GIS-BASED TOOLS TO IDENTIFY TRADEOFFS BETWEEN WASTE MANAGEMENT AND REMEDIATION STRATEGIES FROM RADIOLOGICAL DISPERSAL DEVICE INCIDENTS

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ABSTRACT

Management of waste and debris from the detonation of a Radiological Dispersal Device (RDD) will likely comprise a significant portion of the overall remediation effort and possibly contribute to a significant portion of the overall remediation costs. As part of the recent National Level Exercise, Liberty RadEx, that occurred in Philadelphia in April 2010, a methodology was developed by EPA to generate a first-order estimate of a waste inventory for the hypothetical RDD from the exercise scenario. Determination of waste characteristics and whether the generated waste is construction and demolition (C&D) debris, municipal solid waste (MSW), hazardous waste, mixed waste, or low level radioactive waste (LLRW), and characterization of the wastewater that is generated from the incident or subsequent cleanup activities will all influence the cleanup costs and timelines. Decontamination techniques, whether they involve chemical treatment, abrasive removal, or aqueous washing, will also influence the waste generated and associated cleanup costs and timelines. This paper describes the ongoing effort to develop a tool to support RDD planning and response activities by assessing waste quantities and characteristics as a function of potential mitigation strategies and targeted cleanup levels.

1. INTRODUCTION

The detonation of a Radiological Dispersal Device (RDD) in an urban area by terrorists is one of the National Planning Scenarios [1] for which the U.S. Department of Homeland Security (DHS) is coordinating activities of various government agencies with response preparation requirements. A recent survey by the Government Accountability Office (GAO) found that almost all city and state governments would be overwhelmed by an RDD response and would request aid from the Federal government [2]. Roles and responsibilities of the various government agencies during emergency response activities are described in the National Response Framework (NRF) [3]. Under the NRF, the U.S. Environmental Protection Agency (EPA) is the lead agency for cleanup activities in the aftermath of an RDD event, including decontamination and waste disposal. Other Federal agencies, including the U.S. Department of Energy (DOE), U.S. Department of Defense (DoD) through the U.S. Army Corps of Engineers (USACE), and the U.S. Nuclear Regulatory Commission (NRC) also have major roles in an RDD cleanup [4].

There have been numerous exercises performed by agencies at the federal, state, and local level to help prepare for an RDD incident. However, GAO notes that in spite of over 70 RDD and improvised nuclear device (IND) exercises over the last several years, only three have included interagency recovery discussions following the exercise [2], and none have directly included activities related to the disposal of contaminated waste and debris in the exercise activities.

An integrated RDD response will require inclusion of many competing considerations, including risk to occupants and residents from post-cleanup radiation levels, prioritization of cleanups, costs associated with cleanups, speed of cleanup, decisions to demolish/remove or decontaminate, economic impacts created from denial of access to facilities and businesses, and waste/debris treatment, transportation, and disposal costs. Determination of waste characteristics and whether the generated waste is considered to be construction and demolition (C&D) debris, municipal solid waste (MSW), hazardous waste, mixed waste, or low level radioactive waste (LLRW), and characterization of the wastewater that is generated from the incident or subsequent cleanup activities will influence the cleanup costs and timelines. Selected decontamination techniques to meet the cleanup level goals, whether they involve chemical treatment, strippable coatings, abrasive removal, or aqueous washing, will also influence the types and amounts of waste generated and associated cleanup costs and timelines.

For emergency planners and federal responders to scope out the waste and debris management issues resulting from an RDD response and recovery effort, it is critical to understand not only the quantity, characteristics, and level of contamination of the waste and debris, but also the implications of response and cleanup approaches regarding waste generation. This lesson has been learned during recent cleanups of naturally-occurring *Bacillus anthracis* resulting from contaminated animal hides. The best course of action in the cleanup was determined to be to produce as little waste as possible during the response and recovery. As the waste management issues are raised to a heightened degree of visibility from a planning standpoint, there is a critical need to scope out the magnitude and characteristics of the waste and debris so that staging/storage areas and treatment/disposal pathways can be identified. This paper describes an effort to develop a first order estimate of a waste inventory based on the RDD scenario and plume maps utilized in the Liberty RadEx National Level Exercise from April 2010 [5].

2. APPROACH

The general approach that was used for developing the RDD response planning tool [6] is as follows:

- Define the geographical areas affected by the hypothetical RDD blast and subsequent radionuclide deposition using the geographic information system (GIS) shapefiles created during exercise modeling efforts by the Federal Radiological Monitoring and Assessment Center (FRMAC) supporting the Liberty RadEx exercise;
- Generate an inventory of building structures and other items within the affected geographical areas using the HAZUS®-MH software developed by the Federal Emergency Management Agency (FEMA);

- Estimate the outdoor ground media (asphalt, concrete, vegetation/soils) surface area using overhead satellite imagery;
- Based on the inventory of buildings, outdoor areas, and other items, generate an estimate of the amount and characteristics of debris resulting from the initial RDD blast and waste/debris resulting from building demolition and/or ground surface and building decontamination activities; and
- Based on the above, use a database and spreadsheet to calculate variable waste/debris estimates based on demolition/decontamination decisions and selected decontamination techniques, including estimates of wastewater.

A graphical representation of the methodology is shown in Figure 1.

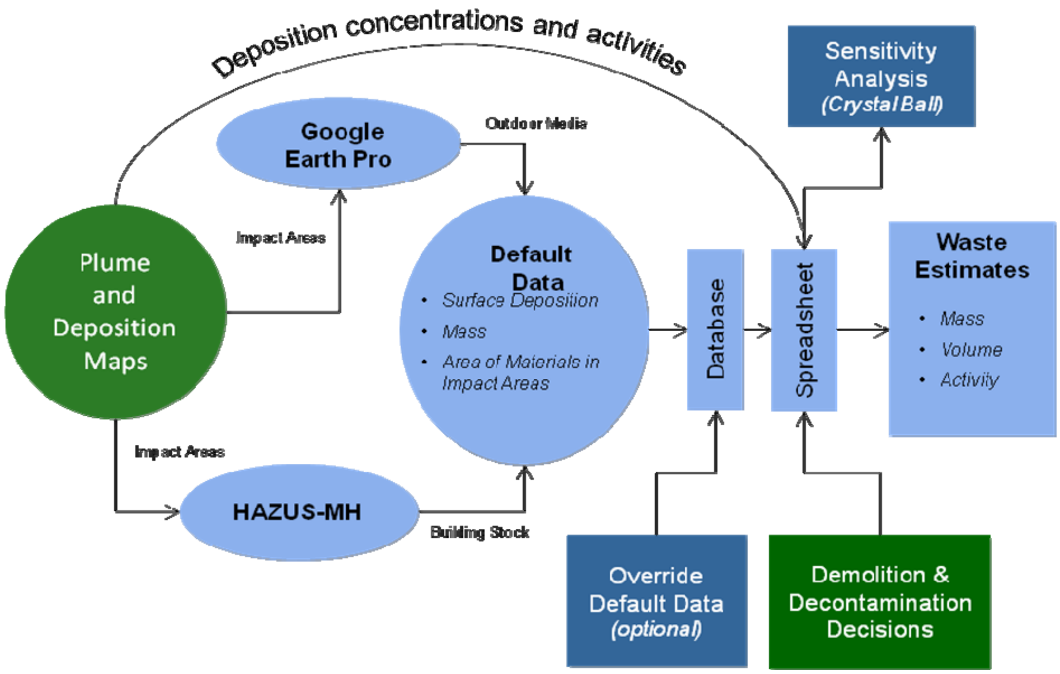

Figure 1. Graphical Depiction of Methodology

2.1 Scenario Description

The Liberty RadEx scenario involved a large truck bomb carrying 2,300 curies (Ci) of Cs-137 in the form of cesium chloride that was hypothetically detonated in downtown Philadelphia, with ensuing atmospheric transport and deposition creating a large area of contamination. Some of the products developed by the Incident Command, using the National Atmospheric Release Advisory Center (NARAC) prior to and during the exercise, were the GIS shapefiles which described the predicted deposition plume from the RDD as it moved downwind from the blast event. These shapefiles included predictions of ground-level deposition of Cs-137 in terms of areal activity, or the activity of the ground surface following deposition in terms of microcuries per square meter ($\mu Ci/m^2$). The predicted deposition activities were segregated into three different levels, designated high, medium, and low, reflecting the isopleths at 37, 8.8, and 4.1 MBq/m^2 (1,000, 240, and 112 $\mu Ci/m^2$) predicted surface activities. These surface activities are designated in the tables below as "Zone 1," "Zone 2," and "Zone 3," respectively, and are shown in Figure 2. The outer two zones are based on Protective Action Guides (PAGs) which represent radiation levels that help state and local authorities make radiation protection decisions, such as evacuation.

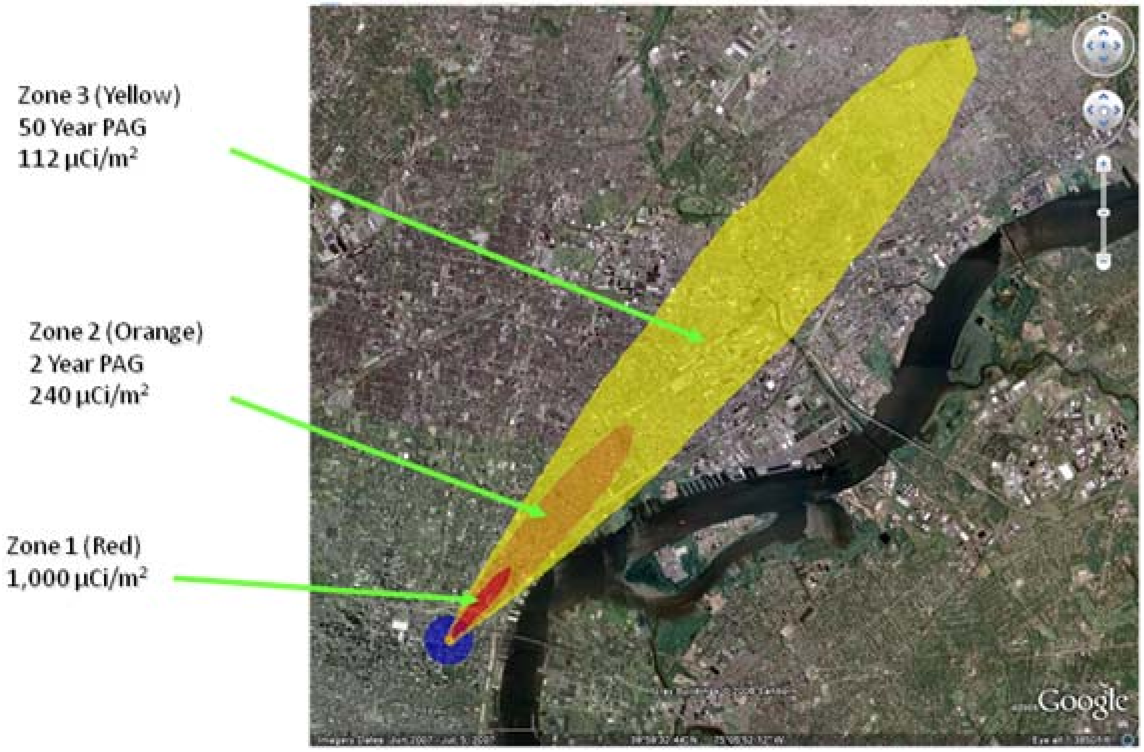

Figure 2. Liberty RadEx Plume Shapefiles Used for Waste Estimate.

2.2 Analysis of GIS Data

Using FEMA's HAZUS®-MH software [7], a listing of census tracts contained in the affected area and within boundaries defined by the GIS shapefiles for the modeled plumes was generated. The databases were then queried to develop inventories of affected buildings, structures, and other items (listed above) that are contained within the identified census tracts. For general buildings, the inventory consisted of total square footage for each building type (type of construction) and specific occupancy type (residential, commercial, government, hospital, etc.) contained within the affected areas. Inventories of essential facilities, high potential loss facilities, transportation systems, utility systems, hazardous materials facilities, and other items were specifically identified (by name) and characterized based on the information available in the respective HAZUS®-MH database. Interior and exterior building surface areas were calculated based on building square footage information and data on typical building heights and number of stories (from HAZUS®-MH).

Based on the GIS shapefiles that contain modeled radionuclide deposition at various distances from the event epicenter, debris and waste quantities were estimated according to the estimated surface activity concentration for each deposition area. Partitioning factors were used to estimate the surface activity concentrations for other types of media (e.g., building exterior and interior walls, roofs, interior floors) relative to the predicted ground deposition values.

The composition and surface area of outdoor sites was estimated by analyzing overhead satellite imagery of the affected areas. Outdoor areas were separated into the following area types:

- Asphalt;
- Concrete;
- Soils (including exposed soils, vegetation, grassy areas, parks, etc); and
- Bodies of water.

As was the case for the buildings themselves, outdoor surface areas (i.e., asphalt, concrete, and soils) were assigned user-definable parameters for decontamination technologies and associated quantities of decontamination debris and decontamination wastewater were estimated.

2.3 Decontamination and Disposal Assumptions

Based on the Liberty RadEx scenario, a number of "best guess" assumptions were made of a hypothetical mitigation strategy for three affected geographical zones, including the fraction of buildings to be demolished versus the fraction to be decontaminated, as well as a potential mix of decontamination technologies that might be deployed.

In the event of an RDD detonation, several options for decontamination exist, including strippable coatings, chemical decontamination technologies, washing and cleaning, and various abrasive techniques such as scabbling. Each of these techniques removes the contaminated material, producing varying amounts of waste in solid and/or liquid form. The decision-making process for the overall remediation effort will need to take several issues into consideration, including human health risk, effectiveness of the decontamination technology, cost of application of the decontamination technology, rate at which materials can be decontaminated using that technology, and the quantity of waste (and level of contamination) produced by that technology and associated disposal costs. Some decontamination parameters were defined by practical limits that occur during operational activities (e.g., minimum amount of soil that could be removed is six inches due to the degree of control operators have over the heavy equipment used for soil excavation).

Based on up to four decontamination technologies that EPA has identified that are likely to be used (the tool currently allows a user to select from strippable coatings, abrasive removal, washing, and a "no decontamination" option) for various surface types, decontamination waste quantities and characteristics were estimated using a combination of default and user-adjustable parameters in the spreadsheet tool. The estimates included:

- Contaminated material (e.g., the layer of radioactive material that must be removed from structures, roads, soil, etc);
- Residues from the decontamination technologies (e.g., removed strippable coatings); and
- Wastewater and sludges from onsite decontamination efforts.

2.4 Waste Estimation

Based on the assumptions and analyses described above and elsewhere, the waste estimation spreadsheet produces an estimate of both waste quantity and activity. The results of the estimated waste quantities from this example scenario are shown in Table 1, and estimates of activity are shown in Table 2. Estimations of certain quantities (e.g., liquid wastes) make no assumptions as to the availability of resources (e.g., wash water) necessary to produce those quantities of wastes.

Table 1. Example Waste Quantity Estimation from Liberty RadEx Scenario

	Zone 1	Zone 2	Zone 3	Total	Units
Solid Waste					
Demolition	66,883	82,548	142,110	291,540	metric tons
Decontamination	22,060	308,651	681,265	1,011,976	metric tons
Total	88,943	391,199	823,375	1,303,516	metric tons
Liquid Waste					
Demolition	52,948,845	65,350,416	112,503,382	230,802,643	liters
Decontamination	-	16,425,394,718	24,797,444,633	41,222,839,351	liters
Total	52,948,845	16,490,745,134	24,909,948,015	41,453,641,994	liters

Table 2. Example Waste Activity Estimation from Liberty RadEx Scenario (μCi/m^3)

Media	Zone 1	Zone 2	Zone 3
Demolition			
All Debris	4.62E+01	1.53E+01	6.63E+00
Liquid Waste *	5.62E+03	1.87E+03	8.10E+02
Decontamination			
Asphalt	3.82E+04	9.18E+03	4.28E+03
Concrete	3.82E+04	9.18E+03	4.28E+03
Soils	6.56E+03	1.57E+03	7.34E+02
Exterior Walls - Porous	4.98E+05	1.19E+05	
Exterior Walls - Non-Porous	4.91E+05	1.18E+05	
Roofs - Porous	9.98E+05	2.40E+05	1.12E+05
Roofs - Non-Porous	9.98E+05	2.40E+05	1.12E+05
Interior Walls - Porous	4.98E+04	1.19E+04	5.58E+03
Interior Walls - Non-Porous	4.91E+04	1.18E+04	5.50E+03
Interior Floors	3.82E+03	9.18E+02	4.28E+02
Liquid Waste *		3.87E+01	1.45E+01
Coating Waste		4.41E+03	2.06E+03

2.5 Time to Produce Waste Estimate

The current methodology requires approximately 8 hours from the time of receipt of the GIS shapefiles until the waste estimation is complete. The timeline is roughly broken up as follows:

- Import study regions into HAZUS®-MH and export building stock data (~ 1 hour);
- Analyze study region satellite imagery to generate outdoor media estimate (~ 3 hours);

- Calculations on building parameter data to convert HAZUS®-MH data into MS Access database needed for RDD Waste Estimation Spreadsheet (~ 3 hours); and
- Import Microsoft Access (Microsoft Corp., Redmond, WA) database into RDD Waste Estimation Spreadsheet and generate waste estimate (~ minutes).

3. ENHANCEMENTS TO TOOL

One current effort to enhance the tool is focused on reducing the time required to produce the waste estimate once the plume deposition shapefiles are received. The time required includes producing the estimate of outdoor material surface area, and manipulating the HAZUS®-MH data to be formatted correctly for importing into the waste estimation spreadsheet. Another enhancement effort is focused on adding the capability to estimate the extent of contamination as a result of the dispersal of additional radionuclides other than Cs-137 and to account for decay products in the waste estimates. Work is also ongoing that will allow users to either specify a pre-determined cleanup level and to account for the effectiveness of selected decontamination techniques. The targeted cleanup level will likely have a profound impact on the quantities and activities of the waste that is generated. Low cleanup level goals will drive decontamination decisions and, in turn, affect waste quantities.

3.1 Automation of Outdoor Surface Detection

The RDD response planning tool introduces a new technology for indentifying surface media in satellite imagery. By utilizing an artificial neural network to determine the Red, Green, and Blue (RGB) fluctuations associated with various surfaces within satellite imagery, the RDD response planning tool is able to automatically identify outdoor media. Due to the flexibility of artificial neural networks, additional surface media can be assimilated. Users will therefore have the ability to teach the tool new outdoor surfaces. Automating the estimation of outdoor surfaces greatly enhances the functionality of the RDD response planning tool by increasing timeliness, consistency, and accuracy. Figure 3 displays this concept on an overhead satellite image of an urban area, showing the original image in the lower right corner and the processed image in the upper left corner, with various surface types identified and color-coded.

Figure 3. Example of Satellite Image Processing Results

3.2 Automation of Building Stock Data Conversion

One of the most arduous elements of loss estimation modeling can be acquiring building stock data for a wide area. The RDD response planning tool confronts this issue by utilizing FEMA's HAZUS®-MH building stock database. HAZUS®-MH, FEMA's loss estimation software, is considered the leading entity in estimating building stock counts for rural and urban environments. Originally designed to estimate loss inflicted by floods, hurricanes, and earthquakes, the RDD response planning tool utilizes HAZUS®-MH building stock data to generate debris estimates. One of the unique functions of the RDD response tool is the ability to automatically extract default building stock data directly from the HAZUS®-MH databases without navigating HAZUS®-MH or FEMA's Comprehensive Data Management System. By automating the building stock extraction process, the time it takes to produce the waste estimates is greatly reduced, and the universe of potential users is expanded beyond those with significant GIS expertise.

3.3 Multiple Radionuclides

The waste estimation spreadsheet currently estimates the remaining activities on various surface media for Cs-137 only. For scenarios that might involve the release of one or more radionuclides other than, or in addition to, Cs-137, efforts are underway to build functionality into the spreadsheet that would allow users to account for multiple radionuclides in the waste estimates. The ability to account for approximately 40 additional radionuclides will be added, in addition to selected decay products to enable the tool to be useful for planning RDD responses, where only a single radionuclide of interest will be present, as well as INDs and nuclear power plant accidents, where multiple radionuclides of interest will be present.

3.4 Additional Decontamination Parameters

The extent to which any given surface may be decontaminated can vary according to many factors, including the properties of the surface material, the decontamination technique used. The fate of the initial radionuclide will be estimated based on the elapsed time since initial deposition or the time phase of the recovery effort. Decontamination factors will be a user-adjustable parameter. Another planned enhancement will allow users of the waste estimation spreadsheet to either specify a pre-determined cleanup level and evaluate the resulting waste amounts, or to evaluate waste amounts based on a user-adjustable decontamination effectiveness value (e.g., decontamination factor or percent of activity removed) for each of the decontamination techniques under consideration for a given scenario.

3.5 Other Planned Improvements

Implementation of additional enhancements to this tool, beyond those discussed in Section 3, are underway or planned, including transportation-related issues and overall remediation cost estimation capabilities.

4. SUMMARY

The EPA has developed a GIS-based tool to estimate the quantity, characteristics, and activities of waste and debris resulting from an RDD detonation or other radiological release event. The tool uses a combination of the HAZUS®-MH software, Microsoft Access, and Microsoft Excel to produce the waste estimate. Adjustable parameters allow the user to estimate the impacts on the waste streams of different demolition and decontamination strategies. Improvements are underway to dramatically lessen the time required from initial receipt of the GIS shapefiles until the resulting waste estimation. Other improvements are underway to broaden the applicability of the tool and expand its usefulness for pre-event or initial response activities. We hope that federal responders and decision makers using this tool will be better able to implement an integrated response to effectively analyze many competing considerations and result in optimal decision making capabilities. Use of this tool may be a useful task to include with cities' planning activities to accompany the background radiation surveys that are being performed.

5. DISCLAIMER

The U.S. Environmental Protection Agency through its Office of Research and Development managed the research described here. It has been subjected to the Agency's review and has been approved for publication. Note that approval does not signify that the contents necessarily reflect the views of the Agency.

6. REFERENCES

1. U.S. DEPARTMENT OF HOMELAND SECURITY, "National Preparedness Guidelines," http://www.dhs.gov/xlibrary/assets/National_Preparedness_Guidelines.pdf, accessed October 27, 2009 (2007).
2. GOVERNMENT ACCOUNTABILITY OFFICE, "Combating Nuclear Terrorism: Preliminary Observations on Preparedness to Recover from Possible Attacks Using Radiological or Nuclear Materials", GAO-09-996T (2009).
3. U.S. DEPARTMENT OF HOMELAND SECURITY, "National Response Framework," http://www.fema.gov/pdf/emergency/nrf/nrf-core.pdf, accessed October 27, 2009 (2008).
4. R.L. DEMMER, "Large Scale, Urban Decontamination; Developments, Historical Examples and Lessons Learned," Proceedings of the WM07 Conference, Tucson, AZ, February 25-March 1 (2007).
5. U.S. EPA, "Liberty RadEx," http://www.epa.gov/libertyradex/, accessed May 26, 2011, (2010).
6. P. LEMIEUX, J. WOOD, D. SCHULTHEISZ, T. PEAKE, M. IERARDI, C. HAYES and M. RODGERS, "A First-Order Estimate of Debris and Waste Resulting from a Hypothetical Radiological Dispersal Device Incident," Proceedings of the WM2010 Conference, Phoenix, AZ, March 7-10 (2010).
7. FEMA, "HAZUS®-MH Overview," http://www.fema.gov/plan/prevent/hazus/hz_overview.shtm, accessed September 28, 2009 (2009).