EM TASK 12 – LASER CLEANING OF CONTAMINATED PAINTED SURFACES

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EXECUTIVE SUMMARY

Several techniques are available or under development for surface decontamination in nuclear facilities. Each technique has its merits; however, none of them is universally the best choice for all surface decontamination applications. Because of the multitude of factors which influence the environmental and economic aspects of selecting a surface decontamination technique, it is difficult to select the best method in a given situation; an objective basis for comparing techniques is needed.

The objective of this project was to develop a software tool for use by personnel selecting a surface decontamination technique. The software incorporates performance data for available surface decontamination techniques.

The beta release version of the Surface Decontamination Assistant Software has been completed and has undergone testing at the Energy & Environmental Research Center. Minor modifications to the software were completed, and a final release version of the software is ready to be issued.

EM TASK 12 – LASER CLEANING OF CONTAMINATED PAINTED SURFACES

BACKGROUND

Surface decontamination of concrete and steel surfaces in nuclear facilities provides cost savings during decommissioning operations by allowing recycling or reuse of concrete and steel structures. Separation of radionuclides and other contamination from the concrete or steel substrates also allows reduction in volume of hazardous materials during the D&D (deactivation and decommissioning) process, resulting in further cost savings.

Several techniques are available or under development for surface decontamination in nuclear facilities. Each technique has its merits; however, none of them is universally the best choice for all surface decontamination applications. Some issues confronting an organization selecting a surface decontamination technique for a particular application are as follows:

- Project scale
- Concrete or metal surfaces
- Contamination by radiological and other hazardous materials
- Stage of surface decontamination technology development (e.g., commercial, R&D [research and development])
- Equipment operating costs
- Collection of waste generated by surface decontamination
- Occupational health and safety requirements
- Utilities required for operations
- Real-time control of surface decontamination
- Recycling or reuse of decontaminated substrates
- Waste
 - Characterization
 - Classification
 - Transport
 - Storage
 - Treatment
 - Disposal
- D&D equipment decontamination

Because of the multitude of factors that influence the environmental and economic aspects of selecting a surface decontamination technique, it is difficult to select the best method in a given situation. An objective basis for comparing techniques is needed.

OBJECTIVE

The objective of this project is to develop a software tool for use by personnel selecting a surface decontamination technique. The software will incorporate performance data for available surface decontamination techniques.

The major activities in the project are broken down as follows:

- Task 1 – Decision Tree Development
- Task 2 – Literature Search for Surface Decontamination Reports
- Task 3 – Compilation of Dataset from Literature Data
- Task 4 – Sensitivity Analysis and Model Design
- Task 5 – Design of Model Data Structure
- Task 6 – PC Software Design and Coding

ACCOMPLISHMENTS

Task 1 – Decision Tree Development

The surface decontamination decision tree developed over the course of this project is depicted in Figures A1 through A3 of Appendix A. The decision tree functions as a framework for design and implementation of the computer model, allowing comparison of surface decontamination technologies.

Task 2 – Literature Search for Surface Decontamination Reports

Literature pertaining to surface decontamination applied in D&D operations was identified and acquired using a number of information resources, including the Remedial Action Program Information Center (RAPIC), the U.S. Department of Energy (DOE) Information Bridge, DIALOG database, Current Contents, and other traditional literature search tools. A complete list of the documents in the literature database for this work is given in Appendix B.

Task 3 – Compilation of Dataset from Literature Data

Available data on surface decontamination operations have been gleaned from available reports. Several articles (1–8) contain evaluations of surface decontamination techniques for specific cases. Data have been compiled from a number of articles and an attempt made to put the data into a form allowing technology comparisons to be made.

In addition to technology performance data gleaned from the literature, a survey of surface removal equipment vendors was completed to obtain additional information for the technology dataset. A listing of the dataset as incorporated into the computer model is given in Appendix C.

Some of the performance data in the dataset are vendor-supplied, and portions of the technology entries were extracted from data collected under less-than-optimal experimental conditions. Therefore, the program is designed to allow additional technologies to be added as well as modifications to the performance data for technologies already resident in the dataset. Modifications and additions to the dataset will maximize the utility of the Surface Decontamination Assistant (SDA) model.

Task 4 – Sensitivity Analysis and Model Design

The model is designed to provide an overall performance index for each applicable surface decontamination technique under a user-defined application scenario. The overall performance index is an aggregate value derived from intermediate performance indices for the major aspects of the surface decontamination process. As defined in the SDA model, intermediate performance indices are computed for the following:

- Surface removal
- Waste transportation
- Waste disposal
- Environment, health, and safety (EH&S)
- Technology implementation, operation, and maintenance

A number of assumptions are built into the current form of the SDA model. Assumptions intrinsic to the execution of the model are as follows:

1. Types of surface contamination are known.
2. Surface coating composition and thickness are known.
3. Depth of surface contamination is known.
4. Technologies are capable of achieving 100% surface decontamination.
5. If only portions of the surface are contaminated, they may be cleaned separately in order to segregate the hazardous from nonhazardous waste.
6. Operation costs are based on a vendor service cost, including technology deployment and transportation to the site of application.
7. Practitioners are willing to employ more than one technique to achieve 100% surface decontamination.
8. No transuranic waste (TRU) or spent nuclear fuel (SNF) is part of the surface decontamination waste stream.
9. Solid and liquid waste streams may or may not be separated.

10. If solid and liquid waste streams are not separated, uniform mixing takes place.
11. On-site waste disposal will employ existing vehicles and personnel.
12. All waste shipments are full loads for the style of transport.

As described above, the model will provide a comparison of techniques based on a user-defined application scenario. The user inputs to the model are as follows:

- Site name, location, substrate, and contamination descriptions
- Surface type (e.g., floor, ceiling) and material (steel or concrete)
- Surface area to be decontaminated, amount of surface that is hard to reach, coating thickness, and substrate removal thickness
- General categories of contamination (e.g., radionuclides)
- Surface area that is contaminated in each category
- Type of transportation for wastes (truck or rail)
- Transportation distance to on- and off-site storage and disposal facilities for remote-handled, contact-handled, and nonhazardous material
- Transportation and disposal costs
- Surface decontamination technologies to be included in the analysis
- Priority ranking for EH&S; operational, maintenance, and reliability issues; surface removal costs; transportation costs; and disposal costs

Details of the SDA model implementation are given in Appendix D.

Calculation of each of the performance indices is carried out using the user-defined application scenario and the performance data for each technology selected by the user from the technology performance dataset.

Derivation of performance indices has been determined for surface removal; waste transportation; waste disposal; EH&S; and technology implementation, operation, and maintenance. They have been defined as described below. Detailed equations are included in Appendix E.

Surface Removal Performance Index Calculation

Calculation of the surface removal performance index is carried out by first estimating the time required to decontaminate (remove) the surface for each selected technology using Equation 1.

$$T_T = [(HR_F - 1) \cdot HR_S + A_S] \cdot \frac{NP_T}{PR_T} \quad [\text{Eq. 1}]$$

Where:

- T_T = Total time for surface decontamination (removal) [time]
- HR_F = Technology correction factor for hard to reach areas [unitless]
- HR_S = Surface area to be cleaned that is hard to reach [length²]
- A_S = Total area to be cleaned [length²]
- NP_T = Number of passes needed to remove surface [unitless]
- PR_T = Technology production rate [length²/time]

The surface removal performance index, which is a basis for comparison of technologies, is estimated using Equation 2. Equation 2 calculates a cost for each technology to complete the surface decontamination. The cost rate to operate the technology is calculated in dollars per unit time using the operating cost of the technology (C_T) in dollars per square foot, the production rate of each technology (PR_T) in square foot per time, and a labor charge in dollars per unit time. This total cost rate and the time (T_T) estimated from Equation 1 are used to determine an operational cost for each technology in the user's application scenario. A setup cost (S_T times S_F) is added to the estimated operating cost to cover costs associated with the setup of each technology. The three categories included are portability of equipment, capital costs, and complexity of calibration. Detailed information is included in the dataset in Appendix C. Then each cost estimated is compared on the basis of the technology that is the least expensive to apply in surface decontamination. Although this method is a less conventional approach than normalization, the result is a surface removal performance index for each technology that ranges in value from 0 to 1, with 1 being the least expensive technology to apply.

$$PI_{SR} = \frac{\min[(C_T \cdot PR_T + F_L \cdot NW_T \cdot C_L) \cdot T_T + (S_T \cdot S_F)]}{(C_T \cdot PR_T + F_L \cdot NW_T \cdot C_L) \cdot T_T + (S_T \cdot S_F)} \quad [\text{Eq. 2}]$$

Where:

- PI_{SR} = Surface removal performance index [unitless]
- C_T = Technology operating cost [dollars/length²]
- PR_T = Technology production rate [length²/time]
- F_L = Boolean variable indicating that labor is not included in operating costs [unitless]
- NW_T = Number of workers needed to operate the technology [unitless]
- C_L = Labor cost of the technology [dollars/time]

- T_T = Total time for surface decontamination (removal) [time]
 S_T = Technology correction factor for setup of technologies [unitless]
 S_F = Setup modification factor [dollars]

Transportation Performance Index Calculation

Calculation of the transportation performance index requires estimation of transport cost for all modes of transport for all potential types of waste. As an example, the calculation of on-site truck transport of contact-handled hazardous waste is outlined in Equation 3.

$$CTOn_{CH} = F_T \cdot F_{OS} \cdot \left(\frac{MS_T \cdot \frac{M_{CH}}{MS_T + ML_T}}{MST_{CH}} \right) \cdot (C_{CHT} \cdot D + MT_{CHT}) \quad [\text{Eq. 3}]$$

Where:

- $CTOn_{CH}$ = On-site truck transport cost of contact-handled hazardous waste [dollars]
 F_T = Boolean variable indicating mode of transport (truck or rail) [unitless]
 F_{OS} = Boolean variable indicating on-site disposal of contact-handled waste [unitless]
 MS_T = Total mass of solid waste [mass]
 M_{CH} = Mass of contact-handled waste [mass]
 ML_T = Total mass of liquid waste generated by the technology [mass]
 MST_{CH} = Maximum capacity of truck hauling contact-handled waste [mass]
 C_{CHT} = Cost to transport contact-handled waste by truck [dollars/length]
 D = Distance from remediation site to storage/disposal site [length]
 MT_{CHT} = Cost to maintain truck used to haul contact-handled waste [dollars]

The transportation performance index represents a comparison of technologies based on the sum of all potential transportation costs. Equation 4 shows the formula for calculation of the index. Detailed equations for the other components are included in Appendix E. Because lower costs are preferable, the transport cost of chosen technologies is compared to the minimum transport cost for all technologies, rather than the more traditional method of normalizing the data to the maximum for all technologies. The resultant transportation performance index for each technology ranges in value from 0 to 1, with 1 incurring the least transportation costs.

$$PI_T = \frac{\min(CTOn_{CH} + CTOff_{CH} + CTOff_{RH} + CTOn_{RH} + CR_{CH} + CTOn_{CD}) + 1}{(CTOn_{CH} + CTOff_{CH} + CTOff_{RH} + CTOn_{RH} + CR_{CH} + CTOn_{CD}) + 1} \quad [\text{Eq. 4}]$$

Where:

- PI_T = Transportation performance index [unitless]

$CTOn_{CH}$ = On-site truck transport cost of contact-handled hazardous waste [dollars]
 $CTOff_{CH}$ = Off-site truck transport cost of contact-handled hazardous waste [dollars]
 $CTOn_{RH}$ = On-site truck transport cost of remote-handled hazardous waste [dollars]
 $CTOff_{RH}$ = Off-site truck transport cost of remote-handled hazardous waste [dollars]
 CR_{CH} = Rail transport cost of contact-handled hazardous waste [dollars]
 $CTOn_{CD}$ = On-site truck transport cost of nonhazardous waste [dollars]

Waste Disposal Performance Index Calculation

Calculation of the waste disposal performance index requires estimation of disposal costs for all potential waste types. Equation 5 details the calculation for the volume of solid contact-handled waste, one component of the waste disposal performance index.

$$VS_{CH} = VS_T \cdot \frac{V_{CH}}{(VS_T + VL_T)} \quad [\text{Eq. 5}]$$

Where:

VS_{CH} = Volume of solid contact-handled waste [length^3]
 VS_T = Total volume of solid waste [length^3]
 V_{CH} = Volume of contact-handled waste [length^3]
 VL_T = Volume of liquid contact-handled waste generated by the technology [length^3]

The waste disposal performance index compares technologies based on disposal costs associated with the volume of each type of waste. Equation 6 expresses the performance index. Detailed equations for the other components are located in Appendix E. As was the case in the previously discussed performance indices, the waste disposal index divides the minimum valued technology by each technology's value to obtain an index number between 0 and 1.

$$PI_{WD} = \frac{\min(fS_{CD} \cdot VS_{CD} + fL_{RH} \cdot VL_{RH} + fS_{RH} \cdot VS_{RH} + fL_{CH} \cdot VL_{CH} + fS_{CH} \cdot VS_{CH})}{fS_{CD} \cdot VS_{CD} + fL_{RH} \cdot VL_{RH} + fS_{RH} \cdot VS_{RH} + fL_{CH} \cdot VL_{CH} + fS_{CH} \cdot VS_{CH}} \quad [\text{Eq. 6}]$$

Where:

PI_{WD} = Waste disposal performance issues [unitless]
 fS_{CD} = Relative disposal cost factor for nonhazardous waste [unitless]
 VS_{CD} = Volume of solid nonhazardous waste [length^3]
 fL_{RH} = Relative disposal cost factor for liquid remote-handled waste [unitless]
 VL_{RH} = Volume of liquid remote-handled waste [length^3]
 fS_{RH} = Relative disposal cost factor for solid remote-handled waste [unitless]
 VS_{RH} = Volume of solid remote-handled waste [length^3]
 fL_{CH} = Relative disposal cost factor for liquid contact-handled waste [unitless]

VL_{CH} = Volume of liquid contact-handled waste [length³]
 fS_{CH} = Relative disposal cost factor for solid contact-handled waste [unitless]
 VS_{CH} = Volume of solid contact-handled waste [length³]

Environment, Health, and Safety Performance Index Calculation

The EH&S performance index presents a normalized basis for comparison of technologies' performance based on human and environmental health and safety issues. The data for this comparison come directly from information included in the technology dataset in Appendix C.

Technology Implementation, Operation, and Maintenance Performance Index Calculation

The technology implementation, operation, and maintenance performance index also presents a normalized basis for comparison of technologies' performance based on reliability issues. The data for this comparison come directly from information included in the technology dataset in Appendix C as well.

Overall Performance Index Calculation

The overall performance index, which is a normalized basis for comparison of technologies, is calculated using Equation 7. Through adjustment of priority values in the Priority Ranking setup screen of the SDA software, the user defines the relative importance of each of the intermediate performance indices. As a result, Equation 7 includes a weighted sum of the above intermediate performance indices normalized from 0 to 1, with 1 being the most desirable technology based on the stated needs and scenario of the user.

$$PI_{Overall} = \frac{P_{SR} \cdot PI_{SR} + P_T \cdot PI_T + P_{WD} \cdot PI_{WD} + P_{ESH} \cdot PI_{ESH} + P_M \cdot PI_M}{\max(P_{SR} \cdot PI_{SR} + P_T \cdot PI_T + P_{WD} \cdot PI_{WD} + P_{ESH} \cdot PI_{ESH} + P_M \cdot PI_M)} \quad [\text{Eq. 7}]$$

Where:

$PI_{Overall}$ = Overall performance index [unitless]
 P_{SR} = Surface removal priority factor [unitless]
 PI_{SR} = Surface removal performance index [unitless]
 P_T = Transportation priority factor [unitless]
 PI_T = Transportation performance index [unitless]
 P_{WD} = Waste disposal priority factor [unitless]
 PI_{WD} = Waste disposal performance index [unitless]
 P_{ESH} = Environment, health, and safety priority factor [unitless]
 PI_{ESH} = Environment, health, and safety performance index [unitless]
 P_M = Technology implementation, operation, and maintenance priority factor [unitless]
 PI_M = Technology implementation, operation, and maintenance performance index [unitless]

Sensitivity Analyses

Several sensitivity analyses were performed during the course of this work to evaluate the software implementation of the logic depicted in the flowcharts of the model design tree and to verify the equations in Appendix E.

Table 1 lists the values for one of the final sets of test scenarios used to evaluate the software. Comparative graphs of the performance indices resulting from some of these scenarios are included in Appendix F.

Task 5 – Design of Model Data Structure

The SDA software has as one of its key components an extendable dataset of surface decontamination technology performance data. The technology dataset is designed to incorporate all of the information unique to each surface decontamination technique necessary to apply the SDA model. Each technology dataset record contains the following fields:

- Technology name
- Description, including type of process (e.g., physical, chemical, effects on the substrate)
- Applicable substrates (concrete, steel, or both)
- Aggressive surface removal capabilities
- Production rate
- Operating cost
- Volume, phase (solid or liquid), and density of secondary waste
- Thickness of cleaning depth
- Number of workers necessary for operation
- Number of passes needed to achieve 100% surface coating removal
- Vertical surface-cleaning ability
- Ability to clean hard-to-reach areas
- On-line analysis capabilities
- EH&S factor
- Implementation state, operation, and maintenance factor
- Technology development stage
- Whether labor charge is included in operating costs
- Comparative setup factors

TABLE 1

Surface Decontamination Assistant Model Test Scenarios

Scenario	Total Area	% Hard to Reach	Thickness of Coating, in.	Substrate Removal Depth, in.	On-Site Separation	% Construction and Demolition Waste	% Contact Handled Waste	% Area Remote Handled Waste	On-Site Storage of solids
1	3000	0	0.5	0	No	20	60	20	No
2	3000	0	0.05	6	No	20	60	20	No
3	3000	0	0.1	0	No	20	60	20	No
4	3000	0	0.1	6	No	20	60	20	Yes
5	3000	0	0.95	0	No	20	60	20	No
6	3000	0	0.95	6	No	0	100	0	No
7	3000	40	0.05	0	No	20	60	20	No
8	3000	40	0.05	6	Yes	20	60	20	No
9	3000	40	0.95	0	No	20	60	20	No
10	3000	40	0.95	6	No	20	60	20	No
11	20000	0	0.05	0	Yes	0	100	0	No
11a	20000	0	0.05	0	No	20	60	20	No
12	20000	0	0.05	6	No	20	60	20	No
13	20000	0	0.95	0	No	20	60	20	No
14	20000	0	0.95	6	No	20	60	20	Yes
14a	20000	0	0.95	6	Yes	20	60	20	Yes
15	20000	40	0.05	0	Yes	20	60	20	No
16	20000	40	0.05	6	Yes	20	60	20	No
17	20000	40	0.95	0	Yes	20	60	20	No
18	20000	40	0.95	6	Yes	0	100	0	No
19	20000	0	0.95	6	No	20	60	20	No
20	20000	0	0.95	0	Yes	20	60	20	No
21	20000	40	0.95	6	No	20	60	20	Yes
21a	20000	40	0.95	6	No	20	60	20	No
22	20000	40	0.1	0	Yes	20	60	20	No

Appendix C contains a listing of the technology dataset. Information in the dataset includes verification of the data.

Task 6 – PC Software Design and Coding

The architecture of the SDA software is based on the major subsections illustrated in Figure 1.

The user interacts with the SDA software through a set of dialog boxes. The user is led through a series of input dialogs where the following aspects of the user-defined application scenario are entered:

1. Scenario summary description – site name, location of site, general substrate description, general contamination description, site activation date, modification date.
2. Detailed site description – surface type, substrate material, total area of the surface, area of hard-to-reach portions of the surface, thickness of surface coating, thickness of the substrate to be removed.
3. General contamination information – generic types of contamination.
4. Quantified contamination information – availability of on-site separation of liquids and solids, percentage distribution of surface area not contaminated by hazardous waste, area contaminated by CH waste, and area contaminated by RH waste.

Figure 1. Surface Decontamination Assistant software architecture.

5. Transportation information – off-site and on-site transportation distances for three types of waste, nonhazardous waste, transportation distance, style of transport, storage of solids on- or off-site.
6. Technology selection – pick technologies to evaluate using the model.
7. Setup inputs – transportation fees, waste disposal fees, priority rankings of the performance categories.

A detailed description of the program structure and illustrations for each of the dialog boxes presented by the program are in Appendix G. In addition, Appendix G is designed to serve as a stand-alone manual for using the software.

CONCLUSIONS

The SDA software program that was developed during this project is a useful tool for selecting appropriate surface decontamination techniques to remediate hazardous and nonhazardous surfaces. The software includes performance data for decontamination technologies currently available and in various stages of development. The information gathered through the literature search served as the basis for the dataset and development of the decision tree from which the model data structures and PC software were designed. Implementation of the model into computer code produced a program that is both effective and user-friendly. Careful examination and thoughtful analysis of sensitivity data indicated discrepancies in the model design and coding which have since been eliminated. The result is a well-researched and executed vehicle for comparing surface decontamination techniques as applied to user-defined scenarios.

Since the goal of the software tool is to provide a guide by which the user can compare and rate various surface decontamination technologies, the performance data from the technologies must be comparable. Great effort was made to obtain the most reliable data on a comparable basis and to verify each datum included in the dataset. The quality, precision, consistency, and availability of data remain issues limiting the accuracy of any information-based tool. Performance data for individual technologies varied in consistency and quality; thus the data set is the weakest element in the final product. The SDA design, however, allows updated performance data to be easily incorporated into the software. The data set can be amended as better data become available without changing other components. The SDA is an excellent tool for surface decontamination technology comparisons.

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APPENDIX A

**SURFACE DECONTAMINATION
DECISION TREE**

Figure A1. Surface decontamination decision tree, Sheet 1.

Figure A2. Surface decontamination decision tree, Sheet 2.

Figure A3. Surface decontamination decision tree, Sheet 3.

APPENDIX B

LITERATURE DATABASE

LITERATURE DATABASE

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APPENDIX C

TECHNOLOGY DATASET

TABLE C1

Technology Dataset

Technology Name	(Minimum) Production Rate, ft ² /hr	Maximum Production Rate, ft ² /hr	(Minimum) Operating Cost, \$/ft ²	Maximum Operating Cost, \$/ft ²	Cleaning Depth, in.	Number of Passes to Complete Cleaning	(Capital) Cost Factor	Size/Delivery Factor	Setup/Calibration Factor	Number of Workers	Assumes Labor is Included	Justification for Labor Inclusion/ Exclusion
Mechanical Scabbling	200	400	1.85	2.50	0.13	1	1	1	1	2	N	Assumed that labor is not included because it is not included for MOOSE and Squirrel listed at the same operating rate.
Milling	3		0.75		1	1	2	2	2	2	N	Labor estimated cost exceeds quoted operating cost.
Drilling Spalling	60	100	3.00	3.55	1	1	2	1	2	2	Y	Educated guess
Sand Blasting	47		5.00	10.00	0.06	1	1	1	1	2	N	Dickerson lists a separate operating cost and labor cost.
Steel Grit	11.6		5.52		0.01	1	1	1	1	2	Y	Ebadian is the source for operating cost data.
Plastic Blasting	240		0.20	2.15	0.06	2	1	1	1	2	N	Ebadian rate was much higher: \$14.
Ultra-Pressure Water	60		2.00		0.06	2	2	1	2	2	Y	Rate is higher than Ebadian calculation.
High-Pressure Water	370		0.06	2.00	0.06	2	2	1	2	2	N	Ebadian rate was much higher: \$6.
Sponge Blasting	32		2.71		0.06	1	2	2	1	3	Y	Ebadian is the source for operating cost data.
Soft Media Blasting - Metal	120		0.77		0.003	1	1	2	1	2	Y	Based on conversation with vendor
Soft Media Blasting - Concrete	60	100	10.00	12.00	0.13	1	1	2	1	2	Y	Quoted operating to labor estimated cost difference is already considerably higher than for metal applications.
Soda Blasting - Metal	24		4.17		0.03	2	2	2	1	2	Y	Ebadian is the source for operating cost data.
Soda Blasting - Concrete	60	240	5.00	7.00	0.03	2	2	2	1	2	Y	Quoted operating to labor estimated cost difference is already higher than for metal applications.
Shot Blasting	30	3000	0.04	5.02	0.25	1	2	3	1	2	Y	The difference is cost between including and excluding labor is inconsequential.
Scarification MOOSE	200	400	1.85	2.50	0.06	1	2	2	2	2	N	Based on conversation with vendor, operating cost does not include labor.
Squirrel Floor Scabbler & Corner Cutter	20	30	1.85	2.50	0.06	1	2	3	2	1	N	Based on conversation with vendor, operating cost does not include labor.
Microwave	40		2.00		2	1	2	2	3	2	N	Dickerson lists a separate operating cost and labor cost.
CO ₂ Laser	500	600	0.66	0.74	0.001	1	3	3	3	1	Y	The difference in cost between including and excluding labor is inconsequential.
Ice Blasting - Metal	5.2		12.69		0.06	2	2	2	2	2	Y	Ebadian is the source for operating cost data.
Ice Blasting - Concrete	45		1.00		0.06	2	2	2	2	2	N	Quoted operating to labor estimated cost difference is considerably lower than for metal applications.
Electrokinetic	132		0.42		3	2	3	3	3	0		
Electro-Hydraulic Scabbling	20	40	0.65	1.85	0.6	1	3	2	3	2	N	Estimated labor cost exceeds quoted operating cost.
TechXtract or Corplex Processes	16	100	4.00	25.00	2.0	1	1	1	1	2	Y	The difference in cost between including and excluding labor is inconsequential.
Carbon Dioxide Blasting - Metal	12		7.89		0.04	1	2	2	3	2	Y	Ebadian is the source for operating cost data.
Carbon Dioxide Blasting - Concrete	10	90	0.90	1.75	0.04	1	2	2	3	1	N	Quoted operating to labor estimated cost difference is considerably lower than for metal applications.

Continued . . .

TABLE C1 (continued)

Technology Dataset

Technology Name	(Minimum) Volume Rate of Liquid Secondary Waste, ft ³ /hr	Maximum Volume Rate of Liquid Secondary Waste, ft ³ /hr	Density of Liquid Secondary Waste, lb/ft ³	(Minimum) Volume Rate of Solid Secondary Waste, ft ³ /hr	Maximum Volume Rate of Solid Secondary Waste, ft ³ /hr	Density of Solid Secondary Waste, lb/ft ³	Safety Factor	Reliability Factor	Description	Cleans Steel	Cleans Concrete	Process Type
Mechanical Scabbling	0		na	0		na	6.57	8.21	Physical/mechanical, destructive surface removal	NO	YES	Destructive
Milling	0		na	0		na	6.2	7.53	Physical/mechanical, destructive surface removal	NO	YES	Destructive
Drilling Spalling	0		na	0		na	6.13	7.8	Physical/mechanical, destructive surface removal	NO	YES	Destructive
Sand Blasting	0		na	1.41		2.63	5.53	8	Physical/mechanical, nondestructive	YES	YES	Nondestructive
Steel Grit	0		na	0.02		105	6.3	6.85	Physical/mechanical, nondestructive	YES	YES	Nondestructive
Plastic Blasting	0		na	0.25		55	6.23	5.88	Physical/mechanical, nondestructive	YES	YES	Nondestructive
Ultra-Pressure Water	24	40	12.8	0		na	6.23	7.55	Physical/mechanical, nondestructive	YES	YES	Nondestructive
High-Pressure Water	11		12.8	0		na	5.67	7.88	Physical/mechanical, nondestructive	YES	YES	Nondestructive
Sponge Blasting	0		na	688.2		0.525	6.8	6.5	Physical/mechanical, nondestructive	YES	YES	Nondestructive
Soft Media Blasting - Metal	0		na	0.06	0.2	52.9	6.8	5.09	Physical/mechanical, nondestructive	YES	NO	Nondestructive
Soft Media Blasting - Concrete	0		na	0.06	0.2	52.9	6.8	5.09	Physical/mechanical, destructive	NO	YES	Destructive
Soda Blasting - Metal	5.8		13.8	0	0	na	5.77	6.85	Physical/mechanical, nondestructive	YES	NO	Nondestructive
Soda Blasting - Concrete	18	112	13.8	0	0	na	5.1	6.85	Physical/mechanical, nondestructive	NO	YES	Nondestructive
Shot Blasting	0		na	0.09	87	294	6.33	7.94	Physical/mechanical, destructive surface removal	YES	YES	Destructive
Scarification MOOSE	0		na	0		na	6.6	8.21	Physical/mechanical, destructive surface removal	NO	YES	Destructive
Squirrel Floor Scabbler & Corner Cutter	0		na	0		na	6.6	7.58	Physical/mechanical, destructive surface removal	NO	YES	Destructive
Microwave	0		na	0		na	7	5.26	Electrical/thermal/physical, destructive surface removal	NO	YES	Destructive
CO ₂ Laser	0		na	0		na	6.2	4.66	Electrical/thermal, nondestructive	YES	YES	Nondestructive
Ice Blasting - Metal	3.2		12.8	0		na	6.3	6.84	Physical/mechanical, nondestructive	YES	NO	Nondestructive
Ice Blasting - Concrete	1.1	2.0	12.8	0		na	6.3	6.84	Physical/mechanical, nondestructive	NO	YES	Nondestructive
Electrokinetic	nd	nd		nd		0	6.3	4.13	Electrical/chemical/physical, nondestructive	NO	YES	Penetrating
Electro-Hydraulic Scabbling	2.0	4.0	12.8	0		na	6.3	5.76	Physical/mechanical, destructive surface removal	NO	YES	Destructive
TechXtract or Corpex Processes	0.1	1.1	12.8	0		na	6.3	5.63	Chemical, nondestructive	YES	YES	Nondestructive
Carbon Dioxide Blasting - Metal	0		na	0		na	6.1	5.96	Physical/mechanical, nondestructive	YES	NO	Nondestructive
Carbon Dioxide Blasting - Concrete	0		na	0		na	6.1	5.96	Physical/mechanical, nondestructive	NO	YES	Nondestructive

na = Not available

nd = No data

Continued . . .

TABLE C1 (continued)

Technology Dataset

Technology Name	Stage of Technology	Waste Type	Cleans Floors	Cleans Walls	Cleans Ceilings	Handles Hard to Reach Areas	On-Line Analysis	Extra Utilities Required
Mechanical Scabbling	Commercial scale	Solid	YES	NO	YES	NO	NO	NO
Milling	Conceptual for decontamination	Solid	YES	NO	NO	NO	NO	NO
Drilling Spalling	Commercial scale	Solid	YES	YES	YES	NO	NO	NO
Sand Blasting	Commercial scale	Solid	YES	YES	YES	YES	NO	NO
Steel Grit	Commercial scale	Solid	YES	YES	YES	YES	NO	NO
Plastic Blasting	Commercial scale	Solid	YES	YES	YES	YES	NO	NO
Ultra-Pressure Water	Commercial scale	Liquid	YES	YES	YES	YES	NO	YES
High-Pressure Water	Commercial scale	Liquid	YES	YES	YES	YES	NO	NO
Sponge Blasting	Commercial scale	Solid	YES	YES	YES	YES	NO	NO
Soft Media Blasting - Metal	Commercial scale	Solid	YES	YES	YES	YES	NO	NO
Soft Media Blasting - Concrete	Commercial scale	Solid	YES	YES	YES	YES	NO	NO
Soda Blasting - Metal	Commercial scale	Liquid	YES	YES	YES	YES	NO	NO
Soda Blasting - Concrete	Commercial scale	Liquid	YES	YES	YES	YES	NO	NO
Shot Blasting	Commercial scale	Solid	YES	YES	YES	NO	NO	NO
Scarification MOOSE	Commercial scale	Solid	YES	NO	NO	NO	NO	NO
Squirrel Floor Scabbler & Corner Cutter	Commercial scale	Solid	YES	YES	YES	YES	NO	NO
Microwave	Full-scale prototype	Solid	YES	YES	YES	YES	NO	YES
CO ₂ Laser	Demonstration	Solid	YES	YES	YES	YES	YES	YES
Ice Blasting - Metal	Commercial scale	Liquid	YES	YES	YES	YES	NO	NO
Ice Blasting - Concrete	Commercial scale	Liquid	YES	YES	YES	YES	NO	NO
Electrokinetic	Bench Scale	Liquid	YES	NO	NO	YES	NO	NO
Electro-Hydraulic Scabbling	Developmental	Liquid	YES	NO	NO	NO	NO	NO
TechXtract or Corpex Processes	Commercial scale	Liquid	YES	YES	YES	YES	NO	NO
Carbon Dioxide Blasting - Metal	Commercial scale	Solid	YES	YES	YES	YES	NO	YES
Carbon Dioxide Blasting - Concrete	Commercial scale	Solid	YES	YES	YES	YES	NO	YES

TABLE C2

Dataset References

Technology Name	Source	Footnotes
Mechanical Scabbling	Dickerson Tbl 3.4 & Vanderbilt pg. 34	(a.), (b.), (c.)
Milling	Dickerson Tbl 3.5, 3.6 & Vanderbilt pg.34	(a.)
Drilling Spalling	Halter (1) pp. 16,22,26, 28	
Sand Blasting	Dickerson Tbl 3.5, 3.6; Vanderbilt Tbl 5-1	(a.), (c.)
Steel Grit	Ebadian Tbl 2; conversation with vendor	(a.)
Plastic Blasting	Dickerson Tbl 3.5; Ebadian Tbl 2	(c.), (d.), (e.)
Ultra-Pressure Water	Dickerson Tbl 3.5, 3.6; Ebadian Tbl 2	(c.), (e.), (f.), (g.)
High-Pressure Water	Dickerson Tbl 3.5, 3.6, 4.3; Ebadian Table 2	(c.), (e.), (f.), (g.)
Sponge Blasting	Dickerson Tbl 3.4; Ebadian Table 2; written correspondence with vendor	(d.), (e.)
Soft Media Blasting - Metal	written correspondence with vendor	
Soft Media Blasting - Concrete	Dickerson Tbl 3.5, 3.6, App C; SAIC Tbl 3-3; written correspondence with vendor	
Soda Blasting - Metal	Ebadian Tbl 2 & 3; conversation with vendor	(h.)
Soda Blasting - Concrete	Dickerson Tbl 3.5, 3.6, App C; conversation with vendor	(h.)
Shot Blasting	Dickerson p. 3-16, Tbl 3.5, 3.6; SAIC Tbl 3-3; conversation with vendor	
Scarification MOOSE	Dickerson App C; conversation with vendor	
Squirrel Floor Scabbler & Corner Cutter	Dickerson Tbl 3.5, App C; conversation with vendor	
Microwave	Dickerson Tbl 3.5, 3.6	
CO ₂ Laser	F2 Associates	
Ice Blasting - Metal	Ebadian Tbl 2	(e.), (f.), (g.)
Ice Blasting - Concrete	Dickerson Tbl 3.6, App C	(e.), (f.), (g.), (i.)
Electrokinetic	Vanderbilt Tbl 5-1; Dickerson Tbl 3.5, App C	
Electro-Hydraulic Scabbling	Dickerson Tbl 3.5, 3.6; SAIC Table 3-3	(f.), (j.), (k.)
TechXtract or Corplex Processes	Dickerson Tbl 2.7, App C; Bonem	(f.), (j.)
Carbon Dioxide Blasting - Metal	Ebadian Tbl 2, 3; conversation with vendor	(l.)
Carbon Dioxide Blasting - Concrete	Dickerson Tbl 3.5, App C; conversation with vendor	(l.)

Notes:

1. It is assumed that destructive technologies will not work for metal substrates.
2. Secondary waste includes only media used during processes, not water spray, HEPA filters, or anything else used for dust control and collection.

Footnote Key

- (a.) Default value: one pass to clean was assumed for destructive technologies and sandblasting.
- (b.) Default value for number of workers is two.
- (c.) Assumed that the technology handles floors, walls, and ceilings because it handles hard to reach areas.
- (d.) Density of secondary waste was calculated based on data from Ebadian.
- (e.) Default value: 0.06 inches was assumed for cleaning depth.
- (f.) Default value: the density of water was used for secondary waste density.
- (g.) Default value: two passes to clean were assumed for nondestructive technologies for which references were not located.
- (h.) Experimental density of a saturated NaHCO₃ solution
- (i.) Default value: production rate was listed as "similar to other blasting technologies (Dickerson). Assumed 45 ft³/hr.
- (j.) Default value: two workers is assumed.
- (k.) Depth of cleaning was listed as "up to 1 inch" (Dickerson Table 3.5).
- (l.) Secondary waste data in Ebadian Table 2 contradict the text in Table 1 which states, "CO₂ media vaporize, leaving only the volume of dry coating residue waste."

TABLE C3

Source Index

Bonem	Bonem, Michael W. "Economical Decontamination of Concrete and Metal Using the TechXtract™ Process," Proceedings of the International Topical Meeting on Nuclear and Hazardous Waste Management Spectruc '94, 1994, pp. 2434–2438. [2027]
Dickerson	<p>Dickerson, K.S.; Wilson-Nichols, M.J.; Morris, M.I. "Contaminated Concrete: Occurance and Emerging Technologies for DOE Decontamination," DOE/ORO/2034; U.S. Department of Energy Oak Ridge National Laboratory, 1995; pp 1–352.</p> <p>Tbl 2.7 = Past experience in concrete decontamination</p> <p>Tbl 3.5 = Summary of candidate technologies for concrete decontamination</p> <p>Tbl 3.6 = Estimated costs for emerging concrete decontamination technologies</p> <p>Tbl 4.3 = Results from technology demonstration evaluation</p> <p>App C = Technology Description Fact Sheets</p> <p>(a) comparable TechXtract(TM) process</p>
Ebadian	<p>Ebadian, M.A.; Lagos, L.E.; Boudreaux, J.F.; Clark, T.R.; Miller, L.K. "Analysis of Potential Surface Blasting Decontamination Technologies for Structural Steel," Fernald Environmental Restoration Management Corporation: Cincinatti, OH, 1995; pp 1–41. [2023]</p> <p>Tbl 2 = Operational Parameters -<((numbers listed are for painted steel plates))>-</p> <p>Tbl 3 = Utility/Nedia Requirements</p>
Grieco	Grieco, S.A.; Neubauer, E.D.; Rhee, J.R. "Removal and Treatment of Radioactive, Organochlorine, and Heavy Metal Contaminants from Solid Surfaces," In Radioactive and Hazardous Surface Decontamination Utilizing Soda Blasting; O'Brien and Gere Technical Services, Inc.: East Syracuse, NY, 1995; pp 1–10. [2050]
Halter	Halter, J.M.; Sullivan, R.G.; Bevan, J.L. "Surface Concrete Decontamination Equipment Developed by Pacific Northwest Laboratory," Prepared for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830 1982. pp26–29.
SAIC	SAIC. <i>Market Assessment Decontamination of Radioactivity - Contaminated Concrete</i> ; 1996. [2478]Tbl 3-3 = Representative Listing of Companies in the Concrete Decontamination Market and Their Associated Techs. (all except Shot Blasting \$/ft² accepted from Dickerson)
Vanderbilt	<p>Ayers, K.W.; Boren, J.K.; Stephen, A.; Parker, F.L. "Reuse of Concrete from Contaminated Structures. Part 1: Economic Analysis of the Feasibility of Recycling Contaminated Concrete," DE-FG05-94OR22343; Department of Civil and Environmental Engineering, Vanderbilt University: Nashville, TN, 1996. [[primary source is Dickerson]]</p> <p>Tbl 5-1 = Technology Summary Table</p>

APPENDIX D

SURFACE DECONTAMINATION ASSISTANT MODEL

SURFACE DECONTAMINATION ASSISTANT MODEL DESIGN

SURFACE CHARACTERISTICS AND WASTE DEFINITION

The model determines a performance index (PI) for decontamination of a metal or concrete surface using a user-defined scenario as input. The user-defined scenario can include various types of substrate material, amount of area to be removed/decontaminated, depth of removal, surface orientation (e.g., floor), type of contamination, type of transportation used for disposal, distance to disposal site, and fees charged for disposal. Outputs include the performance indices listed below, which together provide an overall PI for a decontamination technology:

- Surface removal
- Transportation
- Disposal
- Environment, health, and safety
- Implementability, operation, and maintenance

Assumptions

- User knows types of contamination that occurred on site.
- User has knowledge of surfaces to be decontaminated.
- Depth of contamination is defined.

TECHNOLOGY SELECTION

Included within the model is a dataset of technologies that contains information on the operational aspects of each technology listed. The user can view this information while using the model to help determine which process is most applicable for the user's situation. Listed below are the fields within the dataset records that are based on the variables used in determining the overall PI for a technology:

- Destructive or nondestructive process
- Substrate-cleaning ability – metal or concrete or both
- Surface-cleaning ability only
- Production rate
- Operating cost
- Volume, phase, and density of secondary waste
- Depth of cleaning
- Number of passes needed to achieve 100% decontamination
- Ability to clean vertical and overhead surfaces
- Ability to clean hard-to-reach areas (corners, cracks, etc.)
- On-line analysis capabilities
- Usual utility costs

- Environment, health, and safety factors
- Implementability, operation, and maintenance
- Stage of technology development
- Number of workers necessary to operate technology
- Capital cost, delivery and setup factors
- Labor costs

Decontamination technologies are classified as either destructive or nondestructive processes. Destructive process are considered to have 100% effectiveness of decontamination due to the actual removal of the surface containing the contamination. For nondestructive processes, the model assumes that each technology has the ability to achieve complete removal of the contaminants even if the surface must be cleaned several times. Technologies that are not applicable to cleaning a particular substrate (concrete, metal) will not be selectable by the user for that particular application. For example, if the contaminant has seeped into a concrete floor, a surface-cleaning technology (nondestructive) will no longer be a viable selection. The model also asks the user the orientation of the contaminated surface, then excludes any technology from selection that is not able to clean surfaces of that orientation.

Assumptions

- All technologies are capable of 100% decontamination of the surface.
- Operation cost is a service cost. The inclusion of labor cost in the operating cost is determined on each technology in the dataset.

CALCULATION OF SURFACE REMOVAL FACTOR

This section describes how the cost factor of surface decontamination is determined. Variables used in the calculation include operating cost, production rate, depth of removal, number of passes necessary for 100% cleaning, area to be decontaminated/removed, labor and setup costs.

The model can determine several different contamination scenarios: 1) contamination that has seeped into the concrete below the surface coating, 2) decontamination of a room or building, and 3) easy- versus hard-to-reach areas to be decontaminated.

In Scenario 1, the contamination has seeped down into the concrete. There are two possible ways to achieve the objective of decontamination: 1) removal of both the surface coating and the contaminated concrete with one technology (this technology would have to be a destructive process or a process that is capable of penetrating the contaminated concrete) and 2) performing two separate runs of the model using a nondestructive process to remove the surface coating and another to decontaminate the concrete. One reason for using two different technologies is to reduce secondary waste by using a nondestructive low-waste-producing technology to remove the surface coating.

Scenario 2 involves decontamination of rooms or buildings, which would include horizontal and vertical surfaces. Some technologies are not capable of cleaning vertical surfaces or ceilings. There are two possible ways to approach this scenario: 1) enter the total surface area for the building/room and use one technology that is capable of cleaning all of the surfaces or 2) use several technologies to decontaminate the building/room, and run the model a separate time for each technology and different surface orientation.

Scenario 3 involves areas that are hard to reach, defined as a deep crack or crease or an area within 6 inches of the corners of a room, versus areas that are easily cleaned. Several technologies are not capable of cleaning within 6 inches of a corner. 1) Select a technology that is capable of cleaning all of the contaminated surface. 2) Run the model twice, once using a technology to clean the easily accessible areas, but unable to reach into the corners, and a second time using a technology that is capable of cleaning in the corners.

Assumption

- User is willing to use one or more different technologies to decontaminate a site.

Algorithm Description

For the first step, the model determines the total number of passes needed to completely remove the contaminants using an equation based upon the depth of removal, the depth to which the technology can clean per pass, and the cleaning effectiveness of the technology (Ref. 22, Appendix B, pp 1–26).

The time needed to complete the user-defined decontamination task is provided in a second calculation. The parameters taken into consideration are the surface area to be cleaned, the production rate of a technology, the number of passes necessary, and the percent of the area that is hard to reach (as defined above). A compensation factor is included that determines the rate at which the total hours to decontaminate will increase because of areas that are more time-consuming to clean (hard-to-reach areas). The total hours will be used later to determine the amount of secondary waste produced by a technology.

A third equation determines the surface removal costs for a technology by multiplying total time calculated above by the technology operating cost and production rate, incorporating labor costs, if necessary. Floor surface is treated apart from vertical and ceiling surface areas because some technologies are able to decontaminate only floors (Ref. 22, Appendix B, pp 1–26).

CALCULATION OF WASTE VOLUMES AND WEIGHT

Two primary waste streams are produced during the decontamination process. One is surface debris, resulting from the actual removal of the contaminated surface, and the other is the secondary waste produced from the technology during the cleaning process. The secondary waste can be in liquid or solid phase, and is indicated in the technology dataset. For future definition

of the types of waste to be disposed of at a storage or disposal site, the model tracks both weight and volume of the primary solid waste and secondary liquid and solid waste. Each phase of waste will be treated differently during transportation and disposal.

Assumptions

- No transuranic waste or spent nuclear fuel is being transported or disposed of.
- Technologies and site personnel are capable of removing one specific area, then another, without mixing the removed waste.
- Solid and liquid waste streams are kept separate.
- Primary substrate waste is always solid.
- On-site disposal will use existing trucks and personnel.
- Remote-handling waste cannot be shipped by rail.

Algorithm Description

The volume and weight of debris resulting from the removal of the contaminated surface are calculated by multiplying the surface area by the depth of removal and the solid surface volume by surface density, respectively.

Each technology produces a different amount and phase of secondary waste from the decontamination process (Ref. 1, Appendix B, pp 1–26). The total volume and weight of the secondary waste for both solid and liquid phase are determined by multiplying the volume and weight of waste produced by each technology per hour by the total number of hours.

The total volume amount of solid waste produced during the decontamination process is determined by adding the volume of surface debris and the volume of secondary waste. The amount of solid secondary waste is determined using the percentage of secondary waste that is solid from the technology dataset.

Waste Classification

Most U.S. Department of Energy (DOE) waste streams from decontamination processes fit one of the following categories: low-level waste (LLW), greater-than-Class C (GTCC) LLW and DOE equivalent waste, transuranic waste (TRU), spent nuclear fuel (SNF), and hazardous waste. (Ref. 26, Appendix B, p 1). These wastes streams are grouped together into three transportation categories:

- Contact-handled (<200 mrem/hr contact dose)
- Remote-handled (>200 mrem/hr contact dose)

- Hazardous waste

Most storage/disposal facilities accept LLW, MLLW, and TRU wastes (Refs. 26, 102, 137, Appendix B). For ease of use, the model classifies waste as contact-handled (CH) (<200 mrem/hr contact dose) or remote-handled (RH) (>200 mrem/hr contact dose) for transportation and disposal. Solid CH waste can be disposed of on-site, thus lowering disposal costs. All liquid CH waste is assumed to be disposed of at a DOE or commercial disposal facility.

Another type of waste produced during the decontamination process is general construction and demolition (C&D) waste. Uncontaminated concrete can be disposed of in a C&D landfill at a default charge of \$7/yd³ (Ref. 3, Appendix B).

CALCULATION OF TRANSPORTATION COSTS

Waste is classified for shipping as either contact- or remote-handled. Waste also can be transported by either truck or rail with specific weight restrictions and container device restrictions. As noted in a DOE technology assessment, “The volume of remote-handled waste is very small and does not warrant an estimate of rail costs in addition to truck costs” (Ref. 2, Appendix B, p 9). Also, the standard remote-handled containers are not designed for rail shipment. For this reason, the model does not consider rail shipment of remote-handled waste.

Transportation costs are determined in the form of cost-per-loaded-mile (CPLM) format. Most transportation is by truck, but rail can be used where practical. The CPLM unit rate is a variable cost dependent on the distance traveled. It has two subcomponents:

- Carrier cost – covers the variable costs associated with the cargo carrier. The carrier is the entity that takes title to the waste from the shipper during transportation, i.e., the trucking or railroad company.
- Hardware costs – the variable costs associated with procuring and maintaining the special hardware used during the transportation of waste. Special hardware consists mainly of trailers and railroad cars equipped with special tight-sealing enclosures or shielded casks.

Fixed costs generally consist of demurrage cost of the carrier and the hardware used in the shipment, which are independent of the distance traveled. Fixed costs are incurred during loading and unloading operations.

Guidelines for liquid waste shipments by truck or rail differ from those for solid shipments because of the need to provide secondary containment of spills that might occur in transit. Liquid components will only be 50% of the shipment volume. A common method used for packaging liquids is to place the liquid waste in a 30-gal closed-top drum, which is then placed in a 55-gal open-head drum. Absorbent is placed between the two containers, allowing the absorbent to remain noncontaminated, not adding to the disposal costs (Ref. 26, Appendix B).

Assumptions

- On-site disposal will be solid waste only.
- All loads are full shipments.

Algorithm Description

Truck – Contact-Handled Waste

- 48-ft-long unshielded truck trailers
- Solid type of waste: LLW, MLLW, alpha LLW, alpha MLLW
- Solid load: 44,000 lb per shipment – 88 drums @ 500 lb
- Liquid type of waste: LLW, MLLW
- Liquid load: Type A container, 44,000 lb per shipment – 88 drums @ 500 lb

A calculation is done to determine the number of truckloads necessary to transport the waste to a DOE storage/disposal facility. 2600 gallons is the estimated amount of liquid per shipment. Multiplying 2600 gallons by the density of water equals 21,688 lb/shipment (Ref. 26, Appendix B). Another computation determines the cost of transportation by multiplying the number of loads by the one-way distance traveled to a disposal facility and charge per mile. For the cost per mile, all distances traveled to DOE storage/facility sites are considered to be over 300 miles.

The fixed costs are multiplied by the number of loads and added to the total cost. The format is the same: 1) determine the number of loads necessary to remove waste and 2) calculate the transportation cost for rail CH, truck RH, CH on-site disposal, and C&D disposal costs.

Rail – Contact-Handled Waste

- 40-ft-long intermodal (sea-land) containers
- Solid type of waste: LLW, MLLW
- Liquid load: Type B container, 38,000 lb per container – 76 drums @ 500 lb
- Load: 44,000 lb per container – 11 boxes @ 3945 lb
or 38,000 lb per container – 76 drums @ 500 lb
- Liquids – number of shipments = total quantity of liquid gal/18,240 lb

Truck – Remote-Handled Waste

- Type of Waste: LLW, MLLW, alpha LLW, alpha MLLW, GTCC/DOE equivalent waste
- Load: 13,400 lb per shipment – 14–55 gallon drums per shipment
- Liquids – number of shipments = total quantity of liquid gal/6422 lb

Truck – On-Site Disposal

- Mass of solid waste
- Number of truckloads at 44,000 lb per truckload
- Fixed costs for loading/unloading and other costs associated with the use of trucks (fuel, etc.)

DETERMINATION OF DISPOSAL FEES

The fees charged by DOE and commercial storage/disposal facilities vary greatly from location to location (Refs. 3, 102, 137, Appendix B). The model uses an average for the different types of waste, which is considered fair, because the fee is the same for each technology. If the user wishes to change or knows the fee charged by a particular facility, that number can be entered instead:

- Contact-handled waste, off-site – High \$300/ft³ (Ref. 137, Appendix B), medium \$150/ft³ (Ref. 102, Appendix B,), low \$100/ft³ (Ref. 57, Appendix B)
- Contact-handled waste, on-site – \$60/ft³ (Ref. 26, Appendix B)
- Remote-handled waste – High \$740/ft³, medium \$300/ft³, low \$150/ft³ (Ref. 102, Appendix B)
- Construction and demolition waste – \$0.26/ft³ (Ref. 3, Appendix B)

Assumptions

- User can use default values or will enter local disposal.

Algorithm Description

The disposal values are determined by multiplying the volume of material to be disposed by the appropriate fee.

CALCULATION OF TECHNOLOGY PERFORMANCE INDICES

A PI is computed for each technology when it is selected. PIs can be compared against those for another technology if the decontamination scenario input values are identical. The higher the PI for a technology, the better the technology did decontaminating that scenario. The overall PI is composed of five different factors: surface removal, transport, disposal, safety, and maintenance. To determine the safety and maintenance factors, performance scores were given each of the cleanup technologies in the areas of operation, maintenance, implementability, and environment, health, and safety (Ref. 57, Appendix B). The technologies were assigned nominal

performance scores on a scale of 1 to 10, with 10 being the best. The criteria used were as follows:

- Implementability
 - Availability of the technology
 - Previous use of the technology
 - State of development of environmental management (EM) applications
 - Flexibility and adaptability
- Operation and maintenance
 - Setup
 - Cleaning operations
 - Equipment cleanup after shutdown
 - Equipment maintenance
- Environment, health, and safety
 - Regulatory compliance
 - Emissions of toxic gases, vapors, and dust
 - Worker exposure

The performance scores were independently assigned to the criteria by three raters: a senior chemical engineer with process experience, a research engineer, and a senior research chemist with recent background in developing a computer model for evaluating alternative surface-cleaning methods (Ref. 57, Appendix B).

Algorithm Description

The costs for surface removal, transportation and waste disposal for each technology are the basis for those performance indices. The surface removal costs come from the previously described surface removal factor. The transportation and waste disposal costs are calculated by summing the costs of all potential components. For example, all of the different types of waste disposal costs are added together (CH on-site, CH off-site, RH on-site, RH off-site, C&D waste).

Since the surface removal, transportation and waste disposal factors are all costs, the smaller the resultant factor, i.e., a lower cost, is desirable. To obtain a PI number that gets larger to indicate a greater value, each factor is divided into the minimum factor for all technologies compared.

The software allows the user the ability to give one PI more weight, or importance, than another PI in the calculation of an overall PI by giving each component a priority ranking. Each PI is assigned a priority rank with a value of 1-10, with 10 being the best. The program takes each PI and multiplies its value by the priority ranking given by the user, then sums together the five PIs and divides by the maximum sum of all technologies compared.

APPENDIX E

MODEL DESIGN EQUATIONS

Variables:

NP is the number of passes [unitless].

RD refers to removal depth [length].

RC is the surface removal cost [dollars].

PI is for technology performance indices [index specific units].

C is for cost [dollars/ft² for operating costs; dollars/hr for labor costs].

NW is the number of workers required to operate a technology [unitless].

A refers to an area [length²].

Cap refers to (capital) cost factor.

Siz refers to size/delivery factor.

Cal refers to setup/calibration factor.

Setup refers to the setup cost.

V refers to a volume [length³].

M refers to a mass [mass].

D refers to density [mass/length³].

Time refers to a length of time [time].

PR is the production rate [length²/time].

HR is the portion of the surface which is hard to reach [length²].

V2W is the rate (or amount) of secondary waste volume [length³/time] ([length³]).

M2W is the rate (or amount) of secondary waste mass [mass/time] ([mass]).

S combined with V or M (e.g., VS) is a volume or mass of solid.

L combined with V or M (e.g., VL) is a volume or mass of liquid.

%Solid is the percentage of the external media used by the technology which is solid.

CT is the cost for trucking.

CR is the cost for rail transport.

On combined with CT or CR is for on-site transportation.

Off combined with CT or CR is for off-site transportation.

f combined with S or L is a disposal cost factor.

Subscripts:

Tech subscript refers to technology-specific variables.

Coat refers to the substrate coating.

Sub refers to the substrate.

Surf refers to surface.

Labor refers to workers that operate technology.

Tot refers to totals for the entire surface removal operation.

Fact refers to generic factors (e.g., factor to compensate for hard-to-reach areas).

CH refers to contact-handled waste.

RH is remote-handled waste.

CD is construction and demolition waste.

Rec is for recyclable materials.

Initial removal depth

$$RD_{Init} (RD_{Coat}, RD_{Sub}) := RD_{Coat} + RD_{Sub}$$

Total number of passes to remove surface

NOTE: If NP_{Tot} is not an integer, round up to the next integer.

$$NP_{Tot} (NP_{Tech}, RD_{Tech}, RD_{Init}) := NP_{Tech} \frac{RD_{Init}}{RD_{Tech}}$$

After determining NP_{Tot} , we must now recalculate the total removal depth to compensate for additional depth to make a full pass. When destructive technologies are used to remove surface coatings, we must include a removal depth of substrate into the equation. Therefore, we introduce Destructive factor Des.

If technology is non-destructive, Des=1. If technology is destructive, Des=0.

Total removal depth

$$RD_{Surf} (RD_{Coat}, Des, NP_{Tech}, RD_{Tech}, NP_{Tot}) := RD_{Coat} + \left[(1 - Des) \cdot NP_{Tot} \frac{RD_{Tech}}{NP_{Tech}} \right]$$

We are interested in the case where $RD_{Sub} = 0$. For this case only, calculate a new RD_{Sub} value.

Removal depth of substrate

$$RD_{Sub} (RD_{Coat}, RD_{Surf}) := RD_{Surf} - RD_{Coat}$$

Total number of hours to remove surface

$$Time_{Tot} (A_{Surf}, HR_{Surf}, PR_{Tech}, NP_{Tot}, HR_{Fact}) := \left[(HR_{Fact} - 1) \cdot HR_{Surf} + A_{Surf} \right] \cdot \frac{NP_{Tot}}{PR_{Tech}}$$

The setup factor is a constant the purpose of which is to give weight to the tech setup cost with respect to the operating cost. The preliminary value for this factor is 2000.

Determination of Technology Setup Cost

$$\text{Setup}_{\text{Tech}}(\text{Cap}_{\text{Tech}}, \text{Siz}_{\text{Tech}}, \text{Cal}_{\text{Tech}}) = \text{Cap}_{\text{Tech}} + \text{Siz}_{\text{Tech}} + \text{Cal}_{\text{Tech}}$$

We need to incorporate labor costs into the operating costs. If labor is included in the operating cost listed in the dataset, labor=0, else labor=1. We also want to incorporate the setup factor into the cost equation.

This value may change: $C_{\text{Labor}} := 21.875$

Surface removal cost (units are dollars)

$$\text{RC}_{\text{Surf}}(\text{Time}_{\text{Tot}}, C_{\text{Tech}}, \text{labor}, \text{NW}_{\text{Tech}}, C_{\text{Labor}}, \text{PR}_{\text{Tech}}, \text{Setup}_{\text{Tech}}, \text{Setup}_{\text{Fact}}) := (C_{\text{Tech}} \cdot \text{PR}_{\text{Tech}} + \text{labor} \cdot \text{NW}_{\text{Tech}} \cdot C_{\text{Labor}}) \cdot \text{Time}_{\text{Tot}} + (\text{Setup}_{\text{Tech}} \cdot \text{Setup}_{\text{Fact}})$$

Volume of surface to remove

$$V_{\text{Surf}}(A_{\text{Surf}}, \text{RD}_{\text{Surf}}) := A_{\text{Surf}} \cdot \text{RD}_{\text{Surf}}$$

Mass of surface to remove

$$M_{\text{Surf}}(A_{\text{Surf}}, \text{RD}_{\text{Coat}}, D_{\text{Coat}}, \text{RD}_{\text{Sub}}, D_{\text{Sub}}) = A_{\text{Surf}} \cdot (\text{RD}_{\text{Coat}} \cdot D_{\text{Coat}} + \text{RD}_{\text{Sub}} \cdot D_{\text{Sub}})$$

We also want to know whether the secondary waste is solid or liquid and if liquids are introduced by the process whether or not solids may be separated from liquids on-site. If separation of solids and liquids can be done on-site then we can send liquids only to off-site disposal, otherwise both solids and liquids (mixed) will have to be sent off-site resulting in increased costs for dealing with the wastes. This problem is compounded by the fact that the liquids introduced will not only mix with the (possible) solids used in the process but will also mix with the surface being removed adding more costs.

If solids and liquids can be separated on-site, Sep=1 Else Sep=0

Total Volume of Solid Waste

$$\text{VS}_{\text{Tot}}(V_{\text{Surf}}, \text{V2WS}_{\text{Tech}}, \text{Time}_{\text{Tot}}, \text{Sep}) = \text{Sep} \cdot (V_{\text{Surf}} + \text{V2WS}_{\text{Tech}} \cdot \text{Time}_{\text{Tot}})$$

Total Mass of Solid Waste

$$\text{MS}_{\text{Tot}}(M_{\text{Surf}}, \text{V2WS}_{\text{Tech}}, \text{D2WS}_{\text{Tech}}, \text{Time}_{\text{Tot}}, \text{Sep}) = \text{Sep} \cdot (M_{\text{Surf}} + \text{V2WS}_{\text{Tech}} \cdot \text{D2WS}_{\text{Tech}} \cdot \text{Time}_{\text{Tot}})$$

Total Volume of Liquid Waste

$$ML_{Tot} (V2WS_{Tech}, V2WL_{Tech}, Time_{Tot}, M_{Surf}, D2WS_{Tech}, D2WL_{Tech}, Sep) = Time_{Tot} \cdot [V2WL_{Tech} \cdot D2WL_{Tech} + (1 - Sep) \cdot V2WS_{Tech} \cdot D2WS_{Tech}] + (1 - Sep) \cdot M_{Surf}$$

Total Mass of Liquid Waste

$$ML_{Tot} (V2WS_{Tech}, V2WL_{Tech}, Time_{Tot}, M_{Surf}, D2WS_{Tech}, D2WL_{Tech}, Sep) := Time_{Tot} [V2WL_{Tech} \cdot D2WL_{Tech} + (1 - Sep) \cdot V2WS_{Tech} \cdot D2WS_{Tech}] + (1 - Sep) \cdot M_{Surf}$$

Volume of CH Waste

$$V_{CH} (A_{CH}, RD_{Surf}, V2WS_{Tech}, V2WL_{Tech}, Time_{Tot}, A_{Surf}) = A_{CH} \cdot RD_{Surf} + (V2WS_{Tech} + V2WL_{Tech}) \cdot Time_{Tot} \cdot \frac{A_{CH}}{A_{Surf}}$$

Mass of CH Waste

$$M_{CH} (A_{CH}, RD_{Coat}, D_{Coat}, RD_{Sub}, D_{Sub}, V2WS_{Tech}, D2WS_{Tech}, V2WL_{Tech}, D2WL_{Tech}, Time_{Tot}, A_{Surf}) = A_{CH} \cdot \left[(RD_{Coat} \cdot D_{Coat} + RD_{Sub} \cdot D_{Sub}) + (V2WS_{Tech} \cdot D2WS_{Tech} + V2WL_{Tech} \cdot D2WL_{Tech}) \cdot \frac{Time_{Tot}}{A_{Surf}} \right]$$

Volume of RH Waste

$$V_{RH} (A_{RH}, RD_{Surf}, V2WS_{Tech}, V2WL_{Tech}, Time_{Tot}, A_{Surf}) = A_{RH} \cdot RD_{Surf} + (V2WS_{Tech} + V2WL_{Tech}) \cdot Time_{Tot} \cdot \frac{A_{RH}}{A_{Surf}}$$

Mass of RH Waste

$$M_{RH} (A_{RH}, RD_{Coat}, D_{Coat}, RD_{Sub}, D_{Sub}, V2WS_{Tech}, D2WS_{Tech}, V2WL_{Tech}, D2WL_{Tech}, Time_{Tot}, A_{Surf}) = A_{RH} \cdot \left[(RD_{Coat} \cdot D_{Coat} + RD_{Sub} \cdot D_{Sub}) + (V2WS_{Tech} \cdot D2WS_{Tech} + V2WL_{Tech} \cdot D2WL_{Tech}) \cdot \frac{Time_{Tot}}{A_{Surf}} \right]$$

Percentage of Total Waste Volume Which Is CH

$$\%_{CH} (V_{S_{Tot}}, V_{L_{Tot}}, V_{CH}) := 100 \cdot \frac{V_{CH}}{(V_{S_{Tot}} + V_{L_{Tot}})}$$

Percentage of Total Waste Mass Which Is CH

$$\%_{CH} (M_{S_{Tot}}, M_{L_{Tot}}, M_{CH}) := 100 \cdot \frac{M_{CH}}{(M_{S_{Tot}} + M_{L_{Tot}})}$$

Percentage of Total Waste Volume Which Is RH

$$V\%_{RH}(V_{S\ Tot}, V_{L\ Tot}, V_{RH}) := 100 \frac{V_{RH}}{(V_{S\ Tot} + V_{L\ Tot})}$$

Percentage of Total Waste Mass Which Is RH

$$M\%_{RH}(M_{S\ Tot}, M_{L\ Tot}, M_{RH}) := 100 \frac{M_{RH}}{(M_{S\ Tot} + M_{L\ Tot})}$$

Now recompute waste volumes and masses for each waste category assuming uniform mixing of contaminants, surface removal media (if any), and surface removal debris in contaminated areas

Mass of CH Solid Waste

$$MS_{CH}(M\%_{CH}, MS_{Tot}) := MS_{Tot} \frac{M\%_{CH}}{100}$$

Mass of CH Liquid Waste

$$ML_{CH}(M\%_{CH}, ML_{Tot}) := ML_{Tot} \frac{M\%_{CH}}{100}$$

Mass of RH Solid Waste

$$MS_{RH}(M\%_{RH}, MS_{Tot}) := MS_{Tot} \frac{M\%_{RH}}{100}$$

Mass of RH Liquid Waste

$$ML_{RH}(M\%_{RH}, ML_{Tot}) := ML_{Tot} \frac{M\%_{RH}}{100}$$

Mass of CD Solid Waste

$$MS_{CD}(MS_{Tot}, MS_{CH}, MS_{RH}) := MS_{Tot} - MS_{CH} - MS_{RH}$$

Volume of CH Solid Waste

$$VS_{CH}(V\%_{CH}, VS_{Tot}) := VS_{Tot} \cdot \frac{V\%_{CH}}{100}$$

Volume of CH Liquid Waste

$$VL_{CH}(V\%_{CH}, VL_{Tot}) := VL_{Tot} \cdot \frac{V\%_{CH}}{100}$$

Volume of RH Solid Waste

$$VS_{RH}(V\%_{RH}, VS_{Tot}) := VS_{Tot} \cdot \frac{V\%_{RH}}{100}$$

Volume of RH Liquid Waste

$$VL_{RH}(V\%_{RH}, VL_{Tot}) := VL_{Tot} \cdot \frac{V\%_{RH}}{100}$$

Volume of CD Solid Waste

$$VS_{CD}(VS_{Tot}, VS_{CH}, VS_{RH}) := VS_{Tot} - VS_{CH} - VS_{RH}$$

Transportation Costs

If on-site disposal is used for solids, OnSite=1 else OnSite=0

If Truck is used as transport style, Truck=1 else Truck=0

Some of these values will change:

$$MSTruck_{CH} = 44000 \text{ lb} \quad MLTruck_{CH} = 21688 \text{ lb} \quad CostMile_{CHTruck} = 10 \quad Maint_{CHTruck} = 100$$

Contact Handled Waste Off-Site Trucking Costs

$$CTOff_{CH}(MS_{CH}, ML_{CH}, Dist_{offCH}, Truck, OnSite) = Truck \cdot \left[\frac{ML_{CH}}{MLTruck_{CH}} + (1 - OnSite) \cdot \left(\frac{MS_{CH}}{MSTruck_{CH}} \right) \right] \cdot (CostMile_{CHTruck} \cdot Dist_{offCH} + Maint_{CHTruck})$$

Contact Handled Waste On-Site Trucking Costs

$$CT_{On\ CH}(MS_{CH}, Dist_{onCH}, Truck, OnSite) := Truck \cdot OnSite \cdot \left(\frac{MS_{CH}}{MSTruck_{CH}} \right) \cdot (CostMile_{CHTruck} \cdot Dist_{onCH} + Maint_{CHTruck})$$

Some of these values will change:

$$MS_{Rail_{CH}} = 44000 \text{ lb} \quad ML_{Rail_{CH}} = 18240 \text{ lb} \quad CostMile_{Rail} = 8 \quad Maint_{Rail} = 100$$

Contact Handled Waste Rail Transportation Costs

$$CR_{CH}(MS_{CH}, ML_{CH}, Dist_{offCH}, Truck) := (1 - Truck) \cdot \left(\frac{ML_{CH}}{ML_{Rail_{CH}}} + \frac{MS_{CH}}{MS_{Rail_{CH}}} \right) \cdot (CostMile_{Rail} \cdot Dist_{offCH} + Maint_{Rail})$$

Some of these values will change:

$$MSTruck_{RH} = 13400 \text{ lb} \quad ML_{Truck_{RH}} = 6422 \text{ lb} \quad CostMile_{RHTruck} = 15 \quad Maint_{RHTruck} = 100$$

Remote Handled Waste Off-Site Trucking Costs

$$CT_{Off_{RH}}(MS_{RH}, ML_{RH}, Dist_{offRH}, Truck, OnSite) = Truck \cdot \left[\frac{ML_{RH}}{ML_{Truck_{RH}}} + (1 - OnSite) \cdot \left(\frac{MS_{RH}}{MSTruck_{RH}} \right) \right] \cdot (CostMile_{RHTruck} \cdot Dist_{offRH} + Maint_{RHTruck})$$

Remote Handled Waste On-Site Trucking Costs

$$CT_{On_{RH}}(MS_{RH}, Dist_{onRH}, Truck, OnSite) := Truck \cdot OnSite \cdot \left(\frac{MS_{RH}}{MSTruck_{RH}} \right) \cdot (CostMile_{RHTruck} \cdot Dist_{onRH} + Maint_{RHTruck})$$

Some of these values will change:

$$MSTruck_{CD} = 44000 \text{ lb} \quad CostMile_{CDTruck} = 10 \quad Maint_{CDTruck} = 100$$

Construction and Demolition Waste On-Site Trucking Costs

$$CT_{On_{CD}}(MS_{CD}, Dist_{CD}, Truck) := Truck \cdot \left(\frac{MS_{CD}}{MSTruck_{CD}} \right) \cdot (CostMile_{CDTruck} \cdot Dist_{CD} + Maint_{CDTruck})$$

PERFORMANCE INDICES

Surface Removal

$$PI_{Surf}(Time_{Tot}, C_{Tech}, PR_{Tech}, labor, NW_{Tech}, Setup_{Tech}, Setup_{Fact}, PIM_{Tech}) = \frac{\min_of_all_tech[(C_{Tech} \cdot PR_{Tech} + labor \cdot NW_{Tech} \cdot C_{Labor}) \cdot Time_{Tot} + (Setup_{Tech} \cdot Setup_{Fact})]}{(C_{Tech} \cdot PR_{Tech} + labor \cdot NW_{Tech} \cdot C_{Labor}) \cdot Time_{Tot} + (Setup_{Tech} \cdot Setup_{Fact})}$$

Transport

$$PI_{Transport}(CTOn_{CH}, CTOff_{CH}, CTOff_{RH}, CR_{CH}) := \frac{\min_of_all_tech (CTOn_{CH} + CTOff_{CH} + CTOff_{RH} + CTOn_{RH} + CR_{CH} + CTOn_{CD}) + 1}{(CTOn_{CH} + CTOff_{CH} + CTOff_{RH} + CTOn_{RH} + CR_{CH} + CTOn_{CD}) + 1}$$

Waste Disposal

Included are factors that give each term of the sum weight based on the undesirability of producing that type of waste. These may be based on relative disposal costs. (Disposal factors were taken from EM Task 21 Semiannual for 4-1-98 to 9-30-98.)

$$fS_{CH} := 60 \quad fL_{CH} := 60 \quad fS_{RH} := 300 \quad fL_{RH} := 300 \quad fS_{CD} := 8.18$$

$$PI_{Disposal}(VS_{CH}, VL_{CH}, VS_{RH}, VS_{CD}, fS_{CH}, fL_{CH}, fS_{RH}, fL_{RH}, fS_{CD}) = \frac{\min_of_all_tech (fS_{CD} \cdot VS_{CD} + fL_{RH} \cdot fS_{RH} \cdot fL_{CH} \cdot VL_{CH} + fS_{CH} \cdot VS_{CH})}{(fS_{CD} \cdot VS_{CD} + fL_{RH} \cdot fS_{RH} \cdot fL_{CH} \cdot VL_{CH} + fS_{CH} \cdot VS_{CH})}$$

Safety

$$PI_{Safety}(Use_normalized_values_from_the_dataset)$$

Maintenance

$$PI_{Maint}(Use_normalized_values_from_the_dataset)$$

Overall Performance Index

$$Priority_{Maint} = 1 \quad Priority_{Transport} = 1 \quad Priority_{Disposal} = 1 \quad Priority_{Safety} = 1 \quad Priority_{Maint} = 1$$

$$PI_{Overall}(PI_{Surf}, PI_{Transport}, PI_{Disposal}, PI_{Maint}) = \frac{Priority_{Surf} \cdot PI_{Surf} + Priority_{Transport} \cdot PI_{Transport} + Priority_{Disposal} \cdot PI_{Disposal} + Priority_{Safety} \cdot PI_{Safety} + Priority_{Maint} \cdot PI_{Maint}}{\max_of_all_tech (Priority_{Surf} \cdot PI_{Surf} + Priority_{Transport} \cdot PI_{Transport} + Priority_{Disposal} \cdot PI_{Disposal} + Priority_{Maint} \cdot PI_{Maint})}$$

APPENDIX F

SURFACE DECONTAMINATION ASSISTANCE SENSITIVITY ANALYSES

SURFACE DECONTAMINATION ASSISTANCE SENSITIVITY ANALYSES

Sensitivity analyses were performed to determine the effectiveness of the Surface Decontamination Assistance (SDA) model design. The first step in the process was to create a reasonable matrix composed of scenarios that would test SDA outputs for individual PIs and the overall PI as well as provide data to explore the rigor of the model and its programming implementation. During this process, the model was amended and programming errors identified and repaired. To examine the dynamics of the system by varying each input parameter individually at two levels (for example, depth of coating at 0.05 and 1 in.) would require a factorial design containing more than 8100 scenarios, a daunting task. Therefore, each input datum was evaluated for its importance in affecting model outputs. Those expected to have greater significance were varied in the test matrix. The unabridged matrix is shown in Table F1.

Figures F1 through F6 illustrate the output information from the software. The predicted PIs from Scenario 3 are used in the examples. As the graphs indicate, the specific technologies recommended by the SDA software vary by PI category. As elements of the input data change, the ranking of technologies may change as well. The exceptions to this expectation are the EHS and IOM PIs whose data come directly from the performance dataset and undergo no manipulation prior to the calculation of the PI itself.

An objective of the sensitivity analyses was to show that the ranking of technologies for any given PI could change resultant to changes in scenario inputs. A change in depth of coating, for example, can show a corresponding shift in technologies suggested for exploration with respect to the surface removal PI. This is indicated by the comparison of Scenarios 11 and 13 in Figure F7, where mechanical scabbling and high-pressure water versus microwave perform well for Scenarios 11 and 13, respectively. Figure F8 illustrates variations in recommended technologies for better transportation values based on the difference in depth of coating, on-site separation of solids from liquids, and the distribution of waste types between Scenarios 11 and 13. While the carbon dioxide laser and a few blasting technologies receive favorable results in both scenarios, the waste disposal PI in others such as drilling spalling, scarification MOOSE, and squirrel scabbler vary greatly in value.

An example of input effects on rankings for waste disposal is the comparison of Scenarios 1 and 5 in Figure F9, which vary only in depth of coating. The relative performance of some technologies, such as soft media blasting, improved as the depth of coating increased. Figure F10 shows a different result for waste disposal based on the depth of concrete substrate removed. In Scenario 1, no substrate is removed. In contrast, Scenario 2 has the same amount of coating to eliminate, but also includes the removal of 6 in. of concrete substrate, which must be disposed. As can be seen in the graph, the requirement to remove substrate as well as the surface eliminates some technologies from consideration.

An additional parameter limiting the choice of technologies is the presence of hard-to-reach areas to be decontaminated. This is evident in Figure F11, which compares the surface

TABLE F1

Sensitivity Analysis Test Matrix

Sensitivity Analysis Test Matrix																										
Scenario	Surface Tyle	Substrate Material	Total Area	% Hard to Reach	Thickness of Coating, in.	Substrate Removal Depth, in.	Contaminants	On-Site Separation	% Construction and Demolition Waste	% Contact Handled Waste	% Area Remote Handled Waste	Style of Transport	On-Site Storage of solids	Transportation Information					Priority Ranking		Technology Selection	Environmental, Health, & Safety	Operation, Maintenance, and Reliability	Removal Cost	Transportation Cost	Disposal Cost
														RH	RH	CH	CH	C&D								
														Off-Site	On-Site	Off-Site	On-Site									
1	Floors	Concrete	3000	0	0.05	0	All	No	20	60	20	Truck	No	1500	10	1500	10	40	All	6	4	2	4	6		
2	Floors	Concrete	3000	0	0.05	6	All	No	20	60	20	Truck	No	1500	10	1500	10	40	All	6	4	2	4	6		
2a	Floors	Concrete	3000	0	0.05	6	All	No	20	60	20	Rail	No	1500	10	1500	10	40	All	6	4	2	4	6		
3	Floors	Concrete	3000	0	0.1	0	All	No	20	60	20	Truck	No	2000	30	200	5	2	All	6	4	2	4	6		
4	Floors	Concrete	3000	0	0.1	6	All	No	20	60	20	Truck	Yes	2000	30	200	5	2	All	6	4	2	4	6		
5	Floors	Concrete	3000	0	0.95	0	All	No	20	60	20	Truck	No	1500	10	1500	10	40	All	5	5	5	5	5		
6	Floors	Concrete	3000	0	0.95	6	Heavy metals	No	0	100	0	Rail	No	1500	10	1500	10	40	All	6	4	2	4	6		
7	Floors	Concrete	3000	40	0.05	0	Heavy metals	No	20	60	20	Rail	No	1500	10	1500	10	40	All	6	4	2	4	6		
8	Floors	Concrete	3000	40	0.05	6	All	Yes	20	60	20	Rail	No	1500	10	1500	10	40	All	6	4	2	4	6		
9	Floors	Concrete	3000	40	0.95	0	All	No	20	60	20	Truck	No	1500	10	1500	10	40	All	6	4	2	4	6		
10	Floors	Concrete	3000	40	0.95	6	All	No	20	60	20	Truck	No	1500	10	1500	10	40	All	6	4	2	4	6		
11	Floors	Concrete	20000	0	0.05	0	Heavy metals	Yes	0	100	0	Truck	No	1500	10	1500	10	40	All	6	4	2	4	6		
11a	Floors	Concrete	20000	0	0.05	0	Heavy metals	No	20	60	20	Truck	No	1500	10	1500	10	40	All	6	4	2	4	6		
12	Floors	Concrete	20000	0	0.05	6	All	No	20	60	20	Truck	No	1500	10	1500	10	40	All	6	4	2	4	6		
13	Floors	Concrete	20000	0	0.95	0	All	No	20	60	20	Truck	No	1500	10	1500	10	40	All	6	4	2	4	6		
14	Floors	Concrete	20000	0	0.95	6	All	No	20	60	20	Truck	Yes	2000	30	200	5	2	All	6	4	2	4	6		
14a	Floors	Concrete	20000	0	0.95	6	All	Yes	20	60	20	Truck	Yes	2000	30	200	5	2	All	6	4	2	4	6		
15	Floors	Concrete	20000	40	0.05	0	All	Yes	20	60	20	Truck	No	1500	10	1500	10	40	All	6	4	2	4	6		
16	Floors	Concrete	20000	40	0.05	6	Heavy metals	Yes	20	60	20	Truck	No	1500	10	1500	10	40	All	6	4	2	4	6		
17	Floors	Concrete	20000	40	0.95	0	All	Yes	20	60	20	Truck	No	1500	10	1500	10	40	All	6	4	2	4	6		
18	Floors	Concrete	20000	40	0.95	6	All	Yes	0	100	0	Truck	No	1500	10	1500	10	40	All	6	4	2	4	6		
19	Walls	Concrete	20000	0	0.95	6	Heavy metals	No	20	60	20	Truck	No	1500	10	1500	10	40	All	6	4	2	4	6		
20	Walls	Steel	20000	0	0.95	0	Heavy metals	Yes	20	60	20	Truck	No	1500	10	1500	10	40	All	6	4	2	4	6		
21	Ceilings	Concrete	20000	40	0.95	6	Heavy metals	No	20	60	20	Truck	Yes	2000	30	200	5	2	All	6	4	2	4	6		
21a	Ceilings	Concrete	20000	40	0.95	6	Heavy metals	No	20	60	20	Truck	No	2000	30	200	5	2	All	5	5	5	5	5		
22	Ceilings	Steel	20000	40	0.1	0	Heavy metals	Yes	20	60	20	Truck	No	2000	30	200	5	2	All	6	4	2	4	6

Figure F1. Surface removal performance index for Scenario 3.

Figure F2. Transport performance index for Scenario 3.

Figure F3. Waste disposal performance index for Scenario 3.

Figure F4. Environment, health, and safety performance index for Scenario 3.

Figure F5. Implementability, operation, and maintenance performance index for Scenario 3.

Figure F6. Overall performance index for Scenario 3.

Figure F7. Comparison of surface removal performance indices.

Figure F8. Comparison of transport performance indices.

Figure F9. Comparison of waste disposal performance indices.

Figure F10. Comparison of waste disposal performance indices.

Figure F11. Comparison of surface removal performance indices for scenarios with and without hard-to-reach areas.

Figure F12. Comparison of transport performance indices for scenarios with and without hard-to-reach areas.

removal PIs from Scenarios 20 and 22. Both of these are coating-removal scenarios for metal substrates. Although the scenarios vary in the capacities to separate and store solids on-site, the only difference pertinent to the surface removal PI is in the hard-to-reach component. A similar comparison for concrete substrate removal scenarios is illustrated in Figure F12, where Scenarios 2 and 8 are compared. Scenario 8, with 40% of its area hard to reach and requiring substrate removal, has only three technologies available for comparison.

A comparison of the overall PI is shown in Figure F13, where Scenarios 1 and 5 are again compared. Once again, different technologies come out on top. Plastic and CO₂ blasting and scarification MOOSE lead a group of several technologies for which the overall PI hovers around 0.9–1.0 for Scenario 1. As the depth of coating reaches 1 in., however, drilling spalling tops the list. It should be noted that the SDA software does not automatically eliminate destructive technologies from consideration when no substrate removal is indicated. Rather, the program allows the user to see all options and to eliminate unwanted choices individually. For this reason, a destructive technology might be rated well for a job requiring surface removal only.

The overall PI is affected not only by the PIs generated from the model, but also by the relative weight the user defines for the five PIs that combine to form the overall PI. The user's ability to specify the relative importance of each area of performance renders the model's output more sensitive to individual circumstances. This is illustrated in Figure F14, where the overall PI is depicted first as the sum of the component PIs (giving equal weight to each) and second as the weighted calculation of the SDA program using the priorities indicated in Scenario 14. The former indicates that Drilling Spalling and Microwave may be the top technologies to explore further. The latter suggests Mechanical Scabbling and Scarification MOOSE as potential decontamination technologies for Scenario 14.

Figure F13. Overall performance indices.

Figure F14. Comparison of unweighted to weighted overall performance index of Scenario 14.

APPENDIX G

SURFACE DECONTAMINATION ASSISTANT SOFTWARE DESIGN AND OPERATION MANUAL

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SURFACE DECONTAMINATION ASSISTANT SOFTWARE DESIGN AND OPERATION MANUAL

INTRODUCTION

Surface Decontamination Assistant (SDA) is a user-friendly surface decontamination technology comparison software package. SDA uses information assembled in the technology performance dataset user-provided scenario to compare decontamination performance of selected technologies. All outputs from the SDA model are on a relative basis and are intended to be used for comparative purposes only.

SDA has been developed by the Energy & Environmental Research Center (EERC), a research, consulting, and development organization affiliated with the University of North Dakota in Grand Forks, North Dakota. The Center is recognized as providing energy and environmental research and consulting services for public and private clients in the United States and abroad. Additional information about the EERC is available by calling (701) 777-5000 or by accessing the World Wide Web at www.eerc.und.nodak.edu.

SYSTEM AND SOFTWARE REQUIREMENTS

SDA will run on a 486 or higher personal computer equipped with a SVGA video adapter with a minimum of 800 × 600 resolution and Windows™ 95/NT or higher. It requires a minimum of 8 MB or RAM to operate properly. A 3.5-in. high-density (1.44 MB) disk drive and at least 5 MB or free memory on a hard drive are required to install and run the SDA package. The package consists of 1) the SDA program, which calculates index values and displays them; 2) the technology dataset files; and 3) and INSTALL program.

INSTALLATION

SDA is designed to be installed anywhere on a harddrive. A user-defined directory will be created during installation. To install SDA, execute the INSTALL program found on the disk.

User-Defined Application Scenario

Upon program execution, the user is presented with the main screen dialog, shown in Figure G1.

Interaction between the user and the software model is done via a series of input dialogs. Once the Run Complete Scenario button shown in Figure G1 is pressed, the user is led through a series of inputs defining the application scenario. The inputs requested of the user by each dialog are listed below.

Figure G1. Surface Decontamination Assistant main dialog.

Site Name: test site #1

Site Activation Date: 11/13/97

Location: Grand Forks, ND

Modification Date: 11/15/97

Substrate Description: This building has steel walls heavily contaminated

Contamination Description: Heavy Metals and Radionuclides

Continue Cancel

Figure G2. Input scenario summary description dialog.

First, a summary description of the site is entered as listed below and illustrated in Figure G2:

- i. Site name
- ii. Location of site
- iii. General substrate description
- iv. General contamination description
- v. Scenario (site) activation date
- vi. Scenario modification date

Upon pressing the Continue button shown in Figure G2, the user is prompted for more detailed site information as listed below and shown in Figure G3:

- i. Surface type
- ii. Substrate material
- iii. Total area of the surface
- iv. Area of hard to reach portions to be decontaminated
- v. Thickness of surface coating
- vi. Total thickness of surface to be removed

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The dialog box is titled "Site Information" and contains the following fields and controls:

Field	Value	Unit
Surface Type	☒ Floor	
	☐ Wall	
	☐ Ceiling	
Substrate Material	☐ Steel	
	☒ Concrete	
Total surface area to be removed	10000.0	ft^2
Area hard to reach	100.0	ft^2
Thickness of coating	2.0	in
Total thickness of substrate removal	3.0	in

Buttons: Continue, Cancel

Figure G3. Site Information dialog.

Figure G4. General Contamination Definition dialog.

The dialog box is titled "Quantified Contamination Definitions" with a close button (X) in the top right corner. It contains several input fields and a summary section. The inputs are as follows:

Total Surface Area from Site Information	10000.0	ft ²
On-Site capacity to separate solids from liquids	☒ No ☐ Yes	
Percentage of Construction and Demolition Waste	60.0	%
Percentage of Contact Handled Waste <200 mrem/hr material	40.0	%
Percentage Area Remote Handled Waste >200 mrem/hr material	0.0	%
=====		
Total Percentage	100.0	%

At the bottom of the dialog are three buttons: "Continue", "Default", and "Cancel".

Figure G5. Quantified Contamination Definitions input dialog.

Next, when the Continue button depicted in Figure G3 is pressed, the user can select general categories, as shown in Figure G4.

As before, pressing the Continue button illustrated in Figure G4 brings the user to the input dialog shown in Figure G5, Quantified Contamination Definitions. The program displays the total surface area indicated previously. The inputs needed are estimated surface area percentages of the following waste categories:

- i. Construction and demolition (can be sent to a landfill)
- ii. Contact-handled (<200 mrem/hr)
- iii. Remote-handled (>200 mrem/hr)

and the on-site solid/liquid separation capacity of the facility.

Once the contamination input dialog is completed by pressing the Continue button, the user is prompted for information on the details of transportation to remove waste from the decontamination site. Listed below are the inputs, and the dialog is illustrated in Figure G6.

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Input Field	Value	Unit
Style of Transport	☒ Truck	☐ Rail
Storage of Solids	☒ On-Site	☐ Off-Site
Remote Handled Off-Site Transportation Distance	1500	miles
Remote Handled On-Site Transportation Distance	10	miles
Contact Handled Off-Site Transportation Distance	1500	miles
Contact Handled On-Site Transportation Distance	10	miles
Construction and Demolition Transportation Distance	40	miles

Continue Default Cancel

Figure G6. Waste transportation input dialog.

- i. Style of transport
- ii. Location of solids storage
- iii. Remote-handled waste off-site (RH_{Off}) transport distance
- iv. Remote-handled waste on-site (RH_{On}) transport distance
- v. Contact-handled waste off-site (CH_{Off}) transport distance
- vi. Contact-handled waste on-site (CH_{On}) transport distance
- vii. Construction and demolition (CD) transport distance

Pressing the Continue button shown in Figure G6 brings the user to the surface decontamination Technology Selection dialog depicted in Figure G7. After the user reviews and selects technologies available comparison in the specified scenario, pressing the Continue button illustrated in Figure G7 will return program control to the main input screen shown in Figure G1. At this point, the user can either modify setup inputs for fixed site-specific information or immediately generate technology comparisons.

Setup Inputs for Fixed Site-Specific Information

Some user inputs not contained in the normal input sequence are accessed via the Setup menu. Selections available under this menu are described below.

Technology Selection EERC AG14859.CDR

Available Technologies

- Microwave
- Ice Blasting
- Electrokinetic
- Electro-Hydraulic Scabbling
- TechTract or Corplex processes
- Carbon Dioxide Blasting - Metal
- Carbon Dioxide Blasting - Concrete

Selected Technologies

- Plastic Blasting
- Sand Blasting
- CO2 Laser

Technology Name: CO2 Laser

Description: Electrical/thermal, non-destructive

Structure Type: ☒ Steel ☒ Concrete

Process Type: ☒ Destructive ☒ NonDestructive ☐ Penetrating

State of Technology: Developmental

Number of Workers: 3

Production Rate: 282.0 ft²/hr

Operating Cost: 8.50 \$/ft²

Environmental Health and Safety Factor: 6.20

Operational, Maintenance and Reliability Factor: 4.66

Number of Passes Required For Cleaning: 1

Depth of Cleaning Per Pass: 0.1250 in

Secondary waste Type: ☐ Liquid ☒ Solid

Percent Solid of 2nd waste: 100 %

Volume of 2nd Waste: 0.680 ft³/hr

Weight of 2nd Waste: 51.60 lbs/hr

☒ Extra Utility Costs ☒ On-line Assay ☒ Hard To Reach Areas

Surface Cleaning: ☒ Floors ☒ Walls ☒ Ceilings

Continue Cancel

Figure G7. Surface decontamination Technology Selection dialog.

A dialog is provided to allow the user to specify transportation and disposal costs (Figure G8). The inputs available are as follows:

Transportation fees

- i. Truck contact-handled (CH) waste fee
- ii. Rail CH waste fee
- iii. Truck remote-handled (RH) waste fee
- iv. Construction (nonhazardous) waste fee

Waste disposal fees

- i. CH waste disposal fee
- ii. RH waste disposal fee
- iii. Construction (nonhazardous) waste fee disposal fee

The user is also allowed to give priority to specific aspects of the surface decontamination process by adjusting the ranking of the categories listed on the dialog box shown in Figure G9. This allows the user to calibrate the model to individual preferences.

Technology Comparisons

Technology comparison outputs are obtained by pressing the Generate Results button shown in Figure G1. The SDA program outputs take two forms.

Upon completion of a program run, the user is presented with a tabular output containing a summary of the technology comparisons, as shown in Figure G10. In addition, the program generates a table containing all user-defined inputs and model results in a comma-delimited ASCII file formatted to allow reading the data into other programs such as spreadsheets, graphics programs, and other data analysis packages.

Conversion of Site Information into Inputs Scenarios for the SDA

As noted in the previous discussion, there are certain data which the user must supply to the SDA program in order for results to be generated. Any given decontamination site will need to be broken down into a set of input scenarios. A table similar in form to Table F1 in Appendix F can be completed to facilitate entry of data into the program. In addition to playing with priority weights, transportation modes, and distances and costs for disposal of waste, basic site information can be assembled in a number of ways to obtain different results.

The following is an example of how the SDA software can be used to evaluate potential technologies applicable for decontamination of a hypothetical site. This site work includes the decontamination of the interior of a concrete structure made up of several rooms. Partitions within the structure are concrete with exposed metal I-beam support and metal pipes. The area to

Transportation and Disposal Fees

Transportation Costs

Truck Contact Handled Fee	4.0	\$ / mile
Rail Contact Handled Fee	1.91	\$ / mile
Truck Remote Handled Fee	4.90	\$ / mile
Construction Waste Transportation Fee	1.0	\$ / mile

Disposal Costs

Contact-Handled Disposal Fee <200 mrem/hr material	60.0	\$ / ft ³
Remote Handled Disposal Fee >200 mrem/hr material	300.0	\$ / ft ³
Construction Waste Disposal Fee	0.26	\$ / ft ³

Continue Default Cancel

Figure G8. Transportation and Disposal Fees.

Priority Ranking

Priority

Lowest Highest

5	Environmental, Health and Safety
4	Operational, Maintenance and Reliability
3	Removal Cost
4	Transportation Cost
5	Disposal Cost

Continue Defaults Cancel

Figure G9. Priority Ranking user input.

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Technology Name	Production Rate ft ² /hr	Technology State	Surface Removal Index	Waste Transport Index	Waste Disposal Index	Technology Safety Index	Technology Reliability Index	Overall Technology Performance Index
Mechanical Sc	300.0	Commercial	0.621	0.301	0.378	0.939	1.000	0.721
Milling	3.0	Development	0.338	0.035	0.049	0.886	0.917	0.507
Drilling Spal	80.0	Commercial	0.738	0.035	0.049	0.876	0.950	0.551
Sand Blasting	47.0	Commercial	0.412	0.984	0.936	0.790	0.974	0.955
Steel Grit	11.6	Commercial	0.074	0.996	0.966	0.900	0.834	0.938
Plastic Blast	240.0	Commercial	0.911	1.000	0.980	0.890	0.716	1.000
Ultra-Pressur	60.0	Commercial	0.576	0.487	1.000	0.890	0.920	0.910
High Pressure	370.0	Commercial	1.000	0.487	1.000	0.810	0.960	0.937
Sponge Blast	32.0	Commercial	0.707	0.964	0.027	0.971	0.792	0.725
Soft Media Bl	80.0	Commercial	0.317	0.301	0.378	0.971	0.620	0.624
Soda Blasting	150.0	Commercial	0.158	0.487	1.000	0.729	0.834	0.802
Shot Blasting	1515.0	Commercial	0.942	0.147	0.195	0.904	0.967	0.650
Scarification	300.0	Commercial	0.994	0.775	0.819	0.943	1.000	0.988
Microwave	40.0	Demonstratio	0.843	0.017	0.025	1.000	0.641	0.526
CO2 Laser	550.0	Demonstratio	0.105	1.000	0.983	0.886	0.568	0.889
Ice Blasting	45.0	Commercial	0.723	0.487	1.000	0.900	0.833	0.911
Electro-Hydra	30.0	Development	0.913	0.029	0.083	0.900	0.702	0.535
TechXtract or	58.0	Commercial	0.249	0.487	1.000	0.900	0.686	0.833

Figure G10. Model results output viewer.

be decontaminated includes 20,000 ft² of floor space, 28,000 ft² of wall space, and 20,000 ft² of ceiling space on concrete, and 5000 ft² on metal surfaces. Because the rooms include corners and cracks, it has been estimated that five percent of the total concrete area and 100% of the metal area are in the hard-to-reach category. All surfaces have been coated with paints containing Pb and PCBs to seal in radionuclides. It has been determined that a total of 8 inches of concrete must be removed to ensure complete decontamination. The limit of the depth of contamination, however, has been judged to be 5 inches. There is no capacity to separate solid waste from liquid secondary waste on-site. The transportation mode will be truck, and on-site storage of solid waste is available.

The most obvious use of the SDA program would be to create and run the three scenarios in Table G1. The overall PI for the three concrete scenarios is illustrated in Figure G11. As the figure indicates, this will return a limited ranking of three technologies for concrete removal which are mostly different from the nondestructive technologies recommended for coating removal on metal.

A more detailed approach is suggested by Scheme 2 in Table G2. In this set of scenarios, the surface and substrate removal tasks have been separated. This allows the SDA software to include non-destructive technologies in the surface removal process and to allow the performance of technologies removing, transporting and disposing of non-hazardous waste to be evaluated separately from the hazardous work. As Figure G12 indicates, this will result in a broader selection of technologies available for parts of the work.

TABLE G1

Scheme 1 Representation of Decontamination Scenarios

Scenario	Cleaning Surface	Substrate	Area	% Hard to Reach	Coating Depth, in.	Substrate Removal		% C&D Waste	% CH Waste	% RH Waste
						Depth, in.	Contaminants			
1-1	Floors	Concrete	20000	5	0.75	8	Pb, PCBs, Radionuclides	0	60	40
1-2	Walls	Concrete	28000	5	0.75	8	Pb, PCBs, Radionuclides	0	60	40
1-3	Ceilings	Concrete	20000	5	0.75	8	Pb, PCBs, Radionuclides	0	60	40
1-4	Walls	Steel	5000	100	0.75	0	Pb, PCBs, Radionuclides	0	60	40

Figure G11. Overall Indices for Scheme 1 (Floors, Walls, and Ceilings).

TABLE G2

Scheme 2 Representation of Decontamination Scenarios

Scenario	Cleaning surface	Substrate	Area	% Substrate		Removal Depth, in.	Contaminants	% Waste		
				Hard to Reach	Coating Depth, in.			C&D	% CH	% RH
2-1	Floors	Concrete	20000	5	0.75	0	Pb, PCBs, Radionuclides	0	60	40
2-2	Floors	Concrete	20000	5	0	5	Pb, PCBs, Radionuclides	10	50	40
2-3	Floors	Concrete	20000	5	0	3	none	100	0	0
2-4	Walls	Concrete	28000	5	0.75	0	Pb, PCBs, Radionuclides	0	60	40
2-5	Walls	Concrete	28000	5	0	5	Pb, PCBs, Radionuclides	10	50	40
2-6	Walls	Concrete	28000	5	0	3	none	100	0	0
2-7	Ceilings	Concrete	20000	5	0.75	0	Pb, PCBs, Radionuclides	0	60	40
2-8	Ceilings	Concrete	20000	5	0	5	Pb, PCBs, Radionuclides	10	50	40
2-9	Ceilings	Concrete	20000	5	0	3	none	100	0	0
2-10	Walls	Steel	5000	100	0.75	0	Pb, PCBs, Radionuclides	0	60	40

Figure G12. Overall indices for Scheme 2 (Floor and Metal Scenarios)

The most detailed approach would be to subdivide each decontamination region from Scheme 2 into hard-to-reach and not hard-to-reach areas. The scheme for this approach is delineated in Table G3. The overall performance indices of three scenarios from this scheme are depicted in Figure G13. This will result in a greatest number of technologies examined and a more comprehensive analysis of technologies to recommend for further consideration.

Finally, if the user determines that it is not necessary to remove the surface separately from the contaminated substrate, two levels of removal, rather than the three specified in Table G3 could be set up. In this case, the user would divide the work as presented by Scheme 4 in Table G4. As the overall PIs in Figure G14 show, the results from this scheme would again offer a greater number of technology options to explore than the results from the first two tables.

TABLE G3

Scheme 3 Representation of Decontamination Scenarios

Scenario	Cleaning Surface	Substrate	Area	% Hard to Reach	Coating Depth, in.	Substrate Removal Depth, in.	Contaminants	% C&D Waste	% CH Waste	% RH Waste
3-1	Floors	Concrete	19000	0	0.75	0	Pb, PCBs, Radionuclides	0	60	40
3-2	Floors	Concrete	1000	100	0.75	0	Pb, PCBs, Radionuclides	0	60	40
3-3	Floors	Concrete	19000	0	0	5	Pb, PCBs, Radionuclides	10	50	40
3-4	Floors	Concrete	1000	100	0	5	Pb, PCBs, Radionuclides	10	50	40
3-5	Floors	Concrete	19000	0	0	3	none	100	0	0
3-6	Floors	Concrete	1000	100	0	3	none	100	0	0
3-7	Walls	Concrete	26600	0	0.75	0	Pb, PCBs, Radionuclides	0	60	40
3-8	Walls	Concrete	1400	100	0.75	0	Pb, PCBs, Radionuclides	0	60	40
3-9	Walls	Concrete	26600	0	0	5	Pb, PCBs, Radionuclides	10	50	40
3-10	Walls	Concrete	1400	100	0	5	Pb, PCBs, Radionuclides	10	50	40
3-11	Walls	Concrete	26600	0	0	3	none	100	0	0
3-12	Walls	Concrete	1400	100	0	3	none	100	0	0
3-13	Ceilings	Concrete	19000	0	0.75	0	Pb, PCBs, Radionuclides	0	60	40
3-14	Ceilings	Concrete	1000	100	0.75	0	Pb, PCBs, Radionuclides	0	60	40
3-15	Ceilings	Concrete	19000	0	0	5	Pb, PCBs, Radionuclides	10	50	40
3-16	Ceilings	Concrete	1000	100	0	5	Pb, PCBs, Radionuclides	10	50	40
3-17	Ceilings	Concrete	19000	0	0	3	none	100	0	0
3-18	Ceilings	Concrete	1000	100	0	3	none	100	0	0
3-19	Walls	Steel	5000	100	0.75	0	Pb, PCBs, Radionuclides	0	60	40

Figure G13. Overall indices for Scheme 3 (floor scenarios).

TABLE G4

Scheme 4 Representation of Decontamination Scenarios

Scenario	Cleaning Surface	Substrate	Area	% Hard to Reach	Coating Depth, in.	Substrate Removal Depth, in.	Contaminants	% C&D Waste	% CH Waste	% RH Waste
4-1	Floors	Concrete	19000	0	0.75	5	Pb, PCBs, Radionuclides	0	60	40
4-2	Floors	Concrete	1000	100	0.75	5	Pb, PCBs, Radionuclides	0	60	40
4-3	Floors	Concrete	19000	0	0	3	none	100	0	0
4-4	Floors	Concrete	1000	100	0	3	none	100	0	0
4-5	Walls	Concrete	26600	0	0.75	5	Pb, PCBs, Radionuclides	0	60	40
4-6	Walls	Concrete	1400	100	0.75	5	Pb, PCBs, Radionuclides	0	60	40
4-7	Walls	Concrete	26600	0	0	3	none	100	0	0
4-8	Walls	Concrete	1400	100	0	3	none	100	0	0
4-9	Ceilings	Concrete	19000	0	0.75	5	Pb, PCBs, Radionuclides	0	60	40
4-10	Ceilings	Concrete	1000	100	0.75	5	Pb, PCBs, Radionuclides	0	60	40
4-11	Ceilings	Concrete	19000	0	0	3	none	100	0	0
4-12	Ceilings	Concrete	1000	100	0	3	none	100	0	0
4-13	Walls	Steel	5000	100	0.75	0	Pb, PCBs, Radionuclides	0	60	40

Figure G14. Overall indices for Scheme 4 (floor scenarios).