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Enhanced Chemical Incident Response Plan (ECIRP) – **Appendix F:** Remediation Analysis with Decision Support Tools (DSTs) for Wide-Area Chemical Hazards

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Enhanced Chemical Incident Response Plan (ECIRP) – Appendix F: Remediation Analysis with Decision Support Tools (DSTs) for Wide-Area Chemical Hazards

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Abstract

The Defense Threat Reduction Agency (DTRA) commissioned an assessment of the Consequence Management (CM) plans in place on military bases for response to a chemical attack. The effectiveness of the CM plans for recovering from chemical incidents was modeled using a multiple Decision Support Tools (DSTs). First, a scenario was developed based on an aerial dispersion of a chemical agent over a wide-area of land. The extent of contamination was modeled with the Hazard Prediction and Assessment Capability (HPAC) tool. Subsequently, the Analyzer for Wide Area Restoration Effectiveness (AWARE) tool was used to estimate the cost and time demands for remediation based on input of contamination maps, sampling and decontamination resources, strategies, rates and costs. The sampling strategies incorporated in the calculation were designed using the Visual Sample Plan (VSP) tool. Based on a gaps assessment and the DST remediation analysis, an Enhanced Chemical Incident Response Plan (ECIRP) was developed.

ACKNOWLEDGMENTS

This was a multi-lab project sponsored by the Defense Threat Reduction Agency (DTRA). Personnel from Pacific Northwest National Laboratories (PNNL) and Sandia National Laboratories (SNL) supported the study, and the project was led by personnel from Oak Ridge National Laboratories (ORNL). The sampling strategy described in this report was developed using the Visual Sample Plan (VSP) software package developed by PNNL with the assistance of John Wilson. The remediation analysis using the Analyzer for Wide-area Restoration Effectiveness (AWARE) tool was supported by software developers from SNL including Brad Melton, Kim Grommes, and Bob Knowlton. Finally, subject matter experts (SMEs) from SNL, including Lynn Yang, Dave Franco and Mark Tucker, were consulted on several topics related to wide-area remediation throughout the analysis effort.

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NOMENCLATURE

AWARE	Analyzer for Wide-Area Restoration Effectiveness
CBMS II	Block II, Chemical Biological Mass Spectrometer
CM	Consequence Management
DOD	Department of Defense
DST	Decision Support Tool
DTRA	Defense Threat Reduction Agency
ECIRP	Enhanced Chemical Incident Response Plan
EPA	Environmental Protection Agency
ERLN	Environmental Response Laboratory Network
GIS	Geographical Information System
HPAC	Hazard Prediction and Assessment Capability
HVAC	Heating Ventilation and Air Conditioning
ORNL	Oak Ridge National Laboratory
PHILIS	Portable High-throughput Integrated Laboratory Identification Systems
PNNL	Pacific Northwest National Laboratory
RU	Remediation Unit
SME	Subject Matter Experts
SNL	Sandia National Laboratories
VSP	Visual Sample Plan

1. INTRODUCTION

This report was produced through a study sponsored by the Defense Threat Reduction Agency (DTRA) to assess the current state of Consequence Management (CM) tools that would be employed in chemical hazard incidents impacting Department of Defense (DOD) sites, assets and personnel. It was hypothesized that the existing CM tools would be insufficient to support a comprehensive response to chemical emergencies. Therefore, the goal of the project was to review the current plans, tools, methods, resources and processes for response to chemical hazards in order to identify technology and knowledge gaps that would impact efficient CM. The primary deliverable for the project is an Enhanced Chemical Incident Response Plan (ECIRP), which is intended to address the gaps identified in CM plans that were identified in this study.

This study was a multi-lab effort led by Oak Ridge National Laboratory (ORNL) and supported by Pacific Northwest National Laboratory (PNNL) and Sandia National Laboratories (SNL). To support the assessment of current gaps and future options for CM, a scenario-based analysis of a wide-area hazard remediation effort was performed by SNL. The remediation analysis described in this report was performed with the use of multiple DSTs. Therefore, this report also serves as an example of how decision support tools (DSTs) may be integrated in response planning and implementation. This report will be included as an appendix in the ECIRP.

2. ANALYSIS APPROACH

The wide-area chemical hazard scenario and remediation analysis described in this report should be referred to only as an illustrative example of remediation planning. Not all possible remediation approaches were examined, and not were the approaches discussed optimized. Furthermore, a number of assumptions about the scenario and the remediation resources were made in this analysis that impacts the results. Use of different assumptions may alter the results. Similarly, use of the tools and strategies discussed in an operational remediation setting may yield quite different outcomes than those determined in planning.

2.1. Scenario Development

A wide-area chemical incident was postulated in the Seattle area where an adversary who had acquired a large volume of chemical agent devised an aerial release strategy in hopes of sabotaging several targets simultaneously. In this scenario, a fixed wing aircraft flying due east above the West Seattle Freeway released an aerial spray of chemical agent along a path on the south edge of the Port of Seattle between Highway 99 and Interstate 5. The wind was blowing from the south[1] at 6 m/sec which blew the plume of chemical agent to the north toward South Lake Union (Figure 1).

The scenario was modeled using the DTRA tool Hazard Prediction and Assessment Capability (HPAC).[2] HPAC is an atmospheric dispersion model that allows the user to predict the map of

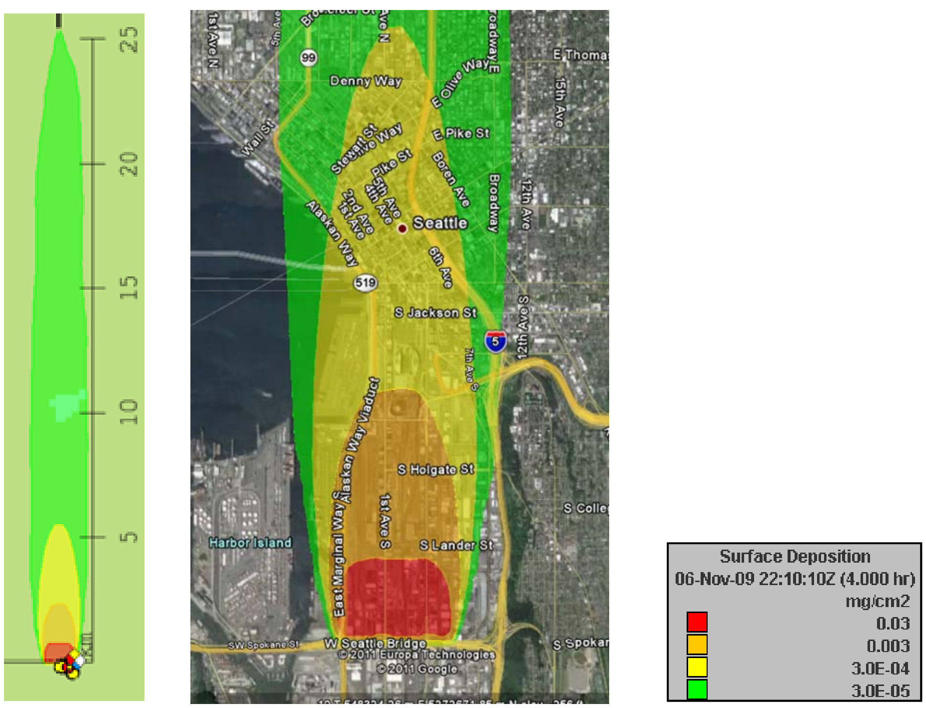

Figure 1. Surface contamination plume calculated in HPAC (left). The yellow contour represents area that is at or above the clearance concentration $3x10^{-4}$ mg/cm^2. An overlay of the contamination map in Google Earth (right) shows the above-clearance level area contaminated in Seattle.

contamination resulting from hazardous atmospheric releases. After all of the agent had either rained out or dispersed, a 2.73 square mile area was contaminated with surface deposition of chemical agent at dangerous concentrations. Had this attack been targeted at a military base, a number of critical assets on base may be impacted and critical functions disrupted. Furthermore, it is likely that civilian areas surrounding the base would also be impacted by the chemical hazard.

2.2. Recovery Analysis using Decision Support Tool

2.2.1. Hazard plume modeling with HPAC

For the recovery analysis of the Port of Seattle scenario, we can postulate that the aerial chemical release was observed by bystanders and was also detected by a deployed chemical monitoring system at the port. A preliminary site map is developed during the initial incident response phase to facilitate evacuation and establish keep-out zones. This contamination map may be calculated using an atmospheric dispersion modeling tool (e.g., HPAC) using local meteorological data, spatial information provided by the monitoring system, and information known about the aerial release. A "flat earth" assumption was used for the plume model calculation in HPAC. While this was sufficient for the illustration purposes of this report, a higher fidelity plume map incorporating terrain and urban areas can be modeled in HPAC if the area data is available. For analysis of the Port scenario, a health-based surface clearance level of $3x10^{-4}$ mg/cm^2 for the chemical agent derived from a study reported in the literature[3] was used in developing restoration goals and remediation strategies. The plume map, which illustrates the contamination with reference to the clearance level, was the starting point for our analysis of the recovery effort (Figure 1).

2.2.2. Remediation Planning with AWARE

The wide-area Port scenario calculated in HPAC was imported into the SNL tool AWARE (Analyzer for Wide Area Restoration Effectiveness).[4] AWARE is a planning tool that calculates time and cost of remediation based on how the user defines and allocates remediation resources. In AWARE, a built-in geographical information system (GIS) database was mined to determine the extent of contamination (e.g. area, number and type of buildings contaminated, critical infrastructure assets, square footage of indoor contamination, etc.). The GIS engine utilizes Google maps technology to display both local and national infrastructure data (e.g., Seattle tax assessor GIS data and Hazus GIS data, respectively). Using this information, critical assets and/or areas may be prioritized for remediation to expedite the recovery of critical functions. According to AWARE, there are several thousand buildings contaminated in the Port scenario, including a number of potentially critical assets (Figure 2). In AWARE, the contaminated areas are assigned to hazard zones by contamination level:

1) Red Zone = highly contaminated, [Agent] $\geq 3\ x10^{-3}$ mg/cm^2
2) Yellow Zone = moderately contaminated, above clearance levels, [Agent] $\geq 3\ x10^{-4}$ mg/cm^2
3) Green Zone = insignificantly contaminated, below clearance levels, [Agent] $<3\ x10^{-4}$ mg/cm^2

Figure 2. Image of the Port scenario in AWARE. Hazard zones are shown as high, moderate, and insignificant (red, yellow and green, respectively). RUs 1-6 (left) are represented as blue polygons in the red and yellow zones. Potentially critical assets (center) and then all buildings (right) impacted by the scenario are shown as colored dots on the maps (red = residential, yellow = commercial, orange = industrial, green = mixed use, purple = public use).

The Red and Yellow Zones were then divided into Remediation Units (RUs) to facilitate the prioritization and remediation planning. The prioritization of critical services and critical infrastructure for remediation is an important part of developing a remediation plan. In this Port scenario a number of assets may be identified as potentially critical in AWARE. These span a variety of functions including health care and emergency services, military, commerce, telecommunications, energy, etc. Methodologies and toolsets have been developed to guide the prioritization of critical assets in wide-area hazard scenarios.[5] For example, the AWARE tool has a prioritization module called PATH (Prioritization Analysis Tool for all-Hazards)[4] that facilitates stakeholder negotiations and objective trade-off analyses to optimize the restoration operations. For this analysis, rather than assigning a priority to each individual critical asset, the six RUs were ordered for remediation based on the assets they contained.

2.2.3. Developing sampling strategies with VSP

Numerous sampling strategies are possible for a scenario depicted by this Port example. Generally the strategy during wide-area characterization would consist of two components that may be sequential or concurrent:

- Delineation of the spatial pattern of contamination (geostatistical model), and extent/boundary of contamination (outdoors) above the clearance level, and

- Determination of which facilities are contaminated (indoors) within the delineated contaminated zone.

Sampling strategies for spatial boundary delineation could include “hot area” detection schemes, geostatistical mapping approaches, plume-model-based sampling (sampling along the contours of the plume concentrations), stratified sampling, sequential sampling, combined judgment and probabilistic sampling, collaborative sampling (use of in-field, real-time measurement systems), inverse sampling approaches (identifying the best locations for a limited number of samples), composite sampling, or some variant of grid sampling. Sampling strategies for indoor sampling may include sampling at most likely contaminated locations within the building to quickly rule-in buildings, stratification of building types/characteristics and sampling a few buildings from each strata, “hot area” detection schemes, composite sampling, combined judgment and probabilistic sampling, or compliance sampling approaches (e.g., 95% confident that at least 99% of surface area is less than clearance levels). Visual Sample Plan (VSP)[6] supports several of these strategies with plans to support all of these approaches in the future. VSP is a software tool which is used to develop defensible sample plans based on specific sampling goals and on statistical sampling theory.

To illustrate a simplified sampling approach using VSP, and to show how VSP and AWARE can be used in tandem, using the initial plume map calculated in HPAC and the building and critical asset data from AWARE, a characterization sampling strategy was developed using the VSP (Figure 3 right). Assuming that the spatial map may require additional sampling to more precisely delineate the contaminated zone, a second grid sampling approach only around the assumed contaminated zone boundary is shown in Figure 3 (left). In this remediation analysis, an

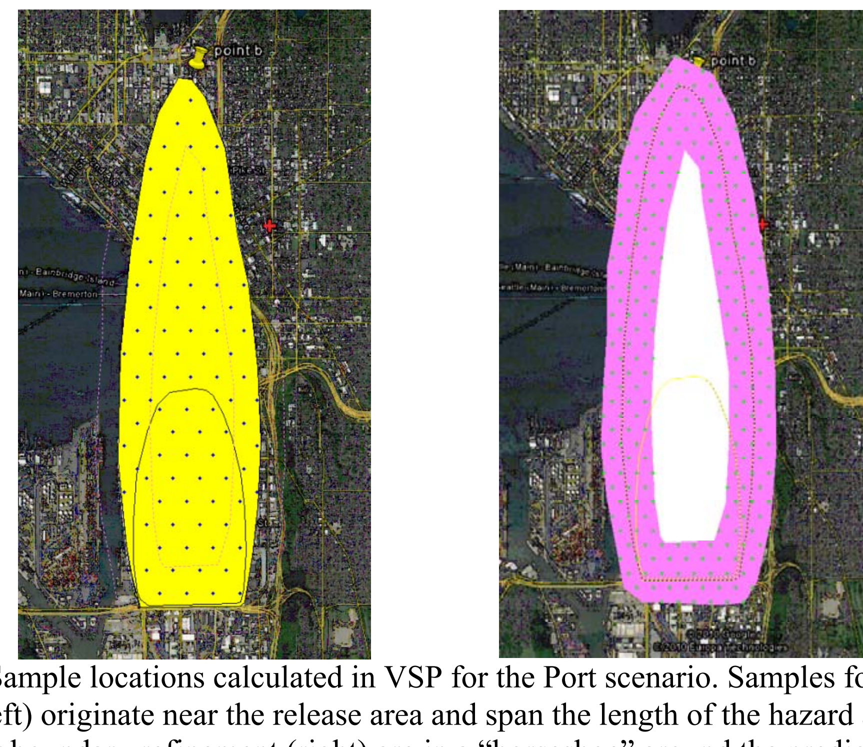

Figure 3. Sample locations calculated in VSP for the Port scenario. Samples for spatial mapping (left) originate near the release area and span the length of the hazard area. Samples for boundary refinement (right) are in a “horseshoe” around the predicted hazard area within a certain distance from the assumed contaminated area boundary.

important assumption was made that the areas requiring sampling (i.e. the contaminated areas) matched those predicted in HPAC. In a real characterization process, the samplers might find that the actual contaminated areas do not match the predicted plume map. In this event, VSP and other operational DSTs can be used to adjust the remediation plan appropriately.

In addition to statistical samples, two judgmental surface samples from the exterior of buildings and three judgmental outdoor samples in each sampling grid were included for characterization (Total samples per grid = 1 statistical sample in the center of the grid + 3 judgmental outdoor samples + 2 building exterior surface samples = 6 samples). If there were a need to characterize the infiltration of contaminant into the interior of buildings, 25 samples per building might be collected, e.g. HVAC filters, in entryways, along footpaths. Again, just as an illustration for this scenario, suppose some indoor samples from all critical assets were obtained, while only a subset of the other buildings were sampled indoors. As inputs for the AWARE analysis and for comparison, a "minimal case" and "extensive case" sampling scenario were postulated for the wide-area characterization. The total characterization sample numbers obtained using VSP and the additional judgmental samples were used as input parameters in subsequent DST calculations (Table 1). It should be noted that other sampling strategies may be more optimal and result in fewer number of samples depending on assumptions and key objectives.

Generally, the clearance sampling strategy may be affected by the method of decontamination, such as surface decontamination versus volumetric decontamination. During clearance sampling, the objective is to demonstrate with confidence that any contamination has either been eliminated or is sufficiently below clearance levels as to pose no further risk. Some of the same sampling strategies listed above may be employed for clearance sampling. For analysis of the Port scenario we assumed that the decontamination methods employed had a proven track record of achieving sub-clearance levels of contamination[3] and was all parameters were controlled to acceptable levels, therefore a minimal clearance sampling strategy incorporating Compliance Sampling and judgmental sampling was designed. The Compliance Sampling strategy and decision rule, as implemented in VSP, assumes a presence/absence measurement, a combination of judgment and random samples, and other specified parameters.

For the outdoors, optimistic, "minimal strategy", we increase by 4-fold the number of grids we used during characterization for the geostatistical model. We take one soil sample in the center of each of 400 regular grids laid out in the original yellow and red zones. For the pessimistic case, we also take 3 judgment samples in most likely contaminated areas within each grid. For buildings and critical assets, we again use stratified sampling by building type, increasing the sampling percentage to 25%. For the more conservative/worst case, we use a Compliance Sampling strategy that says that if all the samples required by the algorithm (software in VSP) come back uncontaminated, you can make the decision/statement "I am 95% confident that 95% of all the locations in the area are uncontaminated." The Compliance Sampling Strategy is from the world of QA/QC and follows a conservative approach, hence the dramatically increased number of samples required.

Table 1. Sampling strategies for the Port scenario (n = proposed number of samples).

	Number of grids/buildings	*Minimal Sampling Strategy*	*Extensive Sampling Strategy*
Characterization Samples			
Outdoors [a]			
Boundary identification	210 grids	• 1 soil sample at center of each grid (n =210) • 3 samples per grid in probable outdoor areas (n=630)	• 840 grids; 1 soil sample at center of each grid (n=840) • 5 samples per grid in probable outdoor areas (n=4,200)
Spatial geostatistical model	100 grids	• 1 soil sample at center of each grid (n=100)	• 1 soil sample at center of each grid (n=100)
Indoors [b]			
Buildings within area of uncertain contamination (yellow area)	654 buildings	• Stratified sampling: 10% of buildings from each usage category are sampled[c]; 10 samples/building (n=650)	• 10 samples in every building (n=6,540)
Buildings within mostly likely contaminated area (red area)	375 buildings	• Stratified sampling: 10% of buildings from each usage category are sampled[c]; 10 samples/building (n=380)	• 10 samples in every building (n=3,750)
Critical assets	69 buildings	• Sample all critical assets, 10 samples per asset (n=690)	• Sample all critical assets, 25 samples per asset; (n=1,725)
Clearance Samples			
Outdoors [a]			
Spatial geostatistical model	400 grids (4x chara grid)	• 1 soil sample at center of each grid (n=400)	• 1 soil sample at center of each grid; 3 samples within grid cell (n=1,600)
Indoors [b]			
Yellow area (Assuming all of yellow area was contaminated)	654 buildings	• Stratified sampling: 25% of buildings from each usage category are sampled[c]; 10 samples/building (n=1,640)	• Require 90% confidence that 95% of surface within each building is acceptable[d] (n = 29,430)
Red area	375 buildings	• Stratified sampling: 25% of buildings from each usage category are sampled[c]; 10 samples/building (n= 940)	• Require 95% confidence that 95% of surface within each building is acceptable[d] (n = 22,125)
Critical assets	69 buildings	• 10 samples per critical asset (n=690)	• Require 95% confidence that 99% of surface within each building is acceptable[d] (n = 20,631)

a) Number of grids determined within VSP using Port scenario assumptions
b) Samples taken from HVAC filters, entryways, footpaths, windows
c) Building usage distribution determined in AWARE
d) From formula in VSP for X% / Y% Compliance Sampling

Once the sampling strategy was developed using VSP and other judgments, we returned to the AWARE tool to complete the remediation analysis. Time, cost and labor input parameters for sampling and analysis, decontamination and waste used in the analysis described here were based on published literature and/or subject matter expertise (Table 2).

Table 2. Parameters for remediation resources used in AWARE analysis.

Resource	*Units*	*Throughput*	*Cost*
Sampling and Analysis			
CBMS II [a]	25 units, 1 person/unit	600-700 samples/day	$1/sample
EPA sample collection [b]	2 people/sample team	48 samples/day	$50/hour (labor)
PHILIS/PHILBERT [c]	2 units (each with 6 GCMS)	500 samples/week	$300/sample
ERLN [d]	Laboratories nation-wide	3,000 samples/week	$300/sample
Decontamination			
Outdoor surface decon	10 units	2,500 sq meters/day	$5000/day
Indoor surface decon	10 units, 3 people/unit	5,000 sq ft/day	
Volumetric decontamination – small	20 units, 3 people/unit	Buildings <5,000 sq ft	$10K
Volumetric decontamination – med	10 units, 6 people/unit	5,000 to 100,000 sq ft	$50K
Volumetric decontamination – large	3 units, 10 people/unit	Buildings >100,000 sq ft	$250K
Waste			
Waste removal	10 units	100 tons/day	$2,000/day per unit
Waste decontamination chambers	10 units	2,000 cu ft/day per unit	$2,000/day per unit
Waste transportation	50 units	50 tons/day	$500/day

a) Chem-Bio Mass Spectrometer, generation II (CBMS II)[8]
b) Standardized Environmental Protection Agency (EPA) sampling methods[9]
c) Portable High-throughput Integrated Laboratory Identification Systems (PHILIS)[10]
d) Environmental Response Laboratory Network (ELRN) analysis methods[11]

To run an AWARE analysis, the model was configured with the following input parameters:

- Surface deposition concentration plume map calculated in HPAC (Figure 1)
- Total samples for the characterization and clearance phases as calculated in VSP (Table 1)
- Predicted sampling and decontamination resources available for restoration (Table 2)

3. RESULTS AND DISCUSSION

3.1. Reference strategy

The initial baseline analysis, termed the "reference strategy," was calculated with a basic set of input parameters for currently available resources and current-practice approaches to remediation. The estimated timeline for the reference remediation strategy are shown in Figure 4. In the reference strategy, all sample analysis was performed in an analytical laboratory (either PHILIS or ERLN) rather than by using man-portable sampling/analysis technologies (e.g., CBMS-II), and the "extensive sampling" strategy was studied. The numbers of decontamination units and the decontamination rates are based on presently deployed systems ("less decon. resources"). In total, the remediation effort estimated for the reference strategy is 3 years and 101 days with a total cost of $454M. Uncertainty bounds are not included in this estimate. To assess the uncertainty in the calculated time and cost, a full sensitivity analysis would be required. A full analysis of the input parameters and assumptions using a Monte Carlo approach may indicate variability in the time and cost results dependant on some parameters and not others. Nonetheless, the reference strategy, along with the other trade studies, provides insight into the complexity of the remediation process.

The timeline plot shows a couple of important features of the ConOps for remediation as implemented in an AWARE analysis:

- For the analysis RUs were prioritized based on the assets they contained and the contamination level. The highest priority RU is where the remediation effort starts. For example, RU1 contains multiple critical assets and therefore may be prioritized for remediation.

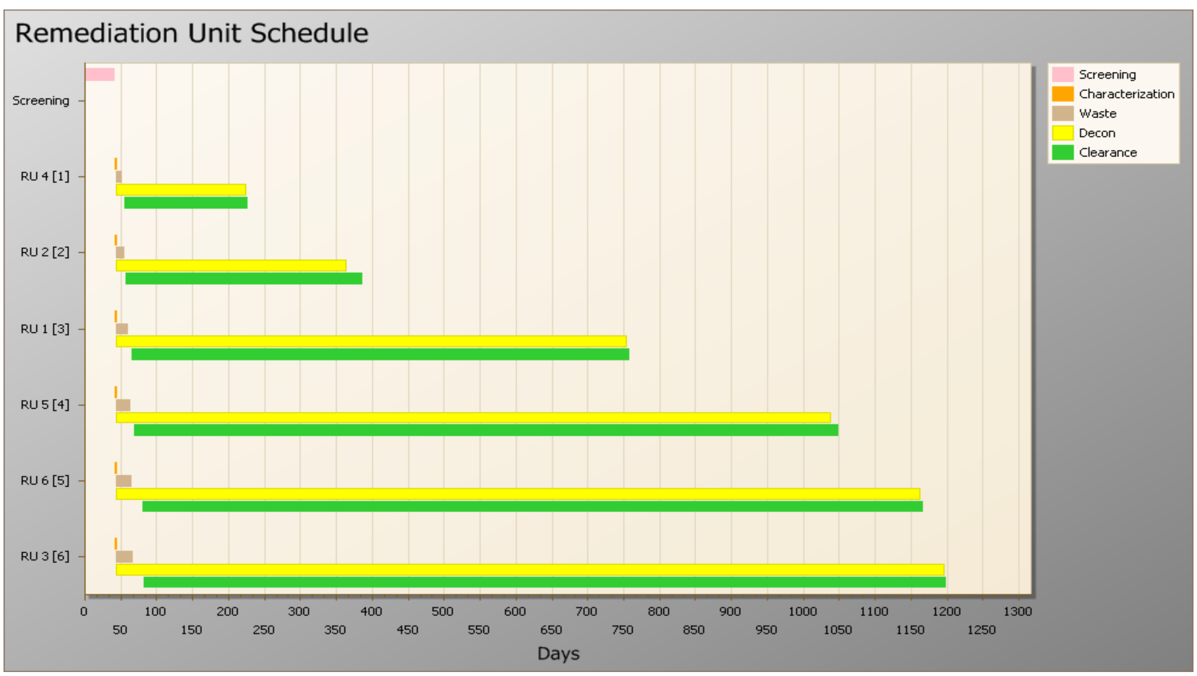

Figure 4. Timeline output from AWARE for the remediation analysis of the reference strategy which incorporated the extensive sampling parameters and decontamination resources.

- Resources are allocated in parallel which means that within the same RU, characterization may be underway at one location, while another location being decontaminated and yet another is in the clearance phase. This is to maximize the efficiency of resource use.
- All of the outdoor area of an RU is remediated before the indoor areas are started. This rule impacts the allocation of resources across the RU. This is good practice to avoid tracking and secondary contamination.

The time and cost of remediation for the reference strategy are sizable. The use of DSTs enables remediation planners to rapidly evaluate and compare several additional remediation strategies to reduce these numbers. As an example of these types of trade analyses, potential improvements in to the sampling and decontamination approaches were analyzed in for the Port scenario to demonstrate the impact on the overall remediation (Figure 5). In these strategies, either the minimal sampling strategy, or the more decontamination resources strategy (using 10 time more decontamination units than the reference strategy), or both were analyzed. From these results we can see that improving either strategy improves the overall remediation. However, implementing both "improved" strategies together results in an improvement that is greater than either one individually. This result highlights the interdependence of the remediation parameters, and the importance of evaluating all aspects of CM as a unified process.

Similarly, factors such as technology advancement and natural attenuation would also lessen the

Figure 5. Timeline output from AWARE for the remediation analysis of the trade studies with minimal or extensive sampling plans and/or more or less decontamination resources. Note the top left chart is the reference strategy (same as Figure 4).

total time and cost over the course of remediation. To this end, information discovered during pre-incident planning through the use of DSTs could potentially steer research and development of new remediation technologies and improved remediation ConOps prior to an attack. Examples of two such alternative strategies are discussed next.

3.2. Man-portable sampling and analysis

Gaps and choke points identified during pre-incident planning through the use of DSTs could steer research and development for new remediation technologies. For example, sampling and analysis are one of the burdens on the remediation cost and timeline estimated in the reference remediation strategy. A significant benefit would be afforded by replacing swipe sampling and off-site laboratory analysis with a man-portable sampling and analysis technology. To demonstrate this, the sampling and analysis parameters of CBMS-II, a near-term technology being developed at ORNL[9], were applied to the remediation analysis. The CBMS-II can collect and analyze a sample and regenerate the system in about 2 min at a cost of about a dollar per sample. While the benefit of using this new technology is highly dependent on other parameters of the strategy (e.g., the sampling plan and the decontamination resources), the use of fielded sampling can result in a significant improvements in the remediation efforts, especially in the total cost (Figure 6). While the output shown is for analysis using the best trade from figure 5 (minimal sampling and more decontamination resources), similar time and cost values were calculated with the more extensive sampling strategy was incorporated. This indicates that with the inclusion of the more efficient sampling and analysis technology, many more samples can be collected without negatively impacting the total time and cost.

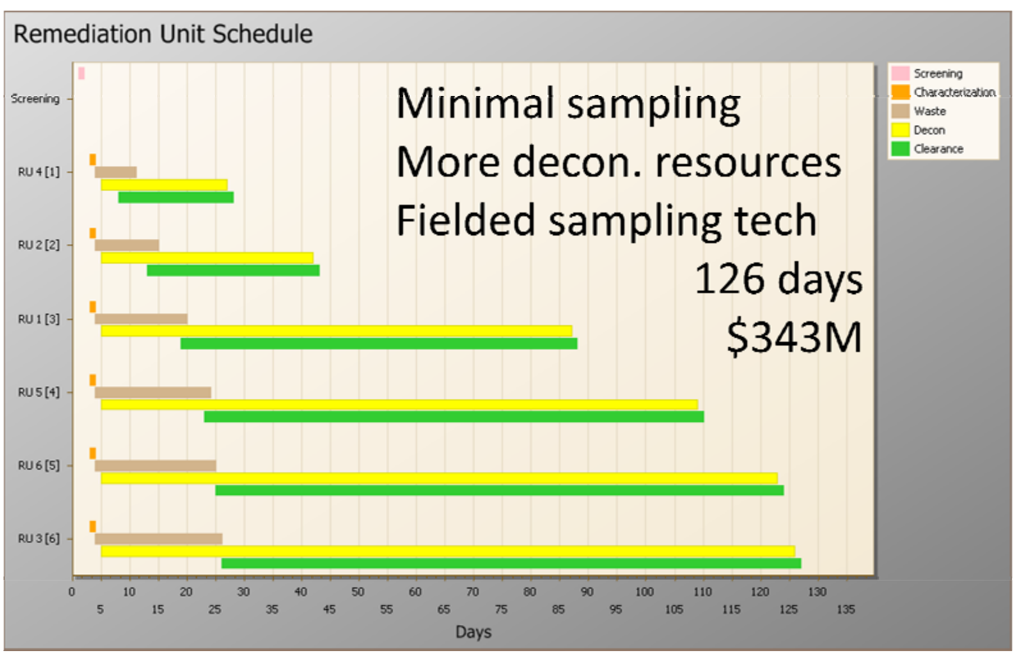

Figure 6. Timeline output from AWARE for the remediation analysis using future, man-portable sampling and analysis technologies.

3.3. Remediation by Natural Attenuation

In a wide-area contamination scenario, such as the Port scenario discussed here, the levels of hazard present initially will change over time due to natural attenuation, bioaccumulation, secondary contamination, etc. In particular, natural attenuation is an important factor to consider in planning and executing a wide-area remediation effort. Natural attenuation is the reduction or elimination of chemical hazard contamination by passive chemical and physical processes. This process is dependent on many factors including the characteristics of the contaminant, and the characteristics of the area contaminated including the types of materials contaminated and the environmental conditions (i.e. temperature, humidity, and ventilation). According to values reported in the literature, the rate of natural attenuation of chemical agents can vary widely, with half-lives of hours to months, in different system conditions. For the Port scenario, natural attenuation would impact the remediation effort in several ways, and would likely improve the remediation effort overall.

First, under some conservative assumptions, the screening phase is scheduled to take approximately a year in order to define a map of hazardous areas requiring remediation (based on the reference strategy analysis, Figure 4). In reality, the contamination would be continually attenuating throughout this entire screening process, making it impossible to estimate a true "initial contamination" map with the current approach. This indicates that the screening process needs to occur on the order of days, rather than weeks or months, in order to provide meaningful information for remediation planning. Second, as a result of the shrinking hazardous area over time, the total effort required for active remediation, including the consumption of resources for sampling, analysis, decontamination, and waste, as well as time and man-power needed would likely be reduced by natural attenuation. Along these lines, the more efficient the remediation effort, the sooner services and normal operations can be restored thereby mitigating additional, long-term consequences of an event (e.g. economic losses). Third, evolving landscape of contamination resulting from natural attenuation should also change the approaches taken in the decontamination verification sampling during the clearance phases.

In some respects, the process of natural attenuation makes the scenario more complex and more difficult to control. However, natural attenuation can potentially reduce the burden of contamination by a significant amount. An initial estimate for the Port scenario indicates that the total time would be reduced by 70% and the total cost by more than half. Therefore, incorporating natural attenuation explicitly into the overall remediation strategy will ultimately reduce the active remediation overall in many wide-area scenarios. For example, fencing off some areas to allow natural attenuation by design may enable a better use of resources. (For a more rigorous analysis of the wide-area attenuation and the potential benefit of including this phenomenon explicitly in remediation plans, please refer to SAND2011-xxxx)

4. CONCLUSION

In the example described in this appendix, three DSTs were used cooperatively to explore remediation strategies for a wide-area chemical hazard scenario:

- HPAC was used to calculate a contamination map for the wide-area scenario
    - Required input data: agent type, atmospheric release method, meteorological conditions
- VSP was used to develop a sampling and analysis strategy
    - Required input data: HPAC contamination plume, AWARE infrastructure data, decision objectives, confidence requirements data quality objective parameters
- AWARE
    - Required input data: HPAC contamination plume, VSP sample strategy, resource information

By using DSTs, remediation planners and decision makers can visualize the hazard scenario, develop and compare remediation strategies, and create a step-by-step plan for recovery after a chemical incident. Given the variation in results, it is clear that this capability is extremely important to a successful remediation effort. However, this is only one example, and there is still a significant amount of work needed to understand the complexities involved in recovery after a chemical hazard incident.

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