Systematic Decontamination and Recovery Following an RDD Event – 11540

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ABSTRACT

The United States has been slow to address the issues associated with the long-term recovery of an area following a potential radiological dispersal device (RDD) event. A simple decision framework is presented that outlines a step-by-step procedure providing a systematic approach to the problem. By breaking the recovery effort into its component parts, the strategy for cleanup can be accelerated. While determining the cleanup areas and setting cleanup goals and priorities may be contested issues, those components of the framework with less uncertainty, such as determining the types and extent of contaminated surfaces and the relevant potential decontamination technologies, provide an objective means to optimize the long-term cleanup effort. Cleanup strategies and the potential surface types are discussed in the context of more than 60 cleanup technologies that have been identified for use in long-term recovery efforts following a potential RDD event.

INTRODUCTION

Ensuring the long-term recovery of an area after the widespread dispersal of radioactive material is a complex problem that requires coordination among many local, state, and federal agencies. The early phase following a radiological event, such as one involving a radiological dispersal device (RDD), is characterized by immediate protection of the public through such actions as sheltering or evacuation. Once the immediate danger is past, an assessment of the current conditions must precede remediation of the affected area as part of a community’s long-term recovery effort. While guidance has been issued on emergency planning for such events at various levels, similar guidance for long-term recovery planning is sparse [1]. A decision framework has been developed that can be used as a tool for both systematic training and planning for RDD long-term recovery. This decision framework can be used to optimize recovery efforts in the context of interim guidance from the Department of Homeland Security [2].

The decision framework takes into account conflicting recovery goals such as the minimization of human exposure, costs, wastes, and cleanup times, while maximizing effectiveness. Use of the framework is an iterative process that begins with categorization of the affected surface types into a small number of groups. This categorization allows the overall problem to be broken up into a smaller number of manageable pieces. A proposed cleanup technology (or technologies) is selected for each group. Consequences of the cleanup are estimated, and the initial surface type categorizations are revisited and modified as necessary; selection of the cleanup technologies is also revisited. Once the overall strategy has been approved and cleanup initiated, the entire decision process or portions of the process related to a particular surface type or technology may need to be revised on the basis of feedback from the field as the actual work is performed.

SURFACE TYPE CATEGORIES

The categorization of surface types allows for a systematic approach to the cleanup process based on the underlying assumption that a single cleanup technology or the same series of technologies can be applied to those surfaces grouped in the same category. This assumption also holds for a single surface type scattered throughout the contaminated area, such as rooftops or tree cover in parks. Because the surface type categorization is location dependent, the classification scheme to be used will be unique for each RDD event. In addition, selection of the surface type categories is not independent of decontamination technology selection.

As a starting point, a number of existing land cover classification schemes, potentially with associated local data, may be leveraged for application in surface type categorization. The U.S. Geological Survey land cover classification scheme for the National Land Cover Database (NLCD) [3] is listed in Table 1. Its applicability to RDD long-term recovery efforts is somewhat limited in urban areas because of the sparse detail relative to the composition of developed areas. Similarly, studies related to the urban heat island effect and stormwater runoff issues can provide supplemental information.

Table 1. NLCD 2001 Land Cover Classification Categories [3].

Category	Category (cont.)
Open water	Mixed forest
Perennial ice, snow	Shrubland
Urban, recreational grasses	Orchards, vineyards, other
Low intensity residential	Grasslands, herbaceous
High intensity residential	Pasture, hay
Commercial, industrial, roads	Row crops
Bare rock, sand	Small grains
Quarry, strip mine, gravel pit	Fallow
Transitional barren	Woody wetlands
Deciduous forest	Emergent, herbaceous wetland
Evergreen forest	

Studies on the urban heat island effect often focus on three primary surface types: paved areas, rooftops, and vegetation [4, 5]. The focus on the first two surface types reflects their importance in solar heating of urban areas, with the vegetative tree canopy playing a mitigative role. Because deposition of radioactive material from an RDD event involving air dispersion would preferentially occur on horizontal surfaces, paved areas and rooftops in an urban area will account for a large percentage of the dispersed contamination. Data from four large metropolitan areas (Chicago, Houston, Sacramento, and Salt Lake City) showed pavement coverages of about 30 to 45%, with rooftop coverages of about 20 to 25% [5]. However, a significant portion of the paved areas, such as the major roads, may require initial cleaning in the early phase following an event for use as evacuation routes or to provide access to critical infrastructure or assets.

Stormwater runoff in urban areas has been studied for decades. Many municipalities have a clear understanding of where precipitation will go once on the ground, from precipitation events or human activities including water-based cleanup activities [6]. Runoff studies typically classify or account for impervious versus permeable areas (e.g., paved versus non-paved). These studies are important, not only in providing a starting point for surface type characterization but also for knowing where radioactive contamination can migrate and concentrate as a result of precipitation events following an RDD event before cleanup efforts are possible.

For existing data on surface types in a local urban environment and surrounding areas, the most detailed spatial information is now becoming readily available to city planners and managers in most metropolitan areas. The trend toward the formation of municipal GIS departments and the continuing migration of spatial data to their systems provides an invaluable resource. Many systems originally began with rudimentary data to track roads, water lines, and other utilities. As such, these systems already contain the spatial infrastructure information needed for decision-makers in times of crisis.

Some of these GIS systems are beginning to add 3D capability as they add building inventories, and as the line with CAD systems begins to blur, are able to simulate a 3D environment for a city or a section of its urban area. For example, the urban center of Philadelphia, Pennsylvania, has been replicated in an online virtual environment (see http://www.geosimphilly.com/). With the detail necessary to build such a model, information on the extent of most exterior surfaces would be available.

Another critical advantage provided by 3D capabilities is the ability to distinguish contaminated areas relative to their height above ground. For example, rooftops and other exterior building surfaces above a certain height may remain uncontaminated because the original airborne contaminant plume did not reach that height. Response managers could better incorporate this 3D information into the long-term recovery efforts.

DECONTAMINATION TECHNOLOGIES

This section provides a summary listing of existing and emerging technologies that might be suitable for use in an urban area during the recovery phase after an RDD event. Applicable radionuclide decontamination technologies have been developed over the past few decades for the maintenance and decontamination of existing nuclear facilities, as well as the remediation of contaminated sites. Recently, more emphasis has been given to decontamination for decommissioning purposes rather than maintenance, as nuclear facilities age and are prepared for dismantlement or reuse. The scale of such decontamination is much larger than that for maintenance and begins to approach what might be required for urban remediation. Thus, automation of many techniques is becoming more important as a criterion for increasing cost-effectiveness by reducing labor costs. However, decontamination for decommissioning often attempts to reduce radionuclide concentration levels so that material qualifies for a disposal category of lower hazard, rather than being clean enough for reuse. Details of decontamination strategies and technologies have been published elsewhere [7-14].

The technologies presented in Table 2 are those expected to be generally relevant to urban cleanup. However, some technologies better suited to small areas are included because they could be the best cleanup remedy for hot spots following an RDD event. The technologies summarized are presented according to their application to solid surfaces, surface soil treatment, and water control. Groundwater contamination and water treatment are associated issues, but relevant cleanup technologies are not covered here.

The cleanup technologies can be classified into three broad categories according to their basic approach: (1) removal of the contaminated substrate in conjunction with the radioactive material, (2) removal of the contamination with minimal effects on the substrate, and (3) fixation of the contamination in place. While the third category does not result in true decontamination of a surface, it may enable the productive use of a given area or reduce the migration hazard of the contamination.

Table 2. Restoration Technologies for Contaminated Areas [7-14].

Technology	Surface Type
Solid Surfaces	
Acid Solutions (etch surface)	Metal
Ammonium nitrate treatment of buildings	Most surfaces
Blast methods	
Grit	Most surfaces except glass and Plexiglas
Hydro	Concrete, metal
Ice	Most surfaces
CO_2	Most surfaces (concrete, metal, plastic, wood)
Sponge (soft media)	Most surfaces
Shot blasting	Usually concrete; can be used on metal
Ultrahigh-pressure water	Concrete, metal
Chelation (organic complex to promote solubility in solution)	Most surfaces except glass
Collection of leaves	Brush
Demolition and removal	Any surface
Detergents and surfactants	Most materials
Early crop removal	Crops
Electrochemical cleaning	Metal
Flaming	Concrete, metal, brick
Filter removal	Filters
Foams and gels	Most surfaces
Lawn mowing and collection	Grass
Organic solvents (grease, oil, paint removal)	Most surfaces
Paint removal (mechanical)	Paint
Paint removal (chemical)	Paint
Pruning vegetation	Trees and shrubs
Redox agents (change oxidation state to promote solubility in solution)	Metal
Resurfacing	Asphalt, brick, concrete, stone
Removal of trees and shrubs	Trees, shrubs
Road planing	Concrete and asphalt
Roof replacement	Any surface
Sanding	Wood

Scarifiers	
Grinders	Concrete
Flame	Concrete
Milling	Concrete
Needle scalers	Concrete and steel
Scabblers	Concrete
Shavers	Concrete
Spallers	Concrete
Snow removal	Snow
Steam cleaning	Most surfaces
Strippable coating	Most surfaces
Ultrasound treatment with chemical decontamination	Metal
Vacuuming	Most surfaces
Vibratory finishing	Metal
Wiping/dusting/scrubbing	Most surfaces
Water flushing	Most surfaces
Soil Treatment	
Application of lime to soil and grass areas	Soil and grass
Application of potassium fertilizers to soil and grass areas	Soil and grass
Covering with sand or soil	Soil
Deep plowing	Soil
Excavation	Soil
Skim and burial plowing	Soil
Shallow plowing	Soil
Soil sorting	Soil
Soil washing	Soil
Strippable coating (lignin or dust control adhesives)	Soil
Triple digging	Soil
Turf and topsoil removal	Soil
Water Control	
Addition of lime to lakes or drainage basins	Surface water
Addition of potassium to lakes	Surface water
Construction of dykes or barriers	Surface water
Flow control of contaminated water through reservoirs	Surface water

DECISION FRAMEWORK

Long-term recovery efforts build on the initial emergency response and intermediate-phase activities of the first few days to weeks. The focus turns from immediate life-saving efforts to restoring the community to a sense of normalcy and regular everyday life as enjoyed prior to an RDD event. The restoration process must address any remaining radioactive contamination to the satisfaction of the community.

Recovery is dependent on the area affected by the contamination, and a faster recovery may be realized if some locations are addressed before others. Any decision framework must first determine which areas should be given priority for cleanup in conjunction with the cleanup goals. For each specific area, the strategy for cleanup must then be determined and implemented. Decision-makers must periodically revisit cleanup priorities as work progresses. If cleanup results are not satisfactory for a given area, either a new strategy must be employed, or priority must be given to other efforts. The decision framework is outlined in Figure 1. Each step in the decision-making process is not strictly isolated from prior and future decisions, but the figure depicts the general order of the steps that are required.

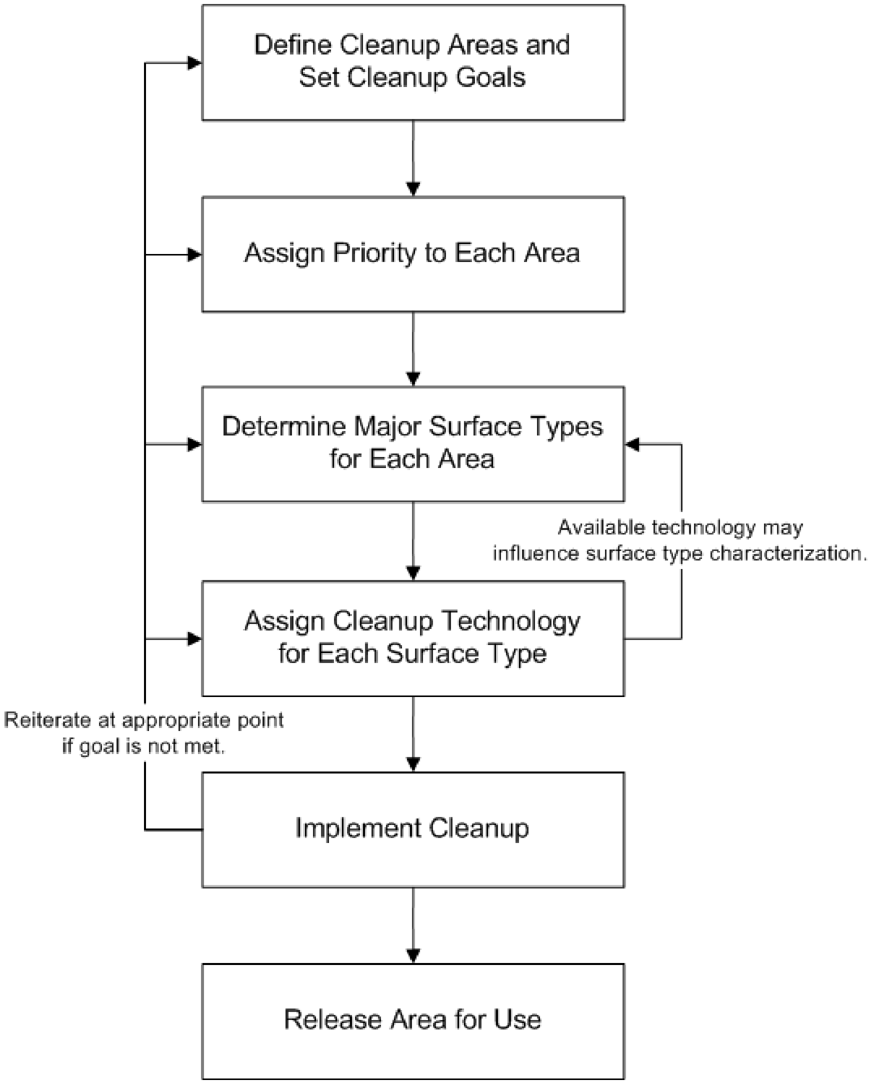

Fig. 1. General structure of the decision framework.

Without clear goals – what the future use of the area will be and the radionuclide concentrations required for a specific use – the proper cleanup strategy cannot be formulated. Definition of these goals will be site specific. However, the acceptability of very low levels of radioactive contamination ("How clean is clean?") is an issue that will need to be addressed. The cleanup goals must reflect the future use of the location and must be accepted, if not supported, by the community.

The priority given to specific areas for cleanup are dictated by a variety of factors. The necessary local infrastructure (transportation and utilities [electric, gas, water, communications]) must be restored if not addressed in the earlier phases. Residents who may have been evacuated from the contaminated zone would require continued sheltering in alternate locations until it is safe to return. Public agencies (schools, police, fire, local government), along with affected industry and businesses, must also be considered, as they may have been displaced or forced to modify their operations.

The nature of the contamination plays a large role in determining what priority is given to cleaning up a given area. If the contamination is in a relatively inaccessible area (e.g., on third-floor or higher exterior surfaces of large high-rise buildings), it may not pose a near-term threat, especially if the radionuclides involved are fixed in place and/or are alpha- or beta-emitters. Another example would be contamination washed into stormwater pipes by precipitation events or emergency response actions immediately after an RDD event. Figure 2 outlines an exercise that provides input as a partial aid to help in setting site-specific goals and priorities. Achieving consensus can be difficult because of subjective considerations, including fears related to the nature of the contamination and the motives behind cleanup decisions.

On the other hand, categorizing surface types and identifying cleanup technologies by using relevant criteria are primary steps within the framework that have a solid objective basis. A good understanding of the potential cleanup technologies available and their potential ramifications will provide for informed decisions when recovery cleanup is necessary.

The contaminated surface type groupings would be scenario based and can be defined by surface characteristics such as common composition, interaction with the contaminated material, reaction to selected proposed decontamination treatments, locations (i.e., indoors, outdoors), proximity to critical venues, accessibility, and the extent of the surface (e.g., an outside wall on a small one-story building versus miles of asphalt roadway).

Once the surface type categories are assigned, each is paired with potential cleanup technologies. To most effectively attain recovery goals, the decision framework requires the use of an up-to-date compilation of potential technologies for decontamination of affected land and property. This compilation must include information such as potential effectiveness, availability, effort/cost, amount and type of waste generated, operator training, and cleanup time. Information on the suitability of a technology for application to different-size areas is also necessary. Given a particular surface type for decontamination, an objective and systematic review of viable options is then possible, and the potential results can be optimized through selection of the technologies most likely to minimize human exposure, costs, waste, and cleanup times while maximizing effectiveness.

As discussed in the previous section, we have assembled a database with over 60 generic technologies, listed in Table 2, that have been compiled from a number of sources, from removal of the top layer of dirt from contaminated soil to chemical foams and gels for the removal of contamination from metal surfaces. The list of technologies provided is not exhaustive, although a common thread is the general idea of waiting out radioactive decay or using physical or chemical removal in some form or in combination with other methods.

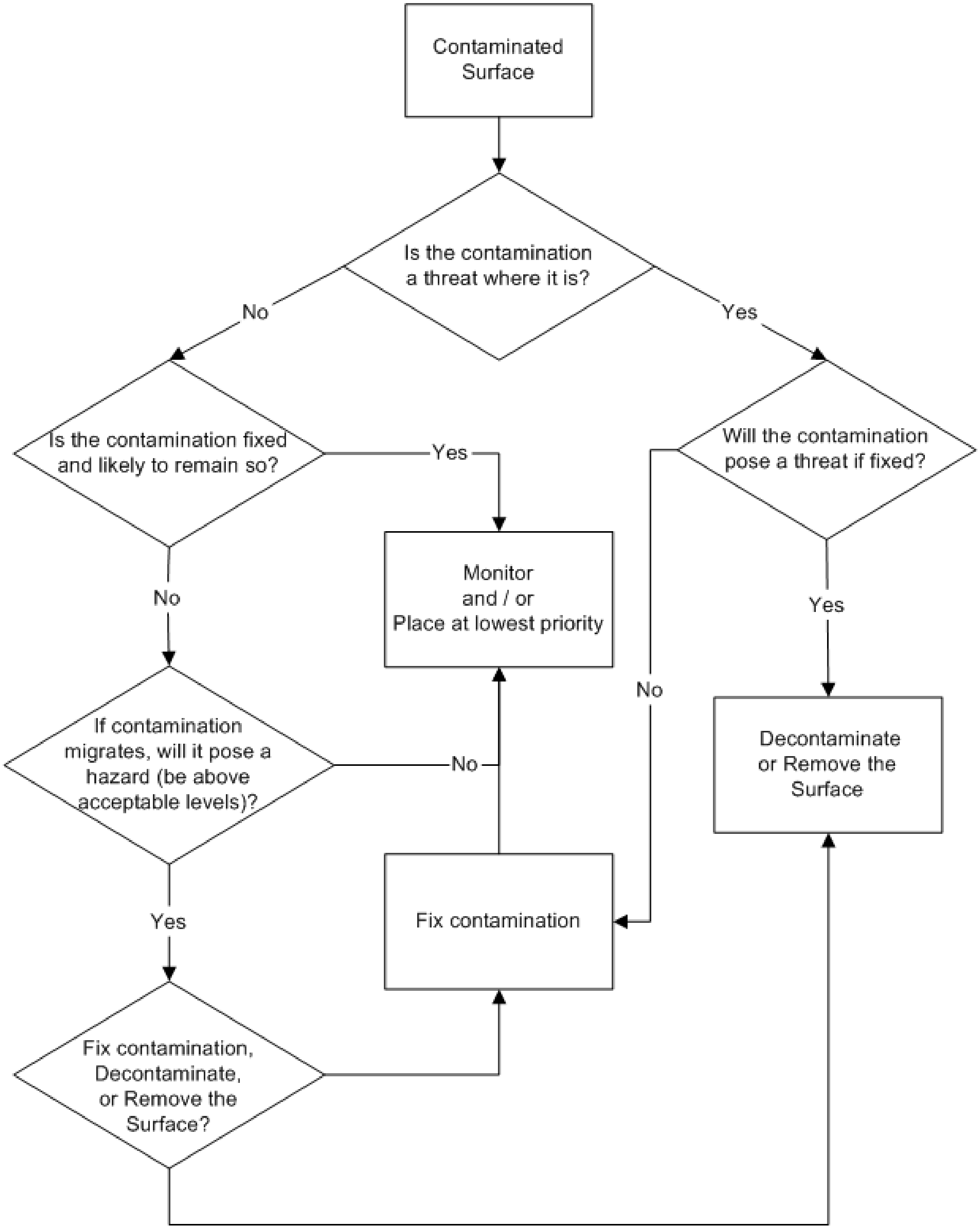

Fig. 2. Decision aid for determining the appropriate recovery strategy for a contaminated surface.

The strategy is to determine which technology best meets all recovery goals for a given location and surface type and whether the results would be acceptable. Each technology must be put into the context of the recovery problem before it can be considered appropriate for a given scenario. For example, the removal of the top several inches of contaminated soil in a small neighborhood park may be reasonable, but the same solution would be problematic for a large agricultural field if disposal space is limited.

Part of the decision process should determine whether cleaning a contaminated area to some acceptable level is better than partially removing or totally removing the contaminated substrate, or whether the contamination should be left in place. If contamination is fixed in the underground pipes of a stormwater system where it does not pose a human health hazard, it may not be reasonable to try removing the contamination if doing so could result in negative human health impacts.

Figure 3 provides an example of options that are available when addressing radioactive contamination in a stormwater pipeline [15]. In addition to the option of simply monitoring the radioactive contamination level when the contamination is relatively immobile and effluent water has concentrations below acceptable levels, it categorizes the available technologies according to options that would fix the contamination in place (re-line the pipe or leave the pipe in place), decontaminate the pipeline (extract the contamination), or remove and replace the contaminated pipeline. Most of the options in Fig. 3 are based on standard pipeline-cleaning technologies (primarily physical removal) [15] and are not typically considered in lists like the one in Table 2. Many specialty cleaning methods for specific systems or locations are variations of technologies listed in Table 2 that may be adapted for similar situations, should radioactive contamination be an issue.

Other considerations include unique situations in which the current compilation of remediation technologies is not readily applicable and a suitable solution must be developed, or when the impacts of a cleaning technology on neighboring surfaces or surface types are uncertain. Of particular concern would be the recontamination of a previously cleaned area, such as the obvious mistake of washing a building exterior from the bottom up rather than from the top down.

SUMMARY

Long-term recovery efforts following an RDD event may encounter complex issues, but the use of a simple decision framework for planning or implementation allows the problem to be broken into more manageable pieces. In first setting goals and priorities for cleanup and recovery, the decision process must be transparent to all stakeholders who, as a community, would be involved in and take ownership of the recovery effort. The uncertainties involved could be significant, and participation by all stakeholders should be facilitated.

The emphasis of this paper is on the more manageable task of determining how to optimize the recovery effort once goals and priorities are set. Knowledge of the surface types (and their extent) that require cleanup within a specific area is becoming more readily available to planners and managers, especially with the establishment of municipal GIS departments. Based on the past experience of the nuclear industry and accidents involving the release of radioactive material, a host of methods have proven effective in previous remediation efforts and have been documented for potential use in recovery efforts. A database of viable technologies that includes information on effectiveness, costs, availability, and the amounts of waste generated provides a solid basis for identifying the optimal cleanup solution and reduces the inherent uncertainties when matching technologies to affected areas.

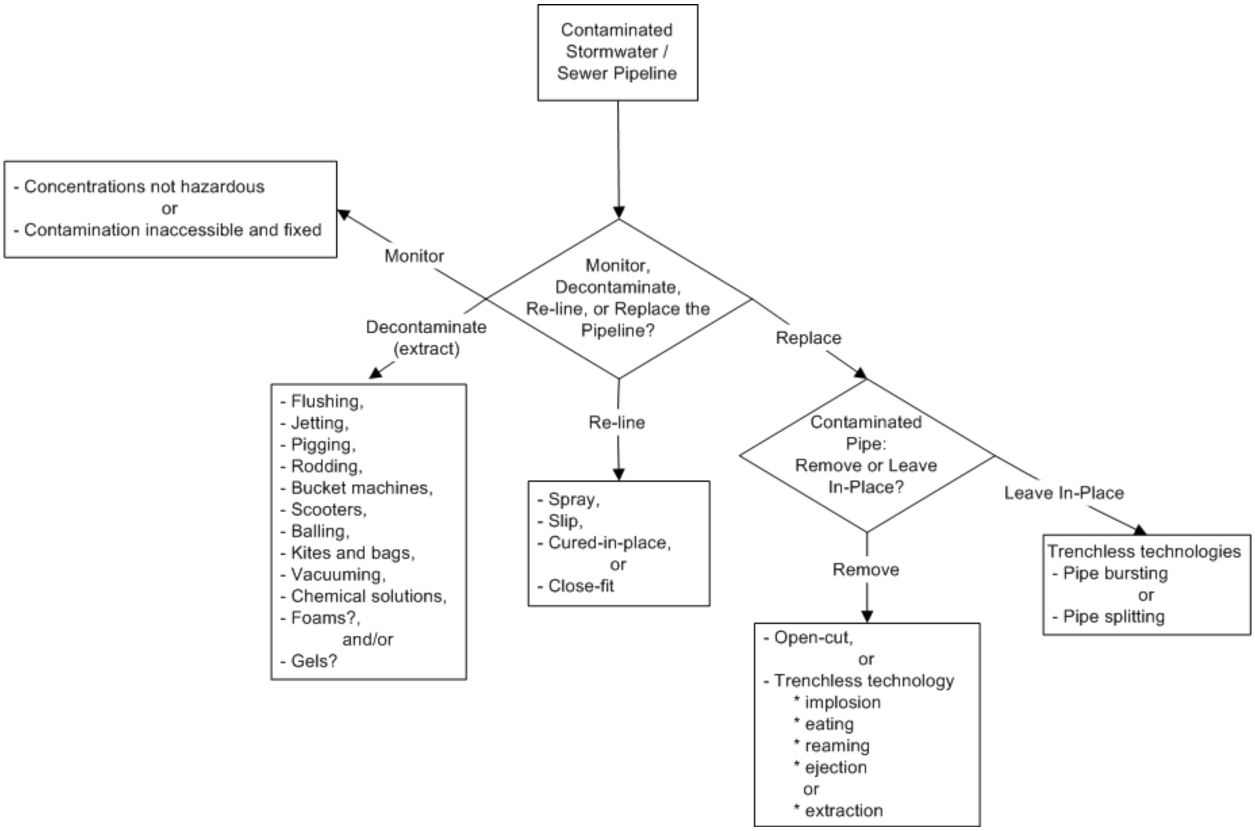

Fig. 3. Recovery strategy options for contaminated pipelines.

Having a database of all potential technologies provides decision-makers with all known options and enables optimization of cleanup efforts through comparison of results among the potential options. However, modifications of existing technologies for specific tasks should also be explored if existing methods may be inadequate. For example, if contamination on high-rise building exteriors needs to be removed, some modifications to equipment used by skyscraper window washers could prove useful.

Because cleanup is location specific, training and planning for such events should consider different areas of a city where goals, topology, and dominant surface types could be unique. For example, cities that border a lake or stream used for drinking water might have different strategies for cleanup when contamination is in or next to the water body, rather than on the other side of town. These types of exercises provide decision-makers with a better comprehension of the range of possible scenarios, as well as their capabilities to address the long-term recovery effort.

ACKNOWLEDGMENT

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