampling Model

Waste Sampling is performed after each round of decontamination is performed in order to characterize the amount of contaminant present on the resulting waste. The Wide-Area Decontamination Tool calculated cost and time results for Waste Sampling using the following model.

The overall cost of WS is broken down into four primary costs of equal weight: 1) cost of labor (C_L), 2) cost of supplies and rentals (C_S), 3) cost associated with entering and exiting the contamination area (C_E), and 4) cost of sample analysis, including shipping and packaging (C_A). The cost of labor for WS is calculated using Equation 54 below.

$$C_L = P_H * \left(\overrightarrow{P_Q} \cdot \overrightarrow{C_P}\right) * T_Q \quad \textbf{(54)}$$

Where:

- P_H = Total WS labor hours
- $\overrightarrow{P_Q}$ = Number of personnel required per team by personnel type
- $\overrightarrow{C_P}$ = Personnel hourly rate by personnel type
- T_Q = Number of teams required for WS

The parameter P_H is calculated using Equation 55 below.

$$P_H = 12 * P_{D_{WS}} \quad \textbf{(55)}$$

Where the personnel onsite days, or $P_{D_{WS}}$, is calculated using Equation 56.

$$P_{D_{WS}} = P_{D_W} + P_{D_O} \quad \textbf{(56)}$$

Where:

- P_{D_W} = Total workdays
- P_{D_O} = Personnel overhead days

The parameter P_{D_L} is calculated using Equation 57 below.

$$P_{D_L} = \frac{1}{12} * \left(\frac{S_Q + L_Q}{W_H * T_Q}\right) \quad \textbf{(57)}$$

Where:

- S_Q = The total number of solid waste samples
- L_Q = The total number of liquid waste samples
- W_H = The quantity of waste samples used per hour per team

- T_Q = The number of sampling teams required

The parameter S_Q is calculated using Equation 58 below. Note that the total area sampled is evenly split among the sample types.

$$S_Q = \frac{W_S * A_T * A_W}{2 * S_A} \tag{58}$$

Where:

- W_S = The mass of solid waste produced per surface area
- A_T = The total surface area of the contamination site
- A_W = The fraction of the total waste produced that will be sampled
- S_A = The mass of solid waste which can be sampled using one waste sample

The parameter L_Q is calculated using Equation 59 below.

$$L_Q = \frac{W_L * A_T * A_W}{2 * L_A} \tag{59}$$

Where:

- W_L = The volume of liquid waste produced per surface area
- L_A = The volume of liquid waste which can be sampled using one waste sample

The cost of supplies for WS is calculated using Equation 60 below.

$$C_S = (S_Q + L_Q) * C_W \tag{60}$$

Where:

- C_W = Cost per one waste sample

A lag time due to time spent analyzing samples at external labs (T_{LAG}) is also calculated for the WS element. T_{LAG} is calculated using Equation 61 below.

$$T_{LAG} = T_P + \max(T_{L_i}) + T_R \tag{61}$$

Where:

- T_P = Total packaging time for all samples
- T_{L_i} = Total time samples spent at lab for each external lab i
- T_R = Time for completed sample result to be transmitted to IC

The parameter T_P is calculated using Equation 62 below.

$$T_P = \frac{T_{P_S} * (S_Q + L_Q)}{60\ min * 12\ h} \tag{62}$$

Where:

- T_{P_S} = Time for one sample to be packaged

Note that this equation includes a conversion from minutes to days as it was necessary to convert the packaging time per sample given in minutes to a total packaging time for all samples in days.

The parameter T_{L_i} is calculated using Equation 63 below.

$$T_{L_i} = T_{S_i} + T_{A_i} \tag{63}$$

Where:

- T_{S_i} = Total shipping time to each external lab i which is assumed to be 12 hours as samples are overnighted to their destination
- T_{A_i} = Total sample analysis time per each external lab i

The parameter T_{A_i} is calculated using Equation 64 below.

$$T_{A_i} = \frac{\frac{S_Q}{Lab_Q} + \frac{L_Q}{Lab_Q}}{L_{T_i}} \tag{64}$$

Where:

- Lab_Q = Number of external labs to which samples are sent for analysis
- L_{T_i} = Lab throughput for each external lab i

Note that an equal number of solid and liquid waste samples are sent to each external lab for analysis.

The cost associated with entering and exiting the contamination site for WS is calculated using the same equations as are used in the calculation of entrance and exit costs for CS. See Equations 27-33 for the appropriate calculations.

The cost of sample analysis for WS is calculated using Equation 65 below.

$$C_A = (S_Q * C_{S_A}) + (L_Q * C_{L_A}) \tag{65}$$

Where:

- C_{S_A}, C_{L_A} = Cost of one solid waste sample or liquid waste sample for analysis, respectively

C_L, C_S, C_E, and C_A combine to give the overall cost of WS (C_{WS}), as illustrated by Equation 66 below.

$$C_{WS} = C_L + C_S + C_E + C_A \tag{66}$$

3.9 Travel

While not an element itself, the Wide-Area Decontamination Tool also considers additional cost and time associated with travel to and from the site area *after* all calculations have been performed for the indoor, outdoor, and underground scenarios. The following sections list the parameters relevant to the various travel and lodging considerations that are not included in any other element as well as the calculations performed to characterize the cost and resource demands of these additional considerations.

3.9.1 Travel Parameters

The parameters related to the various travel and lodging considerations are listed in Table 29 below. Note that this table only includes user-input and baseline parameters. All calculated quantities are explained in detail in the subsequent section.

Table 29: Transportation and Miscellaneous Considerations Parameters

Parameter	Name	Description	Units
CAR_P	Number of Personnel Per Rental Car	Number of personnel per one rental car	personnel
$\overrightarrow{P_{Q_{IC}}}$	Personnel Required (IC)	Number of personnel of each type required for IC team only (OSC, PL-1, PL-2, PL-3, PL-4)	personnel
$\overrightarrow{P_{Q_{CS}}}$	Personnel Required (CS)	Number of personnel of each type required for one CS team only (OSC, PL-1, PL-2, PL-3, PL-4)	personnel
$\overrightarrow{P_{Q_{SR}}}$	Personnel Required (SR)	Number of personnel of each type required for one SR team only (OSC, PL-1, PL-2, PL-3, PL-4)	personnel
$\overrightarrow{P_{Q_{DC}}}$	Personnel Required (DC)	Number of personnel of each type required for one DC team only (OSC, PL-1, PL-2, PL-3, PL-4)	personnel
$\overrightarrow{P_{Q_{WS}}}$	Personnel Required (WS)	Number of personnel of each type required for one WS team only (OSC, PL-1, PL-2, PL-3, PL-4)	personnel
$T_{Q_{CS}}$	Number of Teams (CS)	Number of teams required for CS	teams
$T_{Q_{SR}}$	Number of Teams (SR)	Number of teams required for SR	teams
$T_{Q_{DC}}$	Number of Teams (DC)	Number of teams required for DC	teams
$T_{Q_{WS}}$	Number of Teams (WS)	Number of teams required for WS	teams
$P_{RT_{IC}}$	Personnel Roundtrip Days (IC)	Number of travel days both to and from site for IC teams only	days
$P_{RT_{CS}}$	Personnel Roundtrip Days (CS)	Number of travel days both to and from site for CS teams only	days
$P_{RT_{SR}}$	Personnel Roundtrip Days (SR)	Number of travel days both to and from site for SR teams only	days
$P_{RT_{DC}}$	Personnel Roundtrip Days (DC)	Number of travel days both to and from site for DC teams only	days
$P_{RT_{WS}}$	Personnel Roundtrip Days (WS)	Number of travel days both to and from site for WS teams only	days
C_{CAR}	Cost of Rental Car Per Day	Cost of one rental car per one day	$ / day
C_{TK}	Cost of Roundtrip Ticket Per Person	Cost of one roundtrip ticket per one person	$ / ticket * person
$C_{D_{PD}}$	Per Diem Cost	Allowed per diem cost	$ / day

3.9.2 Travel Model

The travel model consists of airfare for a specified number of travel days, rental car costs for a specified number of travel days, and per diem and lodging costs for the duration of the event (for IC teams) or the corresponding element (for all other teams which are only onsite while needed). The total travel cost is calculated using Equation 67.

$$C_T = C_{T_{IC}} + C_{T_{CS}} + C_{T_{SR}} + C_{T_{DC}} + C_{T_{WS}} \quad \textbf{(67)}$$

The cost of travel for IC ($C_{T_{IC}}$) is calculated using Equation 68.

$$C_{T_{IC}} = C_{P_{IC}} + C_{A_{IC}} + C_{R_{IC}} \quad \textbf{(68)}$$

Where the cost of per diem and lodging for IC ($C_{P_{IC}}$) is calculated using Equation 69.

$$C_{P_{IC}} = \left(\sum P_{Q_{IC_i}}\right) * P_{D_{IC}} * C_{D_{PD}} \quad \textbf{(69)}$$

Where:

- $P_{Q_{IC}}$ = The total number of IC personnel available by type i
- $P_{D_{IC}}$ = The total number of onsite days for IC teams
- $C_{D_{PD}}$ = The cost of per diem and lodging for one day

The cost of airfare for IC ($C_{A_{IC}}$) is calculated using Equation 70.

$$C_{A_{IC}} = \left(\sum P_{Q_{IC_i}}\right) * C_{TK} \quad \textbf{(70)}$$

Where:

- C_{TK} = The cost of one roundtrip airfare ticket for one person

The cost of rental cars for IC ($C_{R_{IC}}$) is calculated using Equation 71.

$$C_{A_{IC}} = \frac{\left(\sum P_{Q_{IC_i}}\right)}{CAR_p} * P_{RT_{IC}} * C_{CAR} \quad \textbf{(71)}$$

Where:

- CAR_P = The number of personnel per one rental car

- $P_{RT_{IC}}$ = The number of roundtrip travel days for IC teams
- C_{CAR} = The cost of one rental car for one day

The cost of travel for CS ($C_{T_{CS}}$) is calculated using Equation 72.

$$C_{T_{CS}} = C_{P_{CS}} + C_{A_{CS}} + C_{R_{CS}} \tag{72}$$

Where the cost of per diem and lodging for CS ($C_{P_{CS}}$) is calculated using Equation 73.

$$C_{P_{CS}} = \left(\sum P_{Q_{CS_i}}\right) * T_{Q_{CS}} * P_{D_{CS}} * C_{D_{PD}} \tag{73}$$

Where:

- $P_{Q_{CS}}$ = The total number of CS personnel available by type i
- $T_{Q_{CS}}$ = The total number of CS teams
- $P_{D_{CS}}$ = The total number of onsite days for CS teams

The cost of airfare for CS ($C_{A_{CS}}$) is calculated using Equation 74.

$$C_{A_{CS}} = \left(\sum P_{Q_{CS_i}}\right) * T_{Q_{CS}} * C_{TK} \tag{74}$$

The cost of rental cars for CS ($C_{R_{CS}}$) is calculated using Equation 75.

$$C_{A_{CS}} = \frac{\left(\sum P_{Q_{CS_i}}\right) * T_{Q_{CS}}}{CAR_P} * P_{RT_{CS}} * C_{CAR} \tag{75}$$

Where:

- $P_{RT_{CS}}$ = The number of roundtrip travel days for CS teams

The cost of travel for SR ($C_{T_{SR}}$), DC ($C_{T_{DC}}$), and WS ($C_{T_{WS}}$) are each calculated using the same equations as are used to calculate the cost of travel for CS. Refer to Equations 72-75 for the appropriate calculations.

3.10 Model Assumptions

Several assumptions were made within the Wide-Area Decontamination Tool in order to simplify the scenarios being modeled and the processes being performed throughout the decontamination incident. These assumptions include the following:

- Fixed Team Sizes
- Application of Multiple Decontamination Methods to the Same Area
- Multiple Sample Analysis Labs

Each of these assumptions is explained in detail in the subsequent sections below.

3.10.1 Fixed Team Sizes

For an individual building, each element may have multiple teams which carry out the processes required for that element (e.g., characterization sampling teams, source reduction teams, decontamination teams). It was assumed that for a given element, the size of each team was fixed (i.e., each characterization sampling team had the same number of members for building one). Note that the team sizes for equivalent elements between buildings could be different. Figure 26 shows the makeup of personnel per one team for each element as well as the number of teams for each element as reported in U.S. EPA's BOTE report and Figure 27 shows equivalent data from U.S. EPA's UTR OTD report.

	OSC/Commander	EMT	PL1	PL2	PL3	PL4	TL1	TL2	TL3	# on Team	# of Teams	Folks
Labor Rates ($/hr Loaded)	$147	$ 58	$86	$102	$124	$170	$66	$79	$88			
Sampling Team	0.33				3.00					3.3	6	20.0
Decontamination Team (Level C)	0.33				2.33	0.67				3.3	3	10.0
Removal Team (Level B)	0.33				3.33	0.67				4.3	3	13.0
Removal Team (Level C)	0.33				2.33	0.67				3.3	3	10.0
Decontamination Team (Level B)	0.33				3.33	0.67				4.3	3	13.0
Decon Line Setup Team									2.00	2.0	1	2.0
Decon Line Ops Team	1.00	1.00						3.00		5.0	1	5.0
Instrumentation Team	0.50		4.00							4.5	1	4.5
Sample Packaging Team			1.00			1.00			1.00	3.0	1	3.0
Waste Handling Team	1.00							3.00		4.0	1	4.0

Figure 26: Team Makeup and Number of Teams for Each Element[7]

	OSC/Commander	EMT	PL1	PL2	PL3	PL4	TL1	TL2	TL3	# on Team	# of Teams	Folks
Labor Rates ($/hr Loaded)	$155	$61	$101	$118	$142	$210	$71	$81	$101			
Sampling Team	0.3				3.0					3.3	6	20.0
Decontamination Team (Level C)	0.3				3.0	1.0				4.3	1	4.3
Decontamination Team (Level A)	0.3				6.0	2.0				8.3	1	8.3
Decon Line Setup Team									2.0	2.0	1	2.0
Decon Line Ops Team	0.3	1.0						3.0		4.3	1	4.3
Sample Packaging Team			1.0			1.0			1.0	3.0	1	3.0

Figure 27: Team Makeup and Number of Teams for Each Element[8]

3.10.2 Application of Multiple Decontamination Methods to the Same Area

It was assumed that one decontamination application method would be fully applied to all applicable surfaces and allowed to dry before another method would then be applied to any remaining surfaces. Not all application methods are suitable for every surface type. As such, different surfaces may require different application methods. If two or more application methods were required to decontaminate every available surface, one treatment of each method was applied at a time and was allowed to fully dry before treatment with another method began. A single round of decontamination ended after one treatment of each necessary application method had been applied to each surface type.

3.10.3 Multiple Sample Analysis Labs

It was assumed that the number of samples sent to each analysis lab is fixed and that the same number of samples would be sent to each external analysis lab. Although text within the UTR OTD report indicated that a variable number of samples were sent to each external lab, this was done for simplicity.

4 FUTURE IMPROVEMENTS

This report outlines the initial development of the Wide-Area Decontamination Tool. While it captures the essentials of a wide-area incident, future improvements can be made to better define and calculate the costs associated with the incident. Future efforts to further develop this model should include the following:

- Currently, indoor, outdoor, and underground scenarios can be modeled in the tool. However, the outdoor scenario model has significantly less supporting detail behind it as a resource similar to the BOTE or UTR OTD field studies could not be found for outdoor events. A similar resource should be identified to support the validity of the outdoor scenarios modeled within the tool.

- The model currently allows for only traditional sampling types, such as sponge sticks and 37 mm cassettes, to be performed. However, EPA expressed interest in the ability to model the use of non-traditional sampling types, such as robotic household vacuum-type sampling and wet vac sampling, as well as air sampling. As such, data for these sampling types should be added to the baseline workbook and should be made available as sampling types within the model.

- Currently, decontamination supplies, equipment, and rental costs are fixed estimates for all decontamination application methods. However, there are notable discrepancies between these costs depending on the application method used. For example, tenting is required for fumigation while it is not required for aerosol spraying. This would add an additional supplies cost when fumigation is performed. As such, higher resolution data regarding the cost of supplies, equipment, and rentals for each application method should be compiled and added to the baseline workbook.

- Currently, for scenarios involving only one building, CS, SR, DC, CL, and WS are performed sequentially. Each element is completed fully before the next element began. The current model applies this same functionality to scenarios with multiple buildings. However, for a scenario involving multiple buildings, model changes should be implemented such that the pre-decontamination CS element would be performed on all buildings first, followed by the SR, DC, CL, and WS elements consecutively one building at a time.

- Currently, the model simulates the CS and CL elements by implementing basic calculations that determine the shipment time of samples to external labs and the analysis time of these samples. However, the CS and CL models should be modified to use a

Stock and Flow model to better simulate the movement of samples, from shipment to external labs to analysis time.

- Currently, there is no functionality within the model to account for additional safety or support teams that may be required to survey the site after decontamination or support sampling efforts. As such, functionality should be added to allow the user to specify any additional teams required for the decontamination process.

- Currently, the model only allows PPE units to be used once, assuming PPE (other than respirators) is discarded after only one use. However, model changes should be implemented to allow the user to designate the number of uses for each PPE unit. PPE would be discarded after this number of uses. Further, the model should also be modified to allow PPE units to be "cleaned" after the specified number of uses and added back into the stockpile of new PPE units. This will reduce the number of units needed for the decontamination incident and, thus, reduce the overall cost associated with PPE for the incident. Both the reuse and cleaning of PPE units could offer users an easy comparison of how each might reduce the overall cost of resources required for the remediation effort.

- Currently, there is no functionality within the model to queue buildings based on personnel availability and buildings are treated sequentially, one after the other. However, functionality should be implemented such that buildings with the largest surface area are prioritized for decontamination when there are not enough personnel available for simultaneous decontamination of all buildings. Geospatial data should also be utilized to determine building populations for the contaminated site areas so that buildings with larger populations can be prioritized for decontamination. In the event that there were an inadequate number of personnel available to decontaminate multiple buildings simultaneously, a priority queue was created.

5 CASE STUDIES

Two real-world examples of biological incidents were used as data inputs into the Wide-Area Decontamination Tool in order to evaluate the validity of the tool: 1) The BOTE Project, and 2) The UTR OTD. Following the conclusion of both mock decontamination events, a report was generated for each summarizing the various scenario details and conditions specific to that effort. A detailed cost and time analysis was also included in each report. The BOTE and UTR OTD projects were chosen as verification cases for the Wide-Area Decontamination Tool since sufficient data from each report could be identified and used to define each scenario within the tool. Additionally, the existing cost and time analyses could be easily compared with model results.

Both incidents were recreated within the tool and the resulting cost and resource estimates were compared to those defined in the literature documenting these incidents, facilitating the assessment of the tool's performance. The following sections detail the incidents used as case studies, the data pulled from the incidents and used within the model, and the results in comparison with what was observed during the mock incidences.

5.1 Case 1

5.1.1 Approach

The BOTE Project report details a comprehensive investigation into the decontamination of a biological agent in a mock indoor scenario. For details about the BOTE project, refer to Section 2.2.1. Table 30 shows the cost results from the BOTE report that were used to validate the resulting cost estimates calculated by the tool. Note that Clearance Sampling was not included as an individual value within the BOTE report. As such, this element was combined here into the CS results.

Table 30: BOTE Cost Results

Cost Results	
Result Name	**Value**
Characterization Sampling Cost	\$618,085 – \$621,934
Source Reduction Cost	\$30,497
Decontamination Cost	\$109,943 – \$172,112
Waste Sampling Cost	\$5,096 – \$124,218
Incident Command Cost	\$46,737 – \$54,907
Total Cost of Effort	\$774,765 – \$887,915

Table 31 shows the time results from the BOTE report that were used to validate the resulting time estimates calculated by the tool.

Table 31: BOTE Time Results

Time Results	
Result Name	**Value**
Characterization Sampling Workdays	4
Characterization Sampling Onsite Days	4
Source Reduction Workdays	2
Source Reduction Onsite Days	2
Decontamination Workdays	3 – 5
Decontamination Onsite Days	3 – 5
Waste Sampling Workdays	*Included in CS
Waste Sampling Onsite Days	*Included in CS
Incident Command Onsite Days	9 – 11

Numerous model tests were performed, each run with 10,000 realizations to allow sampling to account for all uncertainty within the parameters. Results were averaged over all realizations. Changes were made to the model between each test to address any shortcomings of the model.

The input values used for the BOTE verification case can be found in Appendix J. Single values were input as constants, ranges of values were input as a uniform distribution between the minimum and maximum values identified, and any values with a distribution specified in the text were input accordingly. Additionally, some values were estimated or calculated based on contextual information found in the source and surrogate values were used when a value could not be found in the respective text. The WADE tool was used as a source for surrogate values wherever information could not be obtained from either project report.

The BOTE facility consisted of one building with different room compositions throughout to simulate commercial, industrial, and residential spaces. In the initial model verification runs, this was input into the model as three individual buildings of each type (commercial, industrial, and residential). However, certain processes which happened concurrently in the BOTE effort were performed sequentially in the modeling tool, over-estimating the time and cost demand. As such, as the modeling progressed, only one building of the commercial type was simulated in the tool. Note that while different building types are generally characterized by a different breakdown of surfaces, since surface types can be explicitly defined by the user in the tool, the building type did not change the results.

The BOTE facility was decontaminated using three different rounds of treatment method and agent combinations and contaminant was disseminated in between each round of decontamination. As such, each round of decontamination within the BOTE report was considered an individual decontamination event and the cost estimates for decontamination were considered as a range rather than summed between each round.

Note also that the number of lab days *was not* included in the Characterization Sampling onsite days during the initial stages of model verification as this value was not included in the CS onsite days in the BOTE report. As this time estimate directly affects the Incident Command cost, it was removed so that the resulting IC cost from the tool more accurately reflected the corresponding cost in the BOTE report. However, the UTR OTD model verification effort *did* include this value in the overall onsite days. As such, it was included in the final test runs for BOTE in order to remain consistent.

5.1.2 Model Changes

After each model test, changes were made to the model to address known shortcomings and discrepancies between the model results and the results identified in the BOTE report. These changes consisted of various model edits and input data edits, including the following:

- In the original model, decontamination treatment methods were chosen at random for every surface type. This resulted in an over-estimation of the number of unique treatment methods applied to surfaces as some methods can be applied to multiple different surface types. Functionality was added to allow the user to explicitly select the decontamination treatment methods applied to each surface, eliminating this over-estimation.

- In the original model, an 8-hour workday constant was used for various time calculations. This was updated to a 12-hour workday constant to remain consistent with the length of the workday assumed in the BOTE project report.

- In the original model, only pre-decontamination Characterization Sampling was performed. However, sampling to determine the contaminant present on surfaces after each round of decontamination was deemed necessary to include within the tool. As such, post-decontamination Characterization Sampling was added to the model and a total time and cost estimate was included in the final results as a summation of both the pre-decontamination and post-decontamination values.

- In the original model, the lab analysis time was based on the total number of samples sent to each lab and the amount of time it took to analyze one sample. However, this method assumed only one sample was analyzed at a time, eliminating the concurrency of sample analysis given multiple lab personnel. This calculation was updated to consider lab throughput samples per day which accounts for multiple lab personnel analyzing samples at the same time.

- In the original model, a cost for entrances/exits was included. This cost was found to incorrectly double count labor costs for the element durations. As such, this cost was removed.

5.1.3 Results

Table 32 shows the cost results calculated from the Wide-Area Decontamination Tool in comparison with the values identified from the BOTE report, along with the corresponding 5th and 95th percentile values for each result.

Table 32: Wide-Area Decontamination Tool Cost Results: BOTE

Cost Results			
Result Name	**BOTE Value**	**Model Value – Fumigation (5th, 95th)**	**Model Value – Liquid Spray (5th, 95th)**
Characterization Sampling Cost	$618,085 – $621,934	$533,112 ($281,867, $812,251)	$533,112 ($281,867, $812,251)
Source Reduction Cost	$30,497	$161,852 ($147,895, $176,130)	$161,852 ($147,895, $176,130)
Decontamination Cost	$109,943 – $172,112	$192,817 ($149,503, $238,989)	$220,870 ($172,737, $271,427)
Waste Sampling Cost	$5,096 – $124,218	$6,482 ($6,328, $6,673)	$72,465 ($69,719, $75,851)
Incident Command Cost	$46,737 – $54,907	$104,704 ($69,513, $151,204)	$120,173 ($83,817, $166,779)
Total Cost of Effort	$774,765 – $887,915	$998,967 ($710,232, $1,318,030)	$1,108,472 ($818,024, $1,426,867)

Note that Clearance Sampling was not included as an individual value within the BOTE report. As such, this element was combined here into the CS results. Note additionally that these values do not include waste management and the inclusion of waste management will likely increase the overall cost associated with remediation of the event. These values also do not account for differences in the amount of material removed during SR given the two different decontamination methods. Realistically SR costs would not be the same between the two; however, available data was limited and separate SR values could not be determined for each method.

Table 33 shows the time results calculated from the Wide-Area Decontamination Tool in comparison with the values identified from the BOTE report, along with the corresponding 5^{th} and 95^{th} percentile values for each result.

Table 33: Wide-Area Decontamination Tool Time Results: BOTE

Time Results			
Result Name	**BOTE Value**	**Model Value – Fumigation (5^{th}, 95^{th})**	**Model Value – Liquid Spray (5^{th}, 95^{th})**
Characterization Sampling Workdays	4	3.34 (1.22, 7.27)	3.34 (1.22, 7.27)
Characterization Sampling Onsite Days	4	23.22 (12.25, 37.73)	23.22 (12.25, 37.73)
Source Reduction Workdays	2	3.14 (3.14, 3.14)	3.14 (3.14, 3.14)
Source Reduction Onsite Days	2	3.14 (3.14, 3.14)	3.14 (3.14, 3.14)
Decontamination Workdays	3 – 5	4.00 (3.11, 4.90)	3.99 (3.09, 4.91)
Decontamination Onsite Days	3 – 5	4.00 (3.11, 4.90)	3.99 (3.09, 4.91)
Waste Sampling Workdays	*Included in CS	0.12 (0.08, 0.16)	2.06 (1.49, 2.92)
Waste Sampling Onsite Days	*Included in CS	2.29 (2.18, 2.42)	7.14 (5.25, 9.53)
Incident Command Onsite Days	9 – 11	32.66 (21.63, 47.23)	37.50 (26.11, 52.11)

Note that Clearance Sampling was not included as an individual value within the BOTE report. As such, this element was combined here into the CS results. Note additionally that these values do not include waste management and the inclusion of waste management will likely increase the overall time associated with remediation of the event. These values also do not account for differences in the amount of material removed during SR given the two different decontamination methods. Realistically SR times would not be the same between the two; however, available data was limited and separate SR values could not be determined for each method.

In general, the model results were within (or near) the same order of magnitude as the comparison results from the BOTE report. However, there are particular noteworthy discrepancies within the cost results. Each result is detailed below, including the reasoning for any discrepancies that may have existed as well as a note if there were none:

- **Characterization Sampling Cost.** In general, the model results for CS cost were an under-estimation of the report values due to the various number of additional support teams that contribute to labor costs within the BOTE effort. As these teams were not strictly CS teams, they were not accounted for within the tool.

- **Source Reduction Cost.** The model results for SR cost were an over-estimation of the report values likely due to an over-estimation in the fraction of the area that was source reduced. As this value was not explicitly stated in the report, contextual information was used to estimate this value. The result may not be an accurate depiction of the actual value, significantly increasing the total cost calculated by the tool. Additionally, it is unclear if travel costs for the SR teams were included within the total SR cost given in the report. No breakdown of the SR cost was given in the report and, thus, it is difficult to identify what was included and what was not.

- **Decontamination Cost.** While the values calculated for the DC cost were slightly higher than the range of values given within the report, these values are considered reasonably close to the given range.

- **Waste Sampling Cost.** The calculated values are well within the ranges given in the report.

- **Incident Command Cost.** The values calculated for the IC cost were an over-estimation of the report values due to the fact that the total IC onsite days includes the lab days for both CS and WS, days which were not accounted for within the report. The result is a longer event duration and, thus, higher labor costs for the IC teams which are on site during the entire event.

- **Total Cost of Effort.** The total cost of the effort calculated by the tool is an over-estimation of the report values due to the over-estimation in other cost areas.

Additionally, there are noteworthy discrepancies within the time results. Each result is detailed below, including the reasoning for any discrepancies that may have existed as well as a note if there were none:

- **Characterization Sampling Workdays.** While the values calculated for the CS workdays were slightly lower than the range of values given within the report, these values are considered reasonably close to the given range considering the addition of the WS workdays (which are included in one value within the BOTE report).

- **Characterization Sampling Onsite Days.** The values calculated for the CS onsite days were an over-estimation of the report values due to the fact that this value includes lab days, days which were not accounted for within the report.

- **Source Reduction Workdays.** The model results for SR workdays were an over-estimation of the report values, again, likely due to an over-estimation in the fraction of the area that was source reduced.

- **Source Reduction Onsite Days.** The model results for SR on site were an over-estimation of the report values, again, likely due to an over-estimation in the fraction of the area that was source reduced.

- **Decontamination Workdays.** The calculated values are well within the ranges given in the report.

- **Decontamination Onsite Days.** The calculated values are well within the ranges given in the report.

- **Waste Sampling Workdays.** The workdays for WS were included in the workdays given for CS within the report. As such, it is difficult to determine if the calculated values are realistic or not. However, given that the addition of these values to the corresponding CS values does not result in significant over-estimation, it is believed that these values are somewhat reasonable.

- **Waste Sampling Onsite Days.** The onsite days for WS were included in the onsite days given for CS within the report. As such, it is difficult to determine if the calculated values are realistic or not. However, given that the addition of these values to the corresponding CS values does not result in significant over-estimation, it is believed that these values are somewhat reasonable. Additionally, the values calculated for the WS onsite days were an over-estimation of the CS report values due to the fact that this value includes lab days, days which were not accounted for within the report.

- **Incident Command Onsite Days.** The overall IC onsite days calculated by the tool are an over-estimation of the report values due to the over-estimation in other cost areas, as well as the inclusion of CS and WS lab days.

5.1.4 Additional Analysis

Table 34 below shows a further comparison of the cost results, with each result presented as a percentage of the total cost of the effort. Note that the percentages for the BOTE Project report may not add to 100%. That is because the averages were used wherever a range of values was given. As such, these percentages are not exact, and some range should be applied.

Table 34: BOTE Cost Percentages

Cost Percentage Results			
Result Name	**BOTE %**	**Model % – Fumigation**	**Model % – Liquid Spray**
Characterization Sampling Cost	75%	52%	47%
Source Reduction Cost	4%	15%	14%
Decontamination Cost	17%	19%	19%
Waste Sampling Cost	8%	1%	6%
Incident Command Cost	6%	12%	12%

Table 35 below shows a further comparison of the workday results, with each result presented as a percentage of the total IC onsite days (which have been adjusted to exclude any lab days associated with CS or WS). Note that the percentages for the BOTE Project report may not add to 100%. That is because the averages were used wherever a range of values was given. As such, these percentages are not exact, and some range should be applied. Additionally, the CS and WS workdays have been added, as they are presented as one value within the BOTE Project report.

Table 35: BOTE Time Percentages

Cost Percentage Results			
Result Name	**BOTE %**	**Model % – Fumigation**	**Model % – Liquid Spray**
Characterization Sampling + Waste Sampling Workdays	40%	32%	43%
Source Reduction Workdays	20%	29%	25%
Decontamination Workdays	40%	38%	32%

Overall, the percentage breakdowns of all the model results were fairly consistent with what was calculated based on the report values. Slight discrepancies do exist, specifically in the cost percentages; however, given that the comparison percentages are based on averages, there is room for some of this discrepancy.

5.2 Case 2

5.2.1 Approach

The UTR OTD report details a comprehensive investigation into the decontamination of a biological agent in a mock underground transportation scenario. For details about the UTR OTD effort, refer to Section 2.2.2. Table 36 shows the cost results from the UTR OTD report that were used to validate the resulting cost estimates calculated by the tool. Note that Source Reduction for all waste materials was not included in the UTR OTD mock scenario and that a portion of these materials were left in the contaminated area and decontaminated. As such, the cost of SR was assumed to be zero. Additionally, note that Clearance Sampling was not included as an individual value within the UTR OTD report. As such, this element was combined here into the CS results.

Table 36: UTR OTD Cost Results

Cost Results	
Result Name	**Value**
Characterization Sampling Cost	$196,436 – $199,604
Decontamination Cost	$29,910 – $43,849
Waste Sampling Cost	$1,347 – $2,605
Incident Command Cost	$108,669
Total Cost of Effort	$276,542 – $354,727

Table 37 shows the time results from the UTR OTD report that were used to validate the resulting time estimates calculated by the tool. Again, note that the SR workdays and onsite days were assumed to be zero as this element was not performed during the mock scenario.

Table 37: UTR OTD Time Results

Time Results	
Result Name	**Value**
Characterization Sampling Workdays	2
Characterization Sampling Onsite Days	2
Decontamination Workdays	3 – 5
Decontamination Onsite Days	3 – 5
Waste Sampling Workdays	*Included in CS
Waste Sampling Onsite Days	*Included in CS
Incident Command Onsite Days	6 – 8

Numerous model tests were performed, each run with 10,000 realizations to allow sampling to account for all uncertainty within the parameters. Results were averaged over all realizations. Changes were made to the model between each test to address any shortcomings of the model.

The input values used for the UTR OTD verification case can be found in Appendix K. Single values were input as constants, ranges of values were input as a uniform distribution between the minimum and maximum values identified, and any values with a distribution specified in the text were input accordingly. Additionally, some values were estimated or calculated based on contextual information found in the source and surrogate values were used when a value could not be found in the respective text. The WADE tool was used as a source for surrogate values wherever information could not be obtained from either project report.

The UTR OTD facility was decontaminated using two different rounds of treatment method and agent combinations and contaminant was disseminated in between each round of decontamination. As such, each round of decontamination within the UTR OTD report was considered an individual decontamination event and the cost estimates for decontamination were considered as a range rather than summed between each round.

Note that, unlike the BOTE verification case, the number of lab days *was* included in the Characterization Sampling onsite days during the model verification in order to assess a more accurate version of the model results since this value was included in the overall onsite days upon delivery of the final model.

5.2.2 Model Changes

After each model test, changes were made to the model to address known shortcomings and discrepancies between the model results and the results identified in the UTR OTD report. These changes consisted of various model edits and input data edits, including the following:

- In the original model, Waste Sampling was not accounted for. However, waste sampling was deemed an important contributing cost in both the BOTE and UTR OTD analyses, as well as real-world scenarios. As such, this process was implemented in the model in a similar fashion to the Characterization Sampling implementation.

- In the original model, the total number of entries for teams during a specific element was calculated using a number of entries per day. However, it was decided that this did not fully encompass the complexity of entries as entry durations varied based on the level of PPE donned by personnel. As such, this calculation was adjusted to use entry durations based on PPE level instead.

- In the original model, site entries were considered for all decontamination methods, regardless of the differences between the methods. However, in an effort to provide more distinction and accuracy to the specific treatment methods, model functionality was changed such that the fumigation and fogging decontamination methods were assumed to require zero site entries by decontamination teams. Note that although entries by safety teams may still be required for these methods in order to ensure the site is safe for re-entry post-decontamination, this is not yet accounted for in the tool.

- In the original model, per diem and lodging costs were calculated for all teams for the entire event duration. However, this was deemed unrealistic as during a real-world incident, only the necessary teams would be onsite at a given time. As such, the per diem and lodging costs, and by extension, total travel costs, were calculated for each team only for the time that team spent onsite and working.

- In the original model, time and costs associated with entry preparation, decontamination line processes, and post-entry rest periods was not accounted for. However, these contributions were considered significant in terms of producing more accurate results. As such, the model was adjusted to account for all three.

- In the original model, no waste quantities were calculated or included in the model results. However, as this was a desired function of the tool, solid and aqueous waste quantities as a result of decontamination were added as model results.

5.2.3 Results

Table 38 shows the cost results calculated from the Wide-Area Decontamination Tool in comparison with the values identified from the UTR OTD report, along with the corresponding 5th and 95th percentile values for each result.

Table 38: Wide-Area Decontamination Tool Cost Results: UTR OTD

Cost Results			
Result Name	**UTR OTD Value**	**Model Value – Fogging (5th, 95th)**	**Model Value – Liquid Spray (5th, 95th)**
Characterization Sampling Cost	\$196,436 – \$199,604	\$322,979 (\$263,988, \$429,041)	\$322,979 (\$263,988, \$429,041)
Decontamination Cost	\$29,910 – \$43,849	\$129,804 (\$96,745, \$167,617)	\$168,298 (\$126,227, \$217,224)
Waste Sampling Cost	\$1,347 – \$2,605	\$9,658 (\$9,194, \$10,046)	\$8,899 (\$8,449, \$9,249)
Incident Command Cost	\$108,669	\$135,716 (\$106,940, \$179,552)	\$135,418 (\$106,573, \$179,521)
Total Cost of Effort	\$276,542 – \$354,727	\$598,157 (\$500,993, \$733,277)	\$635,594 (\$532,742, \$773,387)

Note that Clearance Sampling was not included as an individual value within the UTR OTD report. As such, this element was combined here into the CS results. Note additionally that these values do not include waste management and the inclusion of waste management will likely increase the overall cost associated with remediation of the event.

Table 39 shows the time results calculated from the Wide-Area Decontamination Tool in comparison with the values identified from the UTR OTD report, along with the corresponding 5th and 95th percentile values for each result.

Table 39: Wide-Area Decontamination Tool Time Results: UTR OTD

Time Results			
Result Name	**UTR OTD Value**	**Model Value – Fogging (5th, 95th)**	**Model Value – Liquid Spray (5th, 95th)**
Characterization Sampling Workdays	2	1.58 (0.72, 3.76)	1.58 (0.72, 3.76)
Characterization Sampling Onsite Days	2	16.02 (11.06, 23.76)	16.02 (11.06, 23.76)
Decontamination Workdays	3 – 5	4.00 (3.10, 4.90)	4.00 (3.09, 4.90)
Decontamination Onsite Days	3 – 5	4.00 (3.10, 4.90)	4.00 (3.09, 4.90)
Waste Sampling Workdays	*Included in CS	0.13 (0.09, 0.18)	0.10 (0.07, 0.15)
Waste Sampling Onsite Days	*Included in CS	3.83 (3.41, 4.11)	3.79 (3.37, 4.05)
Incident Command Onsite Days	5 – 7	23.85 (18.76, 31.62)	23.80 (18.69, 31.62)

Note that Clearance Sampling was not included as an individual value within the UTR OTD report. As such, this element was combined here into the CS results. Note additionally that these values do not include waste management and the inclusion of waste management will likely increase the overall time associated with remediation of the event.

In general, the model results were within (or near) the same order of magnitude as the comparison results from the UTR OTD report. However, there are particular noteworthy discrepancies within the cost results. Each result is detailed below, including the reasoning for any discrepancies that may have existed as well as a note if there were none:

- **Characterization Sampling Cost.** In general, the model results for CS cost were an over-estimation of the report values due to the inclusion of CS lab days in the overall onsite days, resulting in increased travel costs for the CS teams as per diem and lodging was required for a significantly longer duration.

- **Decontamination Cost.** The values calculated for the DC cost were an over-estimation of the report values, due to discrepancies between labor costs for the DC teams. It is not immediately clear if DC teams were contributing to labor costs during decontamination treatment drying days within the report. However, it is assumed that DC personnel are paid hourly during this time within the tool.

- **Waste Sampling Cost.** The values calculated for the WS cost were an over-estimation of the report values, likely due to the estimation of the fraction of total waste that was sampled. As this value was not explicitly stated within the report, it was estimated based on contextual information. The result may not be an accurate depiction of the actual value, significantly increasing the total cost calculated by the tool. Additionally, it is unclear if travel costs for the WS teams were included within the total WS cost given in the report. No breakdown of the WS cost was given in the report and, thus, it is difficult to identify what was included and what was not.

- **Incident Command Cost.** The values calculated for the IC cost were an over-estimation of the report values due to the fact that the total IC onsite days includes the lab days for both CS and WS, days which were not accounted for within the report. The result is a longer event duration and, thus, higher labor costs for the IC teams which are on site during the entire event.

- **Total Cost of Effort.** The total cost of the effort calculated by the tool is an over-estimation of the report values due to the over-estimation in other cost areas.

Additionally, there are noteworthy discrepancies within the time results. Each result is detailed below, including the reasoning for any discrepancies that may have existed as well as a note if there were none:

- **Characterization Sampling Workdays.** While the values calculated for the CS workdays were slightly lower than the range of values given within the report, these values are considered reasonably close to the given range considering the addition of the WS workdays (which are included in one value within the UTR OTD report).

- **Characterization Sampling Onsite Days.** The values calculated for the CS onsite days were an over-estimation of the report values due to the fact that this value includes lab days, days which were not accounted for within the report.

- **Decontamination Workdays.** The calculated values are well within the ranges given in the report.

- **Decontamination Onsite Days.** The calculated values are well within the ranges given in the report.

- **Waste Sampling Workdays.** The workdays for WS were included in the workdays given for CS within the report. As such, it is difficult to determine if the calculated values are realistic or not. However, given that the addition of these values to the corresponding CS values does not result in significant over-estimation, it is believed that these values are somewhat reasonable.

- **Waste Sampling Onsite Days.** The onsite days for WS were included in the onsite days given for CS within the report. As such, it is difficult to determine if the calculated values are realistic or not. However, given that the addition of these values to the corresponding CS values does not result in significant over-estimation, it is believed that these values are somewhat reasonable. Additionally, the values calculated for the WS onsite days were an over-estimation of the CS report values due to the fact that this value includes lab days, days which were not accounted for within the report.

- **Incident Command Onsite Days.** The overall IC onsite days calculated by the tool are an over-estimation of the report values due to the over-estimation in other cost areas, as well as the inclusion of CS and WS lab days.

5.2.4 Additional Analysis

Table 40 below shows a further comparison of the cost results, with each result presented as a percentage of the total cost of the effort. Note that the percentages for the UTR OTD report may not add to 100%. That is because the averages were used wherever a range of values was given. As such, these percentages are not exact, and some range should be applied.

Table 40: UTR OTD Cost Percentages

Cost Percentage Results			
Result Name	**UTR OTD %**	**Model % – Fogging**	**Model % – Liquid Spray**
Characterization Sampling Cost	63%	54%	51%
Decontamination Cost	12%	22%	26%
Waste Sampling Cost	1%	2%	1%
Incident Command Cost	34%	23%	21%

Table 41 below shows a further comparison of the workday results, with each result presented as a percentage of the total IC onsite days (which have been adjusted to exclude any lab days associated with CS or WS). Note that the percentages for the UTR OTD report may not add to 100%. That is because the averages were used wherever a range of values was given. As such, these percentages are not exact, and some range should be applied. Additionally, the CS and WS workdays have been added, as they are presented as one value within the UTR OTD report.

Table 41: UTR OTD Time Percentages

Cost Percentage Results			
Result Name	**UTR OTD %**	**Model % – Fogging**	**Model % – Liquid Spray**
Characterization Sampling + Waste Sampling Workdays	33%	30%	30%
Decontamination Workdays	67%	70%	71%

Overall, the percentage breakdowns of all the model results were fairly consistent with what was calculated based on the report values. Slight discrepancies do exist, specifically in the cost percentages; however, given that the comparison percentages are based on averages, there is room for some of this discrepancy.

6 QUALITY ASSURANCE

Several methods of quality assurance were utilized throughout the development of the WADT, including 1) case studies, 2) hand calculations, 3) SME discussions, and 4) data quality. Each of these is described in more detail below.

6.1 Case Studies

The case studies discussed in Section 5 were used to determine how closely model results aligned with cost and time estimates for similar real-world incidents, in this case represented by mock decontamination events performed and documented by the EPA. These mock events were simulated in the tool to help identify areas of improvement within the tool. For more details on how this was done and some of the changes made to the tool as a result, refer back to Section 5.

6.2 Hand Calculations

Hand calculations were performed to verify that tool results aligned with the expected outcomes of the equations that were developed during this effort. An Excel file was generated implementing all of the developed calculations within the WADT. A notional input file was generated for simulation in the WADT, and similar inputs were used within the Excel file. The results of each were then compared to ensure that they matched.

6.3 SME Discussions

Throughout the development of the WADT, numerous discussions were had with EPA SME's who gave input on realistic processes which occur during remediation events as well as the data driving the tool and the quality of specific values as they relate to wide-area incidents. These discussions helped highlight areas for improved applicability of the tool to the processes it was developed to capture as well as ensured that throughout its development, expert logic pertaining to remediation was being used to guide this development.

6.4 Data Quality

The data driving the WADT was primarily obtained from sources developed by the EPA which underwent their own quality assurance and quality control efforts during their development.

7 CONCLUSION

After assessing various existing decontamination models, studies on mock decontamination scenarios, and a large efficacy dataset, the Wide-Area Decontamination Tool for indoor, outdoor, and underground scenarios was developed to estimate the cost, time, and resource demand associated with biological incident remediation efforts. The careful review of the WADE tool, the WEST application, the Decontamination spreadsheet, and the TOTS tool revealed that these models were limited in scope and didn't fully characterize indoor, outdoor, *and* underground scenarios or efficacy. Additionally, the review of the BOTE report and the UTR OTD report identified valuable information that was deemed important to include in the development of the tool. Finally, the BioDecontamination Compendium played an integral role in defining efficacy and, subsequently, the Efficacy Model. The resulting application was a comprehensive modeling tool that captured the complexity of these decontamination scenarios, including the characterization of efficacy.

The resulting tool performed reasonably well when tested against two case studies, detailed in Section 5. While there is still room for the improvement of various model functionality, the updates made to the model as a result of the analysis of these case studies drastically improved the accuracy of the overall results and, thus, the tool's applicability to real-world scenarios.

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APPENDIX A: REPRESENTATIVE SURFACE NAMES

The following table contains every surface type found in the BioDecontamination Compendium along with the corresponding representative surface types that were chosen for each.

Table A-1: Representative Surface Names for BioDecontamination Compendium Surfaces

BioDecontamination Compendium	Representative Surface Name
acoustic ceiling tiles	Acoustic Ceiling Tiles
aerosol	Aerosol
aerosol (2.8 um spore clusters)	
aerosol (4.4 um spore clusters)	
aerosol (single spores)	
agar plate	Agar Plate
aircraft performance coated aluminum (APC)	Aircraft Performance Coated Aluminum
aluminum with aircraft performance coating	
aluminum	Aluminum
aluminum foil	Aluminum Foil
ambiguous surface	Ambiguous Surface
anti-skid grit tape	Anti-skid Grit Tape
Anti-skid material on aluminum	Anti-skid Material on Aluminum
any painted surface	Any Painted Surface
AOAC carrier (porcelain and suture)	AOAC Carrier (Porcelain and Suture)
apples	Apples
aqueous	Aqueous
aqueous buffer	Aqueous Buffer
aqueous paint mixture	Aqueous Paint Mixture
aqueous solution	Aqueous Solution
aqueous solution of 1g/L glucose	
aqueous suspension	Aqueous Suspension
aqueous suspension with 10% serum	
aqueous suspension with 40% ethanol	
aqueous suspension with protein load	
aqueous suspension	
Archival Paper	Archival Paper
Arizona Test Dust	Arizona Test Dust
Arizona test dust (dried)	
AZ test dust (1-cm deep)	
AZ test dust (2-cm deep)	
asphalt	Asphalt
Asphalt Paving	Asphalt Paving
BI Stainless Steel in Tyvek® Packaging	BI Stainless Steel in Tyvek Packaging

BioDecontamination Compendium	Representative Surface Name
biofilm covered copper pipe	Biofilm Covered Copper Pipe
biofilm covered PVC pipe	Biofilm Covered PVC Pipe
Biological indicator	Biological Indicator Strip
biological indicator 304 SS	
biological indicator strip	
biological indicator strips	
BioStrip (paper)	
Brick	Brick
butyl rubber	Butyl Rubber
Carbon Steel	Carbon Steel
CARC-W coated stainless steel	CARC-W Coated Stainless Steel
carpet	Carpet
Carpet Horizontal	
floor 1: floors and ceilings (epoxy-coated, wood laminate, carpet, and ceiling tile)	
floor 2: floors and ceilings (epoxy-coated, wood laminate, carpet, and ceiling tile)	
cassava starch 18% moisture	Cassava Starch
cassava starch 30% moisture	
ceiling tile	Ceiling Tile
floor 1: floors and ceilings (epoxy-coated, wood laminate, carpet, and ceiling tile)	
floor 2: floors and ceilings (epoxy-coated, wood laminate, carpet, and ceiling tile)	
Cellulose Insulation	Cellulose Insulation
Cement	Cement
ceramic	Ceramic
Ceramics	
chair back	Chair Back
chair seat	Chair Seat
cinder block	Cinder Block
Cinderblock	
Composite epoxy	Composite Epoxy
Concrete	Concrete
concrete (ceiling)	
concrete (floors)	
concrete (walls)	
concrete blocks	
Concrete Horizontal	
Concrete vertical	
Unpainted Concrete	

BioDecontamination Compendium	Representative Surface Name
cork boards	Cork Boards
cotton cloth	Cotton Cloth
Cotton swab	Cotton Swab
Cotton swab with serum	
custard cream	Custard Cream
Deck Wood Horizontal	Deck Wood
deck wood Vertical	
Decorative laminate	Decorative Laminate
desk top	Desk Top
DI water	DI Water
diamond burs	Diamond Burs
dried fig	Dried Fig
Dry Wall Vertical	Dry Wall
egg-yolk residue on stainless steel	Egg-Yolk Residue on Stainless Steel
epoxy	Epoxy
fiberglass lined HVAC duct location A	Fiberglass Lined HVAC Duct
fiberglass lined HVAC duct location B	
fiberglass lined HVAC duct location C	
fiberglass lined HVAC duct location D	
fiberglass lined HVAC duct location E	
fiberglass lined HVAC duct location F	
fiberglass lined HVAC duct location G	
fiberglass lined HVAC duct location H	
fiberglass wall paneling	Fiberglass Wall Paneling
filing cabinet	Filing Cabinet
filter paper (2.8 um spore clusters)	Filter Paper
filter paper (4.4 um spore clusters)	
filter paper (single spores)	
filter paper spore trip	
flour paste on stainless steel	Flour on Stainless Steel
flour residue on stainless steel	
food packaging material (presumably plastic)	Food Packaging Material (Presumably Plastic)
Galvanized Metal	Galvanized Metal
galvanized metal ductwork	Galvanized Metal HVAC Duct
galvanized metal HVAC duct location A	
galvanized metal HVAC duct location B	
galvanized metal HVAC duct location C	
galvanized metal HVAC duct location D	
galvanized metal HVAC duct location E	
galvanized metal HVAC duct location F	

BioDecontamination Compendium	Representative Surface Name
galvanized metal HVAC duct location G	Galvanized Metal HVAC Duct
galvanized metal HVAC duct location H	
galvanized steel	Galvanized Steel
glass	Glass
Glass (small)	Glass (Small)
Glass AOAC 2008.05	Glass AOAC 2008.05
glass beads	Glass Beads
glass bottle interior	Glass Bottle Interior
glass bottle interior coated with bovine serum	Glass Bottle Interior Coated with Bovine Serum
Glass fiber filter swab	Glass Fiber Filter Swab
glass helices	Glass Helices
glass petri dish	Glass Petri Dish
gold foil	Gold Foil
Granite	Granite
greasy aluminum stub	Greasy Aluminum Stub
grimed and washed concrete	Grimed Concrete
grimed and washed steel	Grimed Steel
grimed and washed tile	Grimed and Washed Tile
grimed Concrete	Grimed Concrete
grimed rough-cut barn wood	Grimed Wood
grimed steel	Grimed Steel
grimed tile	Grimed Tile
hardwood	Hardwood
healthcare waste	Healthcare Waste
horse serum residue on stainless steel	Horse Serum Residue on Stainless Steel
Hypalon® Rubber Glove	Rubber Glove
Industrial carpet	Industrial Carpet
Industrial-grade carpet	
industrial sucrose syrup	Industrial Sucrose Syrup
InsulFab	InsulFab
interior of aluminum carton	Interior of Aluminum Carton
interior of polyethylene carton	Interior of Polyethylene Carton
isopore polycarbonate membrane filter	Isopore Polycarbonate Membrane Filter
keyboard	Keyboard
Laminate	Laminate
lard coated stainless steel (spores under lard)	Lard Coated Stainless Steel (Spores Under Lard)
Linoleum	Linoleum
liquid	Liquid
liquid suspension atop agar	Liquid Suspension atop Agar

BioDecontamination Compendium	Representative Surface Name
loop-pile carpet	Loop-Pile Carpet
Metal Ductwork	Metal Ductwork
MgF2 glass	MgF2 Glass
milk	Milk
molecular sieves	Molecular Sieves
mylar	Mylar
natural water (cedar)	Natural Water
natural water (marysville)	
navy ship topcoated stainless steel (NTC)	Navy Ship Topcoated Stainless Steel (NTC)
nitrocellulose filter	Nitrocellulose Filter
nitrocellulose membrane	Nitrocellulose Membrane
nonexposed areas of surgical instruments	Nonexposed Areas of Surgical Instruments
Nylon	Nylon
nylon carpet	Nylon Carpet
office air	Office Air
office carpet	Carpet
paint	Paint
painted aluminum (aircraft performance coating)	Painted Aluminum (Aircraft Performance Coating)
painted aluminum alloy	Painted Aluminum Alloy
Painted Canvas	Painted Canvas
Painted cinder block	Painted Cinder Block
Painted concrete	Painted Concrete
Painted dry wall	Painted Dry Wall
painted office drywall	
Painted drywall paper	
painted I-beam steel	Painted Steel
painted steel	
painted joint tape	Painted Joint Tape
painted metal	Painted Metal
painted paper	Painted Paper
floor 1: walls (painted wallboard and plastic walls)	Painted Wallboard
floor 2: walls (painted wallboard and plastic walls)	
painted wallboard	
painted wallboard coupon	
Painted Wallboard Horizontal	
painted wallboard paper	
paper	Paper
paper catalog	
paprika (low moisture)	Paprika
paprika (medium moisture)	

BioDecontamination Compendium	Representative Surface Name
paprika water slurry interior	Paprika Water Slurry Interior
paprika water slurry overall	Paprika Water Slurry Overall
paprika water slurry surface	Paprika Water Slurry Surface
Particle Board	Particle Board
phosphate buffer pH=6	Phosphate Buffer
phosphate buffer pH=7	
phosphate buffer pH=8	
pin cushion screen	Pin Cushion Screen
Plastic	Plastic
plastic (LDPE) films containing titanium dioxide	Plastic (LDPE) Films Containing Titanium Dioxide
plastic syringe barrel	Plastic Syringe Barrel
floor 1: walls (painted wallboard and plastic walls)	Plastic Walls
floor 2: walls (painted wallboard and plastic walls)	
Plate Glass	Plate Glass
Plywood	Plywood
Polycarbonate	Polycarbonate
Lexan	
Polyethylene	Polyethylene
LDPE	
Low-density polyethylene	
polyolefin	Polyolefin
polypropylene	Polypropylene
Polypropylene swab	Polypropylene Swab
Polypropylene swab with serum	
Polystyrene	Polystyrene
polystyrene petri dish	
polyurethane	Polyurethane
polyurethane painted aluminum	Polyurethane Painted Aluminum
polyvinyl chloride	Polyvinyl Chloride
Porcelain	Porcelain
porcelain penicylinder	
prehumidified cotton cloth	Prehumidified Cotton Cloth
prehumidified glass	Prehumidified Glass
prehumidified painted steel	Prehumidified Painted Steel
prehumidified polyurethane	Prehumidified Polyurethane
prehumidified polyvinyl chloride	Prehumidified Polyvinyl Chloride
prehumidified stainless steel	Prehumidified Stainless Steel
pure sucrose syrup	Pure Sucrose Syrup
rough surface patio tiles	Rough Surface Patio Tiles
rubber flooring	Rubber Flooring

BioDecontamination Compendium	Representative Surface Name
rubber silicone butyl blend	Rubber Silicone Butyl Blend
scaffold of polycaprolactone	Scaffold of Polycaprolactone
scalpel blade	Scalpel Blade
seeds	Seeds
shaved porcine skin	Shaved Porcine Skin
silicone and butyl rubber blend	Silicone and Butyl Rubber Blend
Silk Fabric	Silk Fabric
smooth surface patio tiles	Smooth Surface Patio Tiles
Sol Cont	Sol Cont
soy milk	Soy Milk
spore solution on petri dish inside ambulance	Spore Solution on Petri Dish inside Ambulance
stainless steel	Stainless Steel
stainless steel (Floor, left side)	
Stainless steel (Floor, right side	
stainless steel (horizontal)	
stainless steel (Left wall)	
stainless steel (Rear wall, left side)	
stainless steel (Rear wall, right side)	
stainless steel (Right wall)	
stainless steel (vertical)	
Stainless steel 304	
stainless steel (spores applied after decon agent)	Stainless Steel (Spores Applied after Decon Agent)
stainless steel + 0.3% organic burden	Stainless Steel + 0.3% Organic Burden
stainless steel BI	Stainless Steel BI
stainless steel BI inside a manufacturing machine	
stainless steel BI inside a tube	
stainless steel bioindicator	Stainless Steel Bioindicator
stainless steel biological indicator	
stainless steel in Tyvek	Stainless Steel in Tyvek
stainless steel knife handle	Stainless Steel Knife Handle
stainless steel with organic and soil load	Stainless Steel with Organic and Soil Load
stainless steel with organic load	Stainless Steel with Organic Load
Steel	Steel
steel (chemical resistant coating)	Steel (Chemical Resistant Coating)
suspension of nutrient rich media	Suspension of Nutrient Rich Media
Suture Loop	Suture Loop
swine skin	Swine Skin
Teflon	Teflon
Tile	Tile
tire	Tire

BioDecontamination Compendium	Representative Surface Name
Agvise Topsoil	Topsoil
Topsoil	
topsoil (1-cm deep)	
topsoil (2-cm deep)	
topsoil (dried)	
Earthgro Topsoil	
treated wood	Treated Wood
treated wood vertical	
Pressure-Treated Lumber	
Tyvek	Tyvek
untreated wood	Untreated Wood
used cut-pile carpet	Used Cut-Pile Carpet
vinyl chloride plate	Vinyl Chloride Plate
vinyl floor tile	Vinyl Tile
Vinyl Tile	
vinyl flooring	Vinyl Flooring
vinyl seating	Vinyl Seating
Wallboard	Wallboard
Wallboard Paper	Wallboard Paper
wash down water	Wash Down Water
wash down water with 1% Alconox detergent	
wash down water with 1% Dawn detergent	
water	Water
water (ECA1)	Water (ECA#)
water (ECA2)	
water (ECA3)	
water (ECA4)	
water (ECA5)	
wet polypropylene	Wet Polypropylene
whole milk residue on stainless steel	Whole Milk Residue on Stainless Steel
wiring insulation	Wiring Insulation
wiring insulation	
bare fir wood	Wood
Bare pine wood	
Bare Wood	
maple wood	
Pine Wood	
wood	
rough-cut barn wood	
rough-cut barn wood coupon	
Rough-cut Wood Vertical	

BioDecontamination Compendium	Representative Surface Name
floor 1: floors (epoxy-coated and wood laminate)	Wood Laminate
floor 2: floors (epoxy-coated and wood laminate)	
floor 1: floors and ceilings (epoxy-coated, wood laminate, carpet, and ceiling tile)	
floor 2: floors and ceilings (epoxy-coated, wood laminate, carpet, and ceiling tile)	
Wood Laminate	
wood tiles	Wood Tiles
woven carpet	Woven Carpet

APPENDIX B: BASELINE PARAMETERS

Table B-1 presents the baseline Incident Command parameters that are used as the default values within the tool.

Table B-1: Baseline Incident Command Parameters

Parameter	Description	Units	Value	Lower Limit	Upper Limit
Personnel Required (OSC)	Number of OSC personnel per team	people/team	1	0	100
Personnel Required (PL-4)	Number of PL-4 personnel per team	people/team	0	0	100
Personnel Required (PL-3)	Number of PL-3 personnel per team	people/team	0	0	100
Personnel Required (PL-2)	Number of PL-2 personnel per team	people/team	0	0	100
Personnel Required (PL-1)	Number of PL-1 personnel per team	people/team	0	0	100
Personnel Overhead Days	Number of setup and tear-down days for element	days	0	0	10
Roundtrip Days	Total number of travel days	days	2	0	10

Table B-2 presents the baseline Characterization Sampling parameters that are used as the default values within the tool.

Table B-2: Baseline Characterization Sampling Parameters

Parameter	Description	Units	Value	Lower Limit	Upper Limit
Teams Required	Number of teams required	team	1 – 6	1	50
Personnel Required (OSC)	Number of OSC personnel required per team	person / team	0.3 – 0.333	0	100
Personnel Required (PL-4)	Number of PL-4 personnel required per team	person / team	0 – 2	0	100
Personnel Required (PL-3)	Number of PL-3 personnel required per team	person / team	2 – 3	0	100
Personnel Required (PL-2)	Number of PL-2 personnel required per team	person / team	0 – 2	0	100
Personnel Required (PL-1)	Number of PL-1 personnel required per team	person / team	0	0	100

Parameter	Description	Units	Value	Lower Limit	Upper Limit
Number of Respirators per Person	Number of respirators required per each person	respirator / person	1	0	5
Surface Area per Wipe	Surface area that can be sampled per one wipe	m^2 / wipe	0.064516	0.5	25
Surface Area per HEPA Sock	Surface area that can be sampled per one HEPA sock	m^2 / sock	0.09 – 0.37	0.5	25
Wipes per Hour per Team	Number of wipes used per hour per team	wipe / (hour * team)	mean: 14.51 stdev: 7.35	0	50
HEPA Socks per Hour per Team	Number of HEPA socks used per hour per team	sock / (hour * team)	mean: 10.56 stdev: 7.70	0	50
Entry Duration Based on PPE Level (A)	Duration of each entry for one personnel donning PPE Level A	hours / entry	1.18	0	5
Entry Duration Based on PPE Level (B)	Duration of each entry for one personnel donning PPE Level B	hours / entry	1.495	0	5
Entry Duration Based on PPE Level (C)	Duration of each entry for one personnel donning PPE Level C	hours / entry	1.81	0	5
Entry Duration Based on PPE Level (D)	Duration of each entry for one personnel donning PPE Level D	hours / entry	2.125	0	5
Number of Labs	Number of labs to which samples will be sent	labs	6 – 8	1	50
Lab Uptime Hours per Day	Number of hours lab is operational per day	hours / day	12	1	12
Lab Throughput Samples per Day	Number of samples analyzed per day	samples / day	5 – 84	1	100
Roundtrip Days	Travel days to and from the site area	days	2	0	10
Personnel Overhead Days	Number of setup and teardown days at the start and end of the element	days	0	0	10
Packaging Time per Sample	Time required to package one sample	minutes / sample	1.63	0	5
Analysis Time per HEPA Sample	Time required for one HEPA sample to be analyzed in a lab	hours / sample	0.77 – 1	0	5
Analysis Time per Wipe Sample	Time required for one wipe sample to be analyzed in a lab	hours / sample	0.67 – 0.79	0	5

Parameter	Description	Units	Value	Lower Limit	Upper Limit
Prep Time per Team per Entry	Time required for each team to prepare to enter the contamination site	hours / team * entry	0.6	0	2
Lab Distance from Site	Distance of each external lab from the contamination site	kilometers	322 – 3,700	0	1.00E+06
Personnel Decon Line Time per Team per Exit	Time spent in the personnel decon line upon exiting the contamination site	hours / team * exit	0.81	0	5
Post-Entry Rest Period	Time required for rest after each site entry	hours / team * entry	0.5 – 0.55	0	2
Time of Result Transmission to IC	Time required to transmit analysis results from external labs to Incident Command	hours	24	0	72
Fraction PPE Required (A)	Fraction of all PPE required for one team that is Level A	unitless	0.1 – 0.9	0	1
Fraction PPE Required (B)	Fraction of all PPE required for one team that is Level B	unitless	0.1 – 0.9	0	1
Fraction PPE Required (C)	Fraction of all PPE required for one team that is Level C	unitless	0.1 – 0.9	0	1
Fraction PPE Required (D)	Fraction of all PPE required for one team that is Level D	unitless	0.1 – 0.9	0	1
Fraction of Surface Sampled	The fraction of the total surface area that will be sampled	unitless	0.1 – 0.9	0	1

Table B-3 presents the baseline Source Reduction parameters that are used as the default values within the tool.

Table B-3: Baseline Source Reduction Parameters

Parameter	Description	Units	Value	Lower Limit	Upper Limit
Teams Required	Number of teams required	team	1 – 6	1	50
Personnel Required (OSC)	Number of OSC personnel required per team	person / team	0.333	0	100
Personnel Required (PL-4)	Number of PL-4 personnel required per team	person / team	0 – 0.67	0	100

Parameter	Description	Units	Value	Lower Limit	Upper Limit
Personnel Required (PL-3)	Number of PL-3 personnel required per team	person / team	1 – 3.33	0	100
Personnel Required (PL-2)	Number of PL-2 personnel required per team	person / team	0 – 2	0	100
Personnel Required (PL-1)	Number of PL-1 personnel required per team	person / team	0	0	100
Mass of Waste Removed per Hour per Team	Mass of waste material removed from site per hour per team	kg / (hour * team)	45.36	0	1000
Entry Duration Based on PPE Level (A)	Duration of each entry for one personnel donning PPE Level A	hours / entry	1.18	0	5
Entry Duration Based on PPE Level (B)	Duration of each entry for one personnel donning PPE Level B	hours / entry	1.495	0	5
Entry Duration Based on PPE Level (C)	Duration of each entry for one personnel donning PPE Level C	hours / entry	1.81	0	5
Entry Duration Based on PPE Level (D)	Duration of each entry for one personnel donning PPE Level D	hours / entry	2.125	0	5
Number of Respirators per Person	Number of respirators required per each person	respirator / person	1	0	5
Roundtrip Days	Travel days to and from the site area	days	2	0	10
Personnel Overhead Days	Number of setup and teardown days at the start and end of the element	days	0	0	10
Mass of Waste per Surface Area	Mass of waste per surface area of site	kg / m^2	0 – 9.3	0	50
Prep Time per Team per Entry	Time required for each team to prepare to enter the contamination site	hours / team * entry	0.6	0	2
Personnel Decon Line Time per Team per Exit	Time spent in the personnel decon line upon exiting the contamination site	hours / team * exit	0.81	0	5
Post-Entry Rest Period	Time required for rest after each site entry	hours / team * entry	0.5 – 0.55	0	2
Fraction PPE Required (A)	Fraction of all PPE required for one team that is Level A	unitless	0.1 – 0.9	0	1
Fraction PPE Required (B)	Fraction of all PPE required for one team that is Level B	unitless	0.1 – 0.9	0	1

Parameter	Description	Units	Value	Lower Limit	Upper Limit
Fraction PPE Required (C)	Fraction of all PPE required for one team that is Level C	unitless	0.1 – 0.9	0	1
Fraction PPE Required (D)	Fraction of all PPE required for one team that is Level D	unitless	0.1 – 0.9	0	1
Fraction Surface Area to be Source Reduced	Fraction of the total surface area to be source reduced	unitless	0.1 – 0.9	0	1

Table B-4 presents the baseline Decontamination parameters that are used as the default values within the tool.

Table B-4: Baseline Decontamination Parameters

Parameter	Description	Units	Value	Lower Limit	Upper Limit
Decon + Drying Days	Number of days required for one decontamination application method including drying days	days	3 – 5	0	10
Personnel Required (OSC)	Number of OSC personnel required per team	person / team	0.3	0	100
Personnel Required (PL-4)	Number of PL-4 personnel required per team	person / team	1 – 2	0	100
Personnel Required (PL-3)	Number of PL-3 personnel required per team	person / team	3 – 6	0	100
Personnel Required (PL-2)	Number of PL-2 personnel required per team	person / team	0	0	100
Personnel Required (PL-1)	Number of PL-1 personnel required per team	person / team	0	0	100
Number of Respirators per Person	Number of respirators required per each person	respirator / person	1	0	5
Teams Required	Number of teams required	teams	2 – 6	1	50
Entry Duration Based on PPE Level (A)	Duration of each entry for one personnel donning PPE Level A	hours / entry	1.18	0	5
Entry Duration Based on PPE Level (B)	Duration of each entry for one personnel donning PPE Level B	hours / entry	1.495	0	5
Entry Duration Based on PPE Level (C)	Duration of each entry for one personnel donning PPE Level C	hours / entry	1.81	0	5

Parameter	Description	Units	Value	Lower Limit	Upper Limit
Entry Duration Based on PPE Level (D)	Duration of each entry for one personnel donning PPE Level D	hours / entry	2.125	0	5
Volume of Agent Applied for Fogging/Fumigation	Volume of agent required for fogging or fumigation per room volume	L / m^3	0.33	0	50
Volume of Agent Applied	Volume of agent required for decontaminating room square footage	L / m^2	0.65 – 1.30	0	50
Roundtrip Days	Travel days to and from the site area	days	2	0	10
Personnel Overhead Days	Number of setup and teardown days at the start and end of the element	days	0	0	10
Prep Time per Team per Entry	Time required for each team to prepare to enter the contamination site	hours / team * entry	0.6	0	2
Personnel Decon Line Time per Team per Exit	Time spent in the personnel decon line upon exiting the contamination site	hours / team * exit	0.81	0	5
Post-Entry Rest Period	Time required for rest after each site entry	hours / team * entry	0.5 – 0.55	0	2
Fraction PPE Required (A)	Fraction of all PPE required for one team that is Level A	unitless	0.1 – 0.9	0	1
Fraction PPE Required (B)	Fraction of all PPE required for one team that is Level B	unitless	0.1 – 0.9	0	1
Fraction PPE Required (C)	Fraction of all PPE required for one team that is Level C	unitless	0.1 – 0.9	0	1
Fraction PPE Required (D)	Fraction of all PPE required for one team that is Level D	unitless	0.1 – 0.9	0	1

Table B-5 presents the baseline Clearance Sampling parameters that are used as the default values within the tool.

Table B-5: Baseline Clearance Sampling Parameters

Parameter	Description	Units	Value	Lower Limit	Upper Limit
Teams Required	Number of teams required	team	1 – 6	1	50
Personnel Required (OSC)	Number of OSC personnel required per team	person / team	0.3 – 0.333	0	100

Parameter	Description	Units	Value	Lower Limit	Upper Limit
Personnel Required (PL-4)	Number of PL-4 personnel required per team	person / team	0 – 2	0	100
Personnel Required (PL-3)	Number of PL-3 personnel required per team	person / team	2 – 3	0	100
Personnel Required (PL-2)	Number of PL-2 personnel required per team	person / team	0 – 2	0	100
Personnel Required (PL-1)	Number of PL-1 personnel required per team	person / team	0	0	100
Number of Respirators per Person	Number of respirators required per each person	respirator / person	1	0	5
Surface Area per Wipe	Surface area that can be sampled per one wipe	m^2 / wipe	0.064516	0.5	25
Surface Area per HEPA Sock	Surface area that can be sampled per one HEPA sock	m^2 / sock	0.09 – 0.37	0.5	25
Wipes per Hour per Team	Number of wipes used per hour per team	wipe / (hour * team)	mean: 14.51 stdev: 7.35	0	50
HEPA Socks per Hour per Team	Number of HEPA socks used per hour per team	sock / (hour * team)	mean: 10.56 stdev: 7.70	0	50
Entry Duration Based on PPE Level (A)	Duration of each entry for one personnel donning PPE Level A	hours / entry	1.18	0	5
Entry Duration Based on PPE Level (B)	Duration of each entry for one personnel donning PPE Level B	hours / entry	1.495	0	5
Entry Duration Based on PPE Level (C)	Duration of each entry for one personnel donning PPE Level C	hours / entry	1.81	0	5
Entry Duration Based on PPE Level (D)	Duration of each entry for one personnel donning PPE Level D	hours / entry	2.125	0	5
Number of Labs	Number of labs to which samples will be sent	labs	6 – 8	1	50
Lab Uptime Hours per Day	Number of hours lab is operational per day	hours / day	12	1	12
Lab Throughput Samples per Day	Number of samples analyzed per day	samples / day	5 – 84	1	100
Roundtrip Days	Travel days to and from the site area	days	2	0	10

Parameter	Description	Units	Value	Lower Limit	Upper Limit
Personnel Overhead Days	Number of setup and teardown days at the start and end of the element	days	0	0	10
Packaging Time per Sample	Time required to package one sample	minutes / sample	1.63	0	5
Analysis Time per HEPA Sample	Time required for one HEPA sample to be analyzed in a lab	hours / sample	0.77 – 1	0	5
Analysis Time per Wipe Sample	Time required for one wipe sample to be analyzed in a lab	hours / sample	0.67 – 0.79	0	5
Lab Distance from Site	Distance of each external lab from the contamination site	kilometers	322 – 3,700	0	1.00E+06
Prep Time per Team per Entry	Time required for each team to prepare to enter the contamination site	hours / team * entry	0.6	0	2
Personnel Decon Line Time per Team per Exit	Time spent in the personnel decon line upon exiting the contamination site	hours / team * exit	0.81	0	5
Post-Entry Rest Period	Time required for rest after each site entry	hours / team * entry	0.5 – 0.55	0	2
Time of Result Transmission to IC	Time required to transmit analysis results from external labs to Incident Command	hours	24	0	72
Fraction PPE Required (A)	Fraction of all PPE required for one team that is Level A	unitless	0.1 – 0.9	0	1
Fraction PPE Required (B)	Fraction of all PPE required for one team that is Level B	unitless	0.1 – 0.9	0	1
Fraction PPE Required (C)	Fraction of all PPE required for one team that is Level C	unitless	0.1 – 0.9	0	1
Fraction PPE Required (D)	Fraction of all PPE required for one team that is Level D	unitless	0.1 – 0.9	0	1
Fraction of Surface Sampled	The fraction of the total surface area that will be sampled	unitless	0.1 – 0.9	0	1

Table B-6 presents the baseline Waste Sampling parameters that are used as the default values within the tool.

Table B-6: Baseline Waste Sampling Parameters

Parameter	Description	Units	Value	Lower Limit	Upper Limit
Teams Required	Number of teams required	team	1	1	50
Personnel Required (OSC)	Number of OSC personnel required per team	person / team	0	0	100
Personnel Required (PL-4)	Number of PL-4 personnel required per team	person / team	0	0	100
Personnel Required (PL-3)	Number of PL-3 personnel required per team	person / team	0	0	100
Personnel Required (PL-2)	Number of PL-2 personnel required per team	person / team	0	0	100
Personnel Required (PL-1)	Number of PL-1 personnel required per team	person / team	3	0	100
Mass per Waste Sample	Mass that can be sampled per one waste sample	kg / sample	15.12 – 16.67	0	150
Volume per Waste Sample	Volume that can be sampled per one waste sample	L / sample	200.00 – 208.20	0	200
Waste Samples per Hour per Team	Number of waste samples used per hour per team	samples / (hour * team)	5.9 – 12.5	0	50
Number of Labs	Number of labs to which samples will be sent	labs	6 – 8	1	50
Lab Uptime Hours per Day	Number of hours lab is operational per day	hours / day	12	0	12
Lab Throughput Samples per Day	Number of samples analyzed per day	samples / day	5 - 84	1	100
Personnel Overhead Days	Number of setup and teardown days at the start and end of the element	days	0	0	10
Packaging Time per Sample	Time required to package one sample	minutes / sample	1.63	0	5
Analysis Time per Waste Sample	Time required for one waste sample to be analyzed in a lab	hours / sample	0.79	0	5
Lab Distance from Site	Distance of each external lab from the contamination site	meters	322 – 3,700	0	1.00E+06

Parameter	Description	Units	Value	Lower Limit	Upper Limit
Time of Result Transmission to IC	Time required to transmit analysis results from external labs to Incident Command	hours	24	0	72
Roundtrip Days	Travel days to and from the site area	days	2	0	10
Solid Waste Produced per Surface Area	Mass of solid waste produced per surface area during decontamination	kg / m^2	0 – 9.30	0	100
Liquid Waste Produced per Surface Area	Volume of liquid waste produced per surface area during decontamination	L / m^2	0 – 7.67	0	100
Fraction of Waste Sampled	The fraction of the total waste produced that will be sampled	unitless	0.1 – 0.9	0	1
Entry Duration Based on PPE Level (A)	Duration of each entry for one personnel donning PPE Level A	hours / entry	0	0	5
Entry Duration Based on PPE Level (B)	Duration of each entry for one personnel donning PPE Level B	hours / entry	0	0	5
Entry Duration Based on PPE Level (C)	Duration of each entry for one personnel donning PPE Level C	hours / entry	0	0	5
Entry Duration Based on PPE Level (D)	Duration of each entry for one personnel donning PPE Level D	hours / entry	0	0	5
Fraction PPE Required (A)	Fraction of all PPE required for one team that is Level A	unitless	0	0	1
Fraction PPE Required (B)	Fraction of all PPE required for one team that is Level B	unitless	0	0	1
Fraction PPE Required (C)	Fraction of all PPE required for one team that is Level C	unitless	0	0	1
Fraction PPE Required (D)	Fraction of all PPE required for one team that is Level D	unitless	0	0	1
Prep Time per Team per Entry	Time required for each team to prepare to enter the contamination site	hours / team * entry	0	0	2
Personnel Decon Line Time per Team per Exit	Time spent in the personnel decon line upon exiting the contamination site	hours / team * exit	0	0	5
Post-Entry Rest Period	Time required for rest after each site entry	hours / team * entry	0	0	2
Number of Respirators per Person	Number of respirators required per each person	respirator / person	0	0	5

Table B-7 presents the baseline travel parameters that are used as the default values within the tool.

Table B-7: Baseline Travel Parameters

Parameter	Description	Units	Value	Lower Limit	Upper Limit
Number of Personnel per Rental Car	Number of personnel in one rental car	personnel / car	4 – 8	1	10

Table B-8 presents the baseline Cost parameters that are used as the default values within the tool.

Table B-8: Baseline Cost Parameters

Parameter	Description	Units	Value	Lower Limit	Upper Limit
Cost of Decon Agent	Cost of decontamination agent per volume	$ / L	0.52 – 1.58	0	100
Cost per HEPA Sample Analyzed	Cost per HEPA sample analyzed	$ / sample	247.27 – 370.00	100	1000
Cost per One HEPA Sock	Cost per one HEPA sock	$ / sample	29	10	50
Cost per One Waste Sample	Cost per one waste sample	$ / sample	20 – 29	10	50
Cost per Waste Sample Analyzed	Cost per waste sample analyzed	$ / sample	254.19	100	1000
HEPA Vacuum Rental per Day	HEPA vacuum rental cost per day	$ / day	15	10	50
Per Diem	Per diem cost per day plus lodging	$ / day	185 – 341	150	500
OSC Hourly Wage	Hourly wage for OSC personnel	$ / hour	147 – 155	80	200
PL-1 Hourly Wage	Hourly wage for PL-1 personnel	$ / hour	86 – 101	60	105
PL-2 Hourly Wage	Hourly wage for PL-2 personnel	$ / hour	102 – 118	100	125
PL-3 Hourly Wage	Hourly wage for PL-3 personnel	$ / hour	124 – 142	120	170
PL-4 Hourly Wage	Hourly wage for PL-4 personnel	$ / hour	170 – 210	165	250
Rentals per Day (IC)	Cost of incident command rentals per day	$ / day	235.42	100	500
Respirator	Cost per one respirator	$ / unit	238	100	500
Cost per One Wipe	Cost per one sampling wipe	$ / sample	19 – 20	10	50

Parameter	Description	Units	Value	Lower Limit	Upper Limit
Decon Material Cost per Surface Area	Cost of decontamination materials per surface area of site area	$ / m^2	1.54 – 42.76	0	100
PPE Level A Cost	Cost per one unit of level A PPE	$ / unit	391.59	300	500
PPE Level B Cost	Cost per one unit of level B PPE	$ / unit	144.83	100	300
PPE Level C Cost	Cost per one unit of level C PPE	$ / unit	66.6	0	100
PPE Level D Cost	Cost per one unit of level D PPE	$ / unit	64.32	0	100
Cost for Prep per Entry	Preparation costs for contamination site entry	$ / team * entry	252 – 345	0	1000
Cost for Personnel Decon Line per Exit	Personnel decon line costs for contamination site exit	$ / team * exit	697 – 822	0	1000
Supplies Cost per Day (IC)	Incident command supplies cost per day	$ / day	1,007.08	500	1500
Cost per Wipe Sample Analyzed	Cost per sample analyzed	$ / sample	231 – 640	100	1000
Rental Car Cost per Day	Cost of rental car per day	$ / day	58.00 – 64.29	0	500
Material Removal per Mass	Cost of removing material during Source Reduction based on mass	$ / kg	0.11	0	10
Roundtrip Ticket Cost per Person	Price per one roundtrip ticket to and from contamination site	$ / ticket	450 – 518	0	500

APPENDIX C: USER GUIDE

The following is a user guide for the Wide-Area Decontamination Tool. Upon launching the application, users will see the screen shown in Figure C-1. Users can select the "Create New Scenario" button to begin defining a scenario.

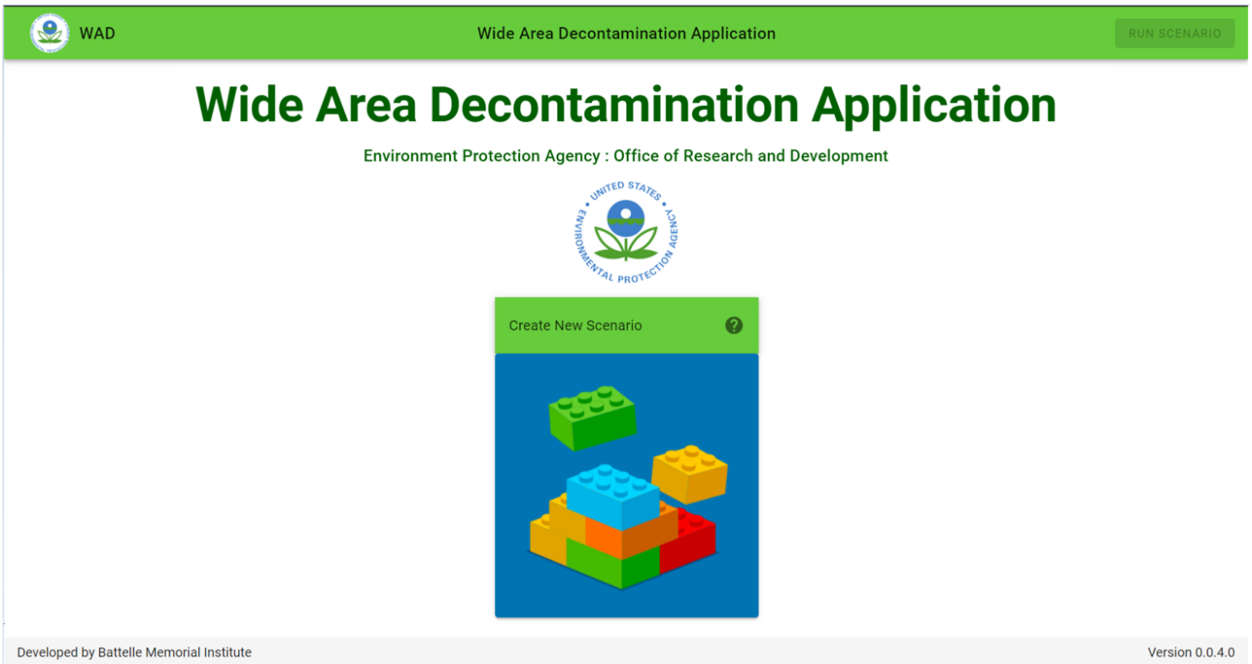

Figure C-1: Wide-Area Decontamination Tool Home Screen

Once the "Create New Scenario" button has been selected, the user is then able to both define the scenario parameters which have no values found in the DefineScenario.xlsx workbook and modify the parameter values which have distributions associated with them in the ModifyParameters.xlsx workbook. Figure C-2 shows the "Define Scenario" tab, where users can define the extent of contamination, the initial spore loading, and the breakdown of surfaces for that particular scenario.

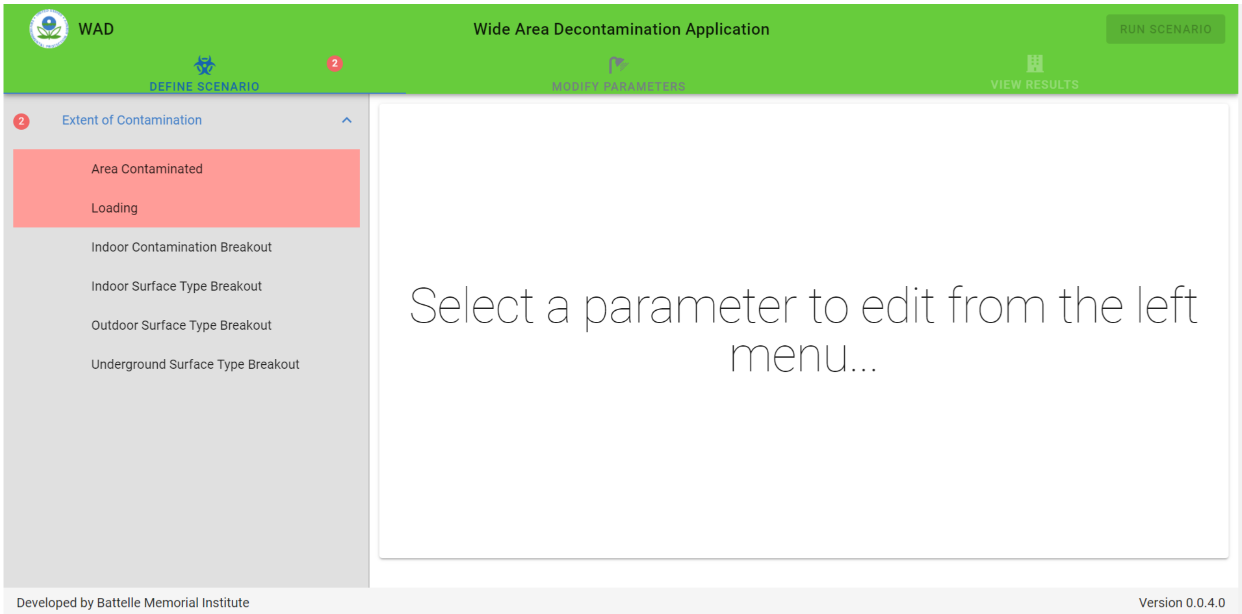

Figure C-2: Define Scenario Tab

The Define Scenario tab allows users to set values for parameters related to the extent of contamination for the scenario. Parameters that are unset will be highlighted in red. By default, all parameters are set except the Area Contaminated and the Loading. Users can select a value for a parameter using either the slider or by typing a value into the textbox, shown in Figure C-3 below.

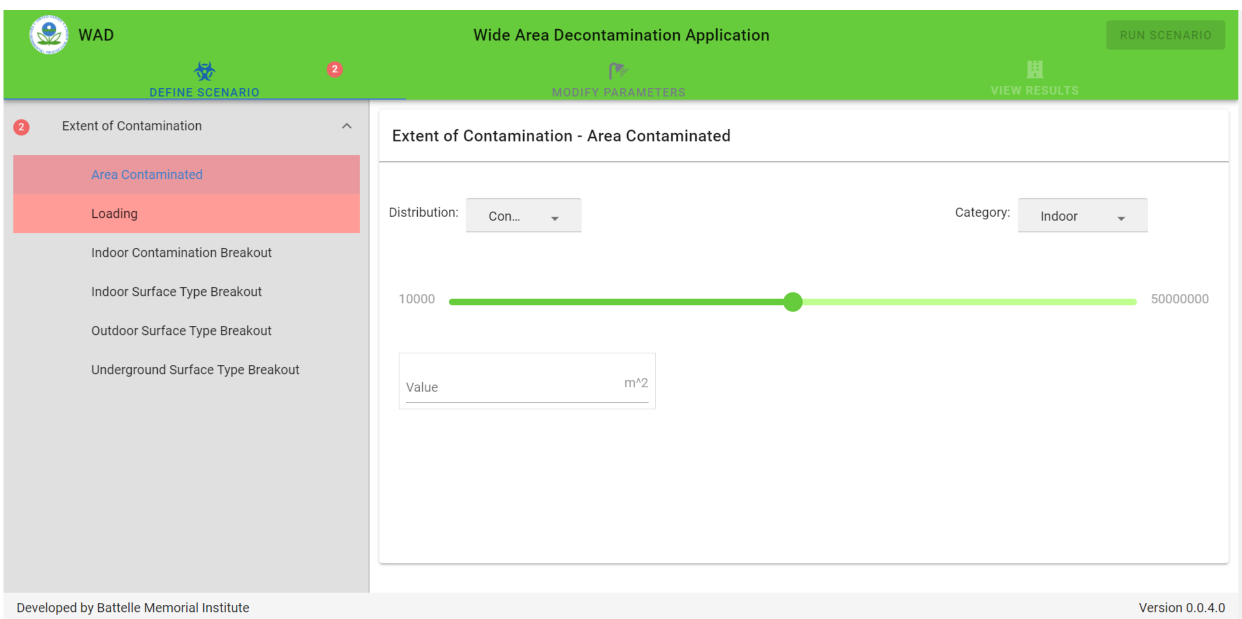

Figure C-3: Area Contaminated Parameter Adjustment

Users can also select a distribution to describe the parameter values. The various distributions are shown in Figure C-4 below.

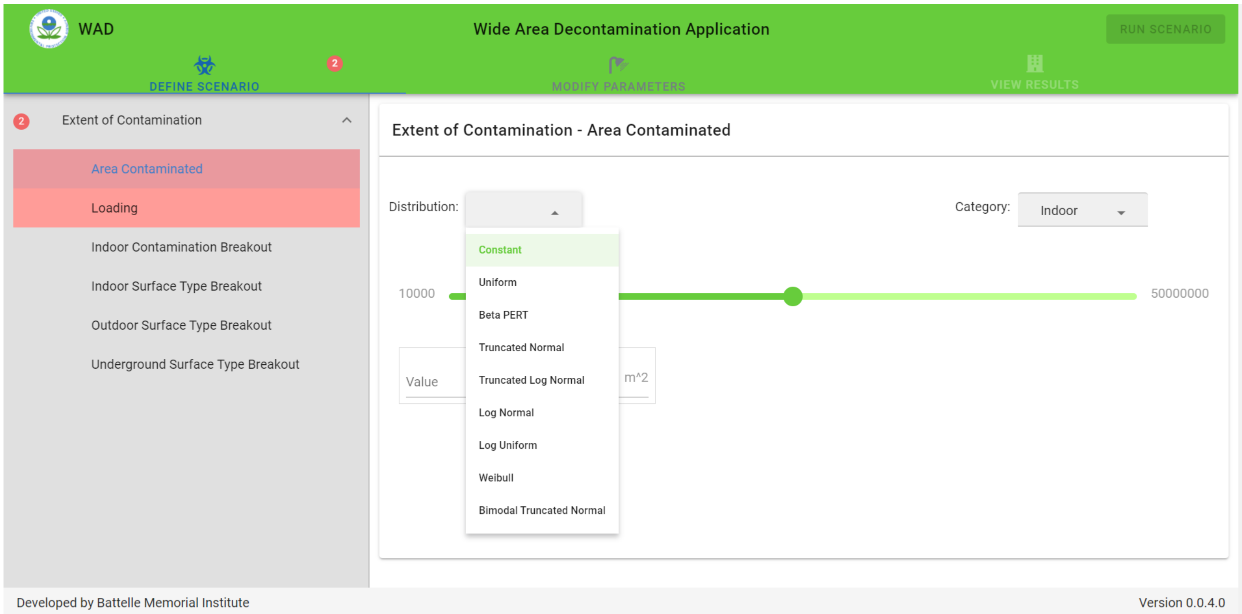

Figure C-4: Define Scenario Distribution List

The selected distribution can be defined using the slider, the textboxes, or the graph itself, as shown in Figure C-5 below.

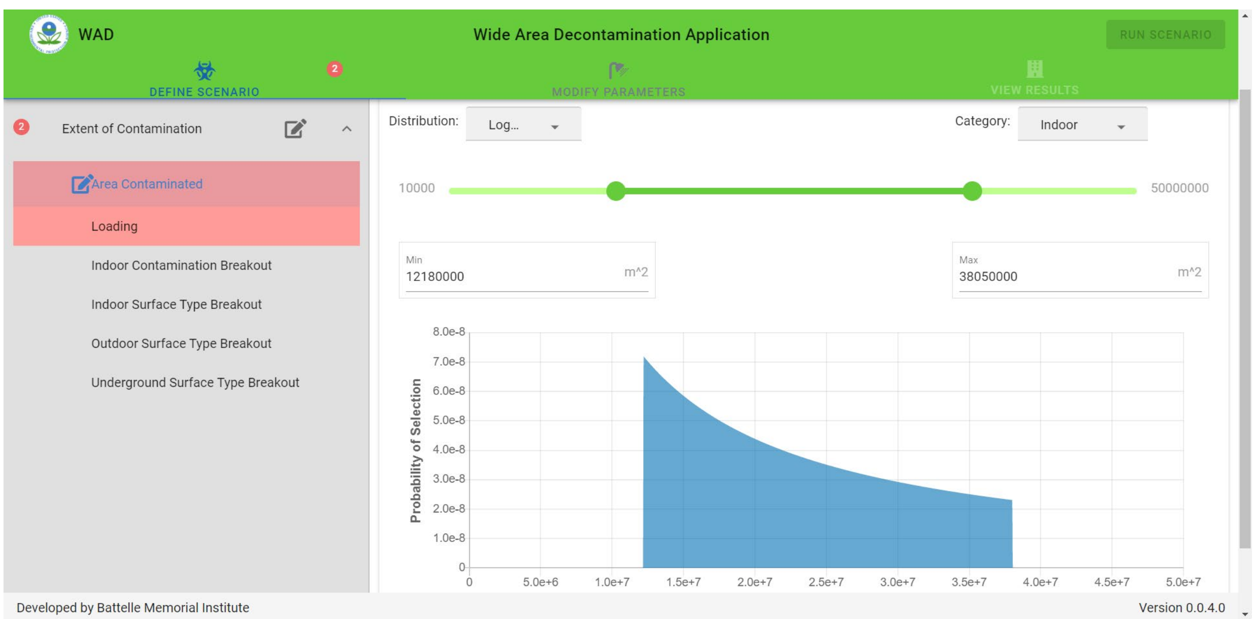

Figure C-5: Parameter Distribution Graph

Users must set an Indoor, Outdoor, and Underground value for both Area Contaminated and Loading before running the model. By default, these values are unset. Users can switch between Indoor, Outdoor, and Underground by using the Category dropdown list, as shown in Figure C-6 below.

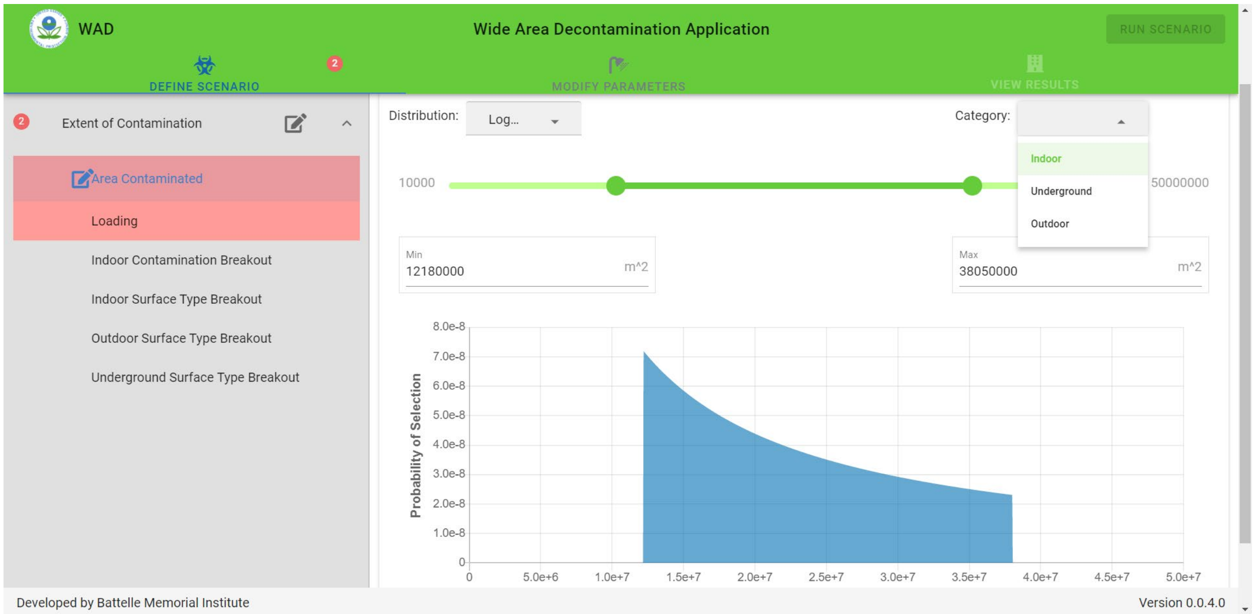

Figure C-6: Category Dropdown List

Once all parameters have been set, the "Run Scenario" button becomes active, allowing the user to run the scenario, as seen in Figure C-7.

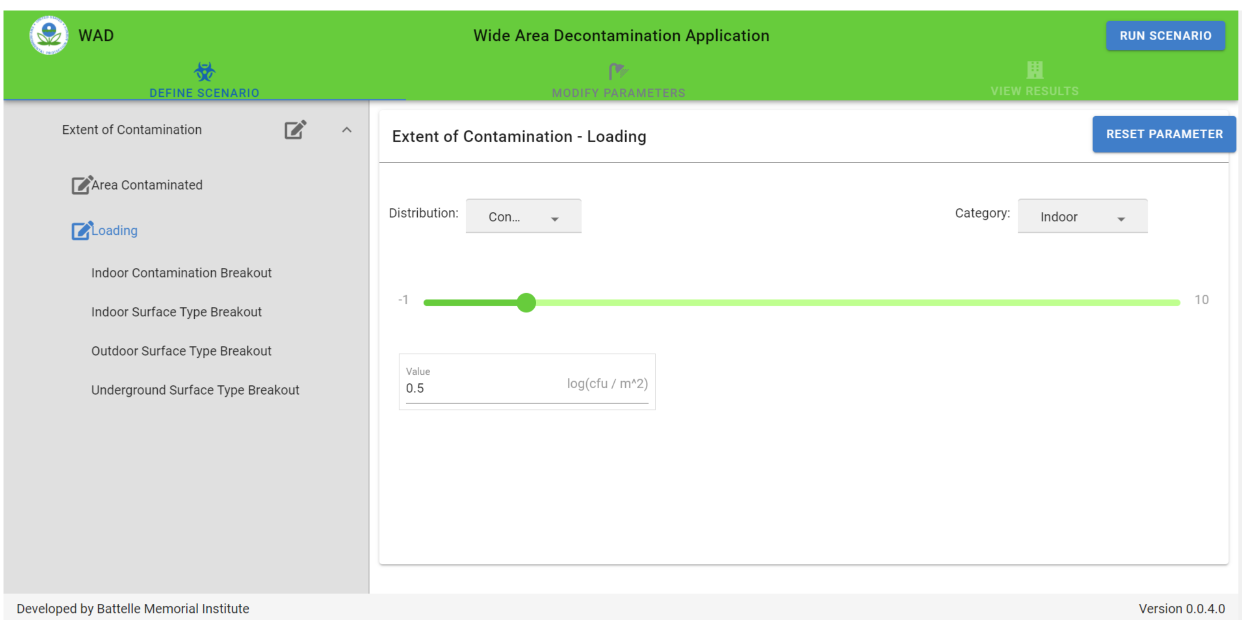

Figure C-7: Active Run Scenario Button

The Modify Parameters tab allows users to adjust values for parameters related to each element of decontamination, including cost parameters, efficacy, and the decontamination treatment methods used on each surface, as shown in Figure C-8.

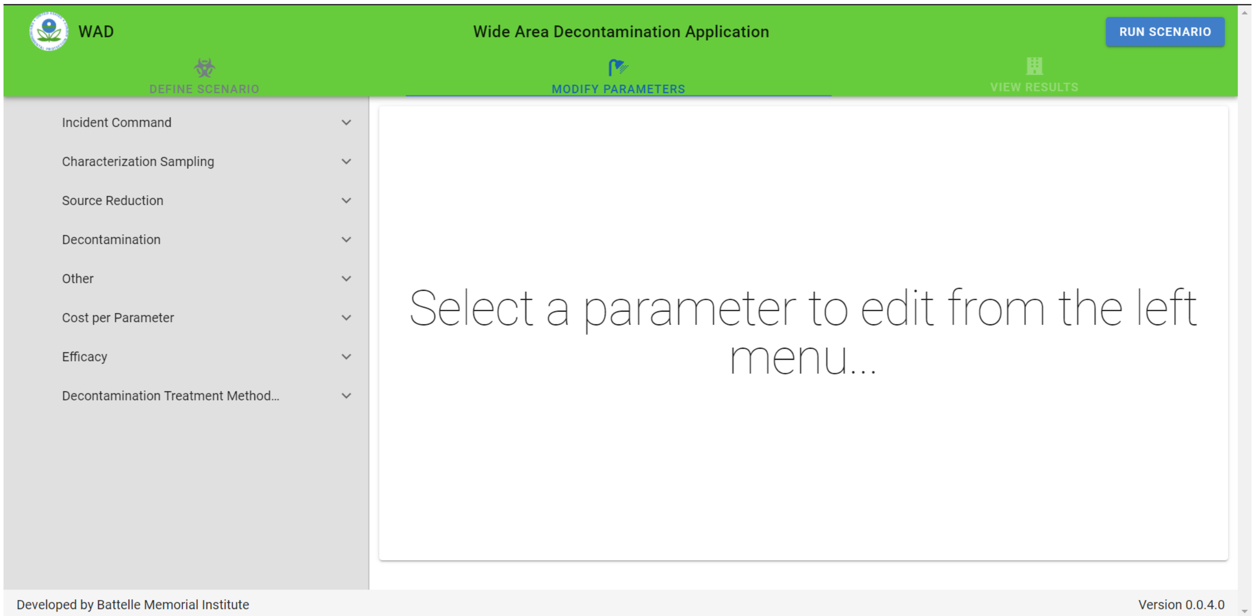

Figure C-8: Modify Parameters Tab

Users can adjust various personnel, logistic, supplies, and safety parameters. Personnel Required (OSC) for Incident Command is shown as an example of a personnel parameter in Figure C-9 below.

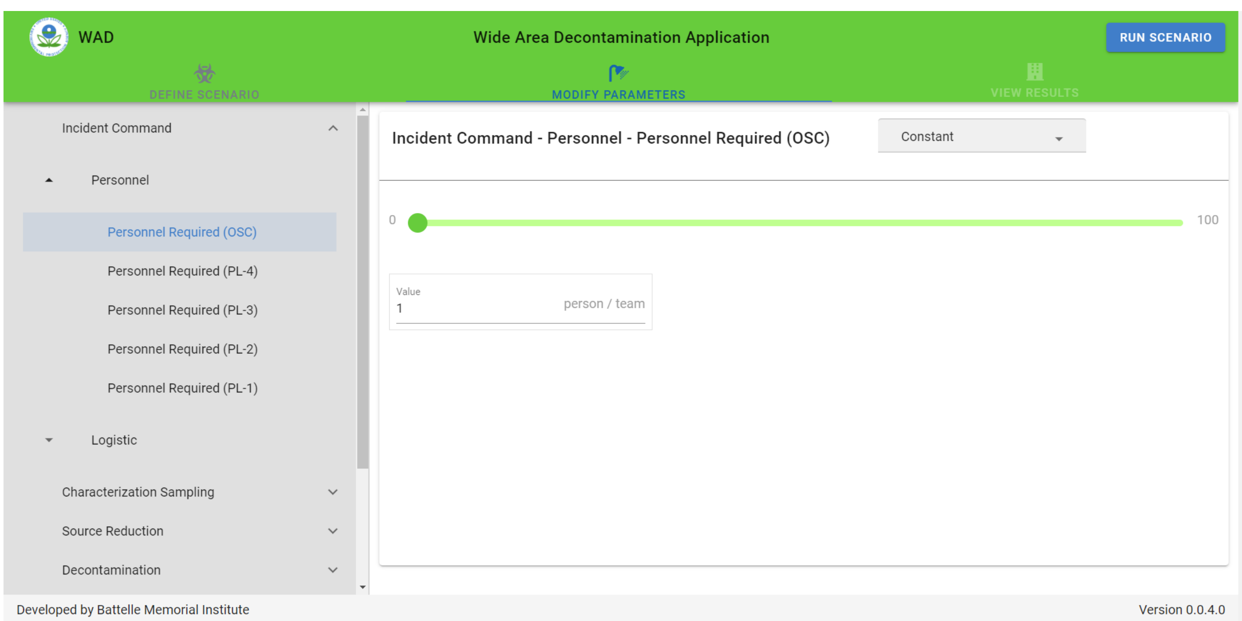

Figure C-9: Example Personnel Parameter

Personnel Overhead Days for Source Reduction is shown as an example of a logistic parameter in Figure C-10 below.

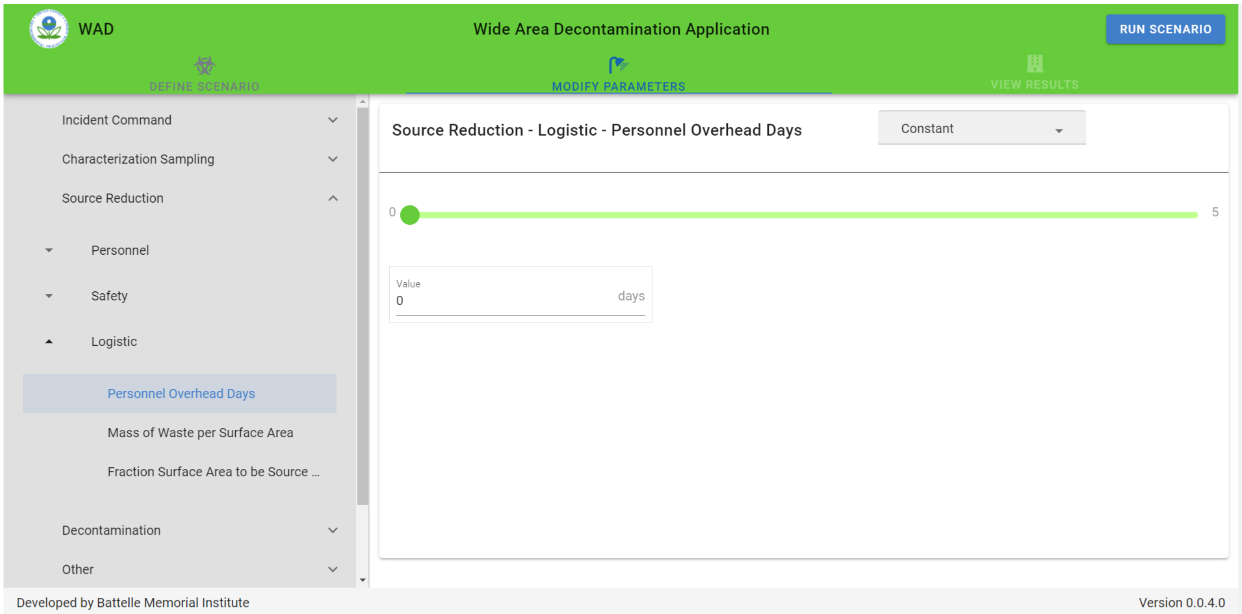

Figure C-10: Example Logistic Parameter

Wipes per Hour per Team for Characterization Sampling is shown as an example of a supplies parameter in Figure C-11 below.

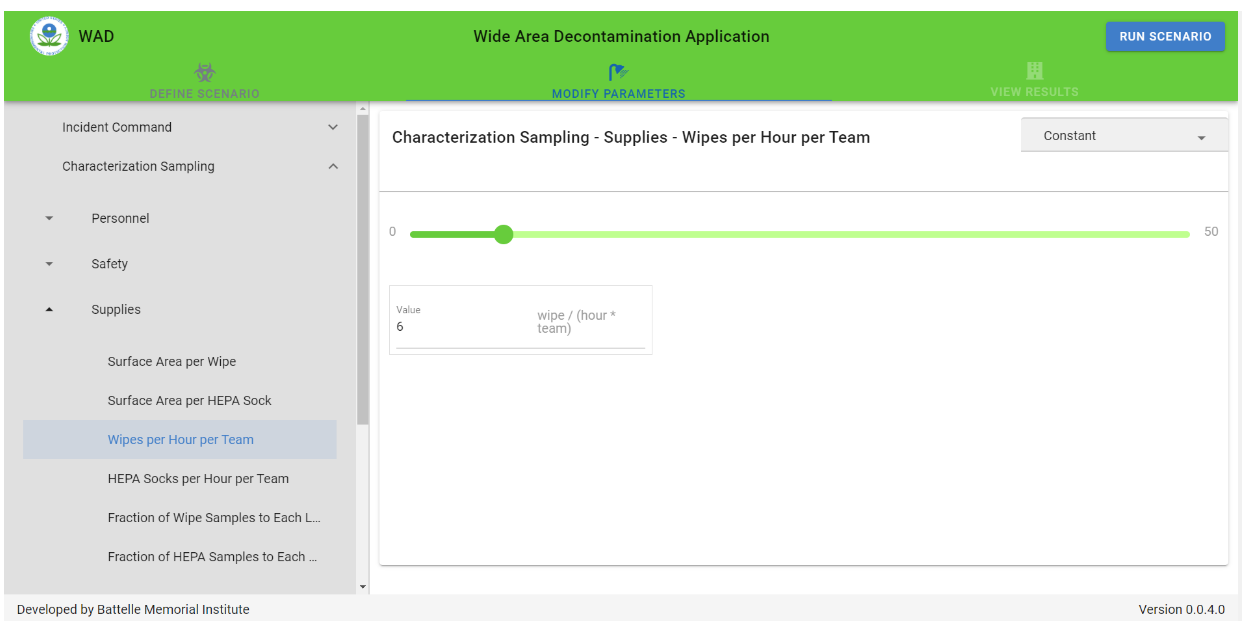

Figure C-11: Example Supplies Parameter

Number of Respirators per Person for Decontamination is shown as an example of a safety parameter in Figure C-12 below.

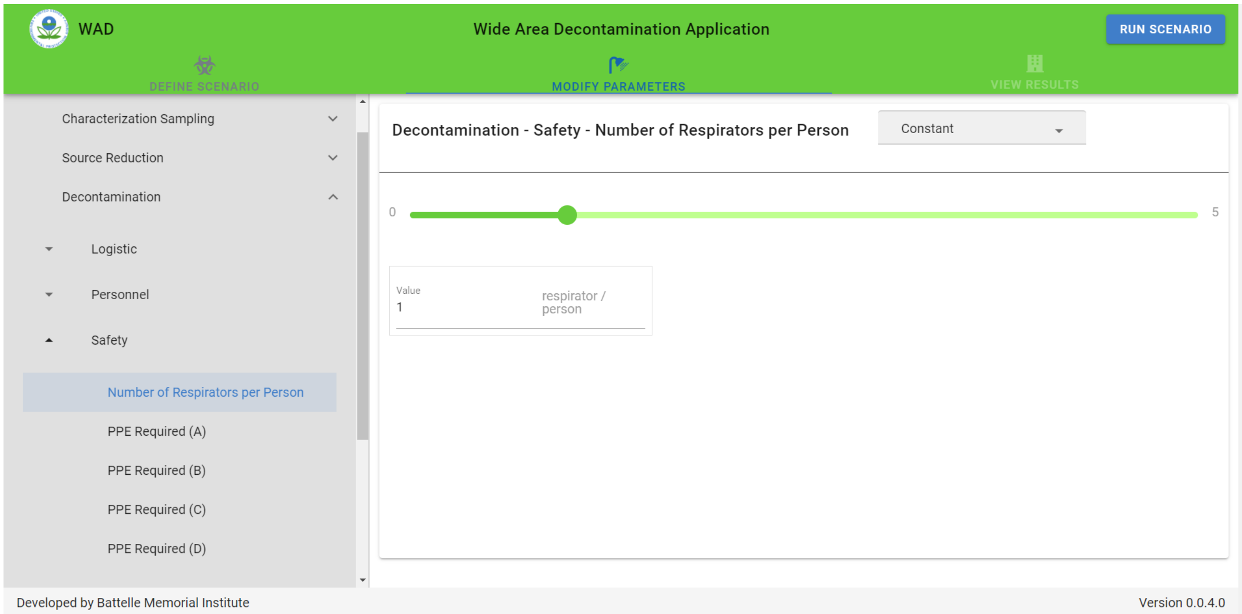

Figure C-12: Example Safety Parameter

Users can again choose between multiple distributions, as shown in Figure C-13.

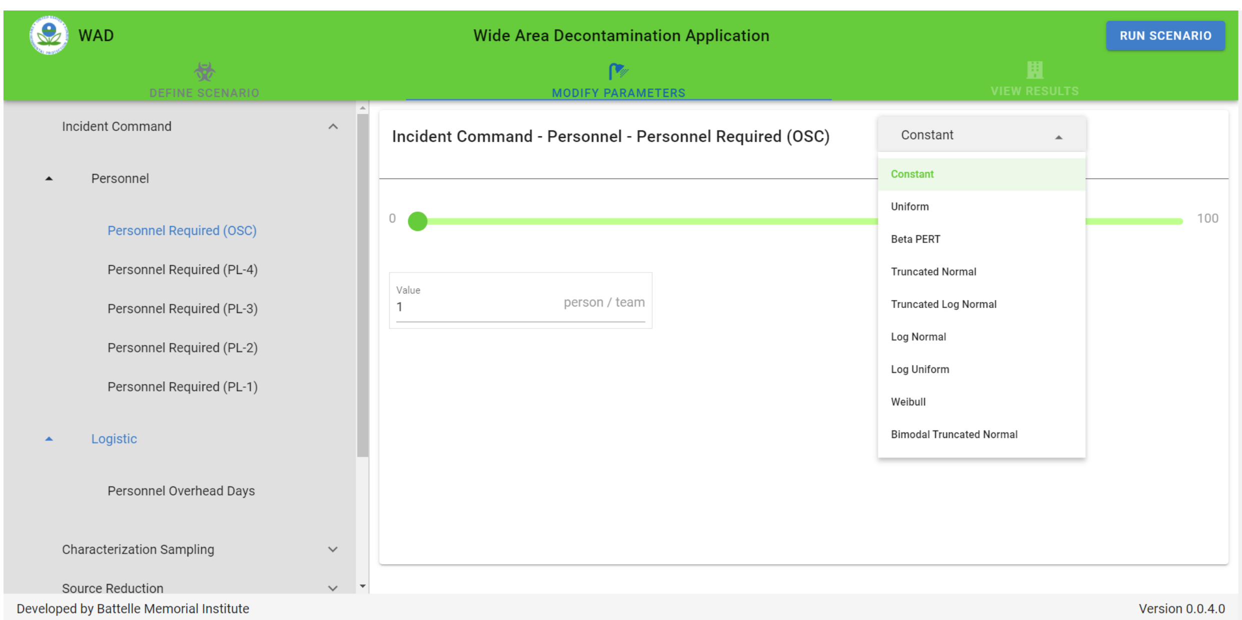

Figure C-13: Modify Parameters Distribution List

Once the scenario parameters have been fully defined, the user can run the scenario using the "Run Scenario" button. The user can select the number of runs for the model to perform as well as set the seeds which allow for repeatability. They can then select the “Run” button to run the scenario. The Run Scenario modal is shown in Figure C-14 below.

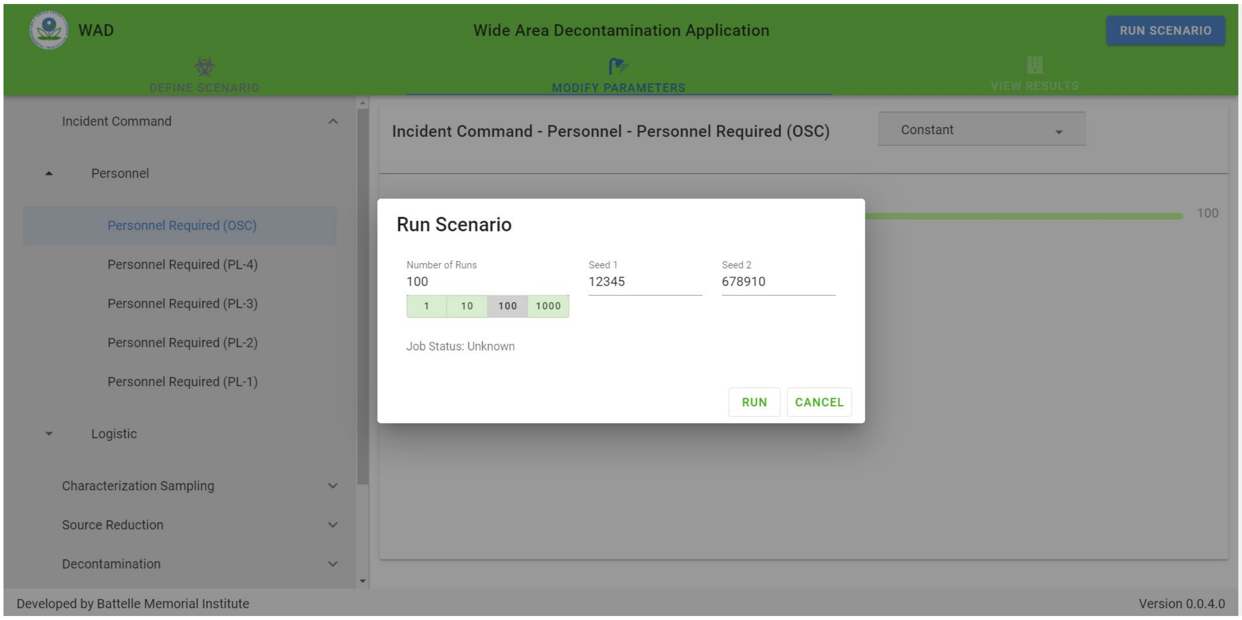

Figure C-14: Run Scenario Modal

Once the scenario has been successfully run, the Job Status will say “Completed”. The “View Results” button will then be available for users to view the results of the completed scenario run, as shown in Figure C-15 below.

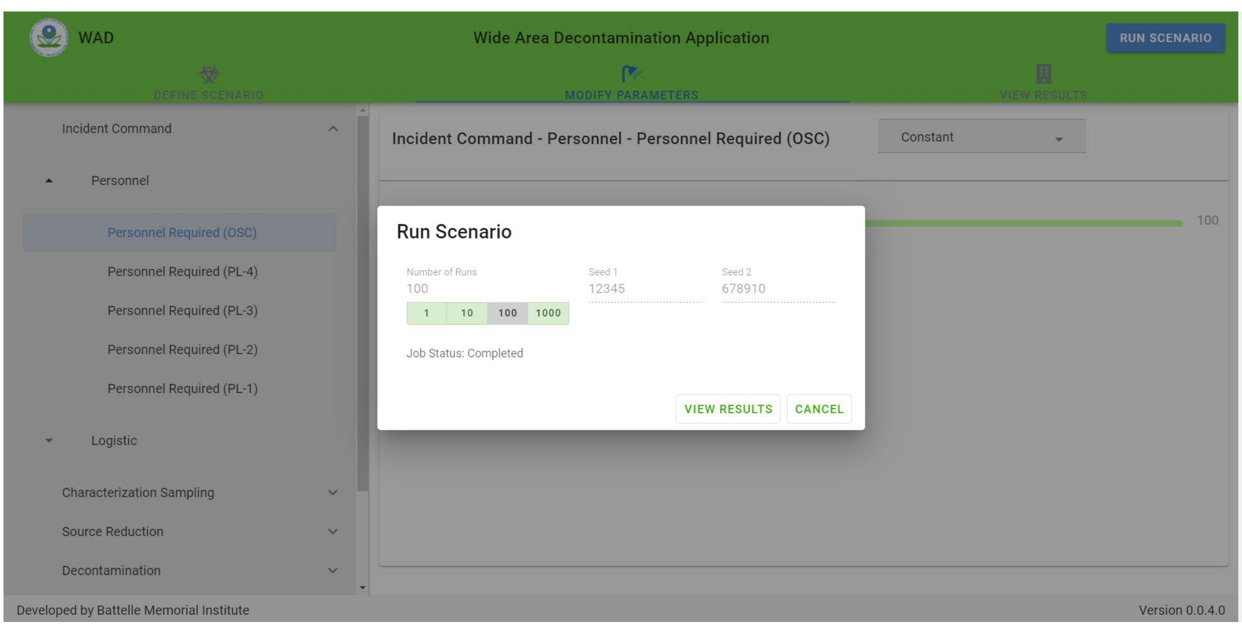

Figure C-15: Completed Job Status

The results dashboard displays various values averaged over all realizations run as well as a cost breakdown and time breakdown by element. From this dashboard, users can select to view the results summary by selecting the "Summary" button, they can return to the parameter definitions using the "View Parameters" button, they can re-run the job by selecting the "Run Job Again" button, or they can export the results to an xlsx by selecting the "Export Results" button, as shown in Figure C-16 below.

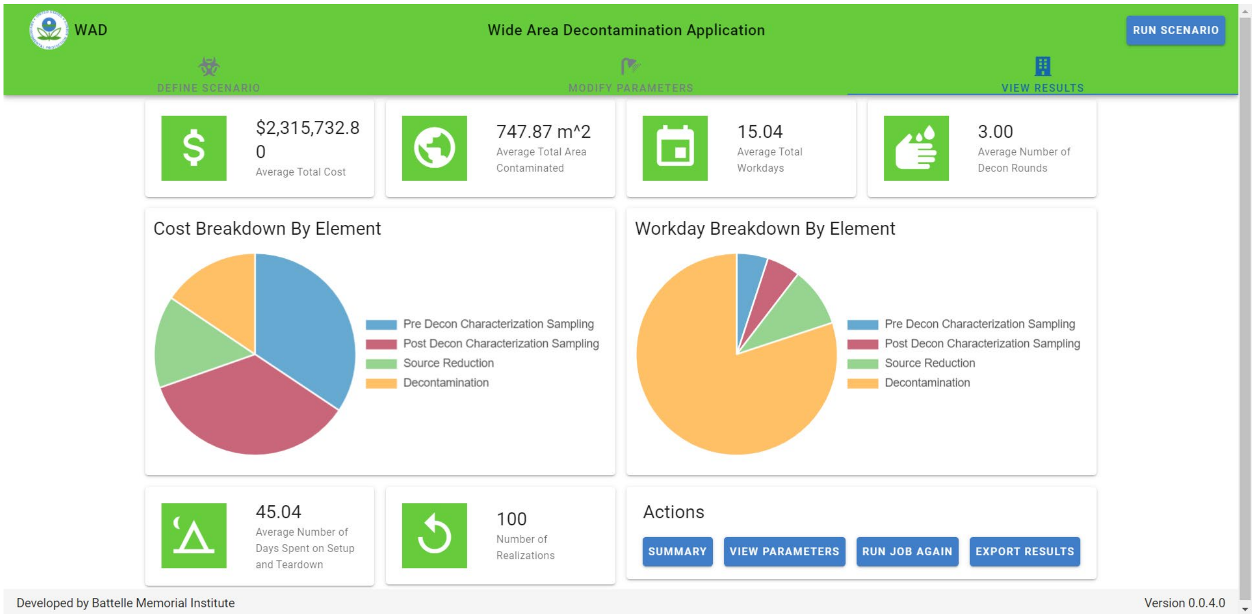

Figure C-16: Results Dashboard

The results summary page allows users to generate different histograms and scatter plots based on the parameters they choose. An example scatter plot of total cost vs element cost is shown in Figure C-17 below.

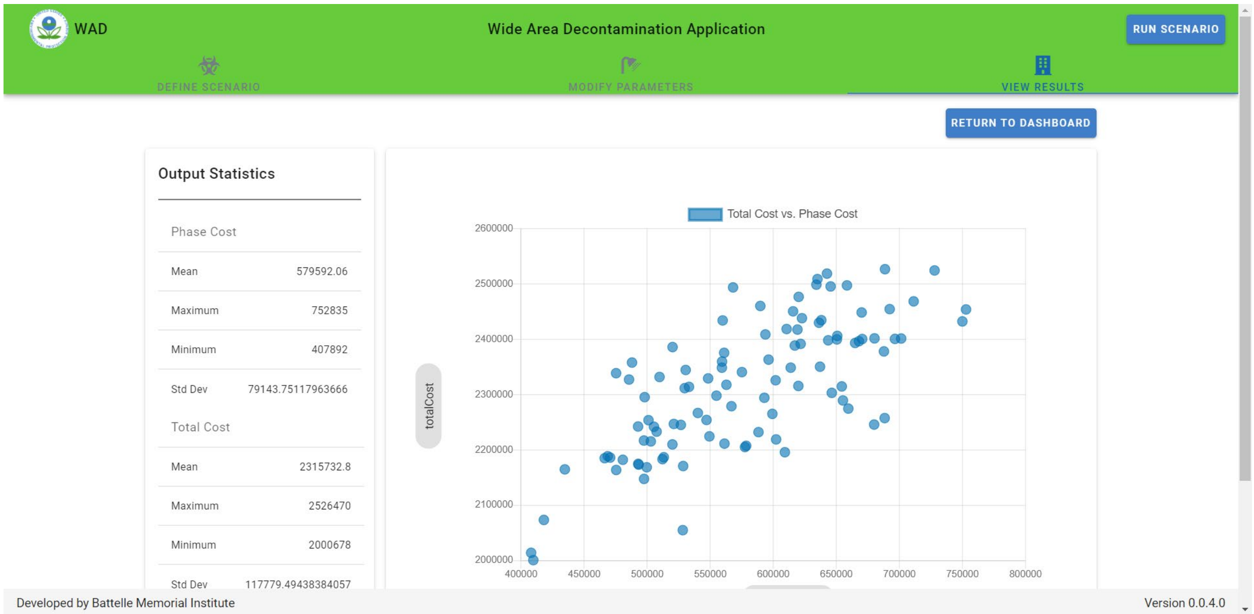

Figure C-17: Results Summary Scatterplot

The results summary page also allows users to view results by realization, as shown in Figure C-18 below.

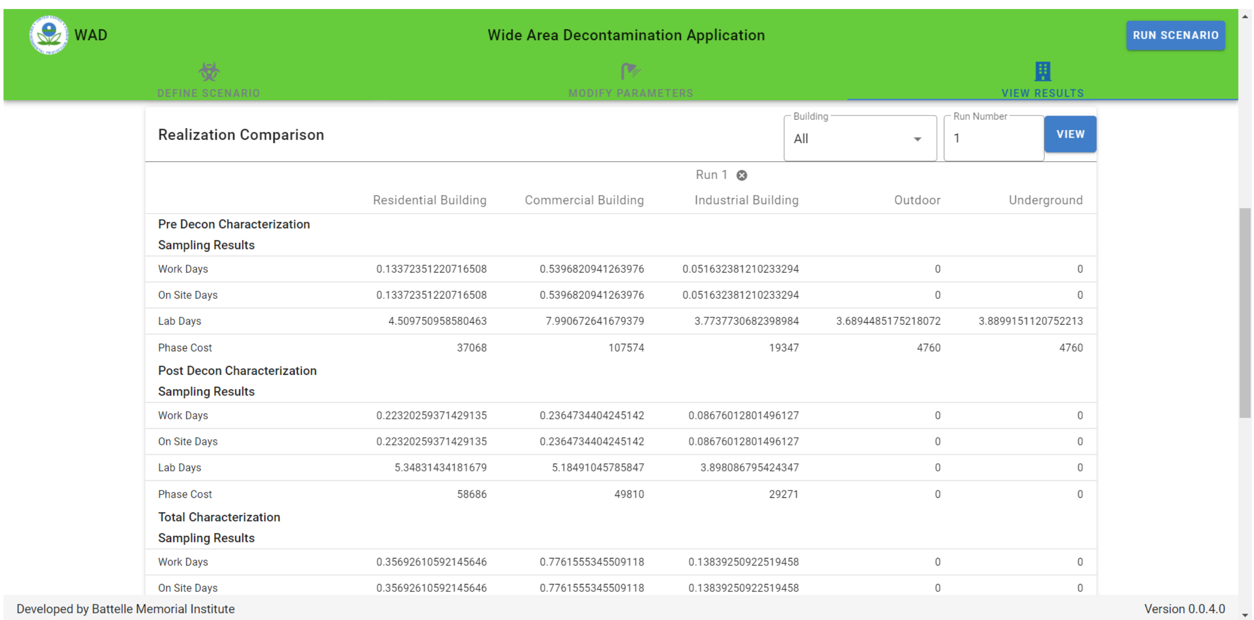

Figure C-18: Results by Realization

Finally, users can export their results to a xlsx file by selecting the “Export Results” button. The file will be generated and automatically downloaded, as shown in Figure C-19.

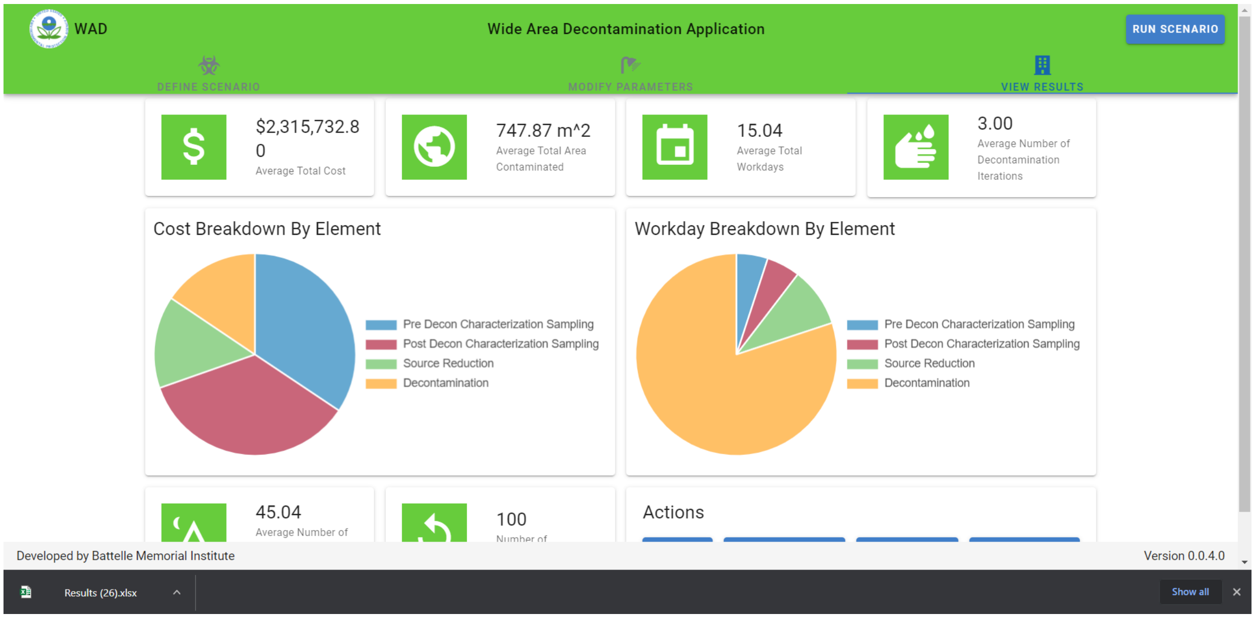

Figure C-19: Exported Results

APPENDIX D: REDUNDANT BIODECONTAMINATION COMPENDIUM COLUMNS

The following table lists the columns that were removed from the BioDecontamination Compendium as they were deemed redundant.

Table D-1: Columns Removed from the BioDecontamination Compendium for Redundancy

Column Name	Description	Equivalent Column
Loading	Target number of spores the surface is initially contaminated with pre-treatment	LoadingNum
ConcDose	Concentration of the active decontamination agent in the treatment	ConcDoseNum
Temp	Temperature of the environment where decontamination is performed	TempNum
RH	Relative humidity of the environment where decontamination is performed	RHNum
ContTime	Amount of time that a surface is exposed to a treatment method	ContTimeNumMin
TotalApp	Total number of applications of decontamination	Similar column was calculated in a later step
SurfMed	Material treated	Similar column was calculated in a later step

APPENDIX E: UNRELATED BIODECONTAMINATION COMPENDIUM COLUMNS

The following table lists the columns that were removed from the BioDecontamination Compendium as they were deemed unrelated to the analysis.

Table E-1: Columns Removed from the BioDecontamination Compendium Due to Being Unrelated to the Analysis

Column Name	Description
EntryDate	Date that data was extracted from the reference
EncRec	Endnote record number
PhysState	Physical state of the surface material
GrimeDirt	Description of dirt or grime if present on the surface
ContTimeDesc	Description of the contact time
InocMeth	Method used to add spores to a surface
SampMeth	Method used to sample a surface after decontamination
AppMethNote	Description of the application method
Strain	Genus species and strain of spore decontaminated
ConcDoseCtrl	Range that the concentration dose falls within
TempCtrl	Range that the environment temperature falls within
RHCtrl	Range that the environment relative humidity falls within
VendProd	Name of the decontamination agent by the vendor
ContTimeUn	Units of the contact time
EffGreater	Indicates if efficacy is reported as “>=EFF”
MatComp	Description of the decontamination method impact on a surface aesthetic or functionality
VendProdDeconAgent	‘VendProd’ + ‘DeconAgent’ columns
VendProdDeconAgentSurfMed	‘VendProd’ + ‘DeconAgent’ + ‘SurfMed’ columns
Entry_order	Order in which records were entered
RinsateLess	Indicates if rinsate is reported as “< Rinsate”
WaterRinse	Indicates if water rinse was used
VolAppDenUn	Units of the volume divided by the coupon area
VendProdDeconAgentAppMeth	‘VendProd’ + ‘DeconAgent’ + ‘AppMeth’ columns
Surface	‘SurfMed’ cleaned using a lookup table in the compendium
TempNumCheck	Boolean indicating if the ‘Temp’ value is a number
ConcDoseNumCheck	Boolean indicating if the ‘ConcDoseNum’ value is a number
ContTimeNumCheck	Boolean indicating if the ‘ContTimeNum’ value is a number
ContTimeNum	Boolean indicating if the ‘Temp’ value is a number
ContTimeNumHrs	Contact time converted to hours
LoadingNumCheck	Boolean indicating if the ‘LoadingNum’ value is a number
RHNumCheck	Boolean indicating if the ‘RHNum’ value is a number
DeconMethod	‘AppMeth’ cleaned using a lookup table with specific decon agents noted
VolAppDen(L/m^2)	Density of the volume of decontamination agent applied in L/m^2
PosCalc	Calculates the number of ‘Positives’ if one is not listed
LposRecCalc	Calculates the ‘LposRec’ for all records that don’t provide one as the efficacy if ‘EffMeas’ is ‘LR’ and ‘EffGreater’ is ‘>’ or ‘>=‘
CT*	Concentration multiplied by contact time
CTUn	Units of the concentration multiplied by contact time

Notes:
* Compendium documentation implies that CT is the concentration multiplied by the contact time. A value is given for this variable for 378 records. Of these records, six have values that are identical to the contact time with the same units. The remaining 372 have zeroes and no units provided. Therefore, this

column was deemed unusable as the data did not imply the same definition given within compendium documentation.

APPENDIX F: SURFACE TYPE LOOKUP TABLES FOR INTERIOR SURFACES

The following tables show the lookup tables used to categorize the representative surface names by interior surface type. Note these are for indoor scenarios only.

Table F-1: Indoor Scenario - Interior Walls Surfaces Lookup Table

Interior Walls Surfaces
Any Painted Surface
Cellulose Insulation
Cement
Cinder Block
Concrete
Decorative Laminate
Drywall
Fiberglass Wall Paneling
Glass
Painted Cinderblock
Painted Dry Wall
Painted Wallboard
Plastic Walls
Plywood
Stainless Steel
Treated Wood
Wallboard
Wallboard Paper
Brick
Wood
Plate Glass
Tyvek

Table F-2: Indoor Scenario - Carpeted Floors Surfaces Lookup Table

Carpeted Floors Surfaces
Carpet
Industrial Carpet
Loop-pile Carpet
Nylon Carpet
Office Carpet
Woven Carpet

Table F-3: Indoor Scenario - Non-Carpeted Floors Surfaces Lookup Table

Non-Carpeted Floors Surfaces
Cement
Ceramic
Concrete
Decorative Laminate
Granite
Grimed and Washed Tile
Grimed Tile
Hardwood
Laminate
Linoleum
Rubber Flooring
Stainless Steel
Tile
Treated Wood
Vinyl Tile
Vinyl Flooring
Wood
Wood Laminate
Wood Tiles
Grimed Concrete
Painted Concrete

Table F-4: Indoor Scenario - Ceilings Surfaces Lookup Table

Ceiling Surfaces
Acoustic Ceiling Tiles
Ceiling Tile
Cement
Concrete
Stainless Steel

Table F-5: Indoor Scenario - HVAC and Duct Work Surfaces Lookup Table

HVAC/Duct Work Surfaces
Biofilm Covered Copper Pipe
Biofilm Covered PVC Pipe
Carbon Steel
Fiberglass Lined HVAC Duct
Galvanized Metal
Galvanized Metal HVAC Duct
Galvanized Steel
Metal Ductwork
Polyvinyl Chloride
Stainless Steel
Steel
Wiring Insulation

Table F-6: Indoor Scenario - Miscellaneous Surfaces Lookup Table

Miscellaneous Surfaces
Aluminum
Butyl Rubber
Chair Back
Chair Seat
Cork Boards
Cotton Cloth
Desktop
Epoxy
Filing Cabinet
Food Packaging Material (Presumably Plastic)
Keyboard
Mylar
Nylon
Office Air
Paint
Painted Canvas
Paper
Particle Board
Plastic
Plywood
Polycarbonate
Polyethylene
Polyolefin
Polypropylene
Polystyrene
Polyurethane
Porcelain
Silk Fabric
Teflon
Vinyl Seating
Painted Paper

APPENDIX G: SURFACE TYPE LOOKUP TABLES FOR EXTERIOR SURFACES

The following tables show the lookup tables used to categorize the representative surface names by exterior surface type. Note these are for outdoor scenarios only.

Table G-1: Outdoor Scenario - Exterior Walls Surfaces Lookup Table

Exterior Walls Surfaces
Brick
Cement
Cinder Block
Glass
Painted Cinder Block
Plate Glass
Treated Wood
Tyvek

Table G-2: Outdoor Scenario - Roofing Surfaces Lookup Table

Roofing Surfaces
Asphalt
Cement
Ceramic
Galvanized Metal
Galvanized Steel
Wood
Wood Tiles
Treated Wood
Grimed Wood

Table G-3: Outdoor Scenario – Flooring and Pavement Surfaces Lookup Table

Outdoor Flooring and Pavement Surfaces
Asphalt
Asphalt Paving
Cement
Concrete
Deck Wood
Rough Surface Patio Tiles
Rough-Cut Wood
Smooth Surface Patio Tiles
Tile
Treated Wood
Wood Laminate
Wood Tiles
Grimed Concrete
Painted Concrete
Wood
Grimed Wood

Table G-4: Outdoor Scenario - Water Lookup Table

Water
Natural Water
Water

Table G-5: Outdoor Scenario - Topsoil and Vegetation Lookup Table

Topsoil and Vegetation
Arizona Test Dust
Topsoil

Table G-6: Outdoor Scenario - Miscellaneous Surfaces Lookup Table

Miscellaneous Surfaces
Any Painted Surface
Chair Back
Chair Seat
Cotton Cloth
Nylon
Painted Aluminum Alloy
Painted Canvas
Painted Steel
Painted Metal
Particle Board
Plastic
Plate Glass
Plywood
Polycarbonate
Polyolefin
Polystyrene
Polyurethane
Polyvinyl Chloride
Silk Fabric
Stainless Steel
Steel
Teflon
Tire
Vinyl Seating
Grimed Steel
Carbon Steel
Aluminum

APPENDIX H: SURFACE TYPE LOOKUP TABLES FOR UNDERGROUND SURFACES

The following tables show the lookup tables used to categorize the representative surface names by underground surface type. Note these are for underground scenarios only.

Table H-1: Underground Scenario - Interior Walls Surfaces Lookup Table

Interior Walls Surfaces
Any Painted Surface
Cellulose Insulation
Cement
Cinder Block
Concrete
Decorative Laminate
Drywall
Fiberglass Wall Paneling
Glass
Painted Cinder Block
Painted Dry Wall
Painted Wallboard
Plastic Walls
Plate Glass
Plywood
Stainless Steel
Tile
Treated Wood
Wallboard
Wallboard Paper
Brick
Wood
Grimed Wood
Tyvek

Table H-2: Underground Scenario – Carpeted Flooring Surfaces Lookup Table

Carpeted Flooring Surfaces
Carpet
Industrial Carpet
Loop-Pile Carpet
Nylon Carpet
Office Carpet
Woven Carpet

Table H-3: Underground Scenario - Non-Carpeted Flooring Surfaces Lookup Table

Non-Carpeted Flooring Surfaces
Cement
Ceramic
Concrete
Decorative Laminate
Granite
Grimed and Washed Tile
Grimed Tile
Hardwood
Laminate
Linoleum
Rubber Flooring
Stainless Steel
Tile
Treated Wood
Vinyl Tile
Vinyl Flooring
Wood
Wood Laminate
Wood Tiles
Asphalt
Asphalt Paving
Grimed Concrete
Painted Concrete
Grimed Wood

Table H-4: Underground Scenario - Ceilings Surfaces Lookup Table

Ceilings Surfaces
Acoustic Ceiling Tiles
Ceiling Tile
Cement
Concrete
Stainless Steel

Table H-5: Underground Scenario - HVAC and Duct Work Surfaces Lookup Table

HVAC/Duct Work Surfaces
Biofilm Covered Copper Pipe
Biofilm Covered PVC Pipe
Carbon Steel
Fiberglass Lined HVAC Duct
Galvanized Metal
Galvanized Metal HVAC Duct
Galvanized Steel
Metal Ductwork
Polyvinyl Chloride
Stainless Steel
Steel
Wiring Insulation

Table H-6: Underground Scenario - Miscellaneous Surfaces Lookup Tab

Miscellaneous Surfaces
Butyl Rubber
Carbon Steel
Chair Back
Chair Seat
Cotton Cloth
Desktop
Filing Cabinet
Galvanized Metal
Galvanized Metal HVAC Duct
Galvanized Steel
Keyboard

Miscellaneous Surfaces
Metal Ductwork
Nylon
Painted Aluminum Alloy
Painted Steel
Painted Metal
Painted Paper
Particle Board
Plastic
Plate Glass
Polycarbonate
Polyethylene
Polyolefin
Polypropylene
Polystyrene
Polyurethane
Polyurethane Painted Aluminum
Polyvinyl Chloride
Silk Fabric
Stainless Steel
Steel
Teflon
Tire
Treated Wood
Tyvek
Untreated Wood
Vinyl Seating
Wiring Insulation
Grimed Steel
Aluminum
Painted Canvas
Fiberglass Lined HVAC Duct
Wood
Paint

APPENDIX I: HIGHLY CORRELATED SCATTER PLOTS

The following scatter plots were fit with a uniform x-dependent distribution in order to calculate an efficacy value.

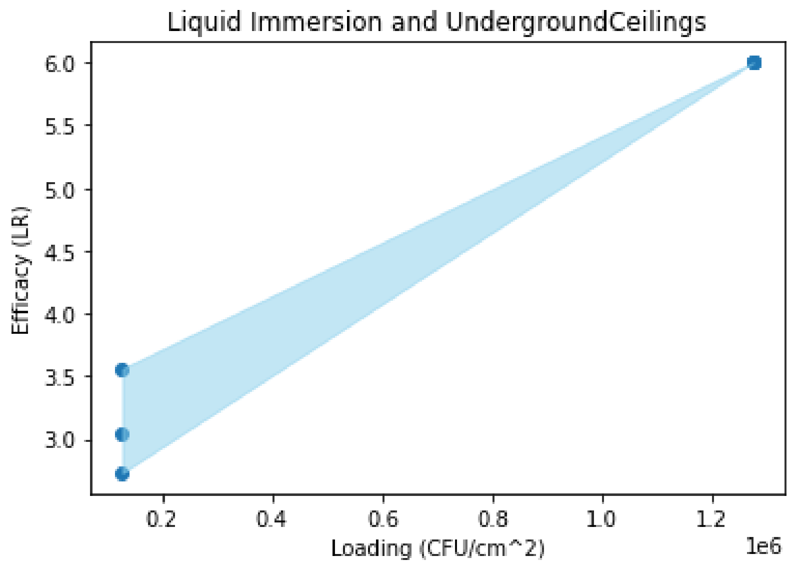

Figure I-1: Correlation Between Efficacy and Loading for Liquid Immersion and UndergroundCeilings

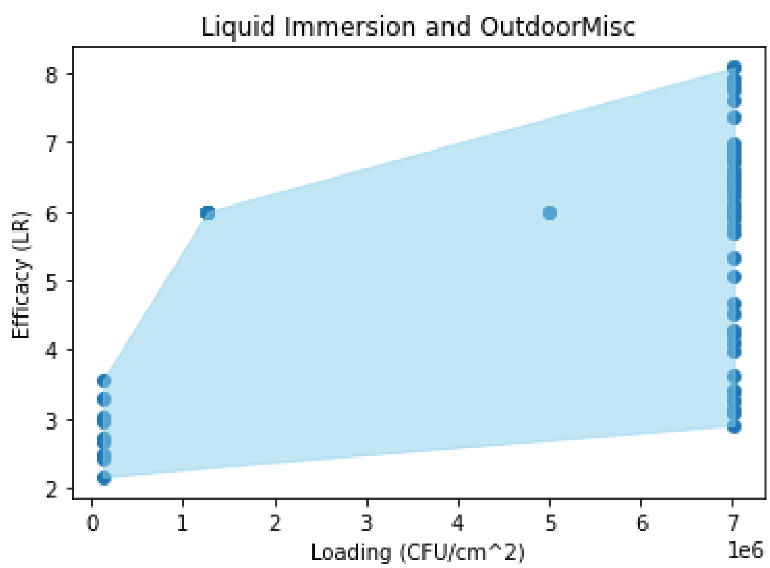

Figure I-2: Correlation Between Efficacy and Loading for Liquid Immersion and OutdoorMisc

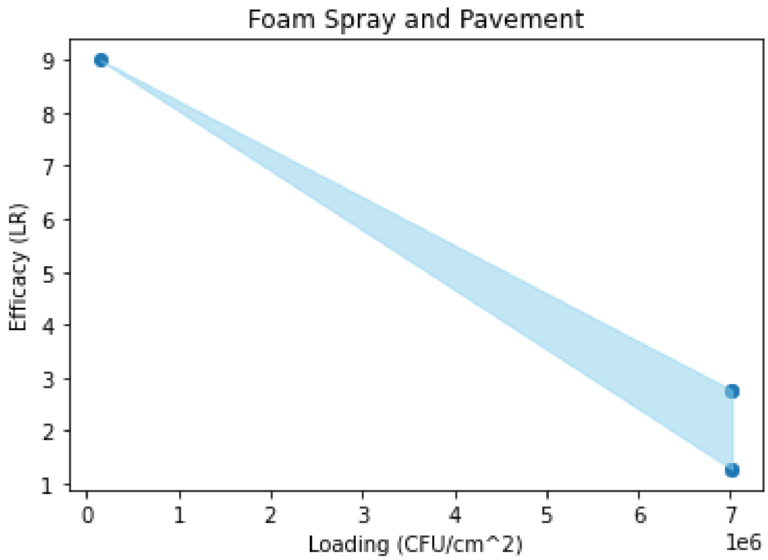

Figure I-3: Correlation Between Efficacy and Loading for Foam Spray and Pavement

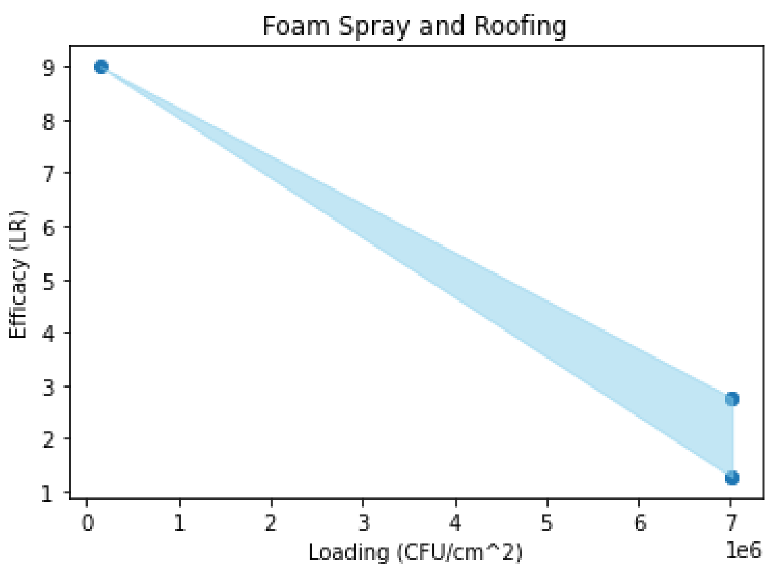

Figure I-4: Correlation Between Efficacy and Loading for Foam Spray and Roofing

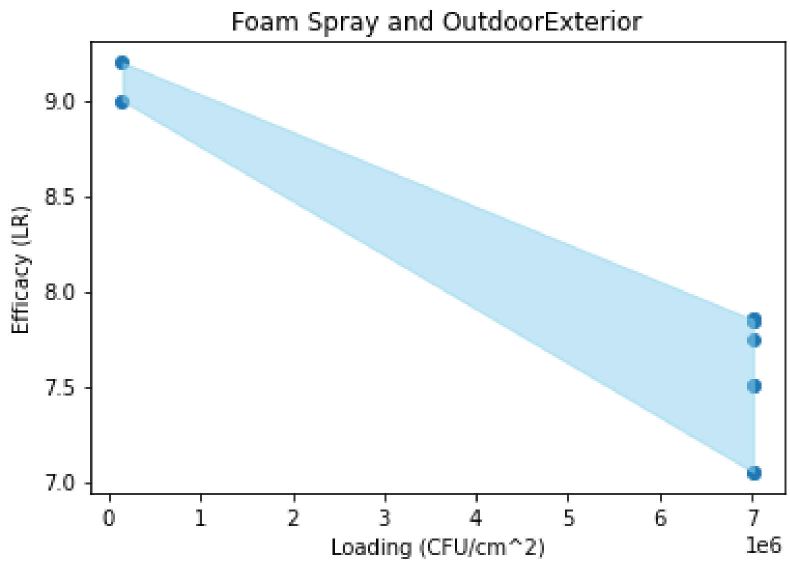

Figure I-5: Correlation Between Efficacy and Loading for Foam Spray and OutdoorExterior

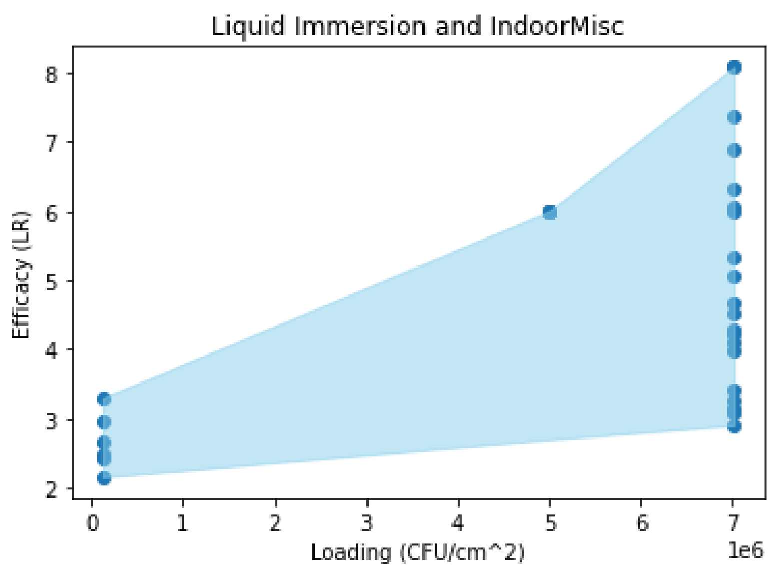

Figure I-6: Correlation Between Efficacy and Loading for Liquid Immersion and IndoorMisc

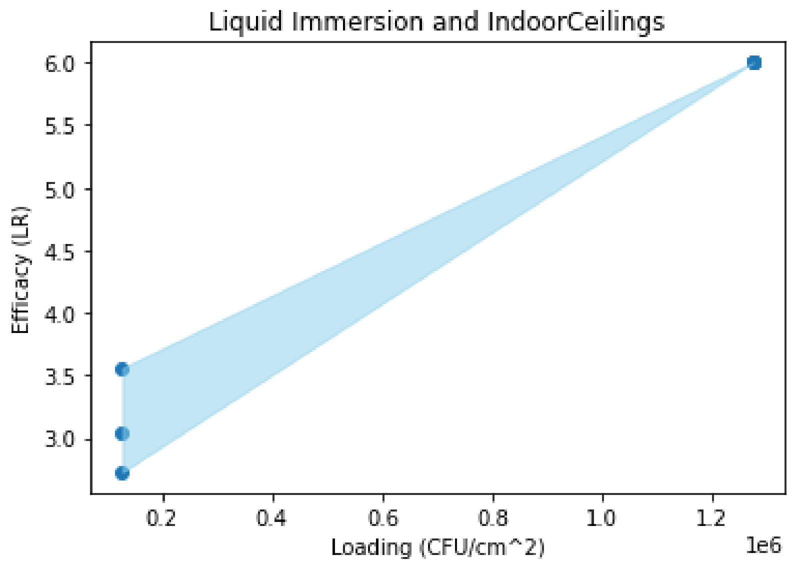

Figure I-7: Correlation Between Efficacy and Loading for Liquid Immersion and IndoorCeilings

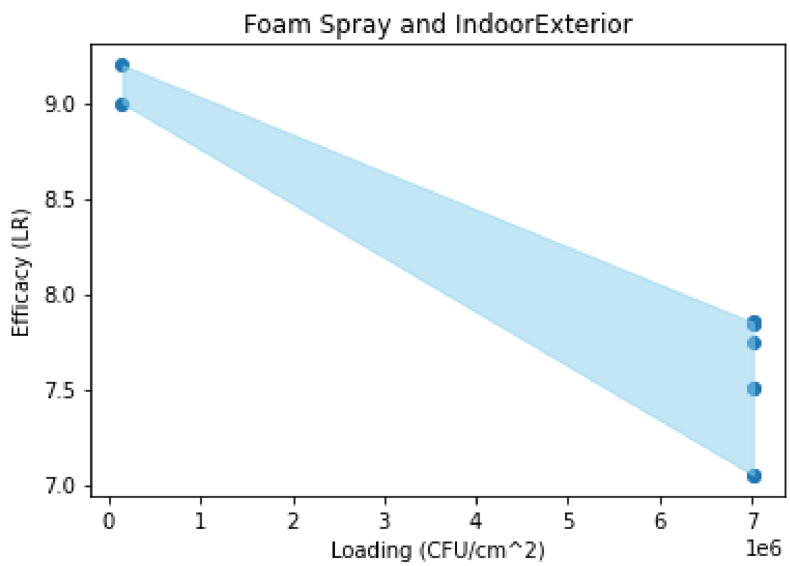

Figure I-8: Correlation Between Efficacy and Loading for Foam Spray and IndoorExterior

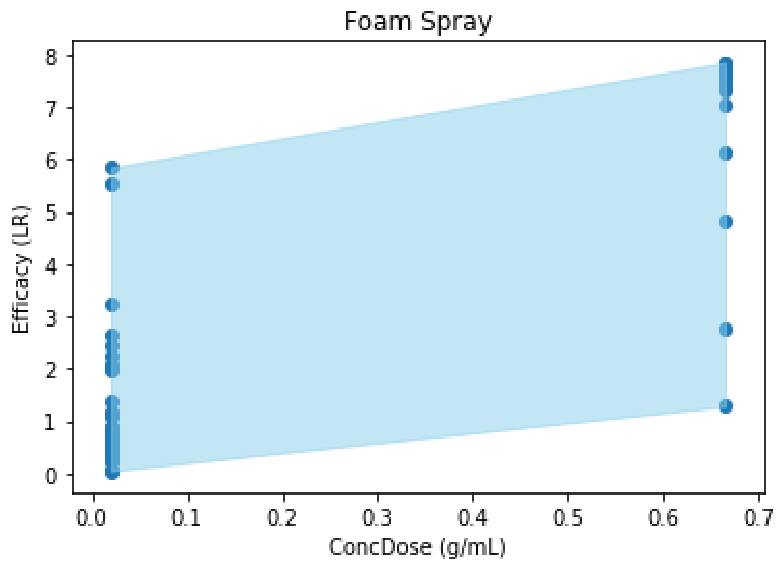

Figure I-9: Correlation Between Efficacy and ConcDose for Foam Spray

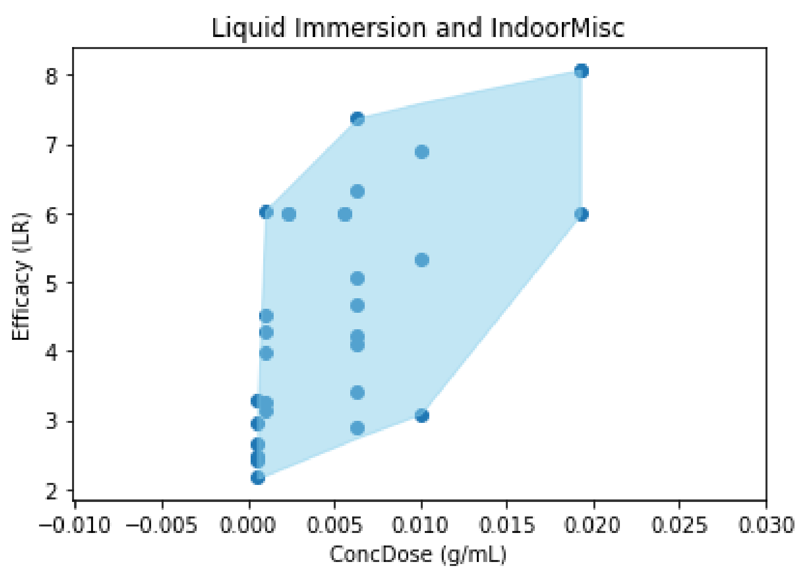

Figure I-10: Correlation Between Efficacy and ConcDose for Liquid Immersion and IndoorMisc

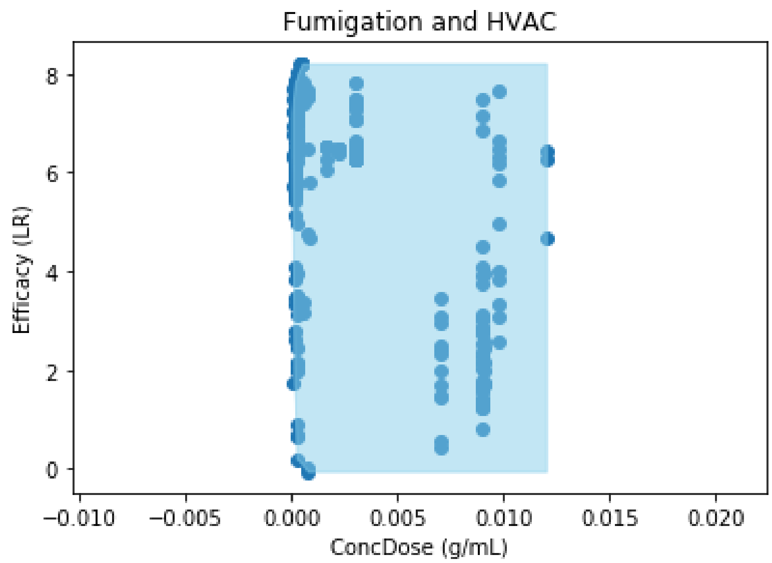

Figure I-11: Correlation Between Efficacy and ConcDose for Fumigation and HVAC

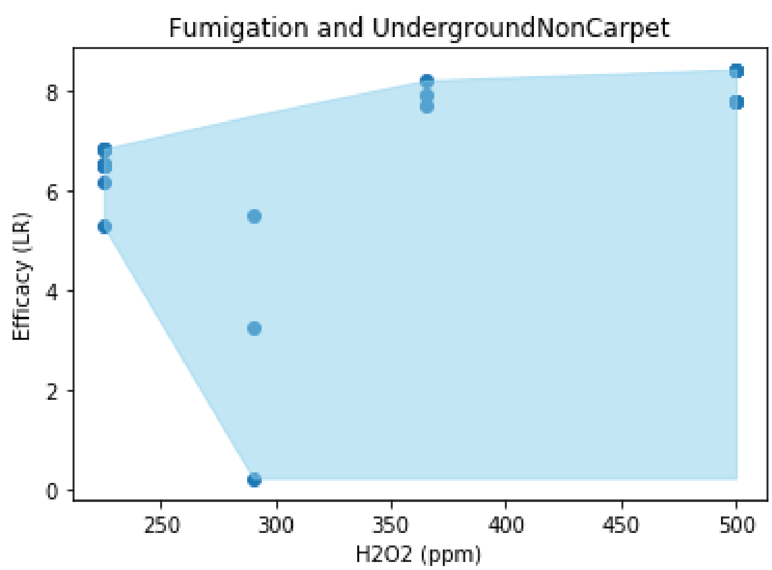

Figure I-12: Correlation Between Efficacy and H2O2 for Fumigation and UndergroundNonCarpet

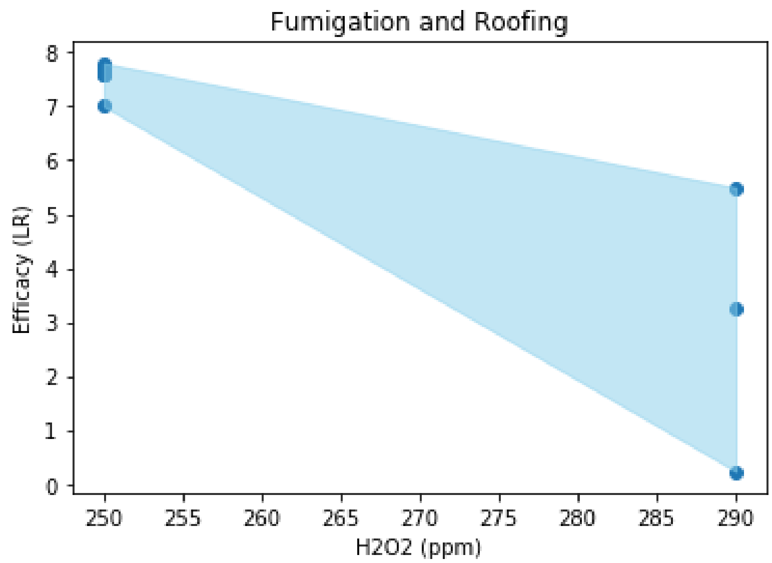

Figure I-13: Correlation Between Efficacy and H_2O_2 for Fumigation and Roofing

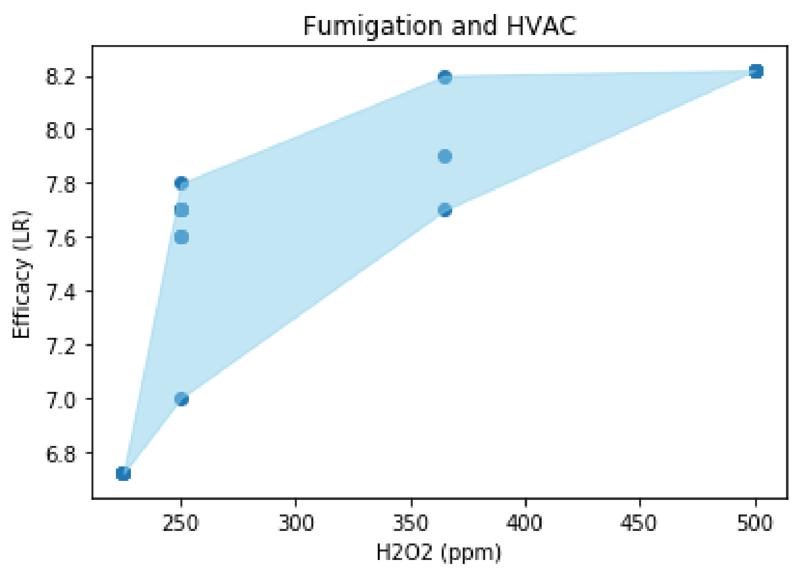

Figure I-14: Correlation Between Efficacy and H_2O_2 for Fumigation and HVAC

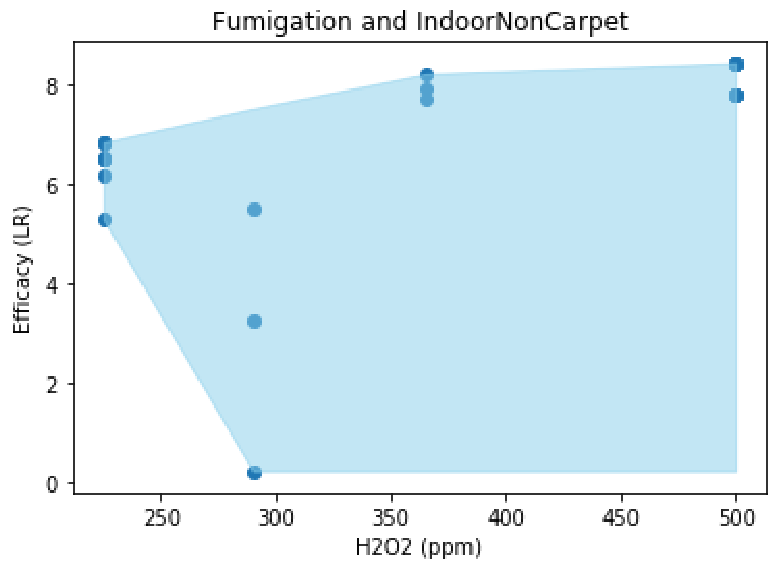

Figure I-15: Correlation Between Efficacy and H_2O_2 for Fumigation and IndoorNonCarpet

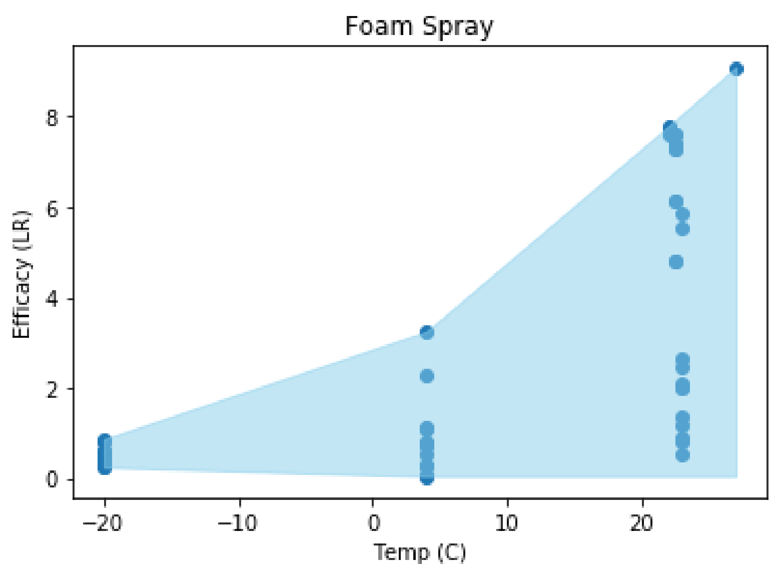

Figure I-16: Correlation Between Efficacy and Temp for Foam Spray

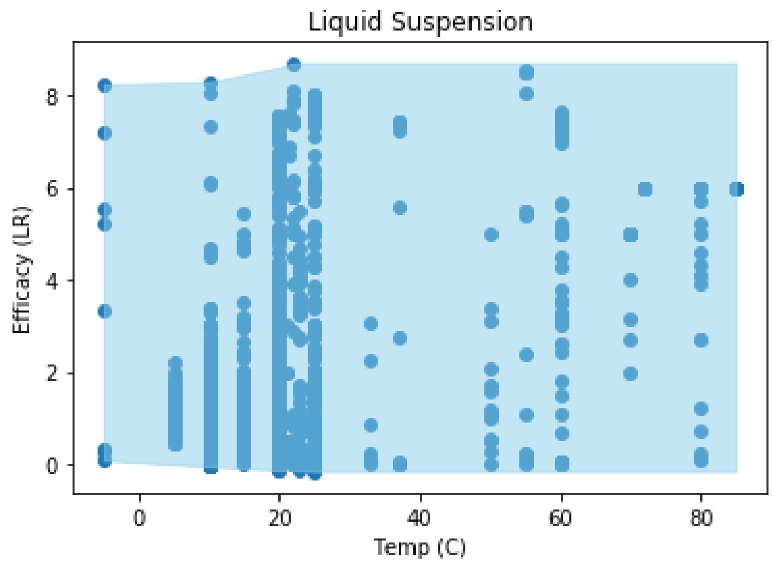

Figure I-17: Correlation Between Efficacy and Temp for Liquid Suspension

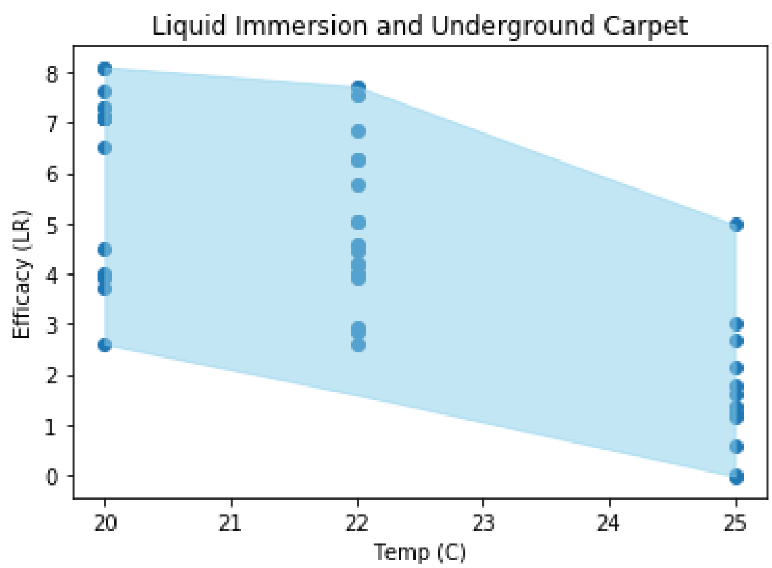

Figure I-18: Correlation Between Efficacy and Temp for Liquid Immersion and UndergroundCarpet

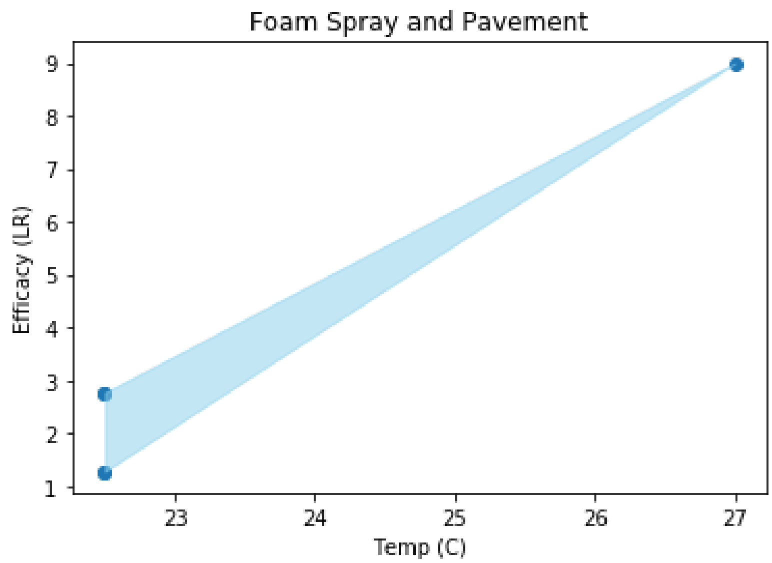

Figure I-19: Correlation Between Efficacy and Temp for Foam Spray and Pavement

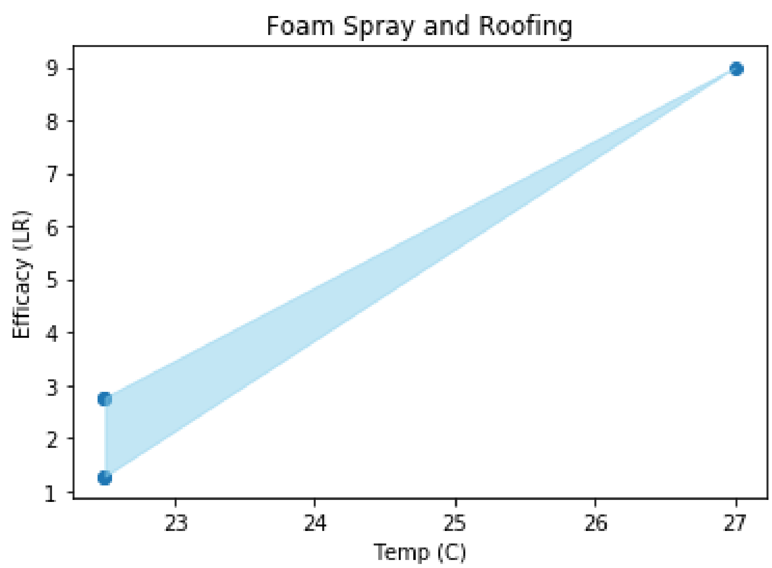

Figure I-20: Correlation Between Efficacy and Temp for Foam Spray and Roofing

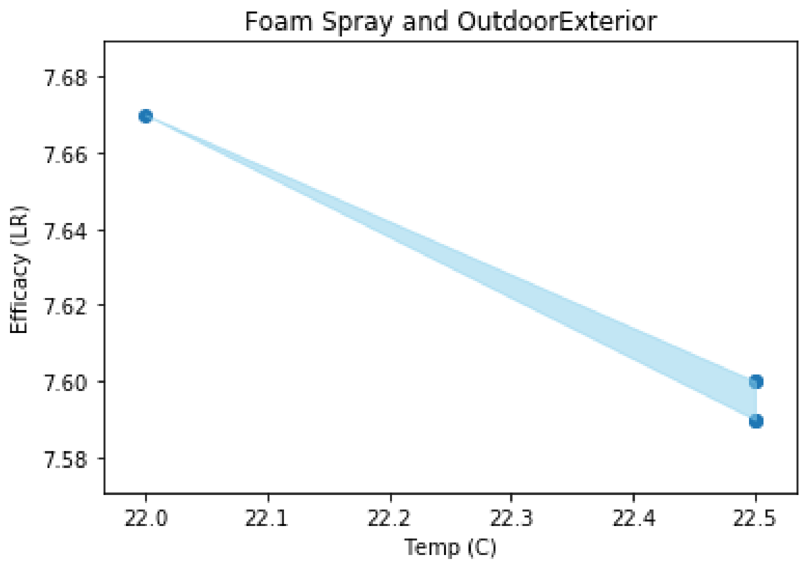

Figure I-21: Correlation Between Efficacy and Temp for Foam Spray and OutdoorExterior

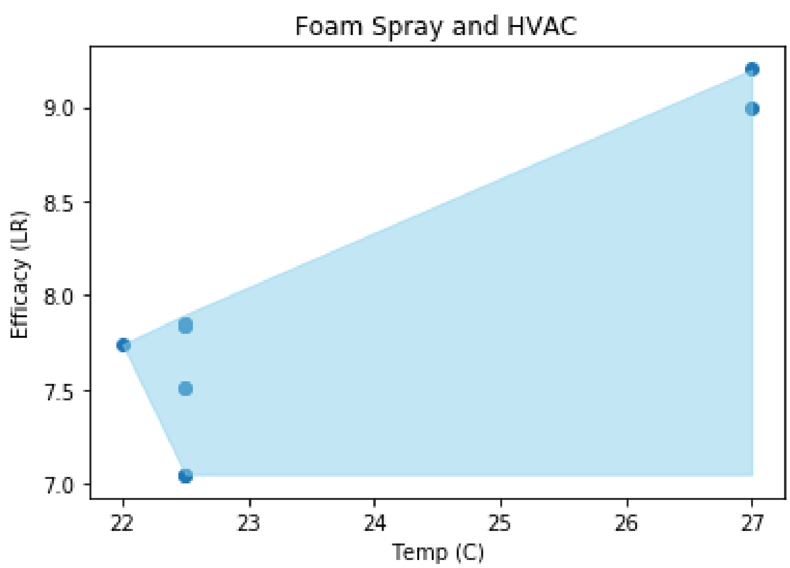

Figure I-22: Correlation Between Efficacy and Temp for Foam Spray and HVAC

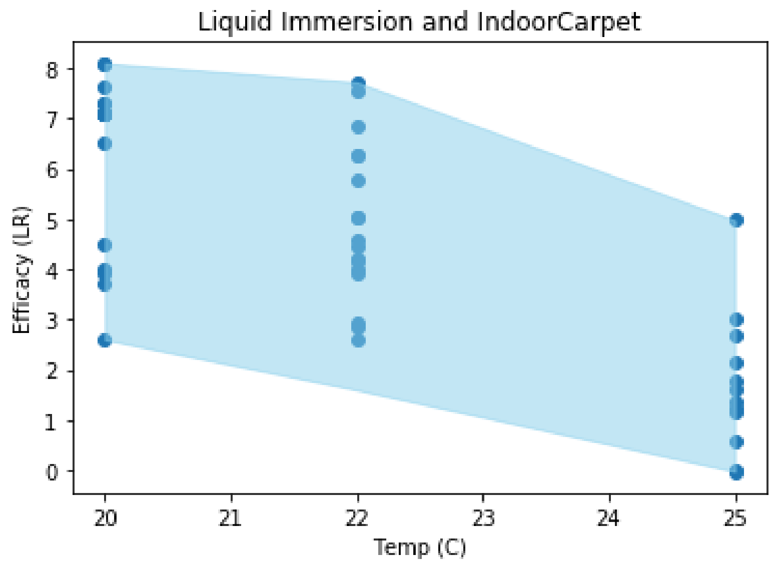

Figure I-23: Correlation Between Efficacy and Temp for Liquid Immersion and IndoorCarpet

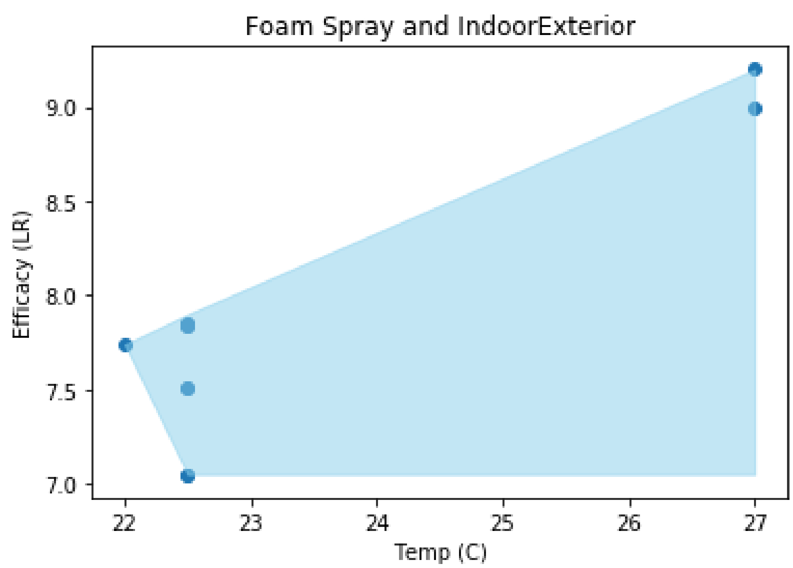

Figure I-24: Correlation Between Efficacy and Temp for Foam Spray and IndoorExterior

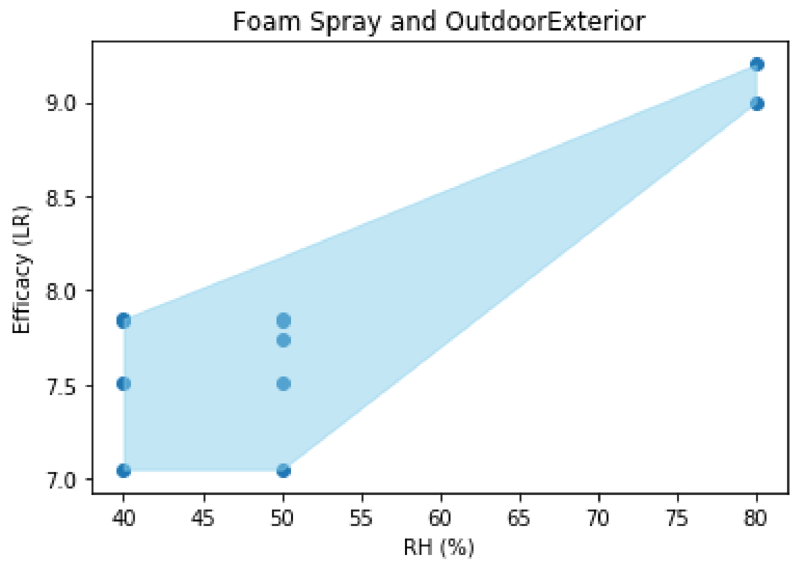

Figure I-25: Correlation Between Efficacy and RH for Foam Spray and OutdoorExterior

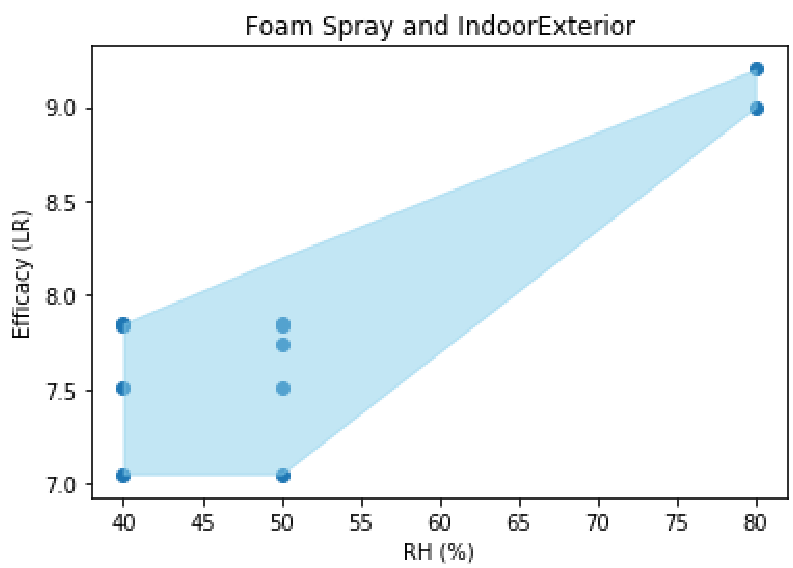

Figure I-26: Correlation Between Efficacy and RH for Foam Spray and IndoorExterior

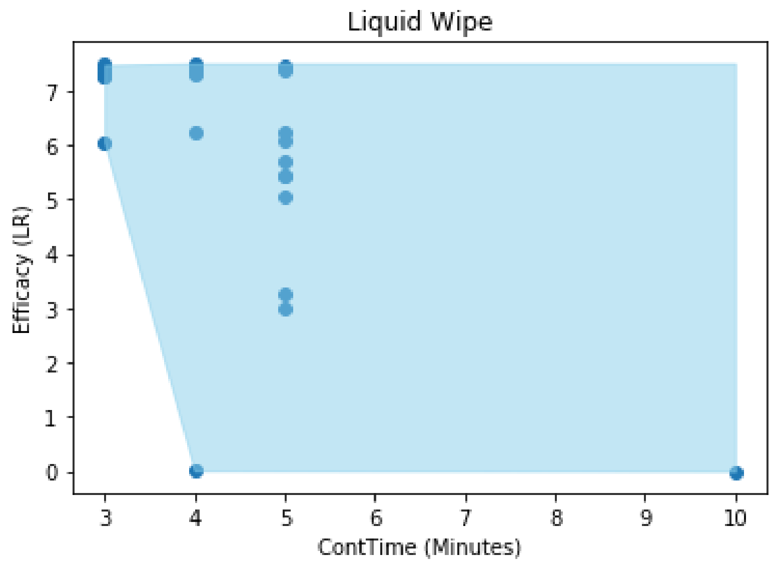

Figure I-27: Correlation Between Efficacy and ContTime for Liquid Wipe

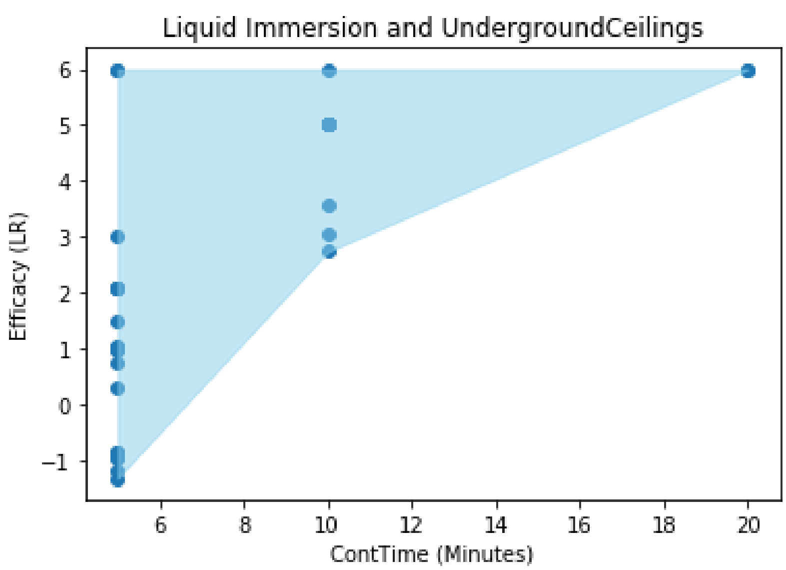

Figure I-28: Correlation Between Efficacy and ContTime for Liquid Immersion and UndergroundCeilings

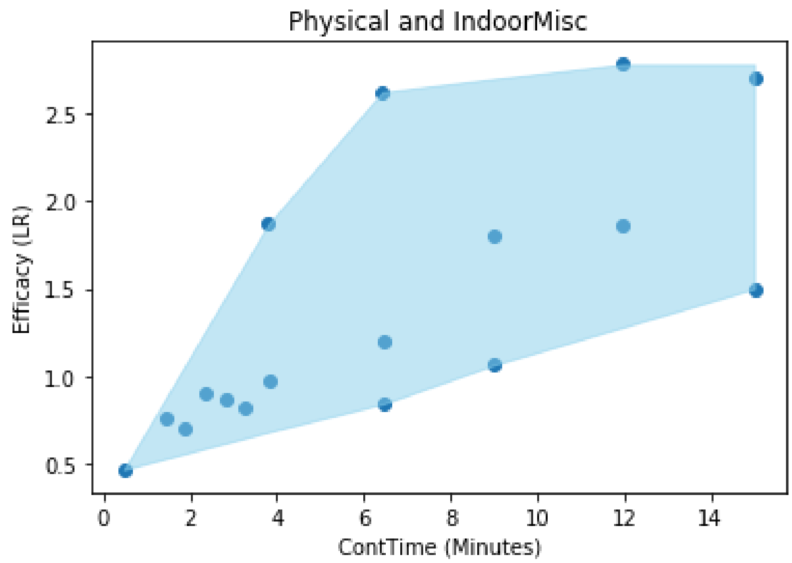

Figure I-29: Correlation Between Efficacy and ContTime for Physical and IndoorMisc

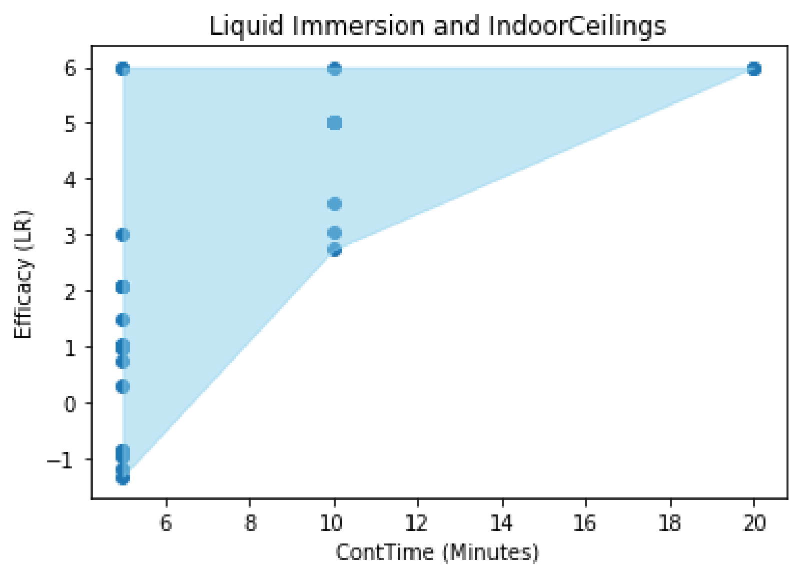

Figure I-30: Correlation Between Efficacy and ContTime for Liquid Immersion and IndoorCeilings

APPENDIX J: VERIFICATION CASE 1 INPUT DATA

The following tables contain the data that were input into the tool to simulate the BOTE scenario for verification case 1, as well as the source of these data if they were not found in the BOTE Project report. Note that at the time this verification case was run, Clearance Sampling had not yet been implemented as an individual element of the model but rather was included within the Characterization Sampling element.

Table J-1 below shows the contamination area and initial spore loading reported in the BOTE Project report for each scenario type. Note that the decontamination event described in the BOTE report was only relevant to the indoor scenario type. As such, the outdoor and underground scenarios were not simulated.

Table J-1: Contamination Area and Loading

Scenario Type	Area Contaminated (m^2)	Loading ($\log(CFU/m^2)$)
Indoor	747.87	3.03 – 8.03
Outdoor	0	0
Underground	0	0

Table J-2 lists the fraction of the total contamination area which each building type makes up. These values were estimated based on room-specific information found in the text. Note that the contamination breakout by building type is only relevant to indoor scenarios.

Table J-2: Indoor Contamination Breakout

Indoor Contamination Breakout	
Building Type	**Value**
Residential	0
Commercial	1.0
Industrial	0
Agricultural	0
Religious	0
Government	0
Educational	0

Table J-3 shows the breakdown of each surface type as a fraction of the total contamination area for the indoor scenario type. Note that the decontamination event described in the BOTE report was only relevant to the indoor scenario type. As such, the outdoor and underground surface types were not defined.

Table J-3: Indoor Surface Type Breakout

Indoor Surface Type Breakout	
Surface Type	**Value**
Walls	0.5
Carpet	0.0625
Non-Carpet	0.0625
Ceilings	0.125
HVAC	0.125
Miscellaneous	0.125

Table J-4 lists the values identified from the BOTE Project report for each Incident Command parameter in the tool.

Table J-4: Incident Command Parameters

Parameter	Value	Units	Note
Personnel Required (OSC)	1	people / team	-
Personnel Required (PL-4)	0	people / team	-
Personnel Required (PL-3)	0	people / team	-
Personnel Required (PL-2)	0	people / team	-
Personnel Required (PL-1)	0	people / team	-
Personnel Overhead Days	0	days	Value was estimated as it was not found in the text
Personnel Roundtrip Days	2	days	-

Table J-5 and Table J-6 list the values identified from the BOTE Project report for each Characterization Sampling parameter in the tool.

Table J-5: Characterization Sampling Parameters

Parameter	Value	Units	Note
Personnel Required (OSC)	0.333	people / team	-
Personnel Required (PL-4)	0	people / team	-
Personnel Required (PL-3)	3	people / team	-
Personnel Required (PL-2)	0	people / team	-
Personnel Required (PL-1)	0	people / team	-
Personnel Overhead Days	0	days	-
Teams Required	6	teams	-
Fraction of Surface Sampled	0.02 – 0.14	unitless	-
Entry Duration (A)	1.18	hours / entry * team	-
Entry Duration (B)	1.495	hours / entry * team	-
Entry Duration (C)	1.81	hours / entry * team	-
Entry Duration (D)	2.125	hours / entry * team	-
Number of Respirators per Person	1	respirators	-
Fraction PPE Required (A)	0	unitless	-
Fraction PPE Required (B)	0	unitless	-
Fraction PPE Required (C)	1	unitless	-
Fraction PPE Required (D)	0	unitless	-
Surface Area per Sponge Stick	0.06	m^2 / sample	Based on sponge sticks in text
Surface Area per 37-mm Cassette	0.37	m^2 / sample	Based on vacuum socks in text
Sponge Sticks per Hour per Team	*	sample / hour * team	-
37-mm Cassettes per Hour per Team	**	sample / hour * team	-
Number of Labs	8	labs	-
Lab Throughput Samples per Day	5 – 84	samples / day	Value not found in text; UTR OTD value used as surrogate
Packaging Time per Sample	1.63	minutes / day	Value not found in text; UTR OTD value used as surrogate
Lab Distance from Site	321.87 – 3,701.49	kilometers	Values were rounded for estimation purposes
Time of Result Transmission to IC	24	hours	Value was estimated as it was not found in the text
Entry Prep Time	0.6	hours / team * entry	-
Personnel Decon Line Time	0.81	hours / team * entry	-
Parameter	Value	Units	Note

Post-Entry Rest Period	0.55	hours / team * entry	-
Personnel Roundtrip Days	2	days	-

Table J-6: Additional Sample Parameters

Parameter	Distribution	Mean	Std Dev	Units
*Sponge Sticks per Hour per Team	Normal	14.51	7.35	sample / hour * team
**37-mm Cassettes per Hour per Team	Normal	10.56	7.69	sample / hour * team

Table J-7 lists the values identified from the BOTE Project report for each Source Reduction parameter in the tool.

Table J-7: Source Reduction Parameters

Parameter	Value	Units	Note
Personnel Required (OSC)	0.333	people / team	-
Personnel Required (PL-4)	0.67	people / team	-
Personnel Required (PL-3)	2.33 – 3.33	people / team	-
Personnel Required (PL-2)	0	people / team	-
Personnel Required (PL-1)	0	people / team	-
Personnel Overhead Days	0	days	-
Teams Required	6	teams	-
Mass of Waste Removed per Hour per Team	45.36	kg / hour * team	Value not found in text; WADE value used as surrogate
Mass of Waste per Surface Area	9.30	kg / m^2	-
Entry Duration (A)	1.18	hours / entry * team	-
Entry Duration (B)	1.495	hours / entry * team	-
Entry Duration (C)	1.81	hours / entry * team	-
Entry Duration (D)	2.125	hours / entry * team	-
Fraction of Surface Area to be Source Reduced	0.67	unitless	Value estimated based on information found in text
Number of Respirators per Person	1	respirators	Value estimated based on information found in text
Fraction PPE Required (A)	0	unitless	-
Fraction PPE Required (B)	0.5	unitless	-
Fraction PPE Required (C)	0.5	unitless	-
Fraction PPE Required (D)	0	unitless	-
Entry Prep Time	0.6	hours / team * entry	-
Personnel Decon Line Time	0.81	hours / team * entry	-
Post-Entry Rest Period	0.55	hours / team * entry	-
Personnel Roundtrip Days	2	days	-

Table J-8 lists the values identified from the BOTE Project report for each Decontamination parameter in the tool.

Table J-8: Decontamination Parameters

Parameter	Value	Units	Note
Decon + Drying Days	3 – 5	days	-
Personnel Required (OSC)	0.33	people / team	-
Personnel Required (PL-4)	0.67	people / team	-
Personnel Required (PL-3)	2.33 – 3.33	people / team	-
Personnel Required (PL-2)	0	people / team	-
Personnel Required (PL-1)	0	people / team	-
Personnel Overhead Days	0	days	-
Teams Required	6	teams	-
Entry Duration (A)	1.18	hours / entry * team	-
Entry Duration (B)	1.495	hours / entry * team	-
Entry Duration (C)	1.81	hours / entry * team	-
Entry Duration (D)	2.125	hours / entry * team	-
Number of Respirators per Person	1	respirators	-
Fraction PPE Required (A)	0	unitless	-
Fraction PPE Required (B)	0.5	unitless	-
Fraction PPE Required (C)	0.5	unitless	-
Fraction PPE Required (D)	0	unitless	-
Volume of Agent Applied (Fogging or Fumigation)	0.03	L / m^3	Value estimated based on information found in text
Volume of Agent Applied (Non-Fogging and Fumigation)	2.56	L / m^2	Value estimated based on information found in text
Entry Prep Time	0.6	hours / team * entry	-
Personnel Decon Line Time	0.81	hours / team * entry	-
Post-Entry Rest Period	0.55	hours / team * entry	-
Personnel Roundtrip Days	2	days	-

Table J-9 lists the values identified from the BOTE Project report for each Waste Sampling parameter in the tool.

Table J-9: Waste Sampling Parameters

Parameter	Value	Units	Note
Personnel Required (OSC)	0	people / team	-
Personnel Required (PL-4)	0	people / team	-
Personnel Required (PL-3)	0	people / team	-
Parameter	Value	Units	Note
Personnel Required (PL-2)	0	people / team	-

Personnel Required (PL-1)	3	people / team	-
Personnel Overhead Days	0	days	Value was estimated as it was not found in the text
Teams Required	1	teams	-
Fraction of Waste Sampled	1	unitless	Value was estimated as it was not found in the text
Entry Duration (A)	0	hours / entry * team	Value was estimated as it was not found in the text
Entry Duration (B)	0	hours / entry * team	Value was estimated as it was not found in the text
Entry Duration (C)	0	hours / entry * team	Value was estimated as it was not found in the text
Entry Duration (D)	0	hours / entry * team	Value was estimated as it was not found in the text
Number of Respirators per Person	0	respirators	Value was estimated as it was not found in the text
Fraction PPE Required (A)	0	unitless	Value was estimated as it was not found in the text
Fraction PPE Required (B)	0	unitless	Value was estimated as it was not found in the text
Fraction PPE Required (C)	0	unitless	Value was estimated as it was not found in the text
Fraction PPE Required (D)	0	unitless	Value was estimated as it was not found in the text
Mass per Waste Sample	15.12	kg / sample	-
Volume per Waste Sample	208.20	L / sample	-
Waste Samples per Hour per Team	5.88 – 12.5	sample / hour * team	-
Number of Labs	8	labs	-
Lab Throughput Samples per Day	5 – 84	samples / day	Value not found in text; UTR OTD value used as surrogate
Parameter	Value	Units	Note

Packaging Time per Sample	1.63	minutes / day	Value not found in text; UTR OTD value used as surrogate
Lab Distance from Site	321.87 – 3,701.49	kilometers	Values were rounded for estimation purposes
Time of Result Transmission to IC	24	hours	Value was estimated as it was not found in the text
Analysis Time per Waste Sample	0.79	hours / sample	-
Entry Prep Time	0	hours / team * entry	Value was estimated as it was not found in the text
Personnel Decon Line Time	0	hours / team * entry	Value was estimated as it was not found in the text
Post-Entry Rest Period	0	hours / team * entry	-
Personnel Roundtrip Days	2	days	-

Table J-10 lists the values identified from the BOTE Project report for each travel parameter in the tool.

Table J-10: Miscellaneous Parameters

Parameter	Value	Units	Note
Number of Personnel per Rental Car	4	people / rental car	Value estimated based on information found in text

Table J-11 lists the values identified from the BOTE Project report for each Cost parameter in the tool.

Table J-11: Cost Parameters

Parameter	Value	Units	Note
Cost of Decon Agent	1.84	$ / L	Value estimated based on information found in text
Cost of 37-mm Cassette Sample Analyzed	288.00	$ / sample	-
Cost per Sponge Stick Sample Analyzed	239.00	$ / sample	-
Cost per Solid Waste Sample Analyzed	254.19	$ / sample	-
Cost per Liquid Waste Sample Analyzed	254.19	$ / sample	-
Cost per One Waste Sample	20.00 – 29.00	$ / sample	-
Cost per One 37-mm Cassette	29.00	$ / sample	-
Cost per One Sponge Stick	20.00	$ / sample	-
37-mm Vacuum Rental per Day	15.00	$ / day	Value not found in text; WADE value used as surrogate
Supplies Cost per Day (IC)	1,007.08	$ / day	Value not found in text; WADE value used as surrogate
OSC Hourly Wage	147.00	$ / hour	-
PL-4 Hourly Wage	170.00	$ / hour	-
PL-3 Hourly Wage	124.00	$ / hour	-
PL-2 Hourly Wage	102.00	$ / hour	-
PL-1 Hourly Wage	86.00	$ / hour	-
Per Diem	185.00	$ / day	-
Rental Costs per Day (IC)	64.00	$ / day	-
Decon Material Cost per Surface Area	2.12 – 42.76	$ / m^2	-
Rental Car Cost per Day	225.00	$ / day	-
Material Removal per Mass	0.11	$ / kg	Standard MSW disposal fee
Roundtrip Ticket Cost per Person	450.00	$ / ticket	-
Respirator	238.00	$ / respirator	Value not found in text; WADE value used as surrogate
PPE Level A Cost	391.59	$ / unit	Value not found in text; UTR OTD value used as surrogate
PPE Level B Cost	144.83	$ / unit	Value not found in text; UTR OTD value used as surrogate

Parameter	Value	Units	Note
PPE Level C Cost	66.60	$ / unit	Value not found in text; UTR OTD value used as surrogate
PPE Level D Cost	64.32	$ / unit	Value not found in text; UTR OTD value used as surrogate

Table J-12 lists the efficacy values identified from the BOTE Project.

Table J-12: Efficacy Values

Efficacy in Log Reductions		
Fumigation	**Liquid Spray**	**All Other Treatment Methods**
1.98 – 5.91	5.49	1.98 – 5.91

APPENDIX K: VERIFICATION CASE 2 INPUT DATA

The following tables contain the data that were input into the tool to simulate the UTR OTD scenario for verification case 2, as well as the source of these data if they were not found in the UTR OTD report. Note that at the time this verification case was run, Clearance Sampling had not yet been implemented as an individual element of the model but rather was included within the Characterization Sampling element.

Table K-1 below shows the contamination area and initial spore loading reported in the UTR OTD Project report for each scenario type. Note that the decontamination event described in the UTR OTD report was only relevant to the underground scenario type. As such, the indoor and outdoor scenarios were not simulated.

Table K-1: Contamination Area and Loading

Scenario Type	Area Contaminated (m^2)	Loading ($\log(CFU/m^2)$)
Indoor	0	0
Outdoor	0	0
Underground	2682.85	5.63 – 6.13

Table K-2 shows the breakdown of each surface type as a fraction of the total contamination area for the underground scenario type. Note that the decontamination event described in the UTR OTD report was only relevant to the underground scenario type. As such, the indoor and outdoor surface types were not defined.

Table K-2: Underground Surface Type Breakout

Underground Surface Type Breakout	
Surface Type	**Value**
Walls	0.5
Carpet	0.0
Non-Carpet	0.125
Ceilings	0.125
HVAC	0.0
Miscellaneous	0.25

Table K-3 lists the values identified from the UTR OTD report for each Incident Command parameter in the tool.

Table K-3: Incident Command Parameters

Parameter	Value	Units	Note
Personnel Required (OSC)	2	people / team	-
Personnel Required (PL-4)	0	people / team	-
Personnel Required (PL-3)	0	people / team	-
Personnel Required (PL-2)	0	people / team	-
Personnel Required (PL-1)	0	people / team	-
Personnel Overhead Days	0	days	Value was estimated as it was not found in the text
Personnel Roundtrip Days	2	days	-

Table K-4 and Table K-6 list the values identified from the UTR OTD report for each Characterization Sampling parameter in the tool.

Table K-4: Characterization Sampling Parameters

Parameter	Value	Units	Note
Personnel Required (OSC)	0.3	people / team	-
Personnel Required (PL-4)	0	people / team	-
Personnel Required (PL-3)	3	people / team	-
Personnel Required (PL-2)	0	people / team	-
Personnel Required (PL-1)	0	people / team	-
Personnel Overhead Days	0	days	Value was estimated as it was not found in the text
Teams Required	6	teams	-
Fraction of Surface Sampled	$7.10 \times 10^{-3} – 7.17 \times 10^{-3}$	unitless	Value was estimated as it was not found in the text
Entry Duration (A)	1.18	hours / entry * team	Value not found in text; BOTE value used as surrogate
Entry Duration (B)	1.495	hours / entry * team	Value not found in text; BOTE value used as surrogate
Entry Duration (C)	1.81	hours / entry * team	Value not found in text; BOTE value used as surrogate
Entry Duration (D)	2.125	hours / entry * team	Value not found in text; BOTE value used as surrogate

Parameter	Value	Units	Note
Number of Respirators per Person	1	respirators	Value was estimated as it was not found in the text
Fraction PPE Required (A)	0	unitless	-
Fraction PPE Required (B)	0	unitless	-
Fraction PPE Required (C)	1	unitless	-
Fraction PPE Required (D)	0	unitless	-
Surface Area per Sponge Stick	0.06	m^2 / sample	Based on sponge sticks in text
Surface Area per 37-mm Cassette	0.09	m^2 / sample	Based on vacuum socks in text
Sponge Sticks per Hour per Team	*	sample / hour * team	Value not found in text; BOTE value used as surrogate
37-mm Cassettes per Hour per Team	**	sample / hour * team	Value not found in text; BOTE value used as surrogate
Number of Labs	6	labs	-
Lab Throughput Samples per Day	5 – 84	samples / day	-
Packaging Time per Sample	1.63	minutes / day	-
Lab Distance from Site	241.40 – 1,931.21	kilometers	Values were rounded for estimation purposes
Time of Result Transmission to IC	24	hours	Value was estimated as it was not found in the text
Analysis Time per Sponge Stick	0.67	hours / sample	Based on sponge sticks in text
Analysis Time per 37-mm Cassette	0.77	hours / sample	Based on vacuum socks in text
Entry Prep Time	0.6	hours / team * entry	Value not found in text; BOTE value used as surrogate
Personnel Decon Line Time	0.81	hours / team * entry	Value not found in text; BOTE value used as surrogate
Post-Entry Rest Period	0.5	hours / team * entry	-
Personnel Roundtrip Days	2	days	-

Table K-5: Additional Sample Parameters

Parameter	Distribution	Mean	Std Dev	Units
*Sponge Sticks per Hour per Team	Normal	14.51	7.35	sample / hour * team
**37-mm Cassettes per Hour per Team	Normal	10.56	7.69	sample / hour * team

Table K-6 lists the values identified from the UTR OTD report for each Decontamination parameter in the tool.

Table K-6: Decontamination Parameters

Parameter	Value	Units	Note
Decon + Drying Days	3 – 5	days	-
Personnel Required (OSC)	0.3	people / team	-
Personnel Required (PL-4)	1 – 2	people / team	-
Personnel Required (PL-3)	3 – 6	people / team	-
Personnel Required (PL-2)	0	people / team	-
Personnel Required (PL-1)	0	people / team	-
Personnel Overhead Days	0	days	Value estimated based on information found in text
Teams Required	2	teams	-
Entry Duration (A)	1.18	hours / entry * team	Value not found in text; BOTE value used as surrogate
Entry Duration (B)	1.495	hours / entry * team	Value not found in text; BOTE value used as surrogate
Entry Duration (C)	1.81	hours / entry * team	Value not found in text; BOTE value used as surrogate
Entry Duration (D)	2.125	hours / entry * team	Value not found in text; BOTE value used as surrogate
Number of Respirators per Person	1	respirators	-
Fraction PPE Required (A)	0.5	unitless	-
Fraction PPE Required (B)	0	unitless	-
Fraction PPE Required (C)	0.5	unitless	-
Fraction PPE Required (D)	0	unitless	-

Parameter	Value	Units	Note
Volume of Agent Applied (Fogging or Fumigation)	0.33	L / m^3	Value estimated based on information found in text
Volume of Agent Applied (Non-Fogging and Fumigation)	0.65 – 1.30	L / m^2	Value estimated based on information found in text
Entry Prep Time	0.6	hours / team * entry	Value not found in text; BOTE value used as surrogate
Personnel Decon Line Time	0.81	hours / team * entry	Value not found in text; BOTE value used as surrogate
Post-Entry Rest Period	0.5	hours / team * entry	-
Personnel Roundtrip Days	2	days	-

Table K-7 lists the values identified from the UTR OTD report for each Waste Sampling parameter in the tool.

Table K-7: Waste Sampling Parameters

Parameter	Value	Units	Note
Personnel Required (OSC)	0	people / team	-
Personnel Required (PL-4)	0	people / team	-
Personnel Required (PL-3)	0	people / team	-
Personnel Required (PL-2)	0	people / team	-
Personnel Required (PL-1)	3	people / team	-
Personnel Overhead Days	0	days	Value was estimated as it was not found in the text
Teams Required	1	teams	-
Fraction of Waste Sampled	1	unitless	Value was estimated as it was not found in the text
Entry Duration (A)	0	hours / entry * team	Value was estimated as it was not found in the text
Entry Duration (B)	0	hours / entry * team	Value was estimated as it was not found in the text
Entry Duration (C)	0	hours / entry * team	Value was estimated as it was not found in the text

Parameter	Value	Units	Note
Entry Duration (D)	0	hours / entry * team	Value was estimated as it was not found in the text
Number of Respirators per Person	0	respirators	Value was estimated as it was not found in the text
Fraction PPE Required (A)	0	unitless	Value was estimated as it was not found in the text
Fraction PPE Required (B)	0	unitless	Value was estimated as it was not found in the text
Fraction PPE Required (C)	0	unitless	Value was estimated as it was not found in the text
Fraction PPE Required (D)	0	unitless	Value was estimated as it was not found in the text
Mass per Waste Sample	16.67	kg / sample	-
Volume per Waste Sample	200	L / sample	-
Waste Samples per Hour per Team	5.88 – 12.5	sample / hour * team	-
Number of Labs	6	labs	-
Lab Throughput Samples per Day	5 – 84	samples / day	-
Packaging Time per Sample	1.63	minutes / day	-
Lab Distance from Site	241.40 – 1,931.21	kilometers	Values were rounded for estimation purposes
Time of Result Transmission to IC	24	hours	Value was estimated as it was not found in the text
Analysis Time per Waste Sample	0.79	hours / sample	-
Entry Prep Time	0	hours / team * entry	Value was estimated as it was not found in the text
Personnel Decon Line Time	0	hours / team * entry	Value was estimated as it was not found in the text
Post-Entry Rest Period	0	hours / team * entry	-
Personnel Roundtrip Days	2	days	-

Table K-8 lists the values identified from the UTR OTD report for each travel parameter in the tool.

Table K-8: Travel Parameters

Parameter	Value	Units	Note
Number of Personnel per Rental Car	7 – 8	people / rental car	Value estimated based on information found in text

Table K-9 lists the values identified from the UTR OTD report for each Cost parameter in the tool.

Table K-9: Cost Parameters

Parameter	Value	Units	Note
Cost of Decon Agent	1.58	$ / L	Value estimated based on information found in text
Cost per 37-mm Cassette Sample Analyzed	247.27	$ / sample	-
Cost per Sponge Stick Sample Analyzed	241.21	$ / sample	-
Cost per Solid Waste Sample Analyzed	254.19	$ / sample	-
Cost per Liquid Waste Sample Analyzed	254.19	$ / sample	-
Cost per One Waste Sample	20.00 – 29.00	$ / sample	Value estimated based on information found in text
Cost per One 37-mm Cassette	29.00	$ / sample	-
Cost per One Sponge Stick	20.00	$ / sample	-
37-mm Vacuum Rental per Day	15.00	$ / day	Value not found in text; WADE value used as surrogate
Supplies Cost per Day (IC)	1,007.08	$ / day	Value not found in text; WADE value used as surrogate
Entry Prep Cost	252.00 – 345.00	$ / team * entry	Value not found in text; BOTE value used as surrogate
Personnel Decon Line Cost	697.00 – 822.00	$ / team * entry	Value not found in text; BOTE value used as surrogate
OSC Hourly Wage	155.00	$ / hour	-
PL-4 Hourly Wage	210.00	$ / hour	-
PL-3 Hourly Wage	142.00	$ / hour	-
PL-2 Hourly Wage	118.00	$ / hour	-
PL-1 Hourly Wage	101.00	$ / hour	-
Per Diem	341.00	$ / day	-

Parameter	Value	Units	Note
Rental Costs per Day (IC)	235.42	$ / day	-
Decon Material Cost per Surface Area	1.54 – 2.73	$ / m^2	-
Rental Car Cost per Day	58.00	$ / day	-
Material Removal per Mass	0.11	$ / kg	Standard MSW disposal fee
Roundtrip Ticket Cost per Person	518.00	$ / ticket	-
Respirator	238.00	$ / respirator	Value not found in text; WADE value used as surrogate
PPE Level A Cost	391.59	$ / unit	Value estimated based on information found in text
PPE Level B Cost	144.83	$ / unit	Value estimated based on information found in text
PPE Level C Cost	66.60	$ / unit	Value estimated based on information found in text
PPE Level D Cost	64.32	$ / unit	Value estimated based on information found in text

Table K-10 lists the efficacy values identified from the UTR OTD.

Table K-10: Efficacy Values

Efficacy in Log Reductions		
Fogging	**Liquid Spray**	**All Other Treatment Methods**
4 – 5	4 – 5	4 – 5