A Planning Tool for Estimating Waste Generated by a Radiological Incident and Subsequent Decontamination Efforts - 13569

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ABSTRACT

Management of debris and waste from a wide-area radiological incident would probably constitute a significant percentage of the total remediation cost and effort. The U.S. Environmental Protection Agency's (EPA's) Waste Estimation Support Tool (WEST) is a unique planning tool for estimating the potential volume and radioactivity levels of waste generated by a radiological incident and subsequent decontamination efforts. The WEST was developed to support planners and decision makers by generating a first-order estimate of the quantity and characteristics of waste resulting from a radiological incident. The tool then allows the user to evaluate the impact of various decontamination/demolition strategies on the waste types and volumes generated.

WEST consists of a suite of standalone applications and Esri® ArcGIS® scripts for rapidly estimating waste inventories and levels of radioactivity generated from a radiological contamination incident as a function of user-defined decontamination and demolition approaches. WEST accepts Geographic Information System (GIS) shapefiles defining contaminated areas and extent of contamination. Building stock information, including square footage, building counts, and building composition estimates are then generated using the Federal Emergency Management Agency's (FEMA's) Hazus®-MH software. WEST then identifies outdoor surfaces based on the application of pattern recognition to overhead aerial imagery. The results from the GIS calculations are then fed into a Microsoft Excel® 2007 spreadsheet with a custom graphical user interface where the user can examine the impact of various decontamination/demolition scenarios on the quantity, characteristics, and residual radioactivity of the resulting waste streams.

INTRODUCTION

Radioactive materials have a wide range of beneficial uses, especially in the areas of medicine, industry, and research. However, conventional radioactive materials can also be used for sinister purposes such as in radiological dispersal devices (RDDs) [1]. An RDD is a weapon in which radioactive material is combined with a conventional dispersal device (e.g., explosive). When detonated, the RDD, coupled with atmospheric transport, disperses radioactive material, potentially over a wide area, contaminating exposed outdoor surfaces and entering buildings through infiltration [1]. RDDs differ from traditional nuclear weapons: nuclear weapons are capable of instantly incinerating a measurable area, but RDDs would probably be dispersed using a conventional explosive, resulting in a much smaller area of direct blast damage. However, both are capable of spreading radioactive particulates over a large area. Casualties from an RDD would likely be determined solely based on the conventional explosive used to disseminate the radiological material [1]. Decontamination and remediation, to reduce residual exposure to the population, are the most arduous tasks associated with detonation of an RDD. As the radioactive particulate matter settles, its behavior will be influenced by the type of surface material upon which it lands and atmospheric conditions during and after deposition. Depending on the radionuclide, permeable surfaces can act as a sponge, absorbing the radionuclide, making it difficult to decontaminate [2]. Decontamination resulting from an RDD that uses cesium may be financially exhaustive, potentially requiring extended recovery efforts. Measures used to plan or prepare for cleanup after an RDD are complex and typically involve incident modeling in addition to response and recovery exercises [1, 3, 4]. For incidents encompassing a wide-area, GIS may be an extremely useful tool to support management during the planning and recovery phases. As Figure 1 conceptualizes, GIS can be used to address a multitude of geographic-dependent remediation variables. The inclusion of these variables can be used to optimize the decontamination approach to provide the most rapid, cost effective remediation while maintaining the safety of the public.

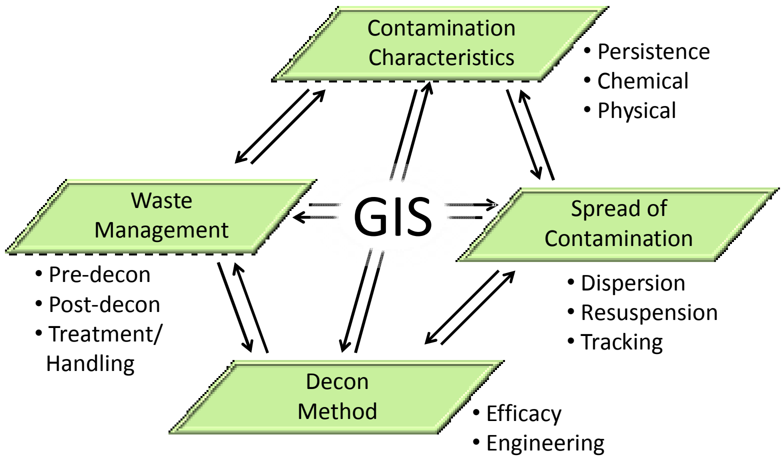

Figure 1. Systems Approach to Wide-Area Remediation

Modeling the distribution of the radionuclides in the plume is only the beginning of the remediation process. Contaminated areas become better defined through sampling and characterization processes that eventually supersede the initial plume modeling. Initial characterization may occur within days or weeks, but it may be much longer before the affected area is fully characterized. Waste will begin to be generated immediately following the initial release of contaminants, and, to minimize remediation timelines, initial development of remediation strategies must start immediately following the contamination incident. This process includes identification of the materials found in both the indoor and outdoor portions of the affected areas and developing approaches for optimal cleanup of those surfaces and materials. Supplying the incident commander (IC) with decision making tools to help prioritize remediation processes as soon as possible is a key element of a rapid, effective remediation strategy that minimizes economic and health impacts to the affected community.

The WEST supports this process by exploiting plume models depicting deposition and concentration levels, outdoor surface classification capabilities using aerial imagery and pattern recognition approaches, and building stock data (i.e., building quantity, size, square footage, and construction materials). Building stock data are extracted from the Hazus®-MH databases, which were initially developed by the Federal Emergency Management Agency (FEMA) to support responses to earthquakes, hurricanes, and floods. Using these modules, researchers have developed a suite of applications for rapidly estimating waste inventories and levels of radioactivity generated by detonation of an RDD as a function of user-defined decontamination and demolition approaches. This rapid estimation enables remediation strategies to be evaluated in terms of their implications for cost, remediation timeline, volumes of waste generated, and level of effort.

APPROACH

The general approach that is used to develop an RDD scenario is as follows [5]:

- Perform geospatial analyses on the geographic region (aggregated at the census tract level) affected by a radiological contamination incident using a shapefile(s) depicting radionuclide deposition;
- Generate an inventory of building structures and other items within the affected census tracts by querying the Hazus®-MH database;
- Classify outdoor surface media (asphalt, concrete, vegetation/soils) based on overhead aerial imagery and the developed pattern recognition algorithm; and
- Using the aforementioned inventory of buildings, outdoor areas, and other items, calculate an estimate of the amount and characteristics of waste/debris resulting from building demolition (including user-inputted estimates of demolition from the initial blast) and selected decontamination techniques of structures and ground surfaces, including estimates of wastewater. A sensitivity analysis could be performed within the tool using software such as Crystal Ball® (an Excel® add-on that supports detailed sensitivity analysis using Monte Carlo simulation techniques) to assess the implications of potential remediation decisions.

A graphical depiction of the methodology behind the tool is shown in Figure 2.

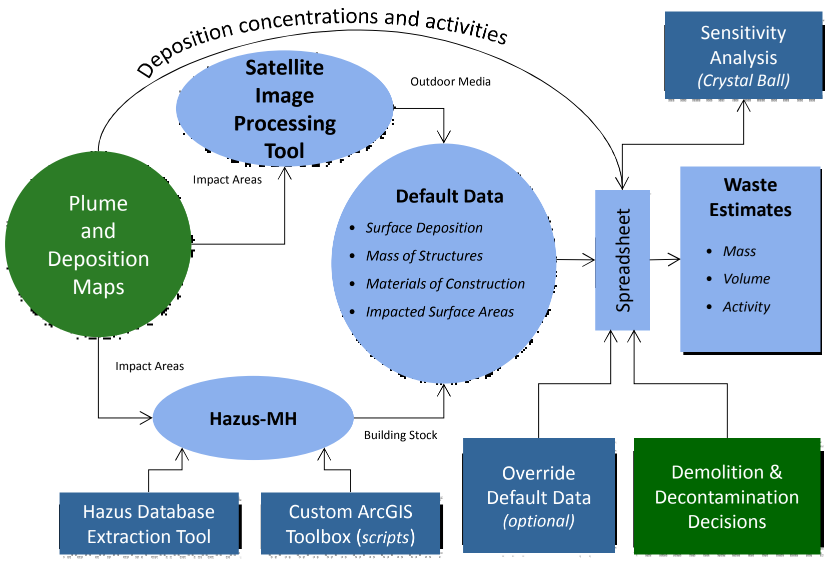

Figure 2. Graphical Depiction of Methodology

Analysis of Geospatial Data

When working with wide-area incidents, it is important to understand the infrastructure and geographical qualities of a specific area. The entire process begins by performing a statistical analysis on data that spatially represent features or boundaries. This process is often referred to as geospatial analysis and is systematically automated using a geographic information system such as Esri's® ArcGIS®. ArcGIS® has various extensions available to extend its functionality. One of the most acclaimed extensions for modeling potential loss of infrastructure is FEMA's Hazus®-MH. Typically used to model losses due to earthquakes, floods, and hurricanes, Hazus®-MH operates using extensive building stock databases covering the entire continental United States. A unique aspect of the WEST is that it applies the Hazus®-MH tool to other large scale disasters such as those that involve radiological incidents.

In an RDD scenario, three-zone shapefiles depicting the deposition activity within the plume would typically be supplied by the National Atmospheric Release Advisory Committee (NARAC), a governmental organization that supplies the "official" plume maps from such incidents, so that subsequent modeling efforts are performed using a common input data set. Using ArcGIS®, a geometric intersection is performed on the Hazus®-MH-derived census tracts and overlapping boundaries as defined by the modeled plume. The above analysis provides the Waste Tool Spreadsheet with two inputs: (1) building stock inventory (i.e., building quantity, size, square footage, occupancy, and construction materials) populated by querying the Hazus®-MH databases using the underlying census tracts and (2) percentage of each census tract overlapping the modeled plume [6]. The resulting data are processed by the Waste Tool Spreadsheet to determine building stock composition and distribution within the three deposition zones.

Surface Media Classification

A key component of estimating decontamination, demolition, and waste/debris disposal options from a wide area radiological incident is the ability to classify outdoor media in an expedited manner. Understanding the composition of outdoor surfaces within the contours of a plume resulting from an RDD is essential when assessing the makeup of waste and establishing decontamination parameters. The need for surface classification capabilities prompted the development of the Image Analysis Tool (one of the standalone applications). By analyzing aerial imagery of a selected area, the Image Analysis Tool classifies outdoor surface areas by type (i.e., soil/vegetation, water, asphalt, or concrete) using a neural network-derived algorithm. The statistical distribution of surface media provides the Waste Tool Spreadsheet an estimated snapshot of materials found in the affected environment. Figure 3 shows an example of how the Image Analysis Tool utilizes pattern recognition approaches to identify surface material types (in this case, concrete) from overhead aerial imagery.

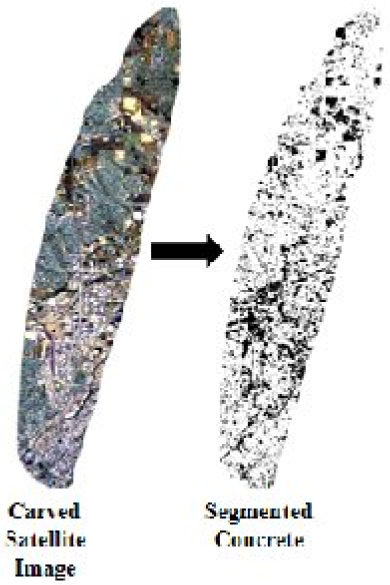

Figure 3. Surface Media Classification

Waste Estimation

The Waste Tool Spreadsheet is a Microsoft Excel® 2007 spreadsheet that provides a simple and intuitive interface for users to specify various required inputs and to modify pre-programmed default parameters. The WEST performs numerous calculations based on the provided building stock data generated from the Hazus®-MH data, distribution of surface media, and additional user inputs to describe the hypothetical scenario including initial deposition activity for one or more radionuclides. Once the preliminary data have been generated and imported into the Waste Tool Spreadsheet, users can specify the type of decontamination technology to be used on various surfaces in each deposition zone or can choose to model the demolition of a fraction of buildings in any given zone. Once the demolition and/or decontamination parameters have been specified, the Waste Tool Spreadsheet estimates the amount and activity of contaminated waste that would be generated based on the user-defined radionuclide(s) deposition at various distances from the incident epicenter at a given elapsed time since initial deposition. Debris and waste quantities are estimated according to the estimated surface activity concentration for each deposition area. Partitioning factors are used to estimate the surface activity concentrations for surfaces other than horizontal ground-level deposition as well as assumed infiltration into buildings (e.g., building exterior and interior walls, roofs, interior floors) relative to the supplied ground deposition values. The waste estimates include building materials and ground surface materials as well as the water that is generated during decontamination activities. Optionally, results from the WEST can be subjected to sensitivity analysis using such Microsoft Excel® addons as Crystal Ball® to identify impacts of decisions on such output variables as amount/activity of waste, type of waste, or remediation costs.

Time to Produce Waste Estimate

The current methodology requires approximately one hour from the time of receipt of the GIS shapefiles until the waste estimation is complete. Assuming an average user with 2 hours of training on the operation of WEST, and a basic knowledge of the use of ArcGIS®, Hazus®, and Excel®, the timeline is roughly broken up as follows:

- Import study regions into Hazus®-MH (~ 10 minutes);
- Execute geospatial tools (~ 15 minutes);
- Classify surface media (~ 5 minutes);
- Create scenario/import data files (~ 10 minutes); and
- Establish decontamination/demolition parameters (~ 20 minutes).

The GIS processing portion of the operation of WEST is completely decoupled from the Waste Tool Spreadsheet portion of WEST. Because of this, it would be possible for a user to receive assistance from a knowledgeable source to perform the GIS-related tasks, and perform all Waste Tool Spreadsheet activities themselves with little or no GIS experience.

This processing time is significantly shortened compared to earlier versions of the tool. In particular, prior to automation of the GIS application and the classification of surface media, a person familiar with the system would need up to eight hours to process the incoming plume data. Once the study regions and decontamination/demolition parameters have been entered into the Waste Tool Spreadsheet, multiple decontamination/demolition scenarios can be investigated more or less instantaneously for a given study region.

EXAMPLE SCENARIO: LIBERTY RADEX

Liberty RadEx, a national Tier 2 full-scale RDD recovery exercise conducted in Philadelphia in April of 2010, was the largest drill of its kind to test the country's capability to clean up and help communities recover from a dirty bomb terrorist attack.

Scenario Description

The Liberty RadEx scenario involved a large truck bomb (approximately half the size of the Oklahoma City bombing in 1995) carrying 2,300 curies (Ci) of Cs-137 in the form of powdered cesium chloride that was hypothetically detonated in downtown Philadelphia, with ensuing atmospheric transport and deposition creating a large area of contamination. The IC used the NARAC plume models prior to and during the exercise to develop the GIS shapefiles which described the predicted deposition plume from the RDD as it moved downwind from the blast incident. These shapefiles included predictions of ground-level deposition of Cs-137 on 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 contaminant 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 levels were selected by the Liberty RadEx planning team to represent certain contamination levels (e.g., the 1000 $\mu Ci/m^2$ in the inner zone) or certain exposure levels that might represent evacuation zones. These surface activities are designated in the tables below as "Zone 1," "Zone 2," and "Zone 3," respectively, and are shown in Figure 4. The outer two zones in Figure 4 are based on Protective Action Guides (PAGs) which represent radiation levels that help state and local authorities make radiation protection decisions, such as evacuations. Zone 2 represents a projected dose of 500 millirem per year (mrem/yr) and Zone 3 represents a projected cumulative dose of 5 rem over 50 years. Protective actions would be designed to prevent these exposures.

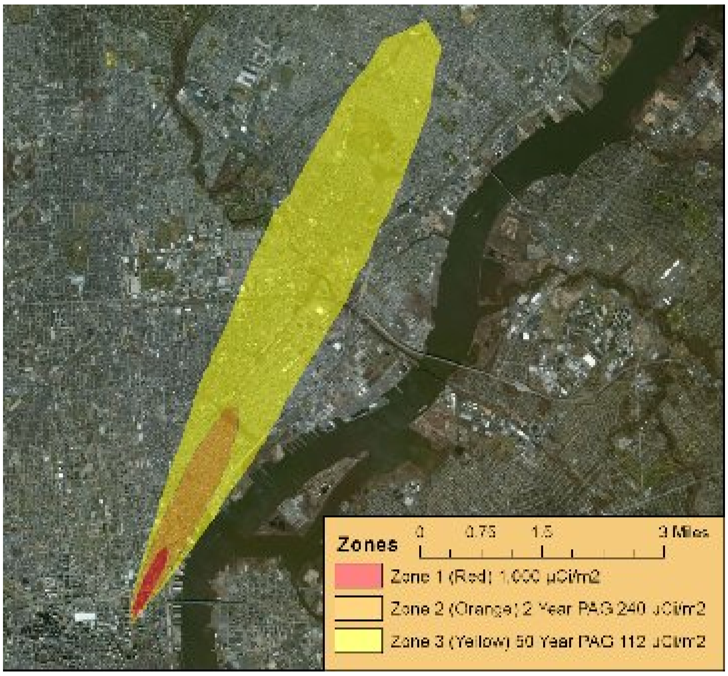

Figure 4. Liberty RadEx Plume Shapefiles

Decontamination and Disposal Assumptions

In the event of an RDD incident, several options for decontamination exist, including excavation and removal, strippable coatings, washing and cleaning, and various abrasive techniques such as scabbling. Each of these techniques removes some contaminated material, and potentially some of the underlying substrate, producing varying amounts of waste in solid and/or liquid form. The decision-making process for the overall remediation effort will need to consider several issues, including human health risk, effectiveness of the decontamination technology, availability of resources to apply a given 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 its associated disposal costs. Some decontamination parameters were defined by practical limits that occur during operational activities (e.g., minimum depth of soil that could be removed was assumed to be six inches due to the relative degree of control operators have over the heavy equipment typically used for soil excavation).

Based on several 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, a “no decontamination” option, as well as a user-defined decontamination technology option) for various surface types, decontamination waste quantities and characteristics were estimated using a combination of default and user-adjustable parameters in the Waste Tool Spreadsheet [7]. The estimates include:

- 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, residues from abrasive surface removal); and
- Wastewater and sludges from onsite decontamination efforts.

Based on the Liberty RadEx scenario, a number of "best guess" assumptions were made for a hypothetical mitigation strategy for the three affected geographical zones shown previously in Figure 4, 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. This process is demonstrated below in Table 1. The decontamination and demolition options selected in no way reflect EPA policy or even likely strategies that would be used in a real RDD incident, although they constituted a first guess at a remediation strategy that might be used based on expertise of EPA response personnel.

Table 1. Decontamination and Demolition Parameters Used in the Liberty RadEx Scenario

Media	Zone 1: 90% demolition 10% decontamination	Zone 2: 10% demolition 90% decontamination	Zone 3 10% demolition 90% decontamination
Asphalt	1" removal	1" removal – 70% Wash – 30%	1" removal – 70% Wash – 30%
Concrete	1" removal	1" removal – 70% Wash – 30%	1" removal – 70% Wash – 30%
Soil	6" removal	6" removal	6" removal
External Walls	1 mm removal	1 mm removal – 20% Wash – 80%	Wash
Roofs	1 mm removal	1 mm removal – 20% Wash – 80%	1 mm removal – 20% Wash – 80%
Interior Walls	1 mm removal	1 mm removal – 20% Wash – 30% Strippable Coating – 50%	1 mm removal – 20% Wash – 30% Strippable Coating – 50%
Floors	1" removal	1" removal	1" removal – 50% Wash – 50%

Waste Estimation

Based on the assumptions and analyses described above and elsewhere, the Waste Tool 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 2, and estimates of activity are shown in Table 3. 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. In fact, one of the useful outputs of the tool is a gross indication of the theoretical viability of certain strategies (e.g., where water supplies are limited, using washing as a primary decontamination option may not be possible).

Table 2 demonstrates the amount of waste generated by demolition and decontamination measures. Note the total waste produced (approximately 1.3 million metric tons) and the amount of liquid waste generated as a result (approximately 41 billion liters). It should be recognized that this is the estimated waste generation only from the three zones identified by the plume, which were defined consistent with current guidance on protective actions. This is likely the minimum area that would have some level of decontamination applied. Depending on the extent of the plume and decisions on cleanup goals, significantly larger amounts of waste could be generated.

Table 3 depicts the amount of residual waste radioactivity by media type. Overall, activity is low, and these estimates may be useful for policy discussions by appropriate decision making personnel to determine disposal pathways, including low level radioactive waste (LLRW) sites, Resource Conservation and Recovery Act (RCRA) Subtitle C hazardous waste landfills, or RCRA Subtitle D municipal solid waste (MSW) landfills.

Table 2. 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 3. 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 - Nonporous	4.91E+05	1.18E+05	
Roofs - Porous	9.98E+05	2.40E+05	1.12E+05
Roofs - Nonporous	9.98E+05	2.40E+05	1.12E+05
Interior Walls - Porous	4.98E+04	1.19E+04	5.58E+03
Interior Walls - Nonporous	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

ENHANCEMENTS TO TOOL

The following paragraphs relate enhancements to the tool that are currently being implemented to make the tool more useful to the response community.

Occupancy Based Infrastructure Scheme

Current debris estimates are based on building type (e.g., wood and masonry), which is ideal for determining debris composition; however, estimates from the current version of the WEST lack the means necessary to determine building use or occupancy (e.g., single family dwellings and schools). By coupling building type and building use, users will be able to explore decontamination/demolition options based on occupancy type (i.e., remediation based on building use or location).

Cost of Remediation

One current effort to enhance the tool is focused on the inclusion of the overall cost of remediation. Costs associated with every facet of remediation (e.g., cleanup, disposal, and logistics) can influence the subsequent cleanup activities. One enhancement under consideration for future versions of the WEST is the ability to calculate costs associated with the selected decontamination/demolition method including direct and indirect economic implications.

Ability to Map Results

One of the advantages of using a GIS system is the ability to georeference data, essentially enabling the user to spatially visualize (i.e., plot) results. This feature will further enhance risk communication and help support remediation decisions, including logistics and the identification of appropriate waste staging and temporary storage sites.

Additional Decontamination and Waste Parameters

Additional decontamination and waste parameters are continuously being explored to increase accuracy, which include: multiple decontamination operations to achieve a specific decontamination level; consideration of additional decay time from the beginning of cleanup activities to an established point in the future; and the incorporation of data from EPA's I-WASTE tool as a waste quantity estimator for building contents [8].

Other Planned Improvements

Implementation of additional enhancements to this tool, beyond those discussed above, is underway or planned, including generating estimates for biomass waste and vehicles (either as waste or destined for decontamination) and support for non-continental US study regions. As lessons are learned from the response to and recovery from the Fukushima nuclear plant disaster, additional enhancements and their prioritization may become clearer. In addition, information learned from the Fukushima incident or other risk analysis tools may enable the outputs from the WEST tool to be corroborated with comparisons to real-world results.

Data integration efforts are being considered for adapting data originating in the private or public sector that is compatible with ArcGIS®. Specifically, the data sets associated with the insurance industries, tax assessors, infrastructure management and maintenance sectors, and maritime sectors may provide valuable information.

SUMMARY

The EPA has developed a GIS-based tool to estimate the quantity, characteristics, and radiological activities of waste and debris resulting from an RDD or other radiological release incident. The tool uses a combination of the ArcGIS® software, Hazus®-MH, and a suite of EPA-developed applications to produce the estimated waste inventories. Adjustable parameters allow the user to estimate the impacts on the waste streams of different demolition and decontamination strategies. Characteristics of waste and wastewater generated from the incident or subsequent cleanup activities will influence the cleanup costs and timelines. Local, State, and Federal planners, responders, and decision makers using this tool may be better able to implement an integrated response by effective analysis of many competing considerations, resulting in optimal decision making capabilities.

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.

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