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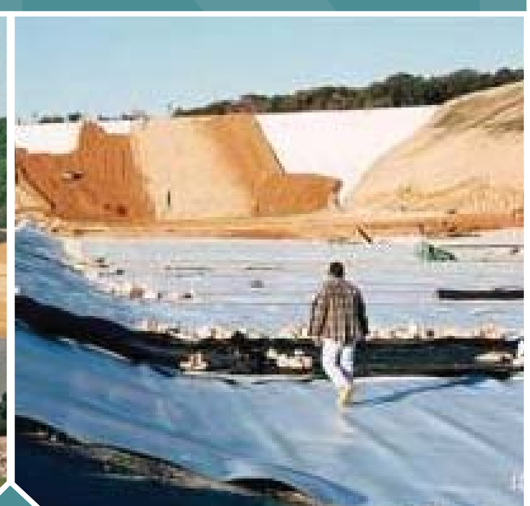
Report on the 2011 Workshop on Chemical-Biological-Radiological Disposal in Landfills



Office of Research and Development
National Homeland Security Research Center

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U.S. Environmental Protection Agency
National Homeland Security Research Center
Decontamination and Consequence Management Division
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List of Abbreviations

°C	Degrees Celsius
CBR	Chemical, biological, and radiological
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CWA	Chemical warfare agent
DHS	U.S. Department of Homeland Security
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EPA	U.S. Environmental Protection Agency
LCRM	Landfill Coupled Reactor Model
LCRS	Leachate collection and removal system
LRN	Laboratory Response Network
MOCLA	Model for Organic Chemicals in Landfills
MSW	Municipal solid waste
NESHAP	National Emission Standards for Hazardous Air Pollutants
NORM	Naturally occurring radioactive material
NYS	New York State
NYSDEC	New York State Department of Environmental Conservation
OHS	Office of Homeland Security
ORD	Office of Research and Development
PADEP	Pennsylvania Department of Environmental Protection
RCRA	Resource Conservation and Recovery Act
TENORM	Technologically-enhanced naturally occurring radioactive material

Executive Summary

This report summarizes discussions from the “2011 Workshop on Chemical-Biological-Radiological (CBR) Disposal in Landfills.” The workshop was held on June 14-15, 2011, in Washington, DC. The workshop objective was to address technical issues to consider when designing, constructing, and operating new landfill facilities for disposal of CBR wastes in an emergency scenario.

The approximately 40 workshop participants included representatives from multiple federal agencies (e.g., the U.S. Environmental Protection Agency, the U.S. Department of Transportation, the U.S. Department of Energy, the U.S. Department of Agriculture), state agencies, academia, and waste management companies. The workshop included scheduled presentations, question-and-answer sessions, and moderated discussions.

This report documents the main points raised during the workshop, but several issues were raised repeatedly throughout the discussions. The recurring issues include:

- CBR events are generally not expected to result in large debris fields of comingled wastes. Instead, these events will more likely result in contaminated surfaces and structures, from which highly homogeneous waste streams will be generated. These waste streams can be handled individually or mixed in a fashion most suitable for disposal (or other waste management option). As a result, biodegradable wastes that can lead to formation of landfill gases will generally be separated from inert material.
- For larger CBR events, the quantities of waste expected to be generated will likely far exceed the capacity of nearby landfills, and new landfill cells could take several months to construct. These observations, combined with external pressure to have affected communities quickly return to normalcy, suggest that temporary waste staging areas will likely be an important element of the overall response. Waste can be first moved to these temporary locations while landfill capacity is being constructed or negotiated.
- Several opportunities were identified for state and local agencies to begin preparing and planning for waste management of CBR events. Examples included specifying criteria for landfill siting, drafting engineering and planning documents required for new landfill cells, and assessing transportation infrastructure based on anticipated volumes of wastes. Resolving these and other matters as part of preparedness activities is generally preferred to trying to assess these issues in the wake of a CBR event.
- Numerous insights were offered on technical issues associated with landfill design. These issues addressed a broad array of topics, including siting, construction quality assurance, fill progression plans, landfill gas control systems, leachate control systems, long-term monitoring, and post-closure care. Specific comments on these—and how they might pertain to different classes of CBR agents—are presented throughout this report.

1.0 Introduction

This report summarizes presentations and discussions from the "2011 Workshop on Chemical-Biological-Radiological Disposal in Landfills," which was held June 14–15, 2011, in Washington, DC. The technical content of this report is based entirely on information and discussions from the workshop.

Approximately 40 individuals from federal agencies, private industry, state programs, and academia participated in the workshop, either in person or via webinar (see Attachment 1). The workshop allowed these participants to share information and discuss issues associated with the disposal of waste resulting from cleanups from chemical, biological, and radiological (CBR) events. The workshop was specifically designed to address technical issues to consider when designing, constructing, and operating new landfill facilities for disposal of CBR wastes in an emergency scenario; use of existing landfill space for this purpose and other waste management strategies (e.g., incineration) were outside the scope of the workshop discussions. Policy and public perception issues were acknowledged as being very important considerations when managing wastes from CBR events, but these topics also were not the focus of this workshop.

The workshop agenda included two distinct discussion formats (see Attachment 2):

- First, ten invited speakers delivered presentations on various topics, including landfill design features, segregation of the waste stream, and considerations for leachate and landfill gas control measures. Participants also discussed research conducted on how CBR agents would persist and migrate within a landfill. A question-and-answer period followed each presentation. Section 2 of this report briefly summarizes the presentations and documents main discussion points raised during the question-and-answer periods.
- Second, the workshop included several hours of moderated open discussions among the participants. These discussions were framed around six questions that were circulated in advance of the meeting (see Attachment 3) and culminated with every workshop participant providing their individual overarching comments on the workshop discussions. Section 3 of this report documents key discussion points from the free-flowing discussions.

This report documents comments made by participants, and the report notes instances where multiple participants supported a given statement. However, this workshop was not designed to reach consensus on technical matters or rank suggestions in terms of importance. In addition, the intent of the workshop was to not attribute comments to specific attendees to encourage open discussion. Accordingly, the report catalogs the entire range of feedback provided, without attempting to assign priorities to the various recommendations and suggestions that participants offered.

2.0 Presentations and Question-and-Answer Periods

This section of the report briefly summarizes presentations given by ten invited speakers and documents key points from the ensuing question-and-answer periods. Attachment 4 lists the presentation topics and speaker names, and original electronic copies of the presentations are available from the EPA workshop coordinator (lemieux.paul@epa.gov).

2.1 Context of the Problem (Juan Reyes)

Juan Reyes, Deputy Associate Administrator of EPA's Office of Homeland Security (OHS), gave the workshop's opening presentation, which addressed "Context of the Problem and Workshop Goals." The presentation underscored the importance of planning waste management as a key element of preparing for CBR events and described what EPA has already done in this regard. Mr. Reyes noted that EPA has already conducted multiple workshops and field exercises to assess and evaluate CBR waste management challenges—one of which was the potential for these incidents generating massive quantities of waste; some calculations based on planning scenarios suggested that CBR events can lead to the need for disposal of up to 40 million tons of potentially contaminated solid waste.

Mr. Reyes listed five broad categories of barriers to effective CBR waste management efforts. These categories were regulatory and statutory, policy and guidance, technical and scientific, socio-political, and capacity and capability. He provided specific examples of these five general issues, but emphasized that the focus of this particular workshop is the technical and scientific considerations. For instance, a greater scientific understanding of the fate and transport of CBR agents in landfill environments is needed to inform decisions about how landfill cells should be designed, constructed, operated, and maintained.

Mr. Reyes then noted that the current workshop is the latest in a series of workshops and exercises that different EPA Offices have organized to investigate issues concerning CBR waste management. He listed the recent workshops that EPA-OHS organized (or contributed to) and noted that these workshops recommended increased U.S. capability to effectively address regulatory challenges, major impediments, research issues, and state and local preparedness (*1–3*). A common theme expressed across these workshops was the need to rapidly construct, operate, and maintain a state or federal facility to dispose of waste generated from CBR events. This potential facility would be built relatively soon after the incident response had initiated, and in relatively close proximity to location of the incident. He concluded his presentation by stating the objective of this workshop: "The goal of this workshop is to identify the technical and scientific requirements [for disposal of CBR wastes] so that the policy discussions are based on the best available science."

A brief question-and-answer session followed the presentation. The questions addressed risk communications to the public regarding the protectiveness of CBR disposal strategies. Mr. Reyes said effective communications will undoubtedly be critical for any event requiring disposal of CBR wastes. However, this issue was not discussed in extensive detail, given that the workshop focused on technical and scientific issues of landfill design, construction, and operation.

2.2 Structure of the Meeting (Paul Lemieux)

Dr. Lemieux, Associate Division Director, Decontamination and Consequence

Management Division, National Homeland Security Research Center of EPA's Office of Research and Development, gave a brief presentation on the structure of the workshop. He began by noting that EPA has held workshops to discuss CBR waste management issues since 2003 (*4*), with the individual workshops focusing on specific topics. He emphasized that the focus of the current workshop was technical issues to be considered when designing, siting, constructing, and operating a new landfill facility to dispose of waste from a CBR event. He acknowledged that CBR disposal often raises a number of related issues (e.g., risk communication to the public), but asked participants to stay focused on the underlying technical and scientific issues.

2.3 Existing Requirements and Capabilities of Landfills (Craig Dufficy)

The first presentation was given by Mr. Dufficy, Environmental Engineer, Materials Recovery and Waste Management Division, Office of Resource Conservation and Recovery of EPA's Office of Solid Waste and Emergency Response. He provided background information on the Resource Conservation and Recovery Act (RCRA) and its Subtitle C and Subtitle D requirements for managing hazardous waste and solid wastes, respectively. He reviewed the roles and responsibilities of EPA, states, and tribes for implementing and enforcing RCRA requirements. Mr. Dufficy then provided an overview of hazardous and municipal solid waste management in the U.S.:

- *Hazardous waste.* Mr. Dufficy reviewed the regulatory definition of hazardous waste (5) and then noted that approximately 20,000 facilities each generate at least 1 ton of hazardous waste annually. RCRA Subtitle C provides standards for the treatment of hazardous waste, places restrictions on its disposal, and sets forth design requirements for landfills. Mr. Dufficy explained that RCRA Subtitle C landfills must be equipped with properly designed leachate collection and removal systems, composite liners comprised of a low-permeability soil layer overlaid with geomembrane, and leak detection systems to ensure that landfill leachate does not contaminate groundwater; and groundwater monitoring is required to detect the presence of any such contamination.
- *Solid waste.* Mr. Dufficy explained that "solid waste" can include municipal solid waste (MSW), industrial non-hazardous waste, and special wastes. He defined these terms and listed the approximate quantities of wastes generated annually. For instance, residences, commercial establishments, and industrial operations generate approximately 230 million tons of MSW annually. Mr. Dufficy reviewed design and operation requirements for RCRA Subtitle D landfills. These landfills either (1) must be designed to ensure that specific groundwater contamination levels will not be exceeded in the uppermost aquifer at the relevant point of compliance or (2) they must be designed with composite liners that achieve a hydraulic conductivity within a required range. Mr. Dufficy showed illustrations of both liners used to protect groundwater from leachate and covers applied to limit the infiltration of precipitation.

Mr. Dufficy offered several considerations for CBR waste management. For instance, he listed important pre-planning activities, such as identifying potential debris types, forecasting waste amounts, taking inventory of existing landfill capacity, and selecting sites for temporary waste staging. Other activities included identifying applicable federal, state, and local environmental regulations; developing a communication plan and debris removal strategy; and considering waste management options other than disposal (e.g., recycling, incineration). As an example of a useful resource, Mr. Dufficy referred to the *Directory of Waste Processing and Disposal Sites*, published by the Waste Business Journal. This publication includes an inventory of available landfill facilities nationwide and recently proved beneficial when selecting disposal sites for debris generated by tornadoes in the Midwest. He concluded by underscoring the importance of advanced planning for managing CBR wastes, given that waste management is an integral element of the overall disaster recovery process.

The question-and-answer session following this presentation addressed several topics:

- One participant acknowledged that published inventories of landfill facilities can be useful, but added that directly consulting with state environmental agencies has proven to be more effective at assessing the capacity and compliance status of individual facilities. That participant added that information from state agencies is likely to be more current and accurate than what can be gleaned from published inventories. During this discussion, another participant commented that EPA has developed a decision support tool for disaster debris management, and this software can also help users identify, locate, and assess the capacity of landfills and other waste management facilities (e.g., incinerators). More information about this tool and how to access it is available on EPA's website at *http://www.epa.gov/nhsrc/news/news051209.html* (6). Another participant noted that EPA Region 5 has online resources for state-specific disaster debris management plans, and the Region has also developed an online, searchable inventory of landfills and other waste management facilities. The Region 5 resources can be accessed at: *http://www.epa.gov/reg5rcra/wptdiv/solidwaste/debris/disaster_debris_resources.html* (7). Finally, the New York State Department of Environmental Conservation (NYSDEC) publishes similar disaster debris guidance information (*http://www.dec.ny.gov/chemical/23682.html*) (8).
- Several participants emphasized the need for advanced planning of landfill capacity for certain waste disposal events. For example, the U.S. Department of Agriculture has already made arrangements with rendering facilities, landfills, and other sites for disposing of animal carcasses following disease outbreaks and other unexpected events. Additionally, some states prone to hurricanes have taken proactive measures to identify and plan for landfill capacity to address large volumes of disaster debris that a major hurricane can generate. Establishing agreements and contracts in advance of CBR events was cited as one example of effective planning for landfill capacity.
- One participant asked how EPA currently classifies waste material that contains anthrax spores. The response provided is that wastes containing anthrax spores might not automatically be classified as hazardous waste under the agency's current regulations, unless the waste exhibited a hazardous characteristic due to other constituents. However, state regulations might require classification of wastes containing anthrax spores as medical waste or infectious waste, which would

therefore dictate disposal options. Another participant added that the U.S. Department of Transportation (DOT) classifies anthrax-containing waste and other medical wastes as hazardous material, which might be prohibited under a landfill's permit. The extent to which the waste has undergone decontamination procedures also affects waste classification and disposal options. Overall, the question and follow-up discussion emphasized the need for clearly articulating the current federal and state regulatory framework for handling wastes containing biological agents.

- During this discussion, a participant remarked that limited capacity of the Laboratory Response Network (LRN) can affect waste management decisions. Following a large-scale CBR event, laboratories might be inundated with samples and not be capable of analyzing them within the desired time frames. Because sampling results from LRN laboratories may be needed to measure residual agent concentration in the waste, officials responsible for managing CBR wastes might handle all materials—including those that have been subjected to decontamination operations—as if they were still contaminated in order to provide the timeliest response.
- Though some participants acknowledged that regulatory frameworks might not be fully developed for certain types of CBR wastes, performance-based criteria for landfill design might still be developed based on a scientific understanding of the specific CBR agents and their chemical and physical properties. The participants revisited these performance-based measures on the second day of the workshop (see Section 3).

2.4 Landfill Gas Control (Susan Thorneloe)

- The next speaker was Ms. Thorneloe, Senior Environmental Engineer, Air Pollution Prevention and Control Division, National Risk Management Research Laboratory of EPA's Office of Research and Development. She presented background information on the formation, characteristics, and control of landfill gas. She opened by noting that landfill gas forms primarily when biodegradable waste decomposes, though chemical decomposition can also release landfill gas. Landfill gas is composed primarily of carbon dioxide and methane; other constituents are found in trace amounts (e.g., volatile organic compounds, sulfur compounds) and their concentrations vary from one landfill to the next. Landfill gas emissions can occur for decades following disposal of biodegradable wastes, and these emissions present various safety, health, and environmental concerns.
- Ms. Thorneloe also briefly discussed factors that affect landfill gas emissions. For instance, most large landfills are now equipped with landfill gas collection systems, which dramatically reduce the amount of landfill gas that would otherwise be emitted to the air, but these controls are typically not installed immediately after landfill cells open. Some sites are equipped with landfill gas flares, which

reduce landfill gas emissions but emit various combustion by-products. Other landfill design and operational features—such as leachate recirculation and breaches in landfill covers—affect the magnitude of landfill gas generation and emission rates. A general theme expressed was that increased infiltration and leachate recirculation rates may cause landfills to generate more gas. Another factor influencing landfill gas emissions is the waste composition, which can be influenced by enhanced recycling efforts, source reduction programs, and other factors. Exposures to landfill gases are largely dictated by the emission rates, proximity of receptors, and institutional controls on closed landfills.

- Ms. Thorneloe described different approaches that have been taken to estimate and measure landfill gas emission rates. For modeling emissions, EPA's Landfill Gas Emission Model (LandGEM) is still one of the most widely-used software programs for estimating landfill gas emissions (9). The model is based on first order decomposition rate equations and estimates how landfill emissions are expected to vary over time, including post-closure. For measuring emissions from area sources, EPA has already developed a remote sensing test method ("Other Test Method 10") (10); and the agency is currently developing additional guidance on how to apply this method specifically to measure landfill gas emissions. Such measurement technologies are needed to quantify efficiencies of landfill gas collection systems, and Ms. Thorneloe acknowledged that a wide range of gas control efficiencies have been reported by multiple parties.
- In terms of regulations, Ms. Thorneloe described the existing New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants (NESHAP). She noted that applicability of regulations is driven by measured or estimated emissions. When measured or estimated emissions of non-methane organic compounds or hazardous air pollutants exceed regulatory thresholds, various landfill gas emission controls and other actions must be implemented. A full review of air regulations pertaining to landfills is not provided here.
- Ms. Thorneloe concluded her presentation by describing various technical and operational issues for ensuring effective landfill gas capture and control. She emphasized the need for effective monitoring and maintenance of landfill caps and gas wellhead pipes. However, even the most efficient landfill gas capture and control systems do not collect all of the gas generated. She also described how many landfills use the collected gas for purposes of energy recovery, while some quantities of gas may be burned in open flares or closed flares.

The question-and-answer session following this presentation addressed several topics:

- The first question asked about the factors that cause landfill gas generation rates to vary across landfills. Ms. Thorneloe listed several factors that affect landfill gas generation rates. First, the amount of biodegradable waste within a landfill largely determines the total amount of gas that might be generated within a landfill (though participants later acknowledged that landfill gas is also generated by other mechanisms). Because MSW typically has more biodegradable waste than hazardous waste and construction and demolition waste, MSW landfills tend to generate more gas than other types of landfills. In addition, landfill design, delays in use of water circulation, waste content, and climate also affect landfill gas generation. For example, Florida has large quantities of yard waste in its MSW stream and many above-ground landfills, which results in increased gas emissions due to the biodegradable content and infiltration rates. Ms. Thorneloe also emphasized that “wet” landfill designs (i.e., landfills with leachate recirculation, infiltration of precipitation) have considerably higher landfill gas generation rates than “dry” landfill designs.

- The second question asked if EPA has conducted field studies to compare landfill gas emission rates estimated by LandGEM to measured emission rates. Ms. Thorneloe noted that EPA is currently collecting field data to assess model performance, and the results from these studies are expected to help EPA better parameterize the model.
- Another question asked Ms. Thorneloe to comment on the duration (in years) for which landfill gas monitoring should occur. She responded that no prescriptive guidance has been established on the duration of long-term landfill gas monitoring, though she acknowledged that even some older landfill sites continue to have considerable landfill gas emission rates. Another participant clarified that monitoring requirements are in part dictated by whether a given landfill was closed prior to, or after, implementation of RCRA Subtitle D. State environmental agencies have some discretion in deciding the long-term duration of landfill gas monitoring, and this determination is typically made based on an evaluation of the long-term emission trends.
- The final question asked how waste solidification practices can affect landfill gas generation rates. No participants were aware of studies that specifically characterized this issue. However, a workshop participant noted that pre-treatment of wastes using solidification (and other practices) can effectively add large quantities of liquids to landfills. Consequently, she suspected that the presence of liquids might affect how quickly a given landfill cell starts generating gas and the rate at which gas is initially formed.
- During this discussion, participants also offered related comments. First, one participant explained that landfill facilities typically have multiple landfill cells, and the individual cells can be designed differently. Thus, a new landfill need not have a single design to accommodate all possible wastes, but can instead have multiple cells with varying designs that are tailored to specific waste types. Second, another participant emphasized that the various types of wastes generated during many CBR event types (e.g., yard waste, soils, building debris) will likely be highly segregated at the site of the response—a concept that was echoed during a later presentation (see Section 2.9). In such cases, landfills used for CBR events might actually receive relatively homogeneous waste streams, rather than co-mingled wastes. However, another participant indicated that event-specific nuances might determine the extent to which wastes can be effectively separated prior to disposal. Regardless, Ms. Thorneloe noted that EPA’s decision support tool for disaster debris management (*11*) includes modules that allow users to estimate the different types of wastes that are expected to be generated during actual events.

2.5 State Perspectives on CBR Landfill Disposal (Robert Phaneuf)

Mr. Phaneuf, Acting Assistant Division Director, Materials Management, New York State Department of Environmental Conservation (NYSDEC) gave a presentation that focused on the state of New York's landfill inventory and its experience with disposing of CBR material. Currently, 26 active MSW landfills operate in the State of New York, down from approximately 1,600 in the 1960s. The large number of closed landfills includes many facilities (e.g., open dumps) that do not meet current design standards, while the remaining active landfills are large, regional facilities—all with double-liner systems and other features designed to minimize human health and environmental impacts. However, the annual permitted disposal capacity across all 26 active landfills is still less than the waste generation rates that could conceivably occur from a single CBR event, suggesting that new landfill capacity will likely be needed for a large-scale scenario.

Mr. Phaneuf shared information on the time needed to construct new landfill cells. Based on recent experience in the State of New York, individual 10-acre landfill cells generally can be constructed over the course of a construction season, not counting the time needed to develop construction plans and contracting agreements. As the best case scenario, a new 17-acre landfill cell was fully constructed in the 1990s with a double-composite liner over a 90-day time frame. The time frame needed to site new landfills is typically much longer, and can take between 5 and 10 years. Therefore, when planning for CBR events, waste management officials should determine what type and size of landfill cells are needed and how long they will take to construct. Also, the potential landfill construction season needs to be accounted for, since ambient conditions profoundly impact the construction timeline for a landfill. This limitation will impact temporary waste staging decisions.

Mr. Phaneuf reviewed the typical landfill design considerations currently applied in the State of New York, including leachate management, load inspections, and monitoring. He emphasized that New York has requirements beyond those outlined in the corresponding Federal RCRA regulations. As just two examples, the state has prescriptive specifications for design and construction of double liner systems and requires landfill owners to proactively monitor the performance of their upper liner systems. This monitoring serves as an indicator of the overall effectiveness of leachate collection and removal systems (LCRS) and provides assurance that liner systems have not been compromised or are in need of maintenance. The presence of the lower liner provides further protection against groundwater contamination in the event that the upper system fails. Mr. Phaneuf attributed the ongoing success of landfill liners to multiple factors, such as attention to detail during construction, a requirement that 5 feet of "select waste material" (being free of large, rigid waste that could impact the liner system) be disposed atop the upper liner before general MSW can be disposed of, and ongoing monitoring and maintenance of LCRS.

Monitoring requirements are also useful for alerting system operators of potential maintenance issues associated with LCRS. Mr. Phaneuf presented results from a 2003 survey that NYSDEC conducted of all active landfills to determine the most common maintenance issues associated with LCRS. Reported *operational* problems included drainage layer clogging, LCRS pipe and sump clogging, faulty flow meters, and landfill side-slope surface seeps; and reported *design* problems included inadequate access for maintenance and the presence of potentially unsafe confined spaces that maintenance personnel must access. Note that proper design needs to address the fact that operational maintenance will be necessary.

As further evidence of the effectiveness of landfill liner systems, Mr. Phaneuf presented information on indicators of groundwater contamination for the state's active landfills. This included analytical sampling of water quality collected from pore pressure relief systems and from perimeter groundwater monitoring wells. Both types of data continue to indicate that the double-liner systems used throughout the State of New York continue to have no groundwater impacts attributed to releases from engineered barrier systems. In short, the various liner performance and groundwater monitoring data, Mr. Phaneuf noted, continue to demonstrate that the containment systems are functioning properly—a finding he viewed as consistent with conclusions in the National Research Council's 2006 report on the *Assessment of the Performance of Engineered Waste Containment Barriers* (*12*).

Finally, to illustrate the importance of the need for quality construction, Mr. Phaneuf presented data on liner defects, based on data previously published (*13*). That previous work found that 97% of all liner defects take place during construction, when heavy equipment is needed to install geomembranes and drainage systems and to place protective soils atop the liners. Proposed regulations in New York will require improved construction quality assurance requirements, including electrical resistivity testing and other measures to ensure the integrity of the liner system is not compromised during construction.

In the context of disposing of waste from CBR events, the demonstrated long-term effectiveness of containment systems in New York's double-lined landfills may help inform decisions about the minimum landfill design features recommended for CBR material. Mr. Phaneuf noted that NYSDEC's landfill permit application requirements could provide useful insights for the technical issues to consider for designing landfills specifically for CBR events. Specifically, numerous technical reports must be submitted and approved during the landfill permitting process, and these various requirements address a broad array of technical and scientific landfill design considerations. Based on this model, Mr. Phaneuf noted that EPA could consider developing the following documents as part of its planning efforts for constructing new landfill capacity in support of CBR events, and separate documents could be tailored to different types of anticipated waste streams and constituents:

- Potential site description and analysis, including waste characterization
- Geotechnical stability analysis, considering actual waste densities
- Sub-base settlement assessment analysis
- Seismic stability analysis
- Leachate collection and removal system design
- Leachate storage facility design
- Storm water management plan
- Construction quality assurance plan
- Facility operations and maintenance manual
- Comprehensive environmental monitoring plan
- Fill progression plan
- Facility closure and post-closure plan, including long-term institutional controls

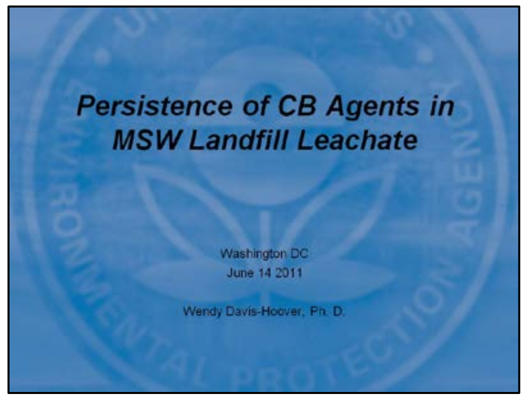
In addition to these and other analyses typically completed for landfill permit applications, Mr. Phaneuf listed numerous considerations specific to CBR waste that will likely factor into the technical analyses. Examples of these specific considerations include designing landfills with adequate space for staging areas and equipment decontamination; the need for exclusion zones, heightened security to prevent trespassing, and vector control; the nature of personal protective equipment required for different landfill employees; and design and operation of water treatment facilities to handle both leachate and decontamination water.

Mr. Phaneuf concluded the presentation by presenting photographs and information from previous waste management responses to the anthrax letters mailed to various New York City locations and removal of debris from the World Trade Center (WTC) disaster. For context, he noted that the WTC disaster generated approximately 1.3 million tons of debris that was transferred to the Fresh Kills Landfill—a quantity considerably smaller than projected debris quantities for a larger scale CBR event. Mr. Phaneuf also discussed the daily capacity for movement of the debris from the WTC site to the Fresh Kills Landfill. It should be noted that approximately 12,000 tons per day was the highest capacity at which the debris was able to be moved, with nominal daily capacities on the order of 6,000 tons per day, in spite of the fact that barge access was close to the location of the WTC site. These data highlight the importance of transportation issues as key to management of the potential large quantities of waste that will likely be generated from a CBR incident.

The question-and-answer session following this presentation addressed several topics:

- One question asked about the assumptions inherent in estimates of geomembrane lifetimes. Mr. Phaneuf clarified that these estimates typically address estimated service life of the geosynthetic components of the liner system and did not consider the additional mitigation that would be offered by the natural clay components of the liner systems that underlie the geomembranes. Thus, even if geomembranes were to fail catastrophically, the secondary clay liner beneath these membranes would provide additional containment following this failure. Therefore, the lifetime of the composite liner would be expected to be longer than the estimates provided.
- The only other question pertained to landfill ownership. Mr. Phaneuf noted that roughly one-third of the MSW landfills in New York are privately owned and operated. Most of the remaining landfills in the state are publicly owned by municipalities, though some of these are operated by private entities.

2.6 Persistence of CB Agents in Landfill Leachate (Wendy Davis-Hoover)



Dr. Davis-Hoover, Research Microbiologist, Land Remediation and Pollution Control Division, National Risk Management Research Laboratory of EPA's Office of Research and Development, presented results of recent EPA research on the persistence of chemical and biological (CB) agents in MSW landfill leachate. After presenting background information on waste quantities generated during previous incidents, she outlined the design and scope of the research. The purpose of the research was to determine whether building decontamination debris containing CB agents can be safely stored or detoxified in MSW landfills. This was done by assessing whether—and for how long—selected CB agents could persist in conditions that simulate MSW landfill leachate.

Dr. Davis-Hoover then described the experimental design of the research. In the study, known quantities of selected CB agents were placed in separate 3-milliliter microcosms designed to simulate anaerobic landfill conditions. The microcosms containing biological agents were incubated at 12°C and

37°C to consider typical soil and body temperatures, respectively. Triplicate microcosms were used for each agent considered. Persistence was assessed by drawing samples from the microcosms at regular intervals, with more frequent sampling (weekly) occurring in the first few months of the study and less frequent sampling (monthly) occurring several months into the study. Sampling was terminated when two consecutive sampling periods result in no agent detections across all three microcosms. Results were presented separately for biological and chemical agents.

The study evaluated persistence of selected bacteria and viruses in landfill environments. The four bacteria considered were *Bacillus anthracis* (anthrax), *Yersinia pestis* (plague), *Francisella tularensis* (tularemia), and *Clostridium botulinum* (botulism). Specific details were provided on the culture medium, incubation temperature, and incubation time used for the different biological agents, before they were charged to the microcosms. Dr. Davis-Hoover presented the following results for the data collected to date, noting that results exhibited little difference for the two microcosm incubation temperatures considered:

- Both *Yersinia pestis* and *Francisella tularensis* died in less than 20 days.
- The two spore-forming bacteria—*Bacillus anthracis* and *Clostridium botulinum*—both persisted for 5 years and continue to exist in the microcosms; a sixth year sampling event is scheduled to occur in the near future.

The study attempted to evaluate the persistence of viruses in landfills. However, the MSW landfill leachate used in the experiment proved to be toxic to the tissue cultures in which the viruses were grown. Therefore, no data could be generated on viruses within the current experimental design, but future research was encouraged due to the fact that previous studies have suggested that certain viruses (e.g., polio) can survive in the landfill environment.

Dr. Davis-Hoover also summarized findings pertaining to the persistence of six chemical agents, which included both vesicants and nerve agents. She first reviewed the analytical methods and detection limits for these agents, noting that the microcosms were examined at a single incubation temperature (12°C). The following results were shared for the sampling that has occurred to date, and the experiment is ongoing. Note that each chemical agent is presented both as its common name (e.g., sarin) and abbreviated name (e.g., "GB").

- Mustard gas (HD) and tabun (GA) did not persist longer than 14 days.
- Three nerve agents—sarin (GB), soman (GD), and VX—have continued to persist in sampling conducted approximately 6 months into the experiment. However, sarin and soman were classified as having "low persistence" in terms of the quantities detected in the samples.
- For lewisite, sampling was conducted for chlorovinyl arsenious acid, a toxic derivative of the agent. This derivative was found to persist at a relatively high concentration in sampling conducted approximately 6 months into the experiment.

The question-and-answer session following this presentation addressed several topics:

- A participant asked if the study results have been published. Dr. Davis-Hoover indicated that the information shared during the workshop has not yet been published, in part because the experiment is ongoing.
- Another participant asked for further information on the landfill leachate used in the study. Dr. Davis-Hoover explained that leachate was drawn from a "young" MSW landfill in the northeastern United States. This particular landfill was selected to examine how newer landfills would be expected to detoxify selected agents.

She encouraged additional research to investigate how results vary with leachate samples.

- A third participant asked how the persistence of *Bacillus anthracis* in landfill leachate compared to its natural occurrence and persistence in soils. Dr. Davis-Hoover acknowledged that this agent exists in native soils in selected parts of the country, but did not directly compare the study results to soil persistence, given the inherent differences in the two scenarios (e.g., the study considered inoculated samples).
- Finally, a participant encouraged EPA to consider the pH of the leachate when interpreting the results for the chemical agents, given that hydrolysis rates are known to vary with pH.

2.7 Fate and Transport of CB Agents in Simulated Landfills (Mort Barlaz)

Dr. Barlaz, Professor and Head, Department of Civil, Construction, and Environmental Engineering, North Carolina State University, summarized findings from a series of projects pertaining to fate and transport of chemical and biological agents in simulated landfills. These studies were conducted with a common overall purpose, which was to provide underlying scientific information needed for developing effective strategies for managing contaminated debris from CBR events. Information on the individual studies and their results follow, organized by topic:

2.7.1 Distribution of Chemical Agents in Landfills

Dr. Barlaz first reviewed results from a modeling study of how chemical agents would be expected to partition among the gas, solid, and liquid phases in landfills. The Model of Organic Chemicals in Landfills (MOCLA) was used in the research (*14*). MOCLA is a spreadsheet-based model that estimates equilibrium partitioning behavior and transformation and degradation activity, based on published partitioning coefficients and reaction rate constants.

The purpose of the initial modeling was to perform equilibrium-based bounding calculations so that the most important physical and chemical phenomena could be identified. The bounding calculations were then used to help design experiments to measure these important phenomena.

The first set of modeling results indicated the anticipated distribution of selected chemical agents in waste. The chemical agents that were modeled included a variety of nerve agents (e.g., GB, VX), blister agents (e.g., HD), and toxic industrial chemicals (e.g., carbon disulfide). The initial simulation considered equilibrium conditions after initial disposal, before abiotic transformation occurs. While individual results varied from one chemical agent to the next, the general finding was that the selected chemical agents would initially be expected to be found primarily in the landfill's solid phase (e.g., adsorbed to waste), with relatively limited quantities partitioned to leachate—a finding that is consistent with the high octanol-water partition coefficient for the selected chemical agents. Additional modeling results were presented to assess the impacts of abiotic transformation, by considering equilibrium conditions 6 months and 30 years after disposal. The 6-month simulation indicated that roughly 5% to 20% of the most volatile chemical agents were lost due to advective gas flow; and the other chemical agents exhibited some evidence of abiotic transformation, with the relative amounts determined by the agents' hydrolysis rates. The 30-year simulation indicated that the most volatile chemical agents had almost entirely been released via advective gas flow (i.e., in landfill gas emissions), while nearly every other chemical agent considered was entirely broken down by abiotic transformation (i.e., hydrolysis). For most of the chemical agents considered, the initial, 6-month, and 30-year results were roughly similar in wet climate and arid climate modeling scenarios. The most notable impact of climate was that volatile chemicals persisted longer in arid scenarios, due to the decreased amount of landfill gas formation.

Overall, the modeling analysis revealed several insights of relevance to landfill design considerations for CBR events, with the modeling results driven largely by the chemical and physical properties of the various agents studied. Every chemical agent considered in the modeling was found to be largely associated with the solid phase in landfills. In terms of chemical fate, abiotic transformation (hydrolysis) and advective gas flow were the most significant mechanisms, underscoring the importance of rapid landfill gas collection and control for the volatile agents. Some chemical agents were predicted to transform relatively quickly (over a period of roughly 6 months), while others were predicted to persist for longer than 5 years. The effect of climate was minimal for most chemical agents studied; and in cases where landfills are promptly sealed, climate effects would be further minimized due to decreased water infiltration rates. Further information on the research described in the previous paragraphs is documented in multiple publications (*15, 16*).

2.7.2 Sorption and Desorption of Organics in Landfill Simulations

Further research was conducted to assess how partitioning behavior in landfills varies with the composition of the solid phase. This research involved two studies: estimating equilibrium partitioning parameters for selected combinations of organic chemicals and waste components and evaluating the factors that affect desorption of organic chemicals from waste material.

The first study estimated underlying parameters needed to model sorption behavior of organic chemicals to plastics commonly found in MSW. Dr. Barlaz reviewed data from earlier research that evaluated chemical sorption to soils and sediments. While those results have been used to assess landfill environments, soils and sediments are not representative of the actual waste streams generated during CBR events, which will include a broad array of other materials, like plastics, carpeting, computer casings, and other building materials. The purpose of the research was to estimate sorption behavior for various combinations of chemicals and waste materials that are typically found in MSW, including “rubbery” or “soft” plastics (e.g., high-density polyethylene) and “glassy” or “hard” plastics (e.g., polystyrene, polyvinyl chloride). Dr. Barlaz presented results demonstrating how material-specific partition coefficients vary across waste materials, which has important implications given that older and newer landfills have considerably different compositions of plastics, food waste, and other materials. Specifically, the research suggested that glassy plastics are important sinks for organic chemicals in landfills—a finding with direct implications on the fate of chemical agents in landfill environments. Overall, the model developed for this study highlighted the importance of considering landfill composition when assessing chemical sorption behavior. It must be noted that landfill composition is uncertain; however, a waste stream with a significant quantity of plastics such as computer casings, is likely to be more sorbent than general MSW that typically has a significant fraction of paper and less computer casings/carpet.

The second study examined the factors that contribute to desorption of organic chemicals from various materials in a simulated landfill environment, such as plastics, office paper, newsprint, and food waste. Dr. Barlaz first reviewed the experimental setup for the laboratory apparatus, and then presented measured desorption rates for selected alklybenzenes and tetrachloroethylene. The experiments were generally consistent with important findings from modeling, such as the fact that desorption rates were rapid for rubbery polymers and slow for glassy polymers. Dr. Barlaz then presented modeling results for the fraction of sarin that would be expected to remain in a landfill after 6 months. Predicted sarin persistence was found to be much less for a model based on generic partitioning coefficients for MSW than on a model based on material-specific partitioning data for individual constituents of synthetic building debris. In short, the study found that chemicals in landfills exhibit different desorption rates for different materials typically found in MSW, and desorption behavior can be reasonably portrayed by mathematical models. Further information on the research described in the previous paragraphs is documented in multiple publications (*17–19*).

2.7.3 Fate and Transport of Chemicals in Packed-bed Reactors Containing Simulated Solid Waste

While the previous research projects focused on individual mechanisms, the persistence of chemicals in landfills is ultimately determined by the net effect of multiple fate and transport mechanisms (e.g., biodegradation, sorption, abiotic transformation). Additional research was conducted to develop laboratory experiments that represent landfill conditions, such that chemical fate and transport behavior can be directly measured and used to assess and enhance the performance of chemical fate and transport models. Dr. Barlaz reviewed the experimental design of this research, which tracked phenol transport in a mixture of degraded newsprint and glass beads under anaerobic conditions. Fate and transport modeling for this setup was conducted with HYDRUS-1D, a commercially available model. Results were shown comparing observed and modeled indicators of fate and transport, with and without considering contributions of biodegradation.

Dr. Barlaz reviewed several conclusions and discussed their implications for landfill disposal of CBR material. The research confirmed the complexities associated with modeling the combined effect of multiple different fate and transport processes. The HYDRUS model provided a reasonable simulation of phenol fate and transport in an anaerobic and fully saturated waste column, in which sorption and biodegradation are the prevailing fate processes.

After discussing his modeling results, Dr. Barlaz presented information on the newly developed Landfill Coupled Reactor Model (LFCR). This model not only simulates fundamental chemical fate and transport mechanisms, but also is believed to include realistic algorithms for simulating landfill filling and covering. LFCR also includes time-variable parameters (e.g., for landfill gas production) that other models hold constant. Given that the model offers one of the most sophisticated and realistic representations of landfill processes, further research was recommended to validate the model and assess its performance. Further information on the research described in the previous paragraphs is documented in multiple publications (*20, 21*).

2.7.4 Transport of Microbial Agents in Landfills

Dr. Barlaz presented results from recent experimental research designed to examine how microbial agents are expected to move through landfill leachate and landfill gas. He explained that all research was conducted using surrogates for biological agents (e.g., *Bacillus atrophaeus* was used as a surrogate for *Bacillus anthracis*), given the restrictions and safety concerns associated with working with actual biological agents; and he described how detection methods were developed for the surrogates. The experimental setup consisted of columns filled with synthetic building materials to a depth of 12 inches and spiked with surrogate organisms. Water infiltration was simulated in some experiments, and leachate recirculation in others. Greater quantities of the surrogates eluted in leachate for the water infiltration experiments, in comparison to the leachate recirculation experiments; and the main inference from these observations was that disposal of biologically contaminated debris in landfills with water infiltration will most likely have biological agents in the leachate. However, Dr. Barlaz encouraged EPA to compare these findings to those presented earlier in the workshop on persistence and survival of biological agents in landfill environments (see Section 2.6).

The final set of experiments evaluated microbial transport from waste into landfill gas. The principal experimental apparatus was an aerosol chamber specifically designed to represent movement of landfill gas out of MSW waste, and the research also involved considerable methods development for detecting and measuring the surrogates in air. Results for two surrogates were presented. *Serratia marcescens* was never detected in chamber air samples, even for experiments involving high initial concentrations and gas flow velocities. Similarly, *Bacillus atrophaeus* was rarely detected in the gas samples, considering the same extreme experimental conditions. While the high gas flow velocities used in the studies might not be characteristic of typical gas flow in landfills, they could be representative of gas flow rates in close proximity to well heads at sites with landfill gas collection systems. Emissions of biological agents in landfill gas may be minimized by ensuring that wastes potentially containing these agents are not disposed of in the immediate proximity of the gas wells. Further information on the research described in the previous paragraphs is documented in multiple publications (*22–24*).

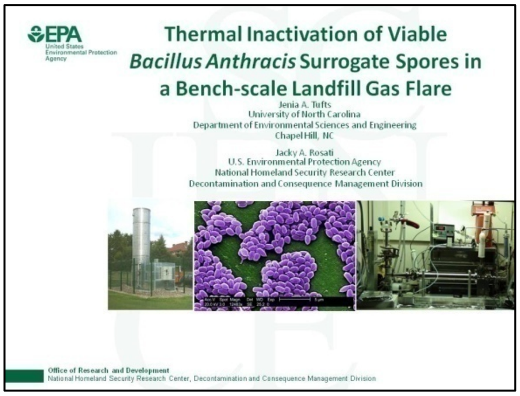
To summarize, Dr. Barlaz acknowledged that scientists could develop ideal landfill design for many different combinations of CBR agents and waste materials. However, the actual waste generated during an event might differ from specific combinations considered in such planning efforts. Therefore, some overarching guiding principles could also prove beneficial, such as the need to ensure that CBR wastes are securely buried and sealed rapidly in landfills equipped with liners, leachate collection and removal systems, and landfill gas controls. Models and experimental studies can continue to be conducted to evaluate the long-term fate and transport behavior for the landfills that are eventually used.

The question-and-answer session following this presentation addressed several topics:

- One participant asked whether the research included any experiments on actual biological agents to demonstrate the representativeness of the selected surrogates. Dr. Barlaz said this was not done, primarily because his laboratory is not licensed to work with select agents. However, he noted that the specific surrogates have also been used by other researchers conducting similar work. This precedent, combined with other considerations, suggested that the use of surrogates was appropriate for assessing the *transport* (as opposed to the *survival*) of the corresponding biological agents. He acknowledged, however, that the use of surrogates is an inherent limitation of the study but maintained that the surrogates did and can continue to provide valuable information, especially given the cost and difficulty of working actual live biological agents.
- Another participant asked why the packed-bed reactor experiments were conducted with glass beads, instead of plastic beads. Dr. Barlaz explained that these particular experiments were carefully designed to ensure that detectable amounts of the chemical being studied (phenol) would be present in the different landfill phases (leachate and gas) within a reasonable amount of time. Initial modeling analyses indicated that use of glass beads would help ensure that these design criteria were met.
- A third participant asked for additional information on the methods developed for identifying pathogens in leachate. Dr. Barlaz indicated that methods development was a major undertaking for the projects involving surrogates for biological agents. For example, roughly one year of research was needed to

develop the detection technique used for identifying surrogates in leachate.

2.8 Destruction of Spores in Landfill Gas Flares (Paul Lemieux)



Dr. Lemieux presented work performed by Ms. Jenia Tufts, Environmental Scientist/Student Services Contractor, Decontamination and Consequence Management Division, National Homeland Security Research Center of EPA's Office of Research and Development, which presented research findings on thermal inactivation of spores in landfill gas flares (using *Bacillus atrophaeus* and *Geobacillus stearothermophilus* as surrogates for *Bacillus anthracis*). Because previous research has found the spores to be highly thermally resistant and extremely persistent, questions were raised about the possibility of viable spores being emitted in landfill gas and whether spores can survive after passing through flares. At landfills, flares are either open or enclosed designs. The main difference between these designs is where combustion occurs—in and above the stack in an open flare system and within an enclosure for the enclosed flares. The research focused on simulating the conditions in enclosed flares, which represent the better control technology for landfill gas control.

Dr. Lemieux then reviewed the experimental design for the study, which considered two surrogates for *Bacillus anthracis* that have been used in many previous research efforts: *Geobacillus stearothermophilus* and *Bacillus atrophaeus*. Like *Bacillus anthracis*, the two surrogates are Gram-positive (those that are stained dark blue or violet by Gram stain), spore forming, rod-shaped, and thermally resistant. The research was conducted inside a laboratory fume hood using a bench-scale apparatus designed to simulate a landfill gas flare. The simulated landfill gas was a mixture of air and methane, into which a spore solution was injected. Multiple quality control steps were implemented to ensure that no stray spores contaminated the gases or equipment used in the experiment. The experimental flame had a temperature of approximately 1,000 °C at flare edges, with a gas residence time of 0.2 seconds; and both values closely correspond to what is typically observed in landfill gas flares. However, the air flow in the experimental system was considerably less turbulent than what is typically observed in the field. This was not considered an important limitation, because less turbulent air flow would be expected to provide a more conservative account of spore viability (due to less effective heat transfer to materials passing through the flame). Seven tests were conducted with each surrogate: five tests were performed with the flare on and two with the flare off. Any spores recovered from the experiment exhaust were cultured in nutrient broths to assess viability of the spores, rather than to characterize their mere presence.

Dr. Lemieux concluded by presenting results from the spore viability measurements. Overall, the bench-scale experimental set-up was found to be reasonably comparable to actual enclosed flare conditions. For every flare test considered, no positive test results were observed for either *Bacillus atrophaeus* or *Geobacillus stearothermophilus*. These findings suggest that, within the parameters of the experiment, spores that do happen to enter landfill gas will not likely survive after passing through well-operated landfill flares.

The question-and-answer session following this presentation addressed several topics:

- One participant noted that the experiment was found to represent a well-operated landfill flare, but wondered about the implications for flares operating outside typical bounds or during process upsets. Dr. Lemieux said the experiments conducted to date did not address non-ideal operating conditions, such as changes in stoichiometric ratios of landfill gases or unexpected increases or decreases in flame temperature. However, the bench-scale setup can be used in future experiments to examine these scenarios.

- Another participant asked if EPA is considering experiments to assess the fate of spores in landfill gas collection systems. Dr. Lemieux acknowledged that many landfills with active gas collection systems process the gas for purposes of energy recovery, but the experiments conducted to date focused specifically on landfill gas flares and not other types of internal combustion engines. Further research would be needed to assess the fate of spores in engines, boilers, and other combustion systems that could be installed at newly sited landfills designed to receive CBR wastes. However, Dr. Lemieux also noted that many internal combustion engines have temperatures and residence times similar to those used in landfill gas flares.

2.9 Waste Streams Generated from CBR Events (Bill Steuteville)

Mr. Steuteville, On-Scene Coordinator in EPA's Region 3, discussed key findings from the Liberty Radiation Exercise (Liberty RadEx) and their implications for waste management following CBR events. Liberty RadEx was an exercise conducted in 2010 to test emergency response to the detonation of a radiological dispersal device in downtown Philadelphia and associated cleanup activities. The hypothetical event was an explosion that released 2,300 curies of cesium-137. The initial explosion for this exercise would have damaged only adjacent buildings, but caused radiological contamination up to five times background levels at downwind distances up to 50 miles away. In this scenario, up to 140,000 residents would likely have been temporary relocated while decontamination and cleanup activities occurred in the most heavily impacted area. Waste generation estimates for this exercise depend on the acceptable risk levels adopted, with some estimates suggesting removal of 40,000,000 tons of waste.

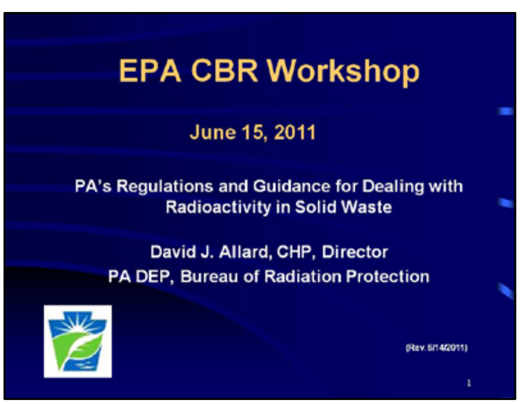
Mr. Steuteville emphasized that the waste streams generated by CBR events should not be considered debris. Natural disasters, such as the recent outbreaks of tornadoes in Missouri in Alabama and the tsunami in Japan, can destroy numerous buildings and other infrastructure, resulting in large debris fields of comingled wastes. In contrast, CBR events are generally not expected to result in massive and widespread physical destruction (though some destruction can occur), and much of the wastes from these events will be removed from intact structures. This distinction has major implications for waste management strategies for CBR events: once contaminated areas are defined, wastes can be segregated during cleanup such that multiple relatively homogenous waste streams are prepared for disposal, rather than hopelessly comingled waste streams. Examples of separate waste streams from cleanup of residential neighborhoods with surface contamination would include, but not be limited to, soils, cement, carpet, white goods, ceiling tiles, and roofing material. Thus, multiple landfill cells can be designed and optimized for the anticipated waste streams generated during these events, rather than trying to plan for a single cell that would accommodate a complex, mixed waste stream.

The question-and-answer session following this presentation addressed several topics:

- One participant asked if extensive waste segregation can truly be anticipated for most CBR events. Mr. Steuteville replied that this should be feasible, based on his experiences with the hypothetical Liberty RadEx event and on actual cleanup activities at sites with chemical contamination. As a result, biodegradable wastes that can lead to formation of landfill gases will generally be separated from inert material. He acknowledged that these events can include small areas where waste segregation is not practical or possible, but the majority of the cleanup area will likely result in relatively homogeneous waste streams.

- Another participant asked how wastes would likely be transported to landfills following major CBR events. Mr. Steuteville indicated that most wastes from these events would first be sent to staging areas for waste characterization, decontamination, and temporary staging, rather than being sent immediately and directly to landfills. The need for rapid removal of wastes is driven by many factors, particularly the need to return communities to normalcy.
- Another participant expressed concern about prolonged staging of wastes in staging areas for events involving highly volatile chemical agents. Mr. Steuteville agreed that this is an important consideration, but noted that extensive waste removal for large-scale CBR attacks will likely take several weeks to initiate and implement, at which point the most volatile chemicals will have largely evaporated and dispersed.

2.10 Disposal of Radiological Wastes in Landfills (David Allard)



Mr. Allard, Director, Bureau of Radiation Protection, Pennsylvania Department of Environmental Protection, provided an overview of Pennsylvania's regulations and guidance for dealing with radioactivity in solid waste. As background, Pennsylvania is a net importer of approximately 10 million tons of solid waste per year, largely due to the available landfill capacity and low tipping fees. The infrastructure for managing MSW and so-called residual waste include 54 landfills, approximately 70 transfer stations, and six waste-to-energy facilities. Current regulations in Pennsylvania require that RCRA Subtitle D landfills be designed to RCRA Subtitle C landfill standards. Therefore, most active MSW landfills in the state have much more extensive control than is required by federal regulation.

Several factors have complicated efforts for disposing of radiological material at solid waste facilities around the country. For example, many MSW landfills have permit provisions that prohibit disposal of "radioactivity," without providing meaningful definitions and criteria for identifying what materials in the solid waste stream are acceptable and what are not. One state (Pennsylvania) has a very comprehensive approach of (requiring via their solid waste regulations) radiation monitors at all facilities, and Action Plans in place to identification of the type of radioactive material present. Without such an approach, facilities find it particularly problematic given the ubiquitous nature of radioactivity, including many natural sources, as well as the very common scenario of medical patient-contaminated solid waste setting off radiation alarms. Without regulations and guidance, MSW landfills have installed radioactive material monitors, but the detection devices, alarm settings, on-site responses, and other factors vary considerably from one landfill to the next. Again, a major complicating factor is that these monitors would frequently alarm when encountering patient-contaminated wastes with little or no radiological significance. In fact, these wastes that are exempt from NRC and DOT regulation, such are the actual patients and excreta from individuals or pets receiving nuclear medicine procedures and therapies. On occasion, orphan sources or low-level technologically-enhanced naturally occurring radioactive materials (TENORM) wastes have been identified in wastes sent to MSW landfills; after detection, these materials are removed from the waste stream, assessed and handled accordingly for disposal.

Mr. Allard provided numerous examples of waste items that contain naturally occurring radioactive materials (NORM) or TENORM. These examples included various industrial wastes (e.g., metal processing slags, coal fly ash, residuals from hydraulic fracturing) and consumer products (e.g., fertilizers, sheet rock, smoke detectors). He also referred to self-luminous “EXIT” signs that contain radioactive tritium gas, because these have contributed to elevated tritium levels recently detected in leachate samples from MSW landfills. Due to the prevalence of these signs in landfills, groundwater monitoring for tritium could be a useful indicator for leachate leakage and liner breaches.

Mr. Allard then reviewed specific regulations and guidelines that the Pennsylvania Department of Environmental Protection (PADEP) developed both to protect the environment, the public, and workers from unnecessary radiation exposure and to protect solid waste facilities from contamination. The regulations specifically prohibit disposal of certain materials, such as low-level radioactive waste, special nuclear material, and transuranic radioactive material. The regulations also allow for facilities to process and dispose of certain radioactive materials (e.g., short-lived radioactive materials from patients undergoing medical procedures, TENORM), but only after receiving written approval from PADEP. The regulations and guidance include various other requirements, which facilities address in Radiation Protection Action Plans. These plans present approaches for monitoring, detecting, and characterizing radioactive material, notifying regulators when certain conditions are met, and recordkeeping. Mr. Allard reviewed several other regulatory requirements and protocols, such as PADEP’s radiation action levels (and how background radiation is considered when evaluating these), corresponding actions that must be implemented when action levels are exceeded, and the specific radiation dose model the agency uses when evaluating waste disposal petitions.

Mr. Allard then reviewed various lessons learned from implementing PADEP’s regulatory framework for disposing of radiological wastes. For instance, the agency recently analyzed the underlying causes for alarm conditions triggered by radiation field measurements at solid waste management facilities. This analysis found that:

- 90% of alarms resulted from nuclear medicine radioactive material in household waste.
- 9% of alarms were due to the presence of NORM or TENORM.
- 1% of alarms resulted from nuclear medicine radioactive material detected on drivers.
- Less than 1% of the alarms were due to regulated or controlled radioactive material.

Other important insights were gleaned from a landfill leachate study that the agency conducted in 2004. In the study, more than 1,000 leachate samples were collected from 54 active landfills, and the samples were analyzed for some combination of gross alpha, gross beta, tritium, total uranium, and radium isotopes. Tritium was found well above background concentrations in more than 90% of the leachate samples. More than half of the landfills considered in the study had tritium concentrations in leachate greater than 20,000 picocuries per liter—EPA’s current drinking water standard for tritium; and one landfill leachate sample contained tritium at more than 350,000 picocuries per liter. Follow-up sampling in more recent years has generally confirmed the findings from the 2004 study.

Mr. Allard also reviewed key points from the Liberty RadEx exercise (see Section 2.9 for a brief overview of Liberty RadEx). One of many challenges faced was how to select acceptable radiation dose values and then back-calculate cleanup levels for contamination in soils, on surfaces, and other media—all while balancing health protectiveness against the feasibility and cost of disposing massive quantities of potentially contaminated waste. The estimated waste volume was several hundred thousand cubic feet of waste for the 2-year PAG area, and half of the total cost for managing this waste was due to transportation.

He concluded by reporting that the Pennsylvania regulatory framework and guidance for disposing of radiological wastes is currently being considered as the basis for (1) model regulations to be developed by other states and (2) a new standard published by the American National Standards Institute (ANSI). Thus, concepts from this regulatory framework could also prove beneficial for designing and operating landfills to receive CBR wastes.

The question-and-answer session following this presentation addressed several topics:

- One participant asked if other states have reported detection of tritium in landfill leachate. Mr. Allard said California has conducted a similar survey, which found leachate tritium levels comparable to those measured in samples from the Pennsylvania landfills. That study also indicated the potential for tritium to be found in condensate from landfill flares.
- Another participant asked about additional lessons learned from Liberty RadEx and the current response to the tsunami in Japan. Mr. Allard said a critical, initial decision in these events is determining which lands will be dedicated to build new disposal facilities. For events involving radiological dispersal devices, multiple types of disposal facilities with different designs will likely be necessary to handle materials with varying degrees of contamination. When extremely large quantities of waste must be removed, consideration should also be given to constructing and operating interim staging areas.
- A participant asked how best to pre-identify locations for constructing staging areas and disposal facilities. Mr. Allard said that, during Liberty RadEx, community involvement proved to be a critical factor when identifying candidate locations for these facilities. A reasonable approach could be to identify in advance specific siting criteria that must be met for these facilities, because one does not know in advance where a CBR event will actually occur. He added that it might be easier to first identify areas that would be excluded as potential facility locations, such as flood plains, certain urban areas, state forests, and sites of cultural significance.
- Another participant asked if responders should segregate tritium-based exit signs when removing materials from buildings following contamination with biological agents. Mr. Allard said decontamination would be an important first step. The preferred subsequent steps would likely be considered on a case-by-case basis; options could include sending the signs to facilities that can recover the tritium or stabilizing the signs or the tritium components in a manner to prevent release of the tritium.
- A participant asked if PADEP had planned any public education campaigns or outreach programs to inform the public of waste management issues surrounding CBR events (e.g., safeguards for transportation and landfill siting). Mr. Allard supported developing these efforts and acknowledged the benefits of stakeholder and public participation, but education and outreach was not a focus during Liberty RadEx.
- A participant asked if disposal of radiological waste would be expected to shorten the service life of a landfill facility. It was the general view that the radiation levels in most building debris from CBR events would not be expected to physically affect

geomembranes or clay liners. Higher level radiological waste may be of concern, but that could be addressed by stabilizing this material or diverting it to specialized facilities.

3.0 Moderated Discussions

The moderated discussions were framed around discussion questions circulated to participants in advance of the workshop (see Attachment 3). Each question considered during the workshop is listed below, and these questions prompted workshop participants to discuss specific topics. This section of the report chronicles the participants' responses and discussions for each question and culminates by documenting the participants' final comments.

3.1 Question 1: Waste-Specific Considerations

The first question considered in the moderated discussions asked: "Based on projections of the different types of waste that might be generated as a result of the response, are there any considerations that might be waste-specific that could affect the land disposal technology selection?" The workshop participants provided multiple responses to this question and raised several additional points. A summary of the responses and discussion points follows:

- *Waste segregation and implications*. Based on discussions earlier at the workshop (see Section 2.9), the likely scenario following a CBR event is that wastes will be highly segregated at the time they are generated. Thus, landfill cells can be designed to most effectively manage the different solid waste streams that are anticipated. As necessary, waste streams can be handled individually or mixed, while achieving narrow windows of bulk density and ensuring that biodegradable wastes and other materials with high gas-formation potential are separated to the extent desired from building components and other "inert" materials. Additionally, the most heavily contaminated materials will be managed separately from wastes likely to have low or minimal contamination. A participant encouraged consideration for the minimal or perhaps optimal amount of segregation at the point of generation that would facilitate downstream waste management, but without leading to an unnecessarily prolonged response. Knowing in advance which waste streams should be comingled could help simplify the initial waste removal and staging following a CBR event.
- *Transportation issues and implications*. Transportation of waste was identified as a potential "bottleneck" in the waste management response to CBR events. For events that generate more than 10,000,000 tons of solid waste, transportation is expected to account for a large fraction of waste management costs and could take three or more years to complete, based on an assumption that standard dump trucks typically used for moving debris haul 12,000 tons of waste per day; this also assumes that local transportation infrastructure has not been compromised by the event itself. This estimated time for waste removal was supported by the recent experience of transporting material from the World Trade Center to the Fresh Kills landfill using a combination of trucks and barges. Consideration for large waste staging areas near the event location can help accelerate the initial waste removal response and allow for waste accumulation, decontamination, dewatering (if necessary), consolidation, and compaction while the ultimate disposal facility is being constructed—an issue that was revisited multiple times during the workshop.
- *Liquids and sludge*. Some CBR events can result in large quantities of liquid waste (e.g., decontamination water generated following a radiological event). Plans can be established now for how best to handle and treat wastewater, considering lessons

learned from the Liberty RadEx exercise and from current practices used to manage wastewater generated during hydraulic fracturing activities. For events resulting in significant quantities of sludge, the landfill design will need to consider slope stability concerns.

- *Site-specific considerations*. Events that occur in heavily industrialized areas or at key transportation nodes could result in large quantities of hazardous waste, manufacturing equipment, vehicles, and other materials that might need to be decontaminated or handled separately from other materials. A participant agreed with this statement, but also encouraged that this particular workshop focus on the components of the CBR waste stream that are expected to account for the greatest percentage of the overall waste (i.e., building components, soil, trees and shrubs, scarified concrete). Sludge, vehicles, and drums of hazardous waste will likely account for a relatively small fraction of the overall waste stream.
- *Animal carcasses*. CBR events with plumes passing over agriculture areas can lead to significant numbers of animal carcasses that must be managed. For example, an event that contaminates (or otherwise affects) a single cattle feed lot could conceivably result in well over 50,000 tons of animal carcasses. Specific challenges posed by this waste stream are rapid decomposition, the significant water content (approximately 60% to 70%) of animal carcasses, and vector control. These challenges argue for the developing and deploying onsite processing technologies, rather than attempting to transport decomposing carcasses. Examples given were use of mobile rendering technologies that remove water content from the carcasses and therefore reduce the volume of waste, along with temporary staging strategies (e.g., refrigeration, tanks with preservatives) that slow or stop decomposition while waste management decisions are made.

3.2 Question 2: Design, Construction, and Operational Requirements

The second question considered in the moderated discussions asked: “What special design, construction, or operational requirements might be appropriate for different types of contaminating agents? What types of routine and long-term monitoring might be appropriate for different types of wastes and for different contaminating agents?”

Two general comments were raised before the participants discussed agent-specific recommendations. One participant noted that preferred landfill *design* strategies might not vary considerably between chemical, biological, and radiological agents, because landfills receiving CBR wastes will likely all have liners, designated decontamination areas, gas control measures, and other various features. However, certain *operational* requirements, such as the nature and extent of long-term monitoring and long-term institutional controls, probably should vary across agent types. One method suggested for documenting specific design, construction, and operational requirements is to populate a multi-dimensional matrix: a user would specify the agent category (e.g., chemical) and waste matrix (e.g., office furniture and carpeting), and the matrix would output a list of the preferred landfill design and operational features. This could include certain elements that apply to all CBR events and special considerations for the agent-waste combination. The output list could also specify landfill features that should be avoided for a given event. Such a matrix can be expanded to account for various other inputs that might be expected to affect landfill design, operation, and maintenance (e.g., extent of decontamination, local climate).

A summary of the responses and discussion points specific to the three categories of agents follows:

3.2.1 Responses for Biological Agents

- *Unique properties of biological agents.* Biological agents have some unique aspects, when compared to chemical and radiological agents. First, measurement methods are not widely available for biological agents. While polymerase chain reaction can detect the presence of an agent, the measurement does not indicate whether the agent is viable. Time is needed to develop culturing methods for biological agents. Second, unlike chemical and radiological agents, whose concentrations will generally decrease over time after initial disposal, the amount of certain biological agents can potentially increase inside landfills. Finally, biological agents have widely varying persistence, with some that die quickly in an open environment and others (e.g., prions, spores) that can persist for decades. These various properties should be considered when disposing of wastes potentially contaminated with biological agents.
- *Siting.* During previous responses to anthrax incidents, including instances of naturally occurring anthrax and anthrax spores sent in the U.S. mail, environmental agencies reported difficulties finding landfills that would accept the waste. The reasons for these difficulties included: public perception of unacceptable risk; the lack of clear direction from governmental agencies on exactly how the waste should be packaged, transported, and handled; and indemnification concerns. Several suggestions were proposed to help overcome these obstacles. Effective risk communication and public involvement was one strategy listed for addressing public health concerns. Siting and constructing new government-owned landfills on state- or federally-owned land, which might include land obtained through eminent domain, would help address siting issues and alleviate the need to indemnify entities that own existing landfills. Further, guidance could be developed to specify how these wastes should be handled, from point of generation through staging to disposal. The significant transportation costs observed during previous exercises provide a compelling case for siting and constructing landfills relatively close to the CBR event location. It was recommended that identification of siting criteria and identification of which sites are clearly inappropriate for such a facility would be a less controversial approach than to recommend sites.
- *Landfill gas control.* Presentations earlier in the workshop indicated that certain biological agents have the potential to enter landfill gas, although they may resist this due to being tightly bound to the waste, and experimental data suggest that spores that do happen to enter landfill gas will not survive after passing through well-operated landfill flares. While the experimental results were encouraging, a participant noted that uncontrolled landfill gas emissions can still occur through seeps and cracks, or when gas collection wells are originally being installed. Several considerations were suggested for minimizing air releases of biological agents from these sources. First, steps could be taken to ensure that gas collection wells are not drilled directly into areas known to have contaminated wastes. Second, pre-treatment of wastes could minimize transport of biological agents into landfill gas. For instance, to the extent practical, specific waste items known or suspected to be contaminated with biological agents can be wrapped, containerized, stabilized, or solidified in order to effectively immobilize the

material of greatest concern. Further, concerns about landfill gas generation can be minimized by having certain landfill cells dedicated primarily to "inert" wastes with minimal gas formation potential. For cells expected to have landfill gas generation issues, the cover material and cap must effectively control gas emissions, with routine inspection, maintenance, and monitoring implemented to identify and control seeps. Finally, the landfill gas that is collected will likely need to be burned onsite, without being treated and distributed into commerce.

- *Leachate control.* Presentations earlier in the workshop indicated that biological agents can transfer into, and persist in, landfill leachate—findings that argue against a landfill design with leachate recirculation system. The remaining two options mentioned were (1) permanently sealing the landfill after disposal is completed (along with any leachate that may exist in the cell) or (2) collecting and treating the leachate. For the former option, decisions will have to be made regarding how specifically to minimize leachate formation (e.g., should t waste with moisture content above a certain threshold be required to t be dried or stabilized before disposal?). For the latter option, specific consideration would have to be given to whether, and to what extent, leachate treatment should occur at the landfill and what type of off-site water treatment facility would be able to receive potentially contaminated leachate.
- *Related regulatory frameworks.* EPA's existing regulatory framework for managing, transporting, and disposing of asbestos-containing material was promulgated in part to minimize fugitive air emissions of a hazardous substance. Accordingly, some participants encouraged EPA to consider whether certain requirements in the asbestos NESHAP (National Emission Standard for Hazardous Air Pollutants) should also be applied to biological agents, given the similar concern about minimizing or eliminating all possible sources of fugitive air emissions. Referring to the asbestos NESHAP can also provide insights into required protective measures for minimizing worker exposures.

3.2.2 Responses for Radiological Agents

- *Unique properties of radiological agents.* One unique characteristic of radiological agents is the known half-lives and decay products of individual radionuclides. These parameters have direct bearing on waste management decisions for various reasons. For example, the half-lives can factor into the proposed duration of long-term monitoring and institutional controls for future uses, and the formation and toxicity of decay products must also be considered when managing these wastes (e.g., uranium decay eventually generates radon gas).
- *Related regulatory frameworks and guidance.* EPA, the Department of Energy, and the Nuclear Regulatory Commission all have extensive experience with managing various types of radioactive waste, including mixed wastes, low-level radioactive waste, and high-level radioactive waste. Regulations have been developed for routine waste management activity, and guidance has been published for emergency response (e.g., accidents at nuclear power plants). These agencies have developed a wide range of information resources to guide responders through waste management activities involving radioactive waste.
- *Anticipated waste volumes and waste management implications.* Experience has indicated that certain types of events involving radioactive materials, such as attacks using radiological dispersal devices, can result in

widespread contamination. Waste volumes following these events have been estimated to exceed 40,000,000 tons, with exact quantities depending on the size of exclusion zones and contamination areas. Within this volume will be a range of materials, in terms of radioactivity. Responders therefore need to be prepared for handling this magnitude of waste, and external pressures from the public and politicians might result in the need to remove the waste as quickly as possible. These factors would further support an idea raised earlier: the preferred response might involve moving massive quantities of materials first to staging areas, while landfill space is being constructed or negotiated.

- *Consideration for decontamination residues.* Decontamination activities will likely occur as part of the waste management response. Therefore, all facilities expected to handle radioactive wastes—landfills, and staging areas—should be designed with a specific area dedicated to decontamination activities, which could include decontaminating large vehicles. These sites will also need to be equipped with means for handling, and possibly treating, large volumes of decontamination water that are expected to be generated.
- *Monitoring considerations.* A participant noted that leachate and decontamination water are likely to be discharged to water treatment facilities. The extent of contamination in the water at the treatment facilities can be evaluated with monitoring or by calculating concentration reductions due to dilution from water received from other sources. But, a possibility remains that trace amounts of radionuclides gradually accumulating and concentrating in the sludge generated at these facilities. In cases where sludge material is used for land application purposes, some consideration should be given to monitoring the sludge for presence of the radionuclides of concern.
- *Other considerations.* While acknowledging that waste management responses must comply with existing regulations, several participants indicated a preference for guidelines and guidance for certain response activities involving radioactive wastes, as opposed to entirely prescriptive requirements. For instance, guidance could indicate when it is preferred to use fixatives in the field to immobilize contamination, under what conditions should wastes be stabilized prior to disposal, and so on. As noted previously, public acceptability will be an important factor in the waste management process, and this can be addressed through effective outreach and educational materials, possibly drawing from experiences gained from the Liberty RadEx exercise and existing documents posted on EPA's website (*25*) (http://www.epa.gov/libertyradex/).

3.2.3 Responses for Chemical Agents

- *Special considerations for chemical agents susceptible to hydrolysis.* Presentations earlier in the workshop noted that certain chemical agents (e.g., sarin) undergo rapid abiotic transformation via hydrolysis. Therefore, exposing these particular wastes to water, whether through leachate recirculation or infiltration of rainwater, would help accelerate the principal mechanism for hydrolyzing and potentially detoxifying the waste. This was the only case where workshop participants noted that leachate recirculation or infiltration of precipitation could be advantageous. In short, the landfill can be designed and viewed as a treatment operation, instead of merely storing the waste.
- *Timeliness of response for volatile chemical agents.* To minimize potential inhalation exposures to the most

volatile chemical agents, some incidents would ideally have rapid waste disposal with prompt installation of landfill gas collection and treatment systems. However, because waste removal following a CBR event is expected to last several weeks, if not longer, a considerable portion of the most volatile constituents may evaporate from wastes, hydrolyze, or possibly disperse before the material ever reaches a landfill.

- *Selection of liner material.* Presentations earlier in the workshop reported on the extent to which certain chemical agents are expected to adhere to different types of plastics. For example, the earlier presentation indicated that certain chemical agents adhere more readily to polyvinyl chloride than they do to high-density polyethylene. Such knowledge could be one of many factors to consider when choosing liner material.
- *Additional evidence of persistence.* Presentations earlier in the workshop reviewed recent experimental and modeling studies indicating that certain chemical agents are highly persistent in landfill environments. Consistent with this observation is the fact that some World War I-era chemical weapons that were previously buried in soil have been recently unearthed, with detectable quantities of the chemical agent still present. This provided additional evidence of persistence, though participants acknowledged differences between burial and disposal in landfills.

3.3 Question 3: Other Strategies and General Comments

The third question considered in the moderated discussions asked: "What else can be done as part of the entire spectrum of the waste management process (e.g., segregation, reuse/recycling, volume reduction, treatment, staging, disposal) that could add to the capacity to operationally recover from a CBR incident?" A general sentiment expressed is that the response for a CBR event will likely need to consider all possible waste management options listed in the question, especially when large volumes of waste need to be moved in short time frames. A summary of specific responses follow, organized roughly into the sequence of events that occurs before, during, and after CBR events:

- *Preparedness.* Multiple recommendations were offered to state agencies and other jurisdictions for becoming better prepared to manage wastes following a CBR event. First, agencies should access existing inventories of landfills and other waste management facilities, possibly drawing from EPA's decision support tool for disaster debris management, though this resource obviously would not be expected to inform decisions about siting new facilities. Second, agencies were encouraged to evaluate and assess their existing inventory of equipment needed to respond to events (e.g., waste hauling vehicles, barges). Third, participants voiced support for conducting additional emergency exercises and drills that specifically include waste removal and management. Further, agencies can enhance their preparedness by developing emergency operation plans, transportation plans, and the various planning documents that typically support landfill construction and operation (e.g., construction quality assurance plan, facility operations and maintenance manual, and comprehensive environmental monitoring plan).
- *Segregation of wastes.* As noted previously, the wastes initially removed from areas affected by CBR events are expected to be highly segregated. Separate waste streams could be generated for a wide range of materials, including soils, concrete, trees and shrubs, vehicles, and so on.

Advanced planning should consider the full range of anticipated waste streams and the preferred waste management strategies for these waste streams, whether handled individually or in combination. Another option raised was the possibility of co-disposal of CBR wastes with MSW. Reuse and recycling may not be feasible, given public perception of risk associated with recovering and reusing material that might have been contaminated with a CBR agent.

- *Role of staging areas.* Following large CBR events, response teams will be under extreme pressure to quickly remove waste material from affected communities to restore order. On the other hand, construction of new landfill facilities is expected to take months, even in cases where extensive planning has occurred. The exact time needed to construct new landfill cells will depend on many factors, some of which are unpredictable (e.g., the weather, unanticipated delays). These two driving forces—the need to remove waste quickly and the likelihood that new landfills will not be ready for several months—make a very strong case for initially transferring waste to safe and secure staging areas. Participants noted that these facilities might need to hold wastes for months, or even years, while landfill capacity is constructed.

Agencies expected to manage CBR wastes were encouraged to start thinking about potential locations for staging areas, recognizing that transporting material over long distances can increase costs substantially. Further, agencies were encouraged to consider what pre-processing activities might occur at these sites in order to facilitate downstream waste disposal. Examples include crushing, compacting, packaging, dewatering, and mixing of waste streams. The one precaution expressed was that repeated or excessive handling of potentially contaminated CBR waste increases the likelihood of further releases of harmful agents and also raises occupational exposure concerns (see below). Thus, some pre-processing activities might be more appropriate to implement at the waste generation site, at the landfill facilities, or in the landfill cells.

- *Transportation.* Previous experience from CBR events and exercises has indicated that transporting waste can account for a large fraction of the overall costs of waste removal and management. Agencies that will oversee waste management l were encouraged to research and develop detailed transportation plans that specify shipping procedures for all transportation modes (e.g., rail, truck, and barge)—an activity that should occur as part of preparedness efforts. Close coordination with DOT was also advised. DOT currently requires security plans for private companies that handle and transport small quantities of select agents, but this approach will likely not apply to the very large quantities of waste that must be transported after a large CBR event. However, DOT officials would likely work with the agency overseeing the waste response to determine minimum requirements for ensuring that material is transported in a safe and secure manner.
- *Landfill gas.* Landfill gas was viewed by some participants as being the most likely route by which CBR agents can be released from landfills in an uncontrolled manner. The gas issues were viewed as problematic not only because the gas can be difficult to control (e.g., due to cracks and seeps in cover material), but also because emissions are difficult to monitor. A possible solution to this issue was to only landfill "inert" materials from CBR events and divert all biomass to incineration facilities, particularly for wastes that are potentially contaminated with chemical and biological agents. A participant said this

option is worth investigating, given that waste materials are expected to be highly segregated upon removal from the event site, as discussed earlier in this report (see Section 2.9).

- *Liners.* Selection of liner material should be based on the type and composition of waste that it will contain, and not entirely on ease of construction. While landfills with geo-synthetic liners can be constructed more quickly than landfills with natural clays in composite liners, wastes with high calcium content will degrade geo-synthetic clay liners. The liner material used should ultimately offer the greatest containment for the specific wastes above it.
- *Monitoring.* Long-term monitoring at landfills that receive CBR wastes can provide assurance that the agents continue to be contained, which is likely to be an important public acceptability issue. Landfills already have monitoring requirements that extend into the post-closure period. Participants noted that the existing monitoring requirements that look for evidence of leakage are adequate, but questioned whether gas monitoring protocols required under the New Source Performance Standards would be sufficient for detecting landfill gas emissions. One specific suggestion for assessing air emissions was to consider monitoring for bio-aerosols at sites that receive biological agents, as is reportedly done at selected medical waste handling operations. As noted in the discussion above for radiological agents, consideration should also be given to monitoring sludge generated at water treatment facilities that handle leachate from landfills, especially when the sludge is used for land application purposes. For CBR wastes, additional criteria will need to be developed to specify which agents should be measured and when long-term monitoring and post-closure care activities can cease. However, even in cases where available data might support a decision to cease monitoring (e.g., continued non-detects over multiple sampling periods), public concern about risk might lead to continued monitoring over even longer time frames, though possibly at decreased frequencies.
- *Prescriptive or performance-based guidance.* Participants discussed two different approaches that EPA could follow when developing guidance or requirements for disposal of CBR wastes: an entirely prescriptive approach that specifies exactly how landfills must be designed and operated or a performance-based approach that outlines general performance criteria and allows the landfill owner to determine how best to meet those criteria. Arguments were made supporting both approaches. Prescriptive approaches would have the benefit of leaving no ambiguity to agencies that manage CBR wastes.
- *Occupational exposures.* EPA's incident response focus is on managing waste in a manner that protects public health and the environment. However, occupational exposures are an important concern for response workers, waste haulers, and other individuals whose jobs could bring them into contact with CBR agents. These exposures could potentially occur when removing waste from incident sites, transporting waste, decontaminating equipment, disposing of waste, and during various other activities (e.g., installation of gas collection wells). The Occupational Safety and Health Administration has authority for ensuring that workers are adequately protected from exposures to harmful materials, and landfills already implement measures to protect their workers from harmful exposures. Some participants noted that EPA's asbestos NESHAP is an example of a regulation with provisions to ensure

that waste removal workers and landfill operators are not exposed to unhealthy levels of harmful materials.

- *Consideration of cost-benefit analyses.* Participants encouraged EPA to consider the full range of costs and benefits when making decisions that affect landfill disposal options. One example cited was weighing the increased cost of conducting more extensive decontamination activities at the event site against the decreased disposal costs that could result from having less contaminated material. A participant noted that cost-benefit analyses can be important when investigating many other recommendations mentioned throughout the workshop (e.g., the feasibility of diverting all biomass from an event to incineration facilities).
- *Other issues.* Participants raised various other issues when responding to this question. First, slope stability issues must be considered in these events, particularly because such events will result in rapid filling of landfill cells and the possibility that some waste material will not be compacted prior to disposal. Second, while some closed MSW landfills have been developed into parks, entertainment venues, and for other uses, much stricter long-term institutional controls will likely be implemented for landfills that receive CBR wastes in order to err on the side of precaution. Third, participants noted that indemnification will be an important consideration if CBR wastes are to be disposed of at privately-owned landfills or at government-owned, contractor-operated landfills. Fourth, a participant encouraged EPA to consider developing private sector partnerships through the U.S. Department of Homeland Security's "Support Anti-terrorism by Fostering Effective Technologies Act" (SAFETY Act), which was designed to spur innovation and create new technologies pertaining to homeland security. Opportunities may exist to have the private sector investigate specific technical issues that would help agencies in the preparedness activities for siting, designing, and operating landfills and staging facilities. Finally, under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), EPA has already developed specific criteria for onsite disposal of hazardous waste. A participant encouraged EPA to consider those criteria when developing design specifications for landfills that will receive CBR waste.

3.4 Final Comments

- The workshop concluded with every participant sharing final comments. Some comments emphasized points raised earlier in the workshop; those issues are not discussed here, because they are already documented in other sections of this report. This section summarizes the final comments that raised new issues or new insights on topics raised during the earlier workshop discussions:
- Several comments underscored the importance of advanced planning and preparedness. Many technical and engineering analyses to inform landfill design and construction can occur prior to events, even if the actual landfill site is not known. Developing plans for construction, operation, and closure should be done in advance so that response efforts can begin immediately following a CBR event; and peer review of these plans by state agencies and other stakeholders was encouraged. Having an agreed-upon landfill design for CBR wastes (or possibly multiple approved designs that states can choose from) will help facilitate waste response activities following future events.

- State and local agencies will play critical roles when responding to CBR events. These entities should be encouraged to move forward in coordination with EPA to plan for future events, whether through workshops, field exercises, or other planning activities. Engaging relevant private sector entities was also encouraged.
- Exercises that simulate waste removal and disposal following CBR events will enhance preparedness. While resource constraints may not allow for additional exercises to the scale of Liberty RadEx, smaller exercises that focus specifically on waste management can be developed and implemented in different states.
- Many integrated components make up the overall waste removal and management response, and planning efforts need to consider these relationships. As an example, when disposal facilities cannot be constructed in a timely manner, staging areas and pre-treatment of wastes becomes increasingly important. These and other interactions should be considered in future planning efforts.
- Extensive waste segregation during the response effort raises many options for managing the waste. For example, the individual waste streams can continue to be handled separately, mixed with certain other waste streams, or possibly even co-disposed of with MSW. An issue revisited during the final comments was whether biomass should be managed separate from “inert” wastes, and possibly even incinerated instead of disposed to avoid excessive formation of landfill gas and the technical challenges that accompany it (e.g., concerns about emissions from seeps and cracks and drilling gas collection wells into wastes that might contain CBR agents).
- In events with widespread contamination, waste minimization will be an important issue. The agencies responding will need to be prepared to make science-based decisions regarding which materials are contaminated versus which materials are “clean,” and the wastes should be handled appropriately.
- One specific recommended activity was to establish a realistic timeline for siting, constructing, and operating new landfill cells. This timeline could be used to identify “bottlenecks” in the overall waste management response, such that those can be addressed in advance. The timeline would also inform many other decisions, such as the need for, and required capacity of, temporary waste staging areas. This analysis could also help planners optimize the overall waste response and determine how CBR wastes can be handled in the quickest and most cost-effective manner, while avoiding excessive handling of the material.
- Another planning activity suggested was to develop rough estimates of landfill cell sizes that might be needed for disposing of different quantities of waste. While participants had previously expressed concern about constructing large landfill facilities during a single construction season, staged construction can help alleviate this concern. For larger events, small landfill cells can be constructed and begin to receive waste while additional cells are being constructed.
- Additional research and modeling on the fate and transport of various chemical, biological, and radiological agents will allow regulators to make science-based decisions regarding design, operation, and monitoring of landfills.

- Public outreach and public acceptance will be important components of the response effort. Keeping the public educated and informed of the cleanup operations and disposal processes can help ensure citizens that the waste is being handled in a manner that does not adversely affect human health or the environment.

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5.0 Attachments

1. List of Workshop Participants

2. Workshop Agenda

3. Seed Questions for Moderated Discussions

4. Presentation Slides

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Environmental Protection Agency
Decontamination and Consequence Management Division

Workshop on Chemical-Biological-Radiological (CBR) Disposal in Landfills

Embassy Suites at Chevy Chase Pavilion
Washington, DC
June 14–15, 2011

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United States
Environmental Protection Agency
Decontamination and Consequence Management Division

Workshop on Chemical-Biological-Radiological (CBR) Disposal in Landfills

Embassy Suites at Chevy Chase Pavilion
Washington, DC
June 14–15, 2011

Agenda

TUESDAY, JUNE 14, 2011

7:30 am	Registration/Check-in	
8:30 am	**Welcome and Opening Remarks**	*ERG*
	PART 1: CONTEXT OF THE PROBLEM	
8:40 am	**Context of the Problem and Workshop Goals**	*Juan Reyes (EPA/OHS)*
9:00 am	**Structure of the Meeting**	*Paul Lemieux (EPA/ORD)*
	PART 2: WHAT DO WE KNOW NOW?	
9:30 am	**Existing Requirements and Capabilities for Subtitle C & Subtitle D Landfills and for Landfilling Low Activity Radiological Waste**	*Craig Dufficy (EPA/ORCR)*
10:15 am	BREAK	
10:30 am	**Landfill Gas Control**	*Susan Thorneloe (EPA/ORD)*
11:15 am	**CBR Landfill Disposal Issues - A NYSDEC Perspective**	*Robert Phaneuf (NYSDEC)*
12:00 pm	LUNCH (on your own)	
1:30 pm	**Persistence of CB Agents in Landfill Leachate**	*Wendy Davis-Hoover (EPA/ORD)*
2:15 pm	**Fate and Transport of CB Agents in a Landfill**	*Mort Barlaz (NC State University)*
3:00 pm	BREAK	
3:15 pm	**Destruction of Spores in Landfill Gas Flares**	*Paul Lemieux (EPA/ORD)*

4:00 pm **Waste Streams Generated from CBR Events** .... *Bill Steuteville (EPA/OHS)*

4:15 pm Q&A Panel

4:30 pm ADJOURN

WEDNESDAY, JUNE 15, 2011

8:30 am **Goals and Structure for Day 2** .... *ERG*

9:00 am **Disposal of Radiological Wastes in Landfills** .... *David Allard (PA DEP)*

PART 3: HOW CAN WE USE WHAT WE KNOW?

9:45 am **Panel Discussion**

10:30 BREAK

10:45 am **Panel Discussion** (Continued)

12:00 pm LUNCH (on your own)

1:00 pm **Synthesis of Panel Discussion** .... *EPA/ERG*

2:00 pm BREAK

3:00 pm ADJOURN

Workshop on Chemical-Biological-Radiological (CBR) Disposal in Landfills
Seed Questions for Panel Discussion on Day #2

The focus of the workshop is to identify technical issues to be considered when landfilling waste resulting from cleanups from chemical/biological/radiological (CBR) events. Although it might be possible to use an existing landfill or re-open a closed landfill to support the response for the CBR event, this workshop is focusing on what criteria would be used for construction of new landfill capacity to support the response for the CBR event.

Here are a few questions to think about before the workshop that might be used to initiate a productive panel discussion on Day 2.

- Based on projections of the different types of waste that might be generated as a result of the response, are there any considerations that might be waste-specific that could affect the land disposal technology selection?
- What considerations might be needed to address wastes generated during pre-treatment activities that generate residues that will eventually be landfilled (e.g., incineration, autoclaving, solidification, vitrification, etc.)?
- What special design, construction, or operational requirements might be appropriate for different types of contaminating agents?
- What types of routine and long-term monitoring might be appropriate for different types of wastes and for different contaminating agents?
- Thinking outside the box, what type of design and operational criteria/considerations could be identified now to expedite the decision-making for construction of a landfill under an emergency CBR scenario?
- What else can be done as part of the entire spectrum of the waste management process (e.g., segregation, reuse/recycling, volume reduction, treatment, storage, or disposal) that could add to the capacity to operationally recover from a CBR incident?

Workshop Presentation Files

Speaker	Title of Presentation
Juan Reyes	Context of the Problem and Workshop Goals
Craig Dufficy	Existing Requirements and Capabilities for Subtitle C and Subtitle D Landfills and for Landfilling Low Activity Radiological Waste
Susan Thorneloe	Landfill Gas Control
Robert Phaneuf	CBR Landfill Disposal Issues—A NYSDEC Perspective
Wendy Davis-Hoover	Persistence of CB Agents in Landfill Leachate
Mort Barlaz	Fate and Transport of CB Agents in a Landfill
Paul Lemieux	Destruction of Spores in Landfill Gas Flares
David Allard	Disposal of Radiological Wastes in Landfills

U.S. Environmental Protection Agency

CBR Disposal

Context of the Problem and Goals of the Workshop





Juan Reyes
Deputy Associate Administrator
U.S. EPA Office of Homeland Security
June 14, 2011

Background

- EPA tasked with the responsibility for supporting state and local decontamination actions following a CBR attack
  - Statutory / Regulatory / Presidential Directives
- Decontamination actions include waste management
- Waste Disposal Capacity is significant preparedness gaps for CBR threat agents

2

Background

- Volume of waste from a CBR incident depends on a number of factors
- EPA has conducted a number of workshops, exercises , investigation to examine the waste issue
  - Wide Area Anthrax attack – waste estimates
    - 20 million gallons of liquid waste
    - 12 million tons of solid waste
  - RDD Attack – waste estimates
    - Up to 40 million tons

3

Barriers to Disposal

- EPA workgroup to examine the potential barriers to disposal
- EPA workgroup established categories of waste defined by the level of contamination

Category	Definition of Waste
I	Uncontaminated Waste (Solid Waste)
II	Verified Decontaminated/Treated Waste
III	Not Verified Decontaminated/Treated Waste
IV	Contaminated Waste
V	Decontamination Effluent/By-Products
VI	Problematic Waste

4

Barriers to Disposal

- **Regulatory/Statutory**
  - Process-laden and/or unclear regulatory or statutory authority for disposing of CBR threat agent derived waste
- **Policy/Guidance**
  - Missing or insufficient national policy or guidance regarding disposal of CBR threat agent derived waste
- **Technical/Scientific**
  - Gaps in technical or scientific understanding regarding disposal options for CBR threat agent derived waste

5

Barriers to Disposal

- **Socio-political**
  - Community-oriented or stakeholder concerns related to risk associated with disposal of CBR threat agent derived waste.
- **Capacity/Capability**
  - Lack of capacity/capability at treatment/disposal facilities to treat/dispose of CBR threat agent derived waste and a lack of laboratory capacity to effectively characterize the waste.

6

Disposal Workshops

- EPA conducted a series of disposal workshops
  - Wide Area Anthrax Attack Seattle, WA (October 2009)
  - RDD Waste Workshop in Philadelphia, PA (November 2009)
  - Wide Area Anthrax Attack Columbus OH (September 2010)

- Workshop design
  - 3 separate groups
    - Local (Owner/operators)
    - State Agencies
    - Federal Department / Agencies
  - Discussions based on issues raised prior to workshops by participants

7

Disposal Workshops

- Each of the 3 groups identified issues / recommended priority actions
- Issue Areas
  - Regulatory issues
  - Major Impediments
  - Research Issues
  - State and Local Preparedness
- Key Findings
  - Large volumes + scientific uncertainty +public perceptions = Trouble

8


Goal of Today's Meeting
Existing facilities may be inadequate / unavailable in a large scale event
Workshop recommendations to develop an incident-specific state or Federal facility
No policy decision at this time
Critical to examine technical, scientific and policy requirements to be able to:
Site / construct / operate / eventually close landfills
The goal of this workshop is to identify the technical and scientific requirements so that the policy discussions are based on the best available science
9

Resource Conservation and Recovery Act (RCRA)

Overview for the Workshop on Chemical-Biological-Radiological Disposal in landfills

Craig Dufficy

Office of Resource Conservation and Recovery

June 14-15, 2011

RCRA

- **Background**
- **Roles and Responsibilities**
- **Subtitle C - Hazardous Waste**
  - Waste Identification,Waste Standards, RCRA
- **Subtitle D - Solid Waste**
  - Municipal Waste, Non-hazardous Industrial Waste

2

RCRA - Background

- **Authority**
  - RCRA 1976 - enacted to address huge volumes of municipal and industrial solid waste generated nationwide. Basic framework for regulating waste generators, waste transporters and waste management facilities
  - Subtitle C - ensures that hazardous waste is managed safely from generation to final disposal - “cradle to grave” - and encourages minimization and elimination of hazardous waste
  - Subtitle D - encourages environmentally sound solid waste management practices that maximize the reuse of recoverable material and resource recovery

3

Background (cont)

- **Amended Significantly in 1984 Hazardous and Solid Waste Amendments (HSWA)**
  - Lacked confidence in EPA’s ability to develop effective program
  - HSWA extremely detailed & comprehensive: established a prescriptive set of over 70 statutory requirements
  - Added Corrective Action and Land Disposal Restrictions as key program features
  - Tightly controlling and paper-intensive program

4

Roles and Responsibilities

- **Headquarters -** Works in partnership with states, tribes, regulated community, and environmental community.
  - Defines hazardous waste/promulgates and reforms management requirements
  - Provides national direction to Corrective Action and other hazardous waste program implementation
  - Provides risk assessments for waste rules
  - Develops hazardous waste minimization and recycling strategies
  - Issues guidances on non-hazardous industrial waste
  - Provides national leadership for municipal source reduction and recycling; establishes minimum national MSW landfill criteria
  - Defines national data needs and develops and implements national data management program

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Roles and Responsibilities (cont)

- **States**
  - Primary implementers of much of RCRA program
    - 47 of 50 states, Guam and the District of Columbia authorized to administer the hazardous waste base program
    - 38 states and Guam have Corrective Action (RCRA cleanup) authority
    - 50 state municipal solid waste landfill programs
  - Administer and enforce hazardous waste programs where authorized
  - Administer municipal solid waste program, including approval for permitting Municipal Solid Waste landfills

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Roles and Responsibilities (cont)

- **Tribes**
  - Use OSW and regional grants to develop capability on solid and hazardous waste, especially closure of open dumps
- **Regions**
  - Authorize/approve state partners to run waste programs
  - Manage hazardous waste program (including Corrective Action) in states not authorized
  - Provide technical assistance and oversight to states and tribes for hazardous waste and solid waste issues
  - Workload sharing with states - particularly for certain expertise (e.g., combustion risk assessment)

7

Subtitle C: Hazardous Waste - Scope

- **Universe:**
  - 20,000 generating facilities (1 ton or more); 41 million tons hazardous waste annually (excluding wastewaters)
  - Approx. 3,500 industrial facilities w/ Corrective Action obligations. Cleanup similar to Superfund via Corrective Action Program
  - Over 2,750 active facilities including combustion facilities, operating treatment, storage, and disposal facilities (TSDFs) and post-closure facilities from point of generation through transportation, storage, treatment and final disposal

8

Subtitle C: Waste Identification

- Wastes identified as hazardous (and subject to regulation) when they are "listed" or meet "characteristic" criteria - ignitable, reactive, corrosive, toxic - of 41M tons - 23% listed; 54% characteristic; 23% both
- **Listings**
  - Major consent decree obligation
  - Significant resource burden but will scale down as milestones completed
- **HW Recycling**
  - Work with industry on hazardous waste recycling opportunities

9

Subtitle C: Waste Standards

- **Treatment Standards/Land Disposal Restrictions**
  - Provides extra level of protection to ensure that land disposal of hazardous wastes is safe (e.g., mercury doesn't respond to traditional treatment processes - working with ORD, DOE on new treatment methods, associated with Agency mercury strategy)
  - No facilities currently permitted to treat dioxins
- **Combustion Strategy**
  - MACT emission standards for HW burning boilers & furnaces
  - MACT emission standards for HW burning incinerators, cement kilns (per Court)
- **Waste Minimization**
  - Voluntary programs to encourage reduction of HW - especially worst chemicals

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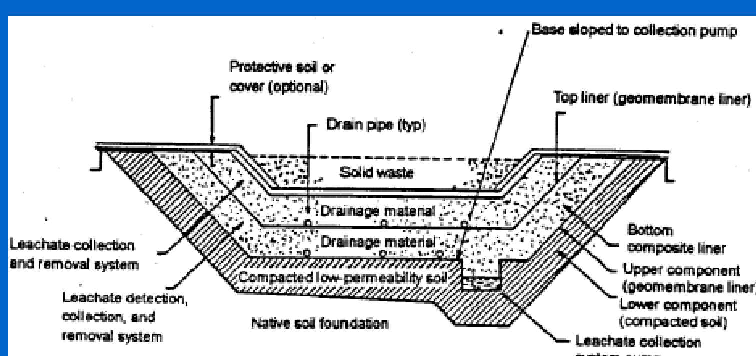
Subtitle C: Design Standards

- In general, geomembrane over a composite liner must be used to prevent a threat to surface or groundwater.
- Leachate collection system installed directly above the geomembrane liner (no more than 30 cm on the geomembrane); leak detection system between geomembrane and composite.
- Segregation of incompatible constituents of hazardous wastes, including separation of solid wastes from liquid wastes.
- Groundwater monitoring wells placed at both upgradient and down gradient of facility.

11

Subtitle C: Design Standards



Cross-Section of a Hazardous Waste Landfill System

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Subtitle C:

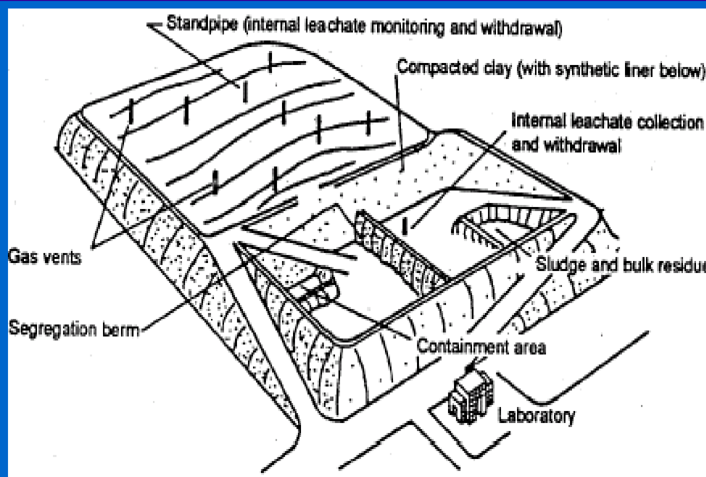

Illustration of a Hazardous Waste Landfill Facility

13

Subtitle D: Solid Waste

- 1980 - Elimination of solid waste as focus shifted to hazardous waste; 1989 - Garbage barge & landfill capacity crisis forced EPA to again address solid waste
- Resources for Subtitle D programs are highly leveraged yet yield strong, positive responses from our stakeholders
- **Universe:**
  - Municipal Solid Waste (MSW) - 230 million tons of generated annually from residences, commercial establishments, institutions and industrial non-process operations
  - Industrial Non-hazardous Waste - More than 70,000 sites; 8 billion tons per year - most from 6 industries: pulp & paper; iron & steel; electric power; inorganic chemicals; stone/glass/clay/concrete; and food
  - Special Wastes - Cement Kilns - 3 million metric tons; Mining and Mineral Processing - 3.4 billion

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Subtitle D: Solid Waste (cont)

- **Municipal Solid Waste (MSW)**
  - National leader for MSW recycling and source reduction programs
    - **WasteWise** - 1,100 partners(businesses, state & local governments and tribes); growth is maintained by leveraging Climate Change resources - availability uncertain from year to year
    - **Pay-as-You-Throw** -economic incentives that residents pay based on the quantity of trash they throw away; since 1994, from 200 to 6000 communities using PAYT
  - Tribal - Support to close open dumps - interagency effort with BIA, IHS, Transportation, Agriculture, etc.

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Subtitle D: Solid Waste (cont)

- **Industrial Wastes**
  - Improve management of all non-hazardous industrial solid wastes; finalizing industrial D guidance
- **Special Wastes**
  - Addressing statutory "Bevill" exclusion for specified waste streams

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Subtitle D: Solid Waste (cont)

- **Designed to ensure that specific concentration values will not be exceeded in the uppermost aquifer at the relevant point of compliance as determined by the Director of an approved State or**
- **Designed with a composite liner- flexible membrane over at least 2 feet of compacted soil with a hydraulic conductivity no more than 2 X 10^{-7} cm/sec**

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Typical design used by states

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Bottom Liners

- Used to protect groundwater from Leachate
- Three types of liners:
  - Single
  - Double
  - Composite (Synthetic Geomembrane liner/Clay or low permeability soil)

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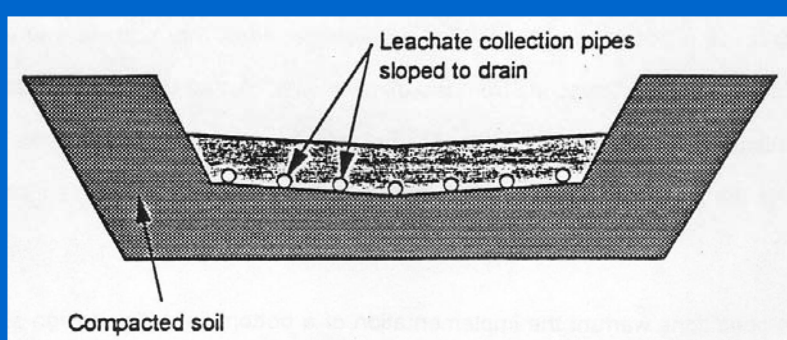
Single Liner



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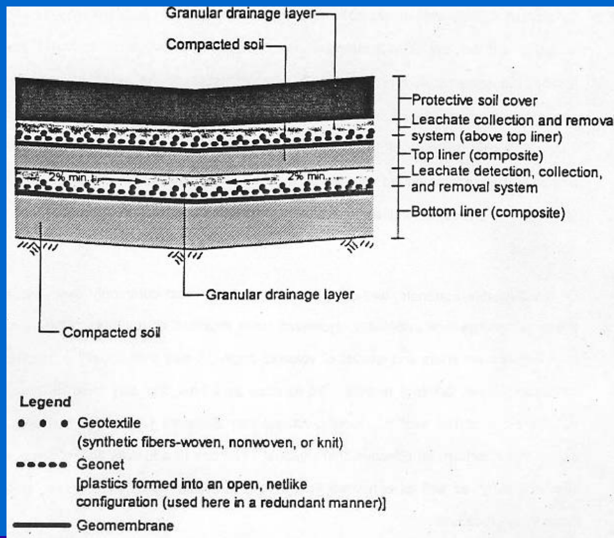
Double Liner



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Composite Liner

Comprised of two dissimilar materials usually a synthetic geomembrane placed directly on top of a clay/ low permeability soil.

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Subtitle D-Landfill Covers

- The final cover serves to limit the inflow of water into the fill from outside sources (precipitation)
- And to reduce the expense of long term care and to reduce adverse environmental inpacts while
- Promoting productive use of the closed landfill.

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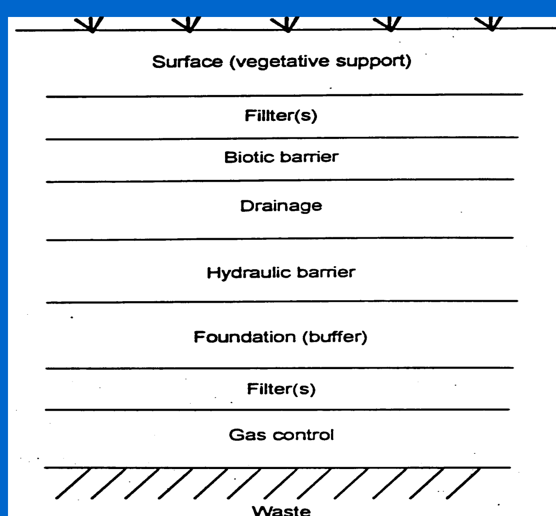
Components of a Cover System



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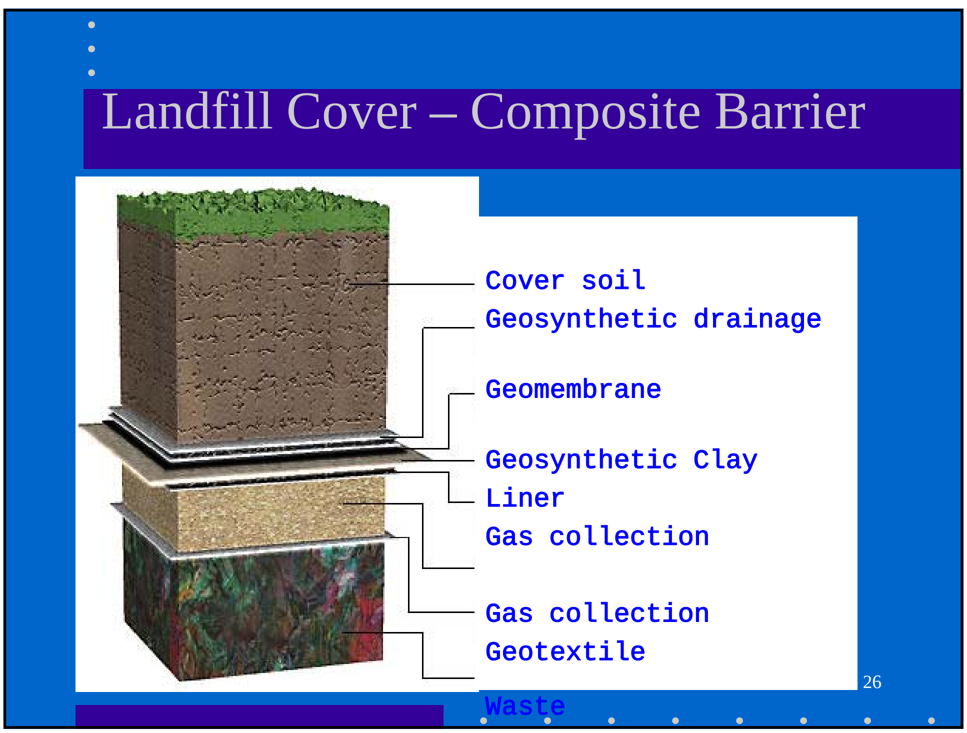
Landfill Cover – Single Barrier
Cover soil
Geosynthetic
drainage
Geosynthetic Clay
Liner
Gas collection
Geotextile
Waste
25


Landfill Cover – Composite Barrier
Cover soil
Geosynthetic drainage
Geomembrane
Geosynthetic Clay
Liner
Gas collection
Gas collection
Geotextile
Waste
26

Lessons Learned on Debris Management

The key elements for pre-event planning are:

1. Pre-planning activities
2. Ancillary activities-
   - a. Identify likely debris types and forecast amounts
   - b. List applicable federal, state, and local environmental regulations
   - c. Inventory current capacity for debris management and determine debris tracking mechanisms
   - d. Pre-select temporary debris storage sites
   - e. Identify equipment and administrative needs (including pre-negotiated contracts)

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Lessons learned on Debris Management (con't)

- f. Develop communication plan
- g. Create a disaster debris prevention strategy

3. Create a debris removal strategy
4. Harmful materials identification and handling recommendations
5. Recycling options
6. Waste-to-energy options
7. Disposal options
8. Open burning options

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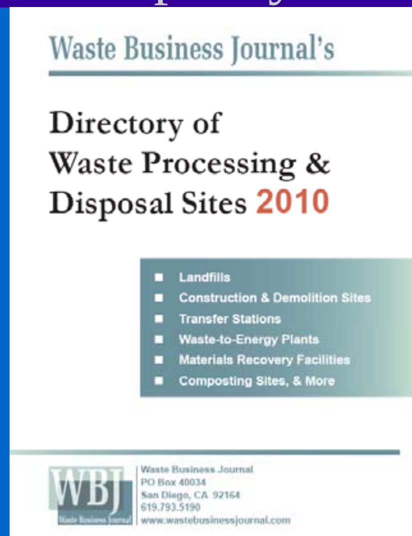
Current Capacity Inventory



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Current Capacity Inventory

30

Current Capacity Inventory- Joplin, MO

31

Current Capacity Inventory


Directory of Waste Processing & Disposal Sites

MISSOURI

PROCESSING FACILITIES

Heritage Environmental Services, LLC

J.T. Brown Enterprises Processing Facility TS

Jackson Material Recovery and Transfer Station LLC

Jackson Solid Waste Transfer Station

PROCESSING FACILITIES

Jefferson County Transfer Station

Joplin Transfer Station

Kingdom Projects Inc

Kraemer Hauling Transfer Station

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Current Capacity Inventory

Joplin Transfer Station

1599

O-58

Location: 3700 West 7th Street, Joplin, MO (Jasper County) — **Map Code:** MO-61
Days & Hours: Mon-Fri 8am-3:30pm
Facility Access: Highway
Avg. Daily Intake: MSW: 201 Tons/Day
Waste Shed: County/Metro.

Owner & Operator: (Private) WCA Waste Corporation (WCA)
Mr. Tim Meier
Title: Operations Manager
Dept./Div.: Joplin Transfer Station
3700 West 7th Street, PO Box 1667
Joplin, MO 64801
Phone: (417) 623-6620
Fax: (417) 623-8238

Avg. Tipping Fee: MSW: $43.00 /Ton
Permit Number: 0409701
Wastes Accepted: C&D, MSW, Recyclables

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Conclusion

Effective disaster debris management has far wider implications in disaster response and recovery than is currently recognized. There is real social, economic and environmental value in planning for the management of disaster debris. It is not just a logistical exercise – it is an integral part of the disaster recovery process.

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Landfill Gas Control

Susan Thorneloe
U.S. EPA/Office of Research and Development

Office of Research and Development
National Risk Management Research Laboratory
Air Pollution Prevention and Control Division

Workshop on CBR Disposal in Landfills
June 14-15, 2011

Outline

- Health and environmental concerns
- Update on Clean Air Act regulation for MSW Landfill air emissions
- Ongoing research to reduce uncertainties associated with quantifying landfill gas emissions
- Conclusions

1

Background

- Over 1650 active municipal solid waste (MSW) landfills as well as several thousand closed landfills.
- MSW landfill refers to entire disposal facility where waste is placed in or on land. Waste landfilled includes
  - Household waste
  - RCRA Subtitle D waste
  - Industrial waste
  - Small quantity generator hazardous waste
  - Disaster-generated waste and debris
  - Special wastes

- Landfill gas is comprised of ~50/50% methane and CO_2 with traces constituents that include GHGs, hazardous air pollutants (HAPs), persistent bioaccumulative toxics (PBTs), H_2S, H_2, and volatile organic compounds (VOC).

Background (Cont.)

- Once waste is deposited in a landfill, emissions are generated for decades.
- Most immediate concern is for the explosive potential of the gas.
- Landfill fires can occur resulting in combustion by-product emissions of concern to human health and the environment.

Trends Impacting Landfill Gas (LFG) Emissions in the U.S.

- Most large landfills have gas collection and control
- Expect continued reliance on landfills for waste discards
- Changes in landfill design and operation such wet/bioreactor operation. Could lead to increased emissions if there is
  - Delay in gas control from onset of liquid additions such as adding liquid to work face
  - Use of alternative covers or porous materials to promote infiltration
  - Incorrect sizing of gas capture and control technology, and
  - Flooding of gas wells due to leachate build up.

4

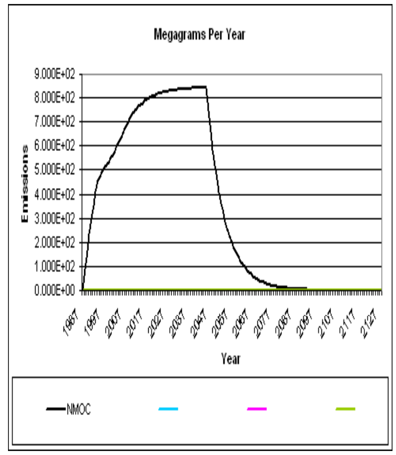
Trends Impacting LFG Emissions in the U.S. (Cont.)

- Changes in waste composition due to
  - Implementation of recycling & source reduction programs
  - Potential increase in metals due to addition of leachate, sewage sludge, treated wood, and industrial waste
- Potential increased exposure due to urban sprawl and wider use of landfills for recreation or development

5

Modeling LFG Emissions

- Use 1st order decomposition rate equation to predict emissions over time.
- Released software for developing emission estimates - EPA's Landfill Gas Emission Model (LandGEM) (Vsn 3.02)
- Different values are recommended in modeling emissions depending upon the use of the estimate
- Defaults for model inputs based on analysis of gas recovery data



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Measuring LFG Emissions

- For area source emissions including landfills, EPA recommends use of optical remote sensing based on EPA OTM10.
- Because of the complexity of measuring LFG emissions, EPA is developing additional guidance for landfill applications of OTM10.
- Recent field test conducted at three MSW landfills to compare fugitive methane loss to header pipe gas. Results in an EPA report
  - will be released within the next few months
  - suggest that gas collection efficiency can from 30s to 80s%
- Current EPA guidance for gas collection ranges 60 to 90% with being 75% the average.

7

MSW Landfill Regulations

- New Source Performance Standards (NSPS) and Emission Guidelines (EG)
  - Large landfills ≥ 2.5 million Mg design capacity
  - Control of landfill gas is triggered by emissions of non-methane organic compounds (NMOC), the trace organic compounds in landfill gas
  - Emission threshold: 50 Mg NMOC must collect and control or treat LFG
  - 30 months to design and install controls
  - Must control gas within 5 years for active cells and 2 years for closed or inactive cells
- National Emission Standards for Hazardous Air Pollutants
  - Requirements similar to NSPS and EG
  - Added procedures for start-up and shutdown as well as timely control of bioreactors

Landfill Gas Capture and Control

- Area source emissions – with temporal and spatial variability.
- Effective gas capture requires maintenance and monitoring over time of the cover material, gas well field and header pipes, and combustion technology.
- When landfill gas is collected and controlled, combustion by-products are formed.
- Even the best landfill gas capture and control systems do not collect all of the gas that is generated.

9

United States Environmental Protection Agency

Crack Found on Slope of landfill

10

United States Environmental Protection Agency

Crack Observed at LFG Well Head

11

Technology Options

- Open Flare
  - Consists of method of regulating gas flow, pipe for pumping gas and pilot light
- Closed flare
  - Considered more efficient than open flare
  - Series of burners within fire resistant walls, maintains peak temperature through limited supply of combustion air
- Achieves at least 98% destruction efficiency of NMOC or meets mass emission rate cutoff (20 ppmv, dry basis, expressed as hexane at 3% O_2)
- Often used at landfills with energy recovery operations for combustion of excess gas and use when equipment is off-line

Technology options that recover energy from LFG

Disclaimer

- This research has been subject to Agency review but does not necessarily reflect the views of the Agency. No official endorsement should be inferred.

14

Questions?

Clean Air Act regulatory contact:

– Hillary Ward, USEPA/OAR/Office of Air Quality Planning and Standards-RTP

Ward.Hillary@epa.gov

Landfill gas research contact:

– Susan Thorneloe, USEPA/ORD/NRMRL-RTP

Thorneloe.Susan@epa.gov

CBR Debris Disposal Landfilling Issues
A NYS DEC Perspective

<u>US EPA Workshop on Landfill Design for CBR Disposal</u>
June 14-15, 2011
Washington, DC

NYS's Landfill Status

Liner Performance Overview

Overview of NYS LF Design & Operational Requirements

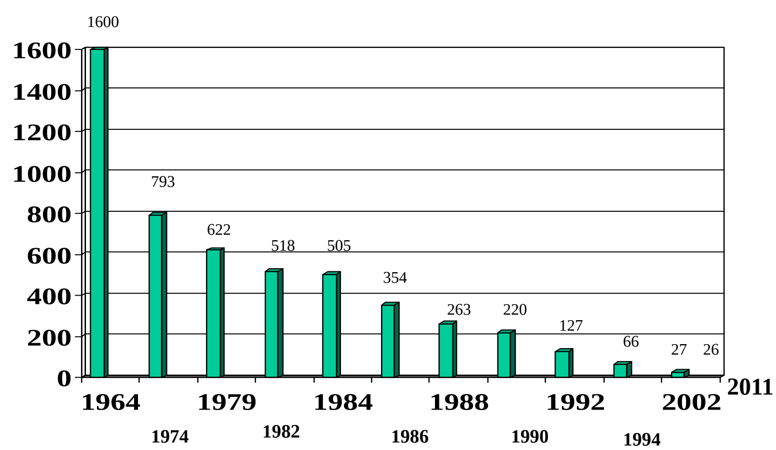
NYS's Approach to Landfill Design, Construction, Operation and Performance Monitoring and how that may be different for CBR Debris Disposal

Robert Phaneuf, PE
NYS DEC
Division of Materials Management
Albany, New York

Phone: (518) 402-8652
E-mail: rjphaneu@gw.dec.state.ny.us

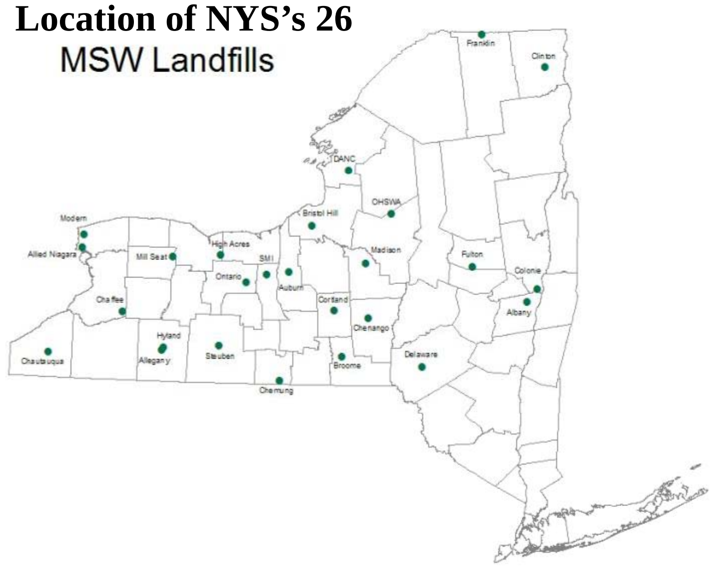
Attrition of NYS MSW Landfills

Number Of NYS MSW Landfills



Year

Location of NYS's 26 MSW Landfills



Remaining Site Life at Active MSW Landfills

The Department posts the annual reporting data that is collected pursuant to the State's solid waste regulations on the Department's ftp site. The direct link to this annual report data is:

ftp://ftp.dec.state.ny.us/dshm/SWMF/

MSW Landfill	Existing Annual Permit Limit (tons/yr)	Existing & Entitled Capacity (tons)	Site Life > 2008 (Years)	Percent of Total Landfill Capacity
0-10 Years				
Albany	275,100	478,351	1	6
~~Sullivan*~~	~~226,000~~	~~140,130~~	~~1~~	
Chautauqua	408,000	2,243,724	2	
Allegany	56,680	249,600	4	
Franklin	125,000	574,861	7	
Ontario	1,200,000	7,349,795	7	
Auburn	96,000	761,301	8	
Chemung	120,000	1,243,383	8	
11-30 Years				
Mill Seat	598,650	6,893,846	11	49
DANC	346,320	3,505,060	12	
Allied Niagara	800,000	9,242,609	13	
Colonie	170,500	4,004,593	15	
Steuben	151,000	2,422,279	15	
Chaffee	600,000	6,084,000	17	
Hyland	312,000	7,708,367	17	
SMI	1,866,000	37,611,560	17	
Clinton	175,000	7,644,201	20	
Delaware	52,800	508,111	20	
Modern	815,000	22,140,000	24	
Cortland	44,500	709,513	28	
31-50 Years				
High Acres	1,074,500	44,400,000	41	26
Chenango	41,550	1,104,009	42	
Broome	232,000	10,554,066	50	
51-100 Years				
Bristol Hill	100,000	3,352,607	60	16
Fulton	134,000	9,450,845	63	
OHSWA	312,000	21,388,497	67	
100+ Years				
Madison	61,000	7,769,992	106	4

[shaded box] Denotes Self-Sufficient or Limited Service Area MSW Landfills

*** The Sullivan Landfill Closed in 2009.**

Electrical Resistivity Testing

(as part of construction specifications)

Select Projects Since 2004

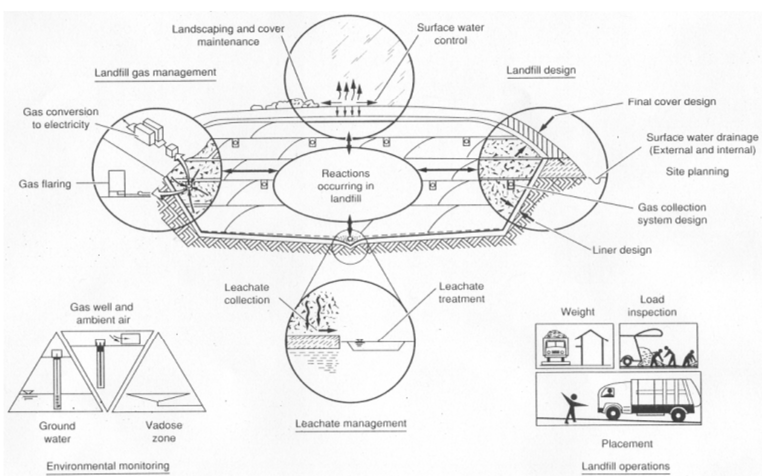
- Case 1 - 13 defects/**9.85 acres** = **1.3 defects/acre** *(3 defects found at pipe penetration)*
  Const Cert 30-day ave start-up ALR = 6.4 gpad
- Case 2 - 2 defects/**5.52 acres** = **0.4 defects/acre**

Typical LF Cell being built in NYS is about 10–12 acres. If everything goes well can typically be built in 1 construction season.

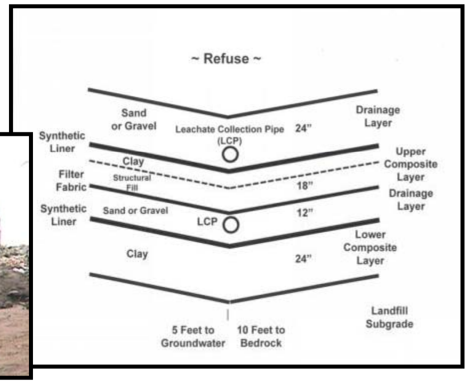
- Case 3 - 4 defects/**6.9 acres** = **0.6 defects/acre**
  Const Cert 30-day ave start-up ALR = 0.48 gpad
- Case 4 - 27 defects/**13.35 acres** = **2 defects/acre**
  Const Cert 30-day ave start-up ALR = 5.8 gpad (average for 3 new cells)
- Case 5 - 4 defects/**5.05 acres** = **0.8 defects/ acre**
- Case 6 - 109 defects/**23.6 acres** = **4.6 defects/acre**
  Const Cert 30-day ave start-up ALR = 6.08 gpad (average for 3 new cells)
- Case 7 - 11 defects/ **7.7 acres** = **1.4 defects/acre**
  Const Cert 30-day ave start-up ALR = 5.06 gpad

Some Start-up ALRs still suffer slightly from: Excessive Construction Water; Problems with Pipe Penetrations; and, Upper & Lower Liner "Edge" Seams.

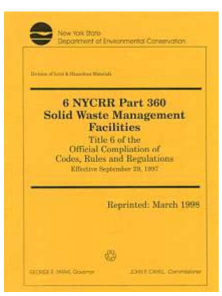
Conventional Modern Landfill Concepts



NYS Modern Landfill Operations - Plus



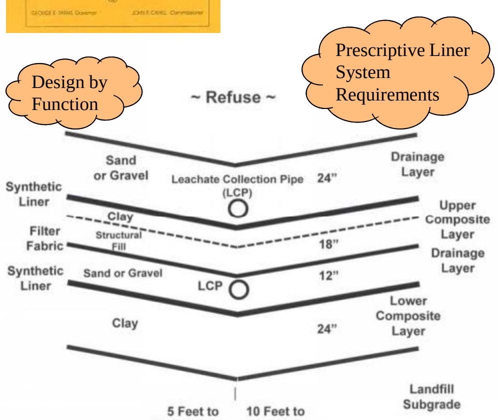
- **Over 37 Active Double Lined Landfills in NYS** ***(some in operation since1987)*** No known GW impacts to date from the double-lined part of these Landfills
- **Attention to detail during construction** = proper containment system performance.
- **Attention to Upper Liner Performance Monitoring during operation =** proper regulatory/permit compliance & containment system performance.


New York State Department of Environmental Conservation
6 NYCRR Part 360
Solid Waste Management Facilities
Title 6 of the Official Compilation of Codes, Rules and Regulations
Effective September 29, 1997
Reprinted: March 1998

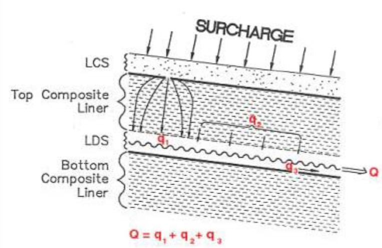
NYS's regulations require upper liner system performance monitoring as a **barometer** of the LF's leachate collection and removal system's effectiveness/condition.

A proactive function for ensuring adequate GW protection.

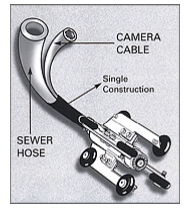
Req'd max 30-day ave ALR of <u>20 gpad</u> for the upper liner system

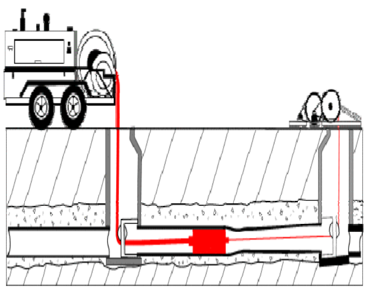


Top Composite Liner Performance Monitoring



Maintenance of LCRSs to Ensure Acceptable ALRs





Leachate Management Related Problems Experienced at NYS Landfill

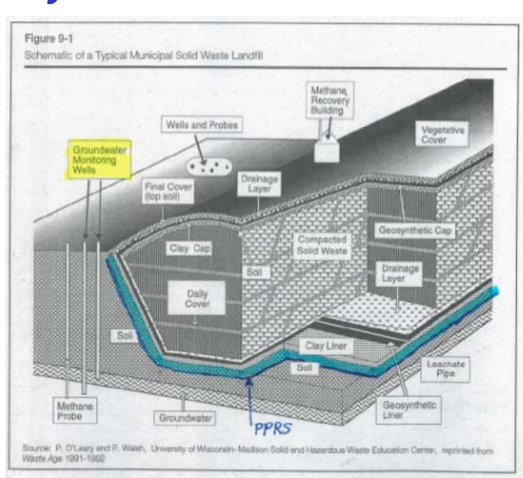
2003 NYS LF Survey

- Operational LCRS Problems
  - Drainage Layer/GT Clogging
  - LCRS Pipe & Sump Clogging
  - Flow Meter Problems
  - LF Side-slope Surface Seeps
- Design Related LCRS Problems
  - Inadequate access for maintenance
  - Confined space (more of a concern)
  - Sump Design

Operator Observation: Simple gravity systems worked well. Need for flow monitoring, and concern for liner penetrations, and deeper landfills caused sump systems to evolve to be the norm.

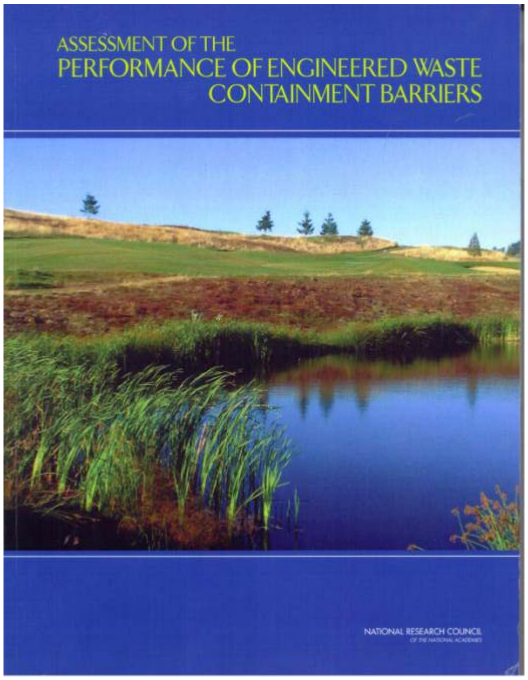
Groundwater Monitoring Data Supporting Liner System Effectiveness

- NYSDEC has GW monitoring data from 37 separate double-lined landfills, some since 1988 or longer. These landfills collectively possess GW monitoring data from monitoring over 1,000 lined acres lined disposal facilities.
- Approximately 65% of the 37 double-lined landfills (74% of MSW LFs) have a **pore pressure relief systems** that are routinely monitored for GW quality.
- **No GW impacts attributed to release from the engineered barrier system!!!**



Do GW Monitoring Systems Work ? YES

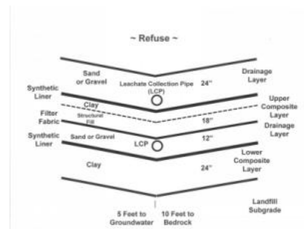
GW impacts are detected from leaking conveyance lines outside the liner system and other GW impacts from adjacent operations or spills outside the disposal areas.



2006 - National Academies of Engineering Science – Performance of Post-RCRA C & D Engineered Barrier Systems (EPA, DOE, NRC, & NSF)

Report concludes that while a containment system's individual components may fail. However, notes that the overall performance of the entire containment "system" is robust and that engineered systems work.

Maintenance is and will always be necessary to ensure long-term performance.



Should the Minimum Regulatory Standards for a CBR Landfill be any different from what we require for a typical MSW landfill ??

Application Processes – Community Outreach – EJ Policies
Siting Requirements
Prescriptive Liner Systems - Double-liner Systems
CQA & Construction Certification Approval Prior to Operation
Comprehensive Environmental Monitoring
Waste Characterization
Operational Controls
Corrective Measures
Closure and Post-Closure Care & Maintenance
Long-term Institutional Controls

Part 360 Landfill Permit Application Requirements

Engineering Drawings

Plans and Drawings
Engineering Drawings – construction plans…
Operational Drawings – fill progression plans – first waste lift…
Landscape Plans – end use, stormwater mgt plans…

Engineering Report

Detailed Site Description and Analysis – siting, waste characterization
Geotechnical Stability Analysis – waste densities and other properties
Subbase Settlement Assessment Analysis
Seismic Stability Analysis – use latest seismic hazard maps
Leachate Collection and Removal System Design – hydraulic, structural, …
Leachate Storage Facility Design
Facility Closure and Post-Closure Design – service life of liner system components

PVC geomembranes in caps already being replaced – after 20+yrs

Supporting Documents

Erosion and Sediment Control Plan
Construction Quality Assurance/Quality Control Plan
Facility Operation and Maintenance Manual
Comprehensive Environmental Monitoring Plan
Contingency Plans
Preliminary Closure Plan

6 NYCRR Part 360-2 Landfills at this web link for the current version of the State's landfill regulations: http://www.dec.ny.gov/regs/2491.html

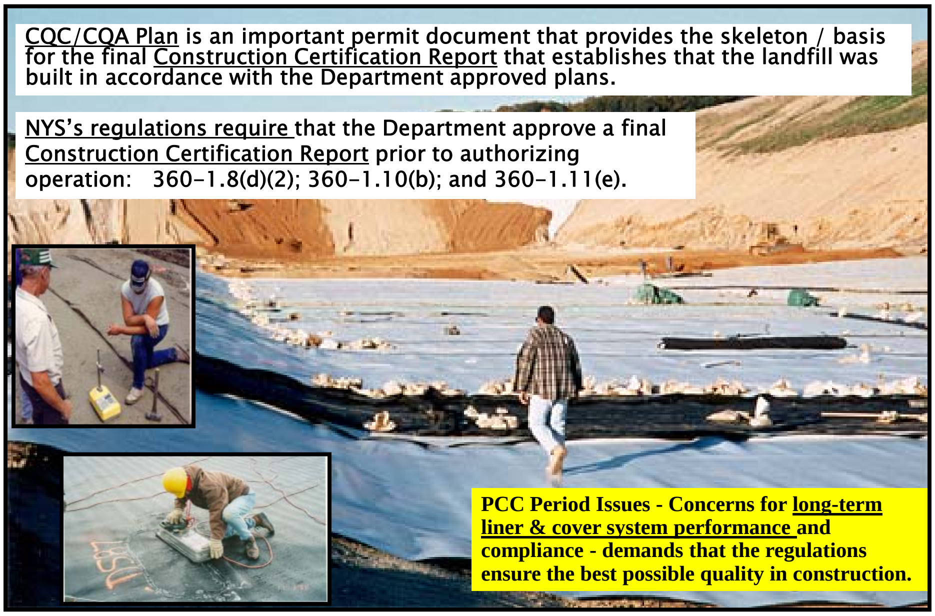
Part 360 Facility Operation & Maintenance Manual

(a) LF Disposal Methods
(b) Personnel Req'ts
(c) Machinery & Equip Description
(d) LF Operational Controls
(e) Fill Progression Plans
(f) Waste Amounts & Characterization
(g) SW Receiving Process
(h) Cover Mat'l Mgt Plan
(i) EMP
(j) Leachate Mgt Plan
(k) Odor Control Plan
(l) Gas Monitoring Plan
(m) Inclement Weather Plan
(n) Convenience Station Operation
(o) First Lift Placement
(p) Fire Prevention Plan

CBR Issues

- Are debris staging areas needed?
- How is CBR debris being transported, handled?
- Equipment differences ?
- PPE, Exclusion Zones, DeCon areas for equipment & personnel ?
- DeCon water mgt ?
- Operational restrictions?
- Leachate generation, storage & treatment concerns?
- Could treatment barriers be pre-designed ?
- LF gas collection and emission/dust control sensitivities?
- Climate controlled working environment?
- Added vermin/vector control issues ?
- Security issues ?

CQC/CQA Regulatory Refresher



CQC/CQA Plan is an important permit document that provides the skeleton / basis for the final Construction Certification Report that establishes that the landfill was built in accordance with the Department approved plans.

NYS's regulations require that the Department approve a final Construction Certification Report prior to authorizing operation: 360-1.8(d)(2); 360-1.10(b); and 360-1.11(e).

PCC Period Issues - Concerns for long-term liner & cover system performance and compliance - demands that the regulations ensure the best possible quality in construction.

Survey Data on Occurrence of Liner Defects

Nosko (1996)

Preliminary Construction Phase
(Geomembrane installation)

24 %

Final Construction Phase
(Drainage/protective soil placement)

73 %

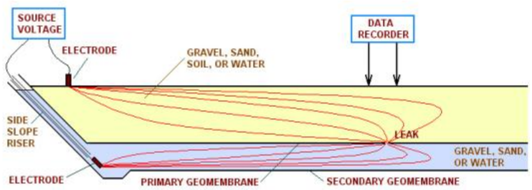
97% of defects are construction related !

Post-Construction, Early Operational Phase
(Waste placement)

2 %

Improved Construction Quality Requirements In the Proposed Regs

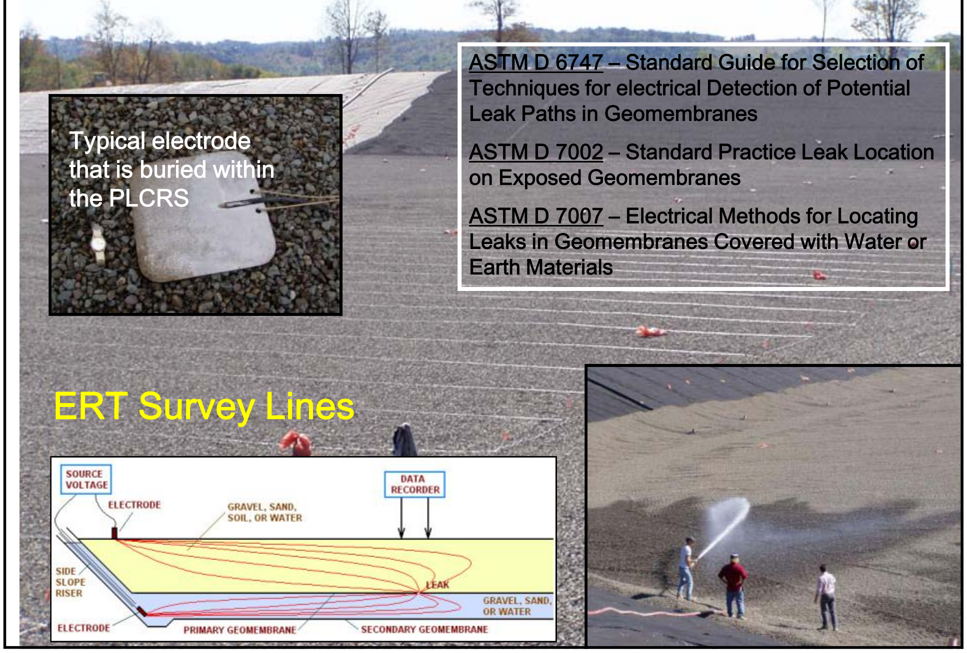
- **Proposed regs will require "Electrical Resistivity Testing" after placement of the soil drainage media on both upper & lower liners where slopes are 10% or less, will require written findings report as part of Construction Certification Report.**



"This method is considered by the Geosynthetic Institute (GSI) to be the ultimate diagnostic method to assure an environmentally safe and secure geomembrane liner system."

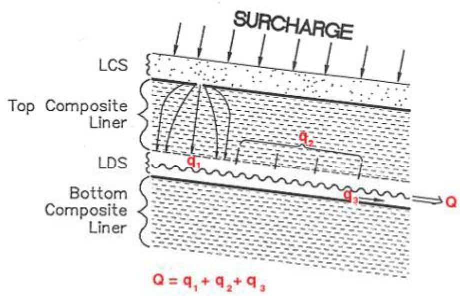
- **Decrease destructive seam testing frequency to one every 1000'contingent on acceptable performance and in areas where slopes are 10 % or less, destructive seam testing may be optional if approved by the design engineer via assurance demonstrated in the CQA Plan that field seam strength is otherwise being adequately addressed for this area.**
- **Required geomembrane installer certification, enhanced attention to qualifications and the numbers of CQA inspection staff needed on-site.**

The Broome County 2002 ERT (Liner Integrity Survey)



How Well Are New York State's Double-Lined Landfill Designs Working ?

Top Composite Liner Performance Monitoring



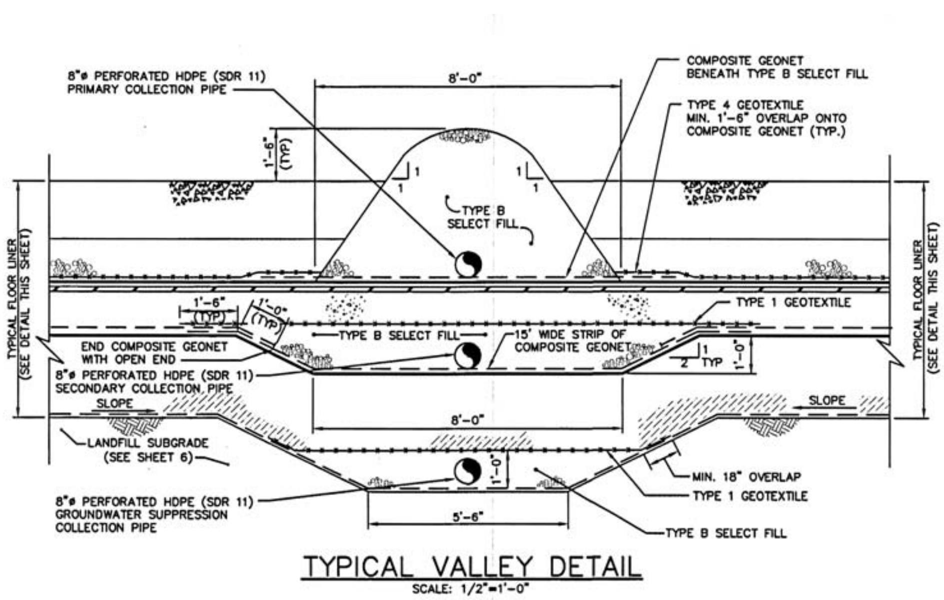
From 2009 Annual Reports

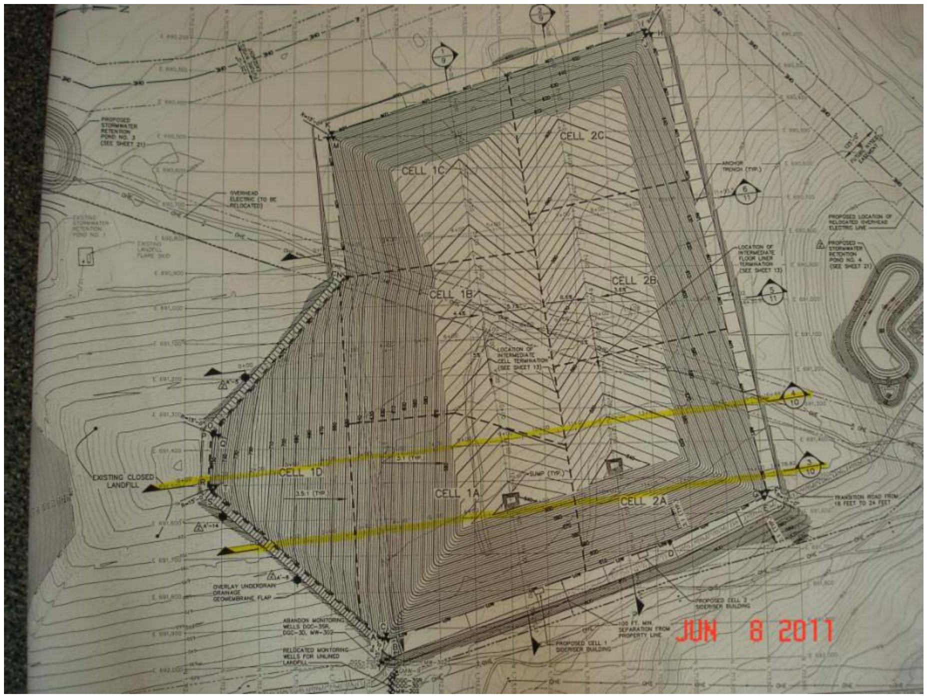
(data on 31 Landfills)

Primary LCRS Flows:
Max: 9,249 gpad; Min: 233 gpad;
Mean: 1,281 gpad

Secondary LCRS Flows:
Max: 30.63 gpad; Min: 0.40 gpad;
Mean: 5.96 gpad

Upper Liner System Efficiency:
Max: 99.98 %; Min: 95.64 %;
Mean: 99.28 %

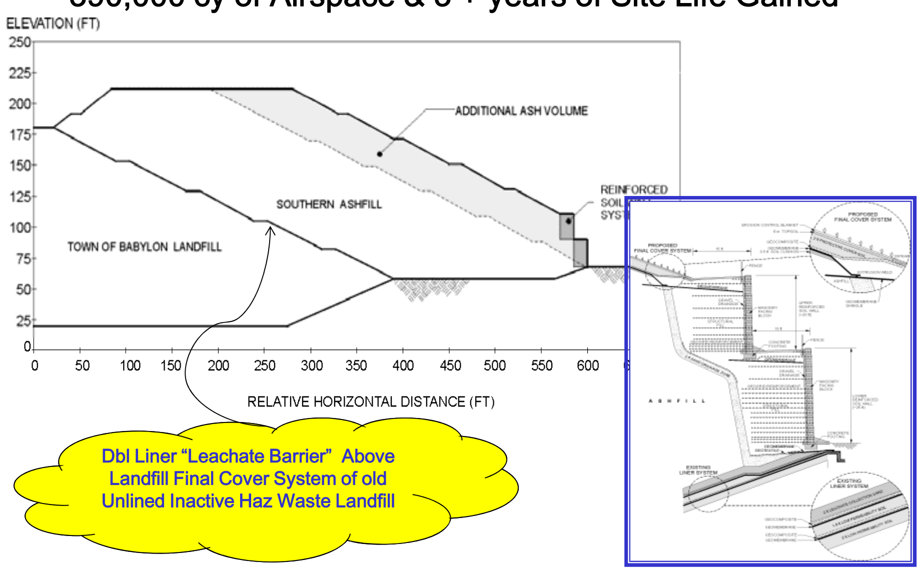


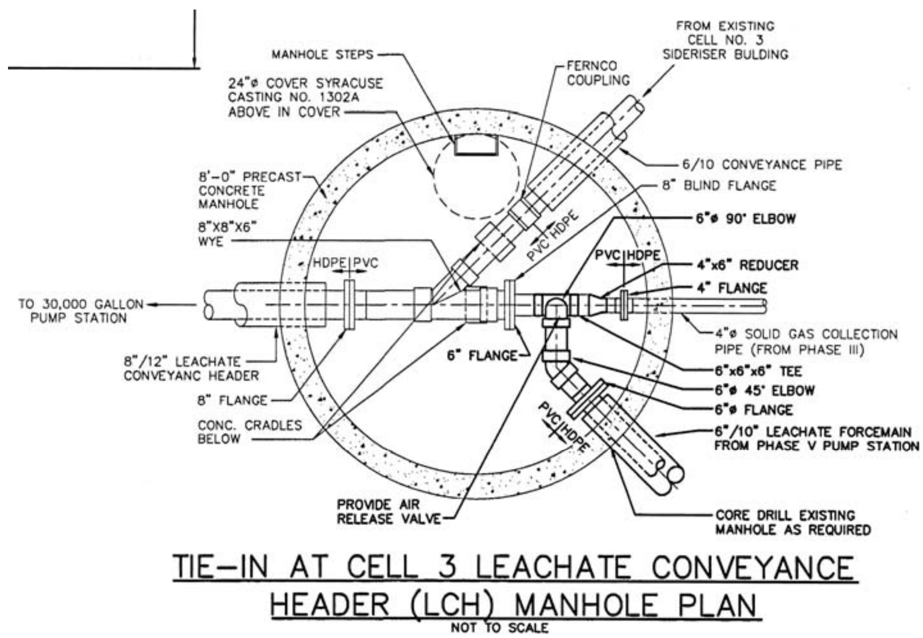


Town of Babylon Ashfill Vertical Expansion

An Innovative Landfill Project

390,000 cy of Airspace & 3 + years of Site Life Gained





2001: 56 Buildings in 9 States and Washington DC Impacted by Anthrax Letters

Other Impacts:

- **Twelve cases of cutaneous (skin) anthrax**
- **Eleven cases of inhalational anthrax & five deaths**
- **Testing of**
  - **- 125,000 clinical samples**
  - **- >1 million environmental samples**
  - **- postal facilities in 34 states tested**
- **Billions of dollars in restoration costs**
- **Disposal of tons of contaminated waste**

2001 NYC Anthrax Cases – 5 Manhattan Locations

Media offices, postal facilities and residences (not shown) contaminated directly or through secondary contamination.

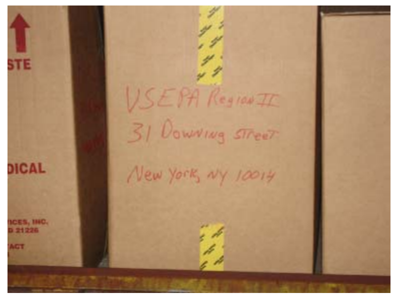
2006 Anthrax Incident
31 Downing Street Set Up





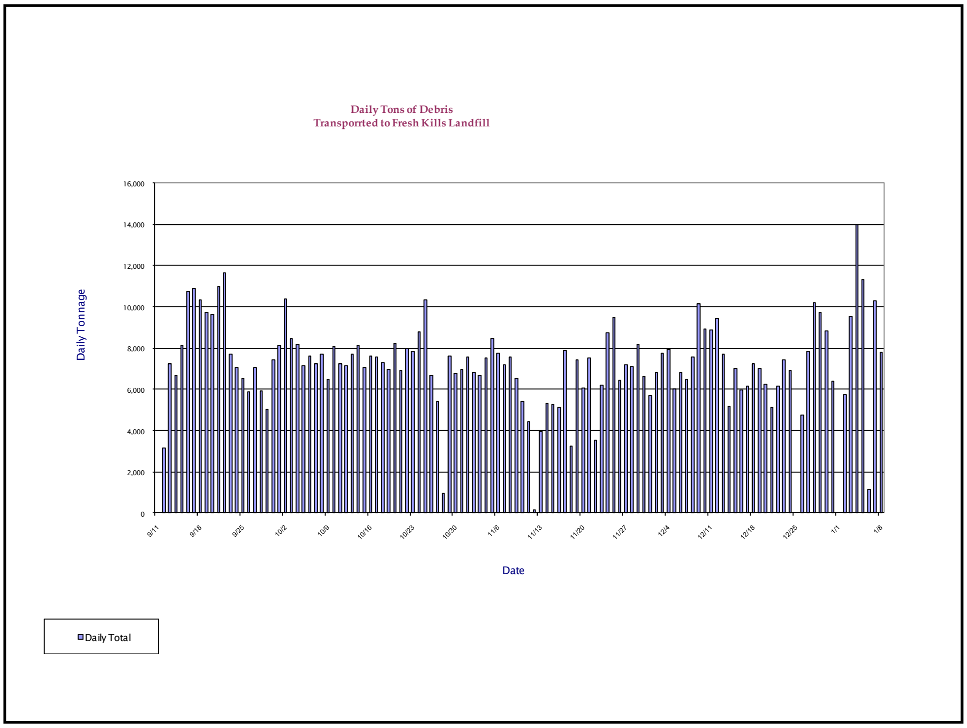

31 Downing Street Cleaning & Disinfection

Loading Waste on the Truck to Treatment



B-25 Boxes for "Rad" Related Material Shipping and Disposal

WTC Debris variety required multiple transport options.



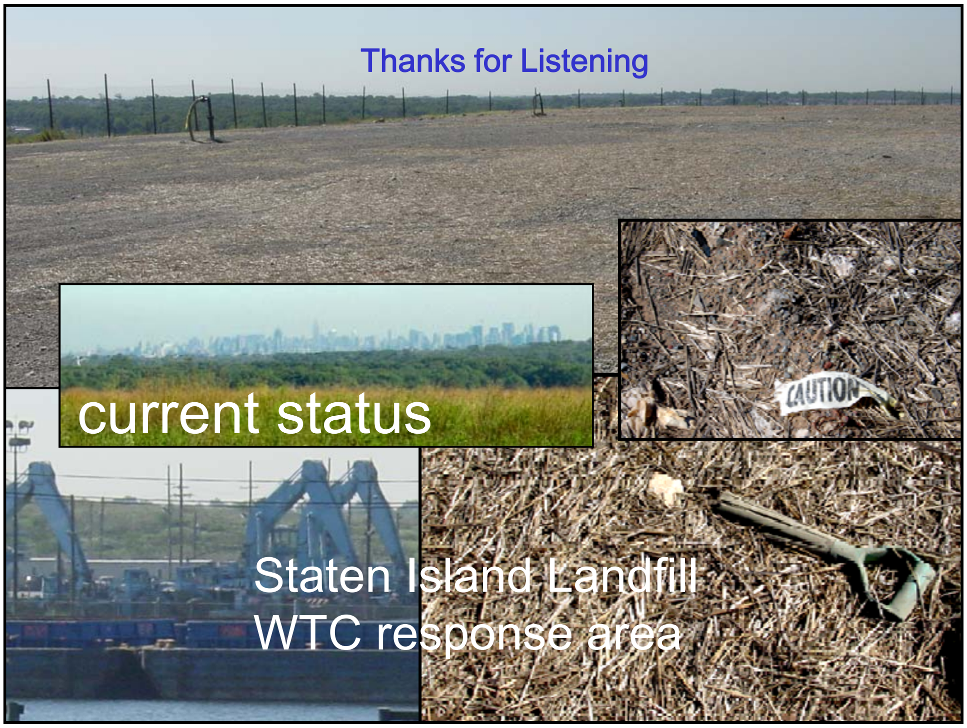
Section 1/9 of the Staten Island Landfill offered a 200 ± acre relatively flat, secure area for WTC debris (evidence) screening.


EXCLUSION ZONE
DO NOT ENTER WITHOUT PROPER PPE:
NO EATING, DRINKING OR SMOKING

WTC Debris Management Statistics at the Landfill

(as of 7/29/02 from our files)

Total Man Hours at LF:	1,723,228 hours
Total WTC Debris Rec'd at LF:	1,460,889 tons
Total Steel Recovered From LF:	190,568 tons
Total amount of WTC deposited at LF:	1,275,171 tons
No. of WTC Vehicles Processed Out of LF:	1358


Thanks for Listening
current status
CAUTION
Staten Island Landfill
WTC response area

Persistence of CB Agents in MSW Landfill Leachate

Washington DC
June 14 2011

Wendy Davis-Hoover, Ph. D.

Homeland Security Related Contaminated Building Debris

Example: 2001 Anthrax Letters

- 5 letters mailed
- 23 confirmed cases of anthrax
  - 11 inhalation, 5 fatal
  - 12 cutaneous
- Contaminated 56 buildings in 10 States and Washington DC

Figure Courtesy of Thea McManus, US EPA

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Hart Senate Office Building Cleanup

Solid waste	166 tons	Ft. Detrick (Incineration)
Liquid waste	15000 gallons	Ft. Detrick (Sterilization)
Steel drums	600	Micro-Med (Autoclave)

Figure Courtesy of Thea McManus, US EPA

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Landfill Cover Design

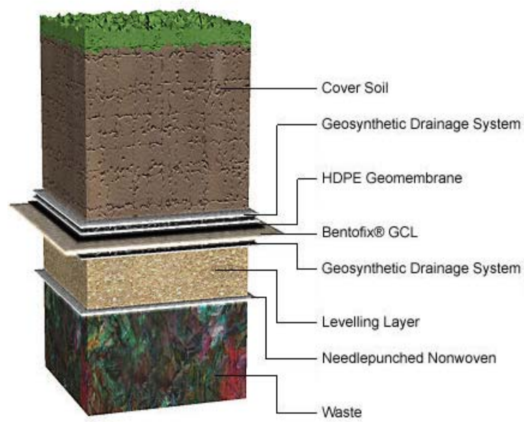

Figure Courtesy of Naue Fasertechnik

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Project Purpose

- Can agent contaminated building debris be safely stored or detoxified in MSW landfill?
  - Will agents survive in leachate?
    - How long?

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Sampling of Agents

Month	Frequency
1-2	Every 7 Days
3-7	Every 14 Days
8-12	Every 30 Days

. Sampling will be altered if statistical analysis of the data show merit in more or less frequency.
. Sampling is terminated when two consecutive sampling periods result in no detects in all replicates.

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Assumptions Made

- Triplicate leachate microcosms will allow us to understand the world.
- 3 ml microcosms will mimic anaerobic conditions of landfills.
- Incubate at 12 °C with bacteria and also run at body temperature (37 °C).
- Agents will always encounter undiluted leachate before release.

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Bacterial Methods

Bacteria	Culture Media	Incubation Temperature	Incubation Time
Bacillus anthracis Spores	Polymyxin Lysozyme EDTA Thallous-Acetate	37^0C	24 hours
Yersinia pestis	Yersinia Selective	28^0C	48 hours
Francisella tularensis	Chocolate	35^0C	3-5 days
Clostridium botulinum	Phenylethanol Anaerobically	37^0C	48 hours

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Hypotheses

- Bacterial spore formers will survive.
- Facultative anaerobic bacteria will survive longer than aerobic bacteria.
- Viruses will survive.

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RESULTS

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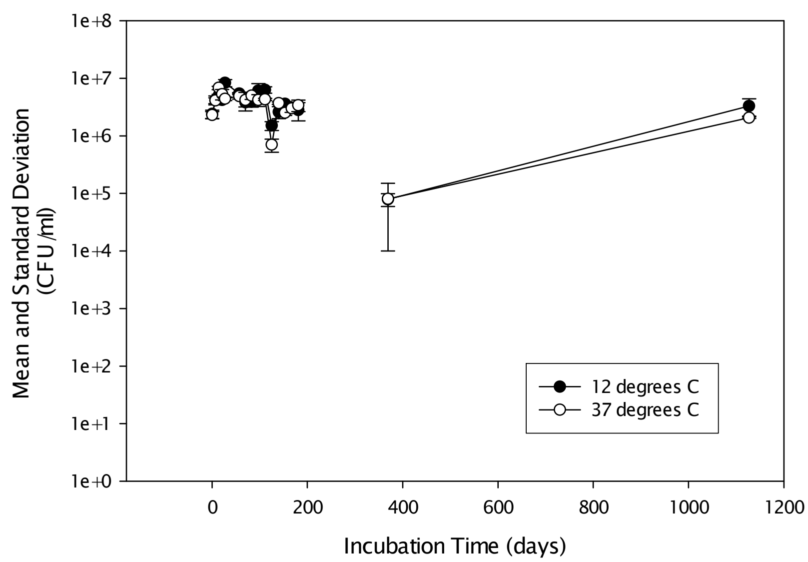
Bacterial Weapons Summary

Little Difference in Results between 12 and 37 °C

	Hypothesis	Data
Francisella tularensis	Persist	Die < 20 Days
Yersinia pestis	Persist	Die < 20 Days
Clostridium botulinum	Persist	Persist >1113 Days
Bacillus anthracis	Persist	Persist > 1127 Days

B. anthracis spores



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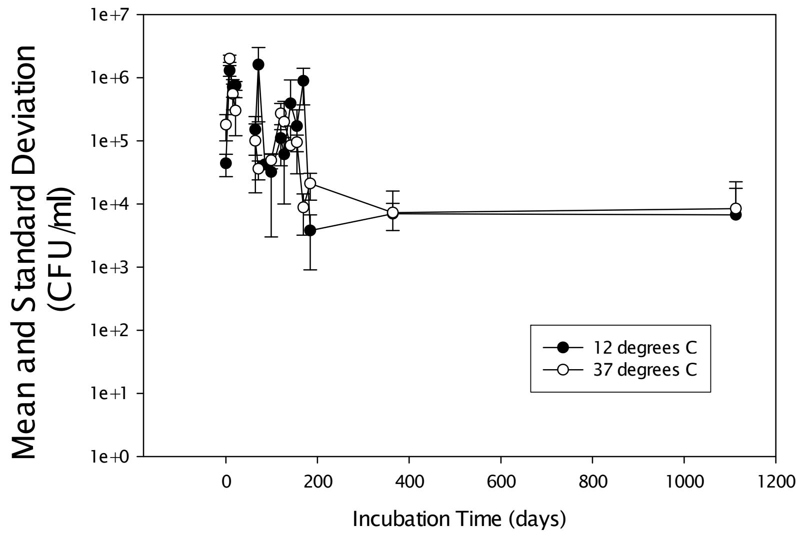
Clostridium botulinum



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Viruses in Landfills ?

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Homeland Security Research

Chemical Agents

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Homeland Security Research

Sampling of Agents

Month	Frequency
1-2	Every 7 Days
3-7	Every 14 Days
8-12	Every 30 Days

. Sampling will be altered if statistical analysis of the data show merit in more or less frequency.
. Sampling is terminated when two consecutive sampling periods result in no detects in all replicates.

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Chemical Analytical Methods

All extracted by USEPA 3500 series method

Analyte	Primary	Secondary
Lewisite (L)	ATT-005 (HPLC)	USEPA 200.8 (ICP-MS)
Mustard (HD)	USEPA 8270D*	ATT 101* / ATT-003 **
Sarin (GB)	USEPA 8270D*	ATT 101* / ATT-001 **
Soman (GD)	USEPA 8270D*	ATT 101* / ATT-002 **
Tabun (GA)	USEPA 8270D*	ATT 101* / ATT-006 **
VX	USEPA 8270D*	ATT 101* / ATT-004 **

*GC-MS ** GC-FID

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Detection Limits

Name of Chemical Agent	Minimum Detection Limit in MSW Leachate (ppm)
GA	0.004
GB	0.005
GD	0.005
HD	0.004
L	Derivative CVAA 5.3 ug/mL
VX	0.010

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Hypotheses

- Chemicals will mostly dissipate before arrival to landfill or hydrolyze in landfill except for Mustard Gas and VX.

RESULTS

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Chemical Weapons Summary

	Hypothesis	Data
Tabun (GA)	Not Persist	Not Persist <14 Days
Sarin (GB)	Moderate Persistence	Low but Persist >182 Days
Soman (GD)	Moderate Persistence	Low but Persist >168 Days
Mustard Gas (HD)	Persist	Not Persist < 7 Days
Lewisite	Not Persist, Derivative Unknown	Derivative Persists >168 Days
VX	Persist	Persists >182 Days

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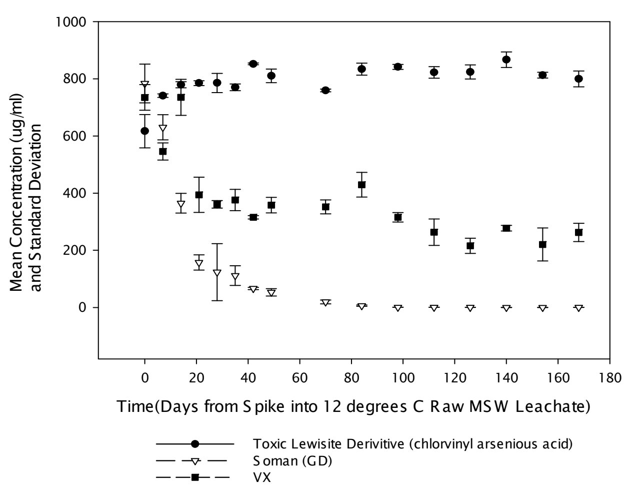
Persistence of Lewisite Toxic Derivative. Soman and VX



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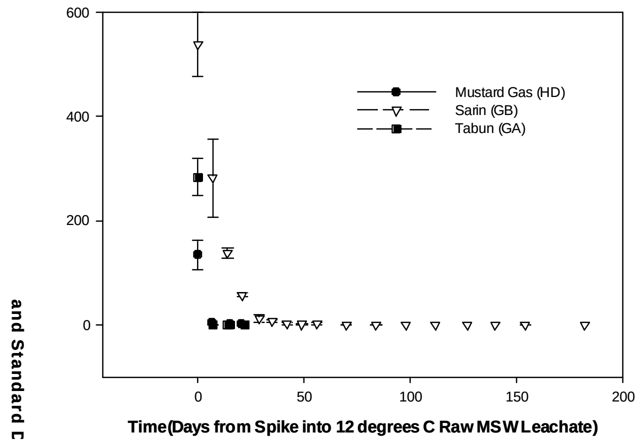
Persistence of Mustard Gas, Sarin and Tabun

Figure 2. Persistance of Mustard Gas, Sarin and Tabun in Raw MSW Landfill Leachate



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Thank you.

Questions ?

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Disclaimer

- This research has been subject to Agency review but does not necessarily reflect the views of the Agency. No official endorsement should be inferred.

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RESEARCH & DEVELOPMENT

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Fate and Transport of Chemical and Biological Agents in Simulated Landfills

Morton A. Barlaz
North Carolina State University

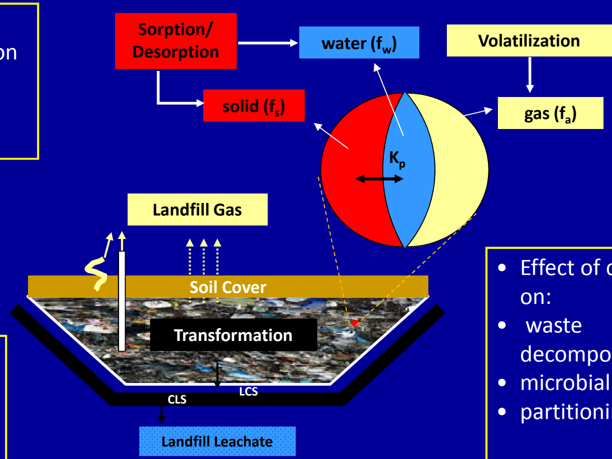
NC STATE UNIVERSITY

Objectives

- Provide information to inform the development of plans for the management of contaminated debris
- Summarize major findings
  - Chemical fate and transport
  - Microbial fate and transport

Distribution of Organic Contaminants in Landfills

- Biodegradation
- Abiotic transformation
- Sorption/desorption
- Volatilization



- K_p, K_h,
- K – biodegr
- K – abiotic
- Mass trasfer/difusion

- Effect of chemical on:
- waste decomposition
- microbial ecology
- partitioning

(Modified from Kjeldsen and Christensen (2001))

Transformation mechanism

- Importance of transformation products?
- Chemical signature of daughter products
  - Chlorinated aliphatics, PFCs

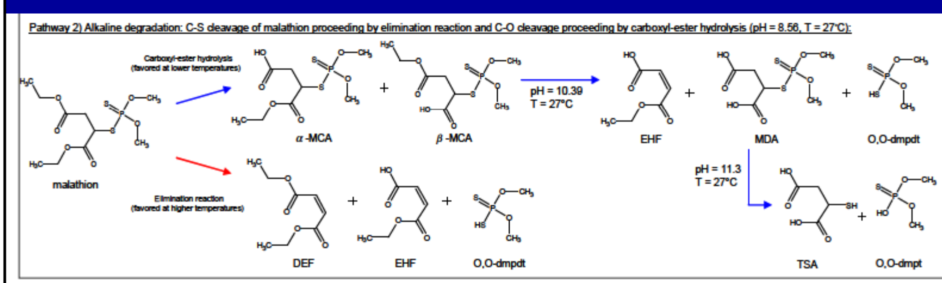


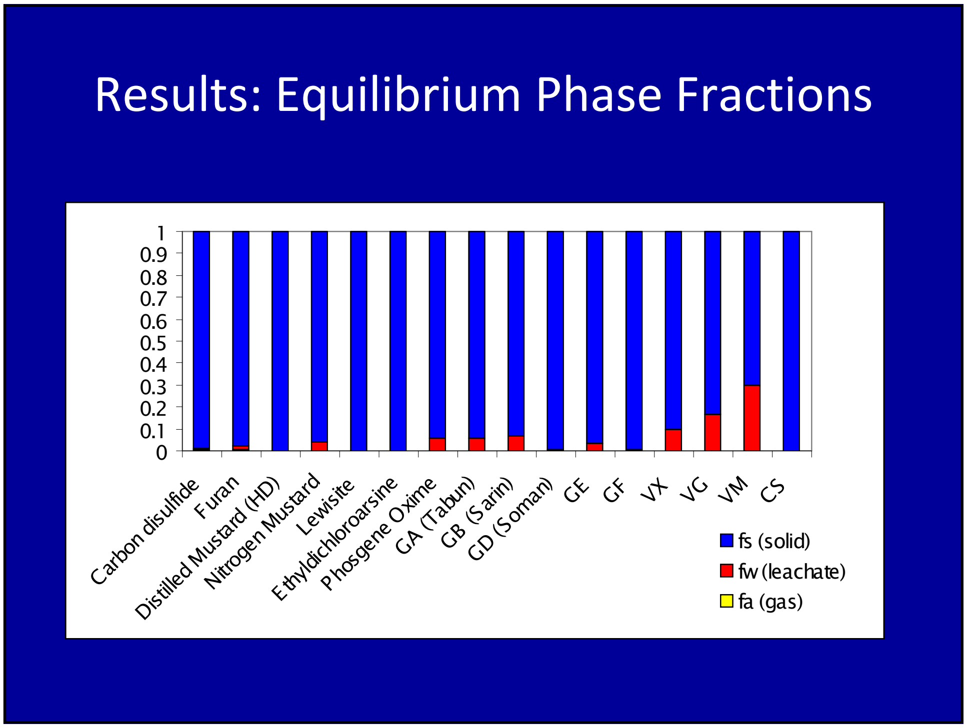
Figure 1. Description of the pathways obtained by Wolfe et al. (1977) on the hydrolysis of malathion.

Approach

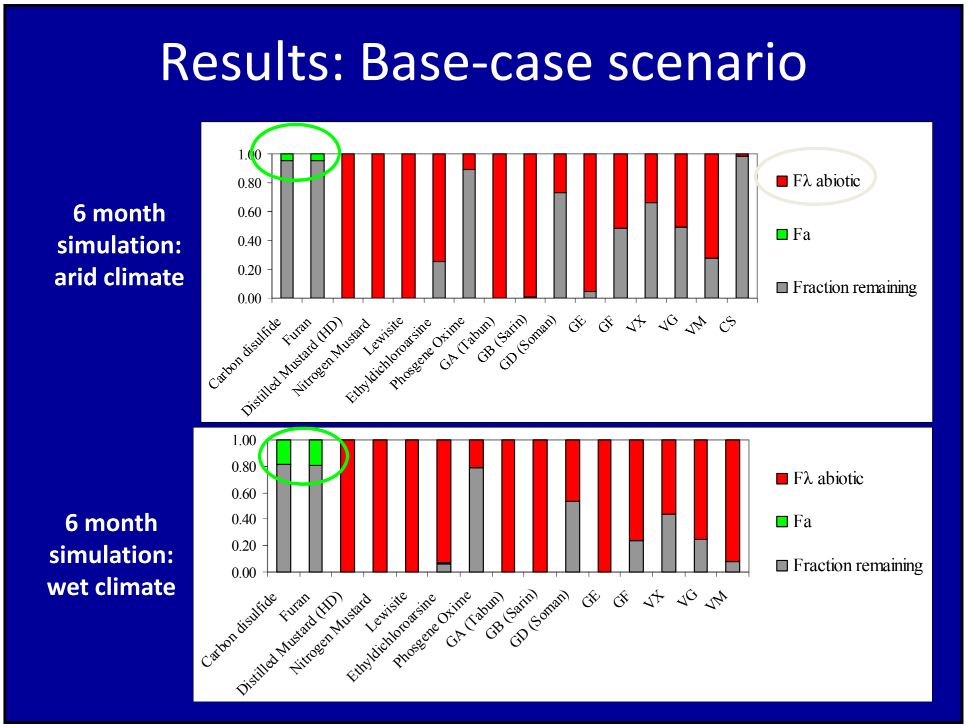
- MOCLA – a simple model to capture major partitioning and fate of organics in landfills
- Experimental work to evaluate ability to parameterize predictive models
- Experimental work to measure microbial transport in leachate and landfill gas
  - tremendous effort in technique development

MOCLA

- Model assumes equilibrium between the solid, liquid and gas phases and calculates partitioning
  - Requires parameters to characterize the landfill and the contaminant of concern



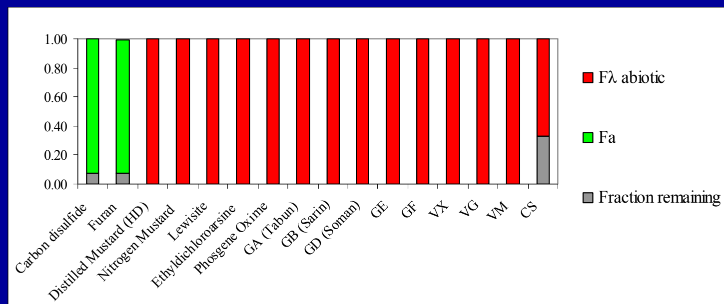
Results: Equilibrium Phase Fractions
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Carbon disulfide
Furan
Distilled Mustard (HD)
Nitrogen Mustard
Lewisite
Ethyldichloroarsine
Phosgene Oxime
GA (Tabun)
GB (Sarin)
GD (Soman)
GE
GF
VX
VG
VM
CS
fs (solid)
fw (leachate)
fa (gas)



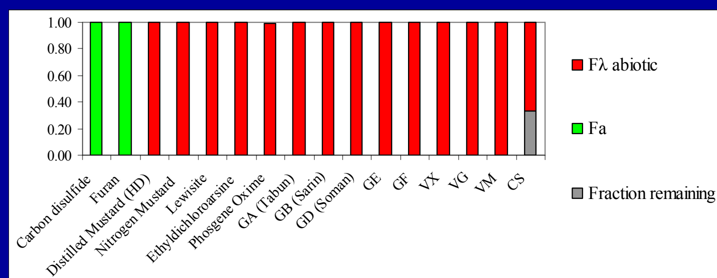
Results: Base-case scenario
6 month simulation: arid climate
1.00
0.80
0.60
0.40
0.20
0.00
Carbon disulfide
Furan
Distilled Mustard (HD)
Nitrogen Mustard
Lewisite
Ethyldichloroarsine
Phosgene Oxime
GA (Tabun)
GB (Sarin)
GD (Soman)
GE
GF
VX
VG
VM
CS
Fλ abiotic
Fa
Fraction remaining
6 month simulation: wet climate
1.00
0.80
0.60
0.40
0.20
0.00
Carbon disulfide
Furan
Distilled Mustard (HD)
Nitrogen Mustard
Lewisite
Ethyldichloroarsine
Phosgene Oxime
GA (Tabun)
GB (Sarin)
GD (Soman)
GE
GF
VX
VG
VM
Fλ abiotic
Fa
Fraction remaining

Results: Base-case scenarios

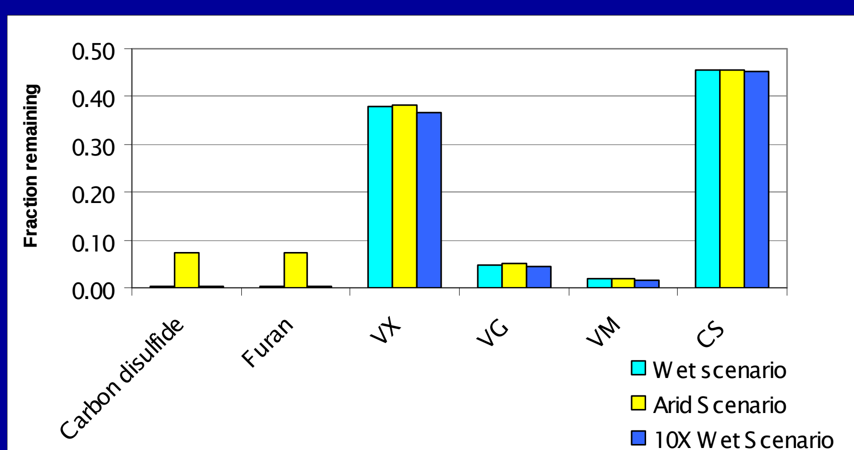
30 year simulation: arid climate



30 year simulation: wet climate



Impact of Climate



Findings and Implications

- All CWAs studied are largely associated with the solid phase in the landfill due to high log K_{ow} values
  - Consider models that account for different solid phases
- Significant fate routes are abiotic hydrolysis and gas phase advection
  - Rapid gas collection and control is essential
- Blister agents (HD, HN-2, ED, L) and some G-agents (GA and GB) are predicted to be transformed quickly (~6 months)
  - Understand transformation products
- VX, GD, CS and toxic industrial chemicals are predicted to persist in landfills for 5 yr or longer
  - Minimize infiltration in perpetuity

Findings and Implications

- Effect of climate is minimal for chemicals studied
  - Slight increase in F_a (advective loss) due to increase in gas production rate
  - No effect on abiotic hydrolysis rate
  - Climate not significant if cell is sealed quickly
- Decreasing biotic half-life to 10 days impacts fate only for compounds with long abiotic hydrolysis half-lives relative to the simulation period
- Knowledge of fate of hydrolysis products is critical

(De)Sorption of Organic Contaminants in Landfill Simulations

- Study 1: Estimating Equilibrium Parameters of Organic Contaminants in Landfills
- Study 2: Factors Controlling Alkylbenzenes and PCE Desorption from MSW Components

Estimating Equilibrium and Kinetic Parameters of Organic Contaminants in Landfills

$q = K_p C_e$ $K_p = f_{oc} K_{oc}$

Information needed:

- f_{oc} of sorbent
- K_{oc} for sorbate/sorbent pair

$$\text{Log } K_{oc} = a \cdot \log K_{ow} + b$$

One parameter - linear free energy relationship (op-LFER) between K_{oc} and K_{ow} (sorbent-specific)

q = solid phase concentration (µg/kg)

C_e = equilibrium liquid phase concentration (µg/L)

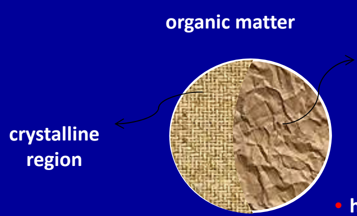
K_p = partition coefficient (L/kg)

K_{oc} = partition coefficient normalized to organic carbon (L/kg)

f_{oc} = fraction of organic carbon

K_{ow} = octanol-water partition coefficient

Characteristics of Plastics



Glassy → T (ºC) > T_g → Rubbery

- higher cohesive forces
- more condensed

- more mobile
- more flexible

Glassy or "hard" plastics

Rubbery or "soft" plastics

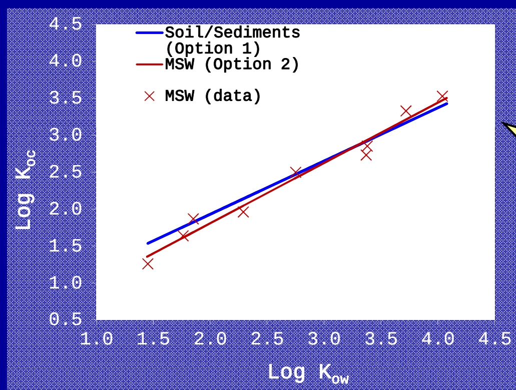
Estimating Sorption Equilibrium Parameters for Organic Contaminants in Landfills

Objectives

- To establish op-LFERs that relate organic-carbon-normalized partition coefficients (K_{oc}) and to sorbate octanol-water partition coefficients (K_{ow}) for a range of MSW components
- To validate op-LFERs estimate of toluene's K_p in mixed solid wastes

$$K_p = f_{oc} K_{oc}$$

Estimating Sorption Equilibrium Parameters



Predicted K_{oc} for toluene (log K_{ow} = 2.69):

Option 1: K_{oc} = 267

Option 2: K_{oc} = 235

Option 1

- soil/sediment sorption studies (Schwarzenbach and Westall 1981)

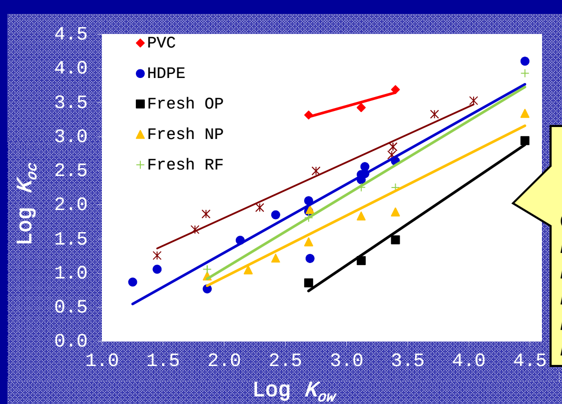
  log K_{oc} = 0.72*log K_{ow} + 0.49

Option 2

- a MSW mixture sorption study (Reinhart et al. 1990)

  log K_{oc} = 0.815*log K_{ow} + 0.179

Estimating Sorption Equilibrium Parameters



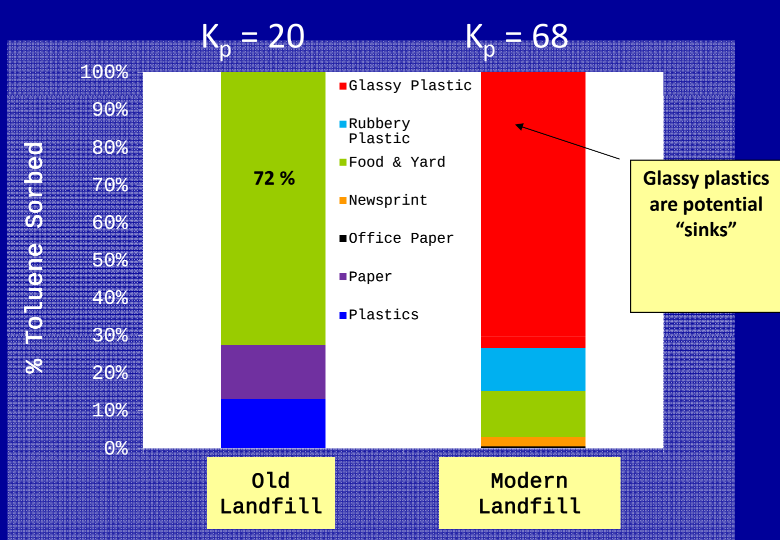
Predicted K_{oc} for toluene (log K_{ow} = 2.69):

Option 3:
K_{oc}- PVC = 1,940
K_{oc}- HDPE = 98
K_{oc}- FRF = 65
K_{oc}- FNP = 29
K_{oc}- FOP = 6

- Individual op-LFER for a range of MSW components: rubbery plastics (e.g. HDPE); glassy plastics (e.g. PVC);
- Toluene, o-xylene, PCE, DCE, malathion, phenanthrene, diethylfumurate
  - HDPE: TCE, benzene, 1,2-DCA, ethylbenzene, methylene chloride, p-xylene

Organic Matter Composition	f_{oc}	Predicted Toluene K_p: Soil op-LFER	Predicted Toluene K_p: Mixed MSW op-LFER	Predicted Toluene K_p: MSW Component op-LFER	Measured Toluene K_p
Old Landfill (1960) • 43.3 % office paper & newsprint • 56.0 % food & yard wastes • 0.7 % plastics	**0.418**	**112**	**98**	**20**	
Modern Landfill (2007) • 22.2 % office paper • 17.1% newsprint • 42.1 % food & yard wastes • 13.0 % rubbery plastics • 5.6 % glassy plastics	**0.474**	**127**	**111**	**68**	
Solid Wastes Mixture 1 • 75% office paper • 20% newsprint • 5% HDPE jug	**0.412**	**110**	**97**	**8**	**13**
Solid Wastes Mixture 2 • 73% office paper • 20% newsprint • 5% HDPE jug • 2% PS solo cup	**0.421**	**113**	**99**	**41**	**33**

OPTION 3: op-LFER based on MSW model components



Estimating Sorption Equilibrium Parameters for Organic Contaminants in Landfills

Conclusions

- Current models to predict organic contaminant sorption to MSW overestimate sorption for older MSW and could underestimate sorption for MSW with considerable glassy plastics (PET, PS, PVC) content.

- The model developed in this research shows that glassy plastics (PET, PS, PVC) are important sinks for organic contaminants.

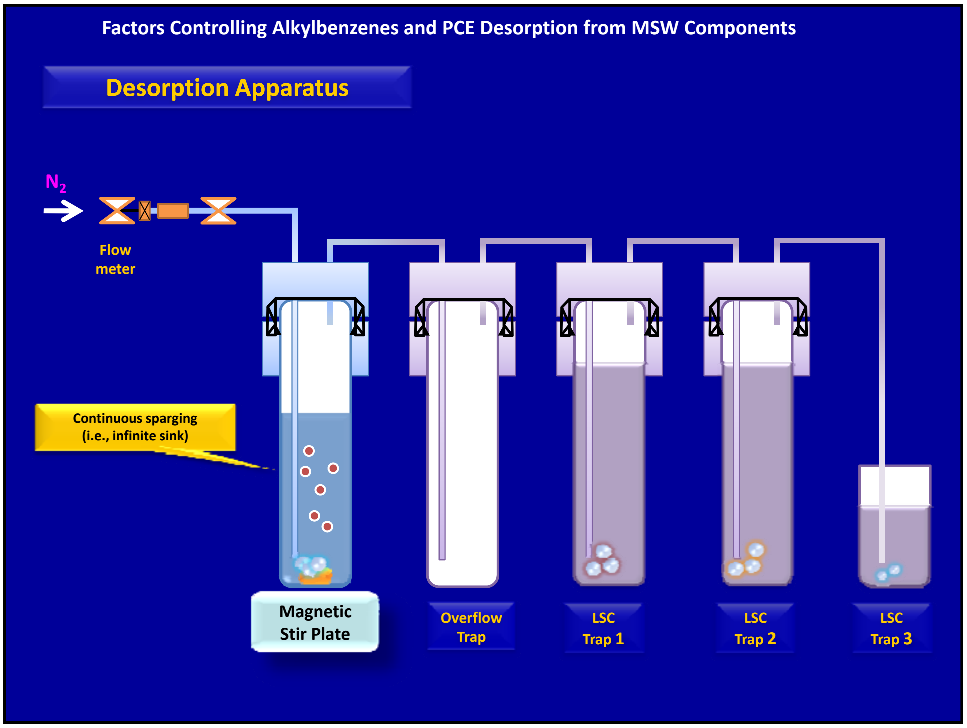
Factors Controlling Alkylbenzene and PCE Desorption from MSW Components

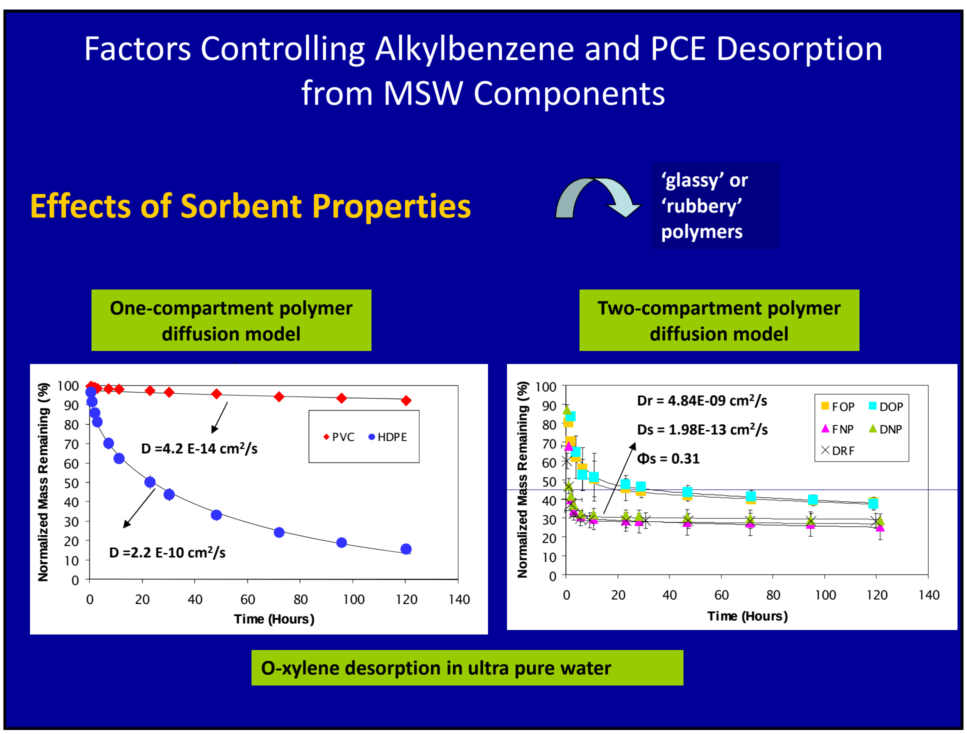
Objectives

- Determine desorption rates of model HOCs (toluene, *o*-xylene and PCE) from model organic MSW components:
  - high density polyethylene (HDPE), poly(vinyl chloride) (PVC), newsprint (NP), office paper (OP), rabbit food (RF) as a model food and yard waste
- Examine the effects of (i) sorbent decomposition; (ii) sorbate properties; (iii) aging; and (iv) leachate composition on desorption rates of model HOCs.

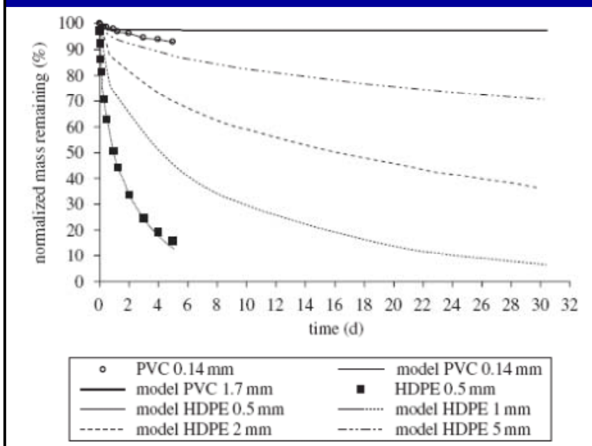
Background

- For some materials, equilibrium will be achieved slowly and the desorption rate could control leachate concentrations


Factors Controlling Alkylbenzenes and PCE Desorption from MSW Components
Desorption Apparatus
N_2
Flow meter
Continuous sparging (i.e., infinite sink)
Magnetic Stir Plate
Overflow Trap
LSC Trap 1
LSC Trap 2
LSC Trap 3

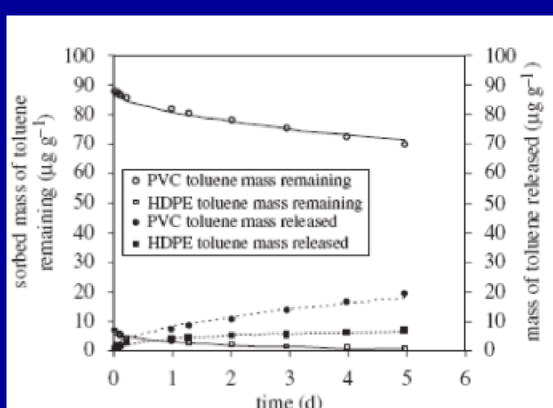

Factors Controlling Alkylbenzene and PCE Desorption from MSW Components
Effects of Sorbent Properties
'glassy' or 'rubbery' polymers
One-compartment polymer diffusion model
Two-compartment polymer diffusion model
Normalized Mass Remaining (%)
Time (Hours)
D =4.2 E-14 cm²/s
D =2.2 E-10 cm²/s
PVC
HDPE
Dr = 4.84E-09 cm²/s
Ds = 1.98E-13 cm²/s
Φs = 0.31
FOP
DOP
FNP
DNP
DRF
O-xylene desorption in ultra pure water

Comparison of o-xylene desorption data and one-compartment diffusion model fits as well as predictions of o-xylene desorption rates from PVC and HDPE spheres of different diameters



These data illustrate the significance of the diffusion length and the behavior of a glassy (PVC) and rubbery (HDPE) polymer.

Effect of polymer type on sorbed toluene mass remaining and released per gram of sorbent.



HDPE loses mass faster but more toluene is lost from PVC because there was more mass sorbed initially

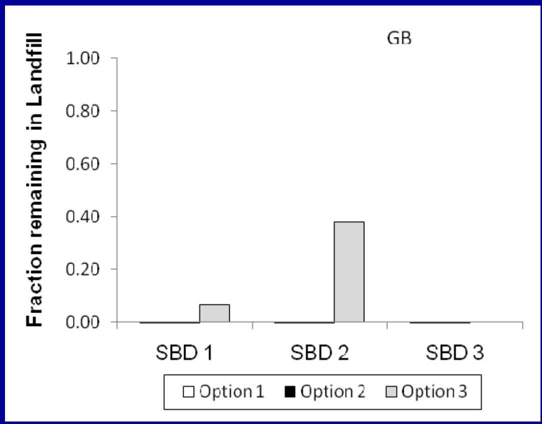
Predicted *Kp* values describing HD (sulfur mustard) sorption to different SBD mixtures by various op-LFERs

Sorbent	Closely Related Model Material	SBD mixture 1	SBD mixture 2	SBD mixture 3
		% by weight		
Electronics (plastic parts)	PVC	5.5	16.5	0.5
Ceiling tiles	NP	12.8	11.3	13.5
Folders	OP	4.2	3.7	4.5
White paper	OP	34.2	30.2	36.0
Mixed office paper	NP	4.2	3.7	4.5
Furniture	HDPE	33.7	29.8	35.5
polyurethane foam	NP, PVC	1.7	1.5	1.8
formica sheet	NP	0.3	0.3	0.3
medium density fiberboard	HDPE	31.7	28.0	33.4
Carpet	PVC, NP	4.5	4.0	4.7
Vinyl flooring		0.8	0.7	0.8
f_{oc}		0.395	0.434	0.378

Predicted *Kp* values describing HD (sulfur mustard) sorption to different SBD mixtures by various op-LFERs

Sorbent	Mixture 1	Mixture 2	Mixture 3
op-LFERs	**Predicted HD K_p (L/kg)**		
Soils/Sediments	66	73	63
MSW mixture	55	60	52
Individual MSW components	62	173	11

Predicted fraction of Sarin remaining in a landfill after 0.5 yr using Kp estimated by three alternatives for three SBD mixtures



Kp estimated by op-LFER for individual MSW components predicted 38% of sarin would remain in a landfill when SBD contains 16.5% electronics, while *Kp* estimates from Options 1 and 2 predicted negligible sarin remaining after 0.5 yr. Sarin has a short hydrolysis half-life but has some hydrophobicity (log *Kow* = 0.3).

Conclusions

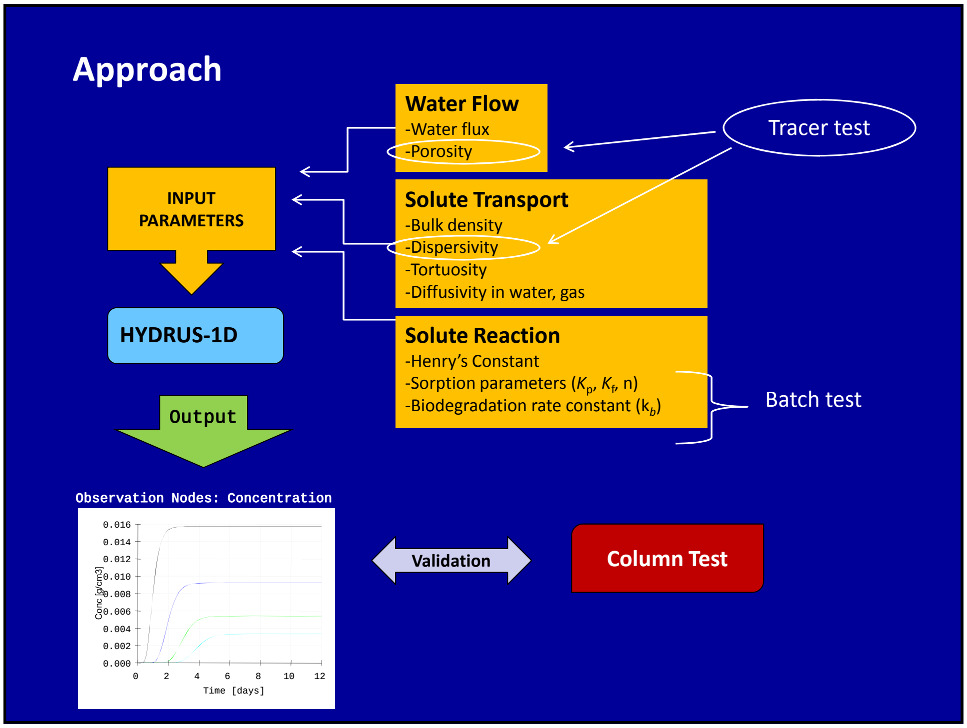
- HOC desorption rates from plastics were rapid for HDPE (D = 10^{-10} cm^2 s^{-1}), a rubbery polymer, and slow for PVC (D = 10^{-13}-10^{-14} cm^2 s^{-1}), a glassy polymer.
- For biopolymer composites, a large fraction of sorbed HOCs was rapidly released (D_r = 10^{-9} to 10^{-10} cm^2 s^{-1}) while the remaining fraction desorbed slowly (D_s = 10^{-11} to 10^{-16} cm^2 s^{-1}).

Fate and Transport of Phenol in a Packed bed Reactor Containing Simulated Solid Waste

- Conduct column experiments to measure the fate and transport of an organic contaminant (OC) in a simulated solid waste mixture
- Compare the results of column experiments to model predictions using HYDRUS-1D (version 4.13)
- Determine model input parameters from independently conducted batch experiments

Model Contaminant and MSW

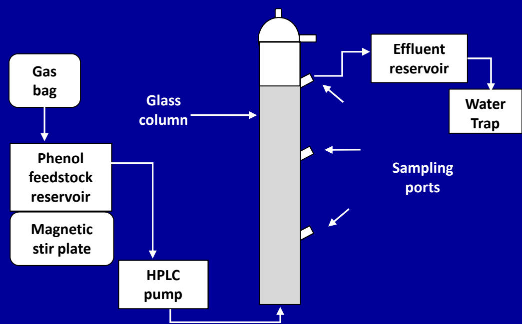
- Phenol
  - model organic contaminant
  - frequently detected in landfill leachates
  - sorbs to refuse
  - biodegrades in decomposing refuse
- Degraded newsprint (DNP)
  - representative MSW component
  - sorbent
  - biodegradable
  - lignocellulosic



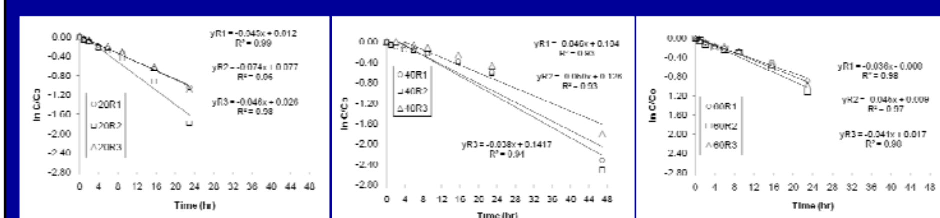
Experimental and modeling parameters for phenol biodegradation-sorption column test

	Sampling Ports	
Distance from column inlet (cm)	**20**	**40**
Biodegradation $t_{1/2}$ (day)	0.58	0.68
k_b (day^{-1})	1.19	1.02
K_p phenol-DNP (L/kg)	4.51	4.51
K_p column (L/kg)	0.21	0.21
Q (mL/min)	1.45	1.45
Q (L/day) BMP Medium	2.09	2.09
HRT (days)	0.412	0.824
Glass beads mass (g)	1747.6	3495.1
DNP mass (g)	87.1	174.2
Weighted particle density (kg/L)	2.49	2.49
Bulk density (kg/L)	1.05	1.19
Porosity (θ)	0.58	0.52
Dispersivity (cm)	4.98	9.46

Experimental Set-up

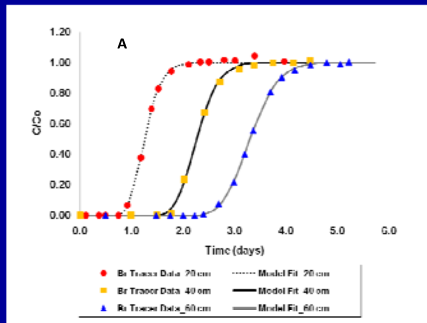


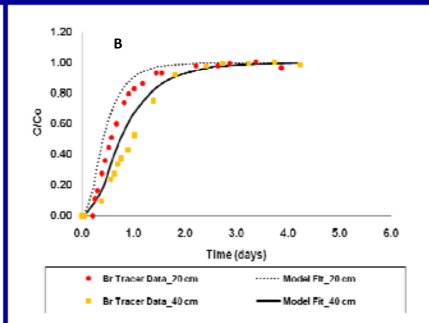
Batch Experiments



Linearized first-order biodegradation of phenol.
Mean anaerobic biodegradation rate of phenol was 1.0 ± 0.24 d^{-1} resulting in an average half-life of 16.7 ± 3.1 hr.

Bromide Tracer Tests

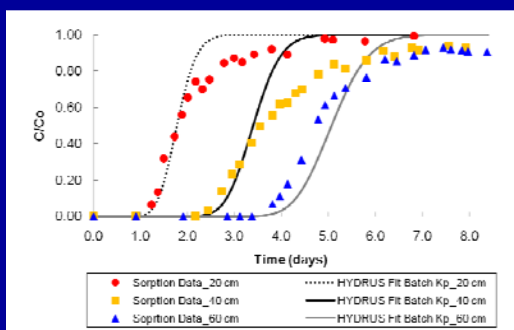




Observed and simulated relative concentrations of bromide as a function of time in (A) first and (B) second tracer tests.

Model fits for (A) used porosity and dispersivity parameters derived for each sampling port. Model fits for (B) used porosity from first tracer test and derived dispersivity for respective sampling ports.

Sorption Column Test



Relative concentrations of phenol as a function of time in sorption column test with model fits using porosity and dispersivity parameters from first tracer test

Sorption parameters for phenol

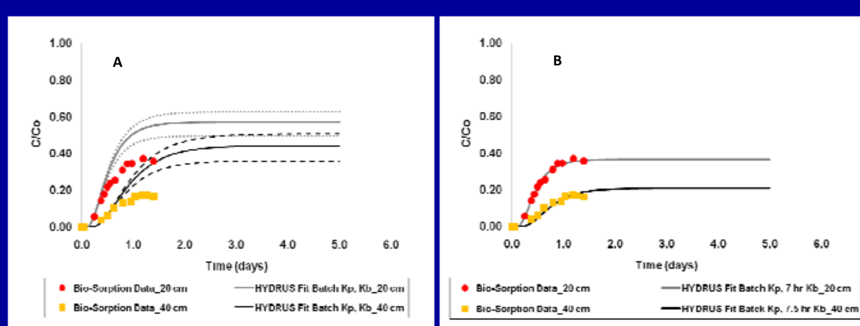
Sampling Port	Partition Coefficient[a] K_P (mgKg^{-1}/mg^{-1})	
	Batch K_p Fit[b]	HYDRUS Fit[c]
20 cm	4.51 (2.5E-01)	5.53 (2.3E-01)
40 cm	4.51 (6.3E-01)	6.03 (4.6E-01)
60 cm	4.51 (2.9E-01)	4.01 (2.0E-01)

[a]Values in parentheses represent standard error.

[b]Batch K_p value based on batch sorption isotherm experiment.

[c]HYDRUS fit K_p value derived from sorption column test.

Biodegradation-Sorption Column Test



Relative concentrations of phenol as a function of time in biodegradation plus sorption column test with model fits using (A) batch K_p and k_b (B) batch K_p, fitted k_b.

Biodegradation parameters for phenol

Sampling Port	Batch Test Measured Biodegradation Rate[a,b] k_b (d^{-1})	Column Test Fitted Biodegradation Rate k_b (d^{-1})		
		HYDRUS Fit[c]	Lower[d]	Upper[d]
20 cm	1.19 (0.32)	2.32 (1.6E-02)	2.28	2.35
40 cm	1.02[e] (0.28)	2.23 (7.6E-02)	2.11	2.46
60 cm	1.00[f] (0.24)			

[a]Average of replicate analyses, based on linearized first order anaerobic biodegradation of phenol.

[b]Values in parentheses represent one standard deviation.

[c]Values in parentheses represent standard error.

[d]Values at 95% confidence interval.

[e]Average value for 40 cm sampling port includes 20 cm data.

[f]Average value for 60 cm sampling port includes 20 cm and 40 cm data.

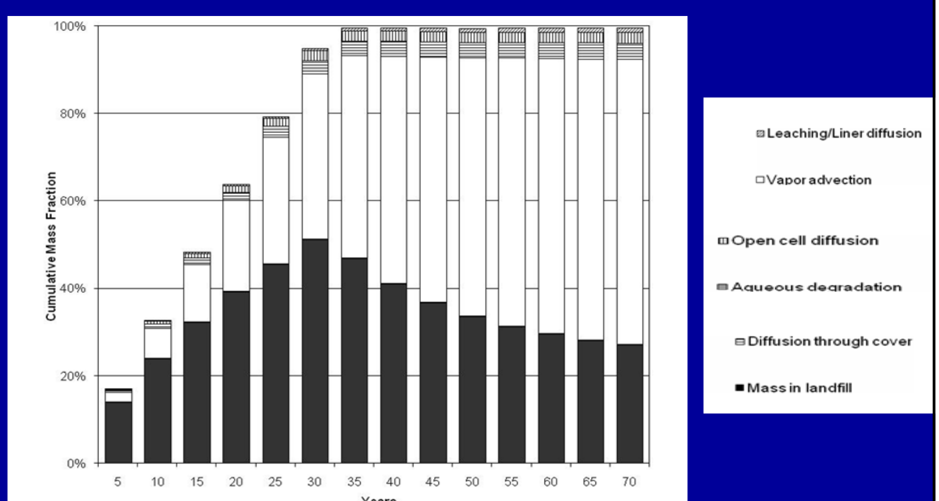
Conclusions and Implications for Landfill Disposal

- Simulating the effects of various fate processes during transport of organic contaminants is complex.
- HYDRUS-1D appears to reasonably simulate the fate and transport of phenol in an anaerobic and fully saturated waste column, in which biodegradation and sorption are the prevailing fate processes.
- Agreement between model predictions and column data for sorption plus biodegradation test was about a factor of 2 and mainly attributed to difficulty in measuring a biodegradation rate that is applicable to the column conditions.
- Given the extended retention time and engineering controls on leachate release in lined landfills, differences in biodegradation rate within a factor of 2 or even 5 is considered reasonable.

Landfill Coupled Reactor Model (LFCR)

- Work done with Dr. Shannon Bartelt-Hunt (Nebraska) and RTI outside of ORD
- The most sophisticated fate and transport model available for a landfill
    - LFCR is an extension of MOCLA
    - Utilizes a fully-mixed reactor approach.
- – More realistic landfill filling algorithm
- – Time variable parameters (changing gas production, gas transport, losses during filling, fill sequence). MOCLA cannot do this.

Landfill Coupled Reactor Model (LFCR)



Landfill Coupled Reactor Model (LFCR)

- Not validated and work could be done to validate at pilot-scale
  - Model predictions are consistent with field observations

Microbial Transport

- Solids (synthetic building debris)
- Leachate
- Gas
- All work done with surrogates

Microbial Transport - Leachate

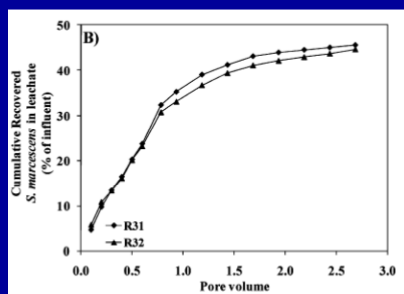
- Substantial work to develop PCR assays that were specific to the selected microbial surrogates in live and spore form
- Demonstrated ability to quantify the presence of surrogate bacteria and spores in leachate and after extraction from a solid phase
  - Multiple extraction and spore lysis methods were tested
  - Detection limits of 10 to 100 cells

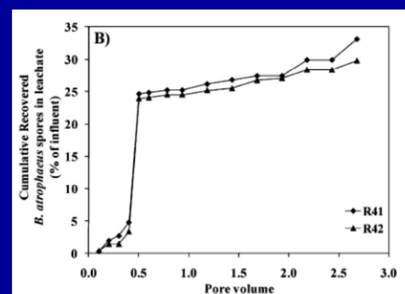
Microbial Transport - Leachate

- Columns filled with synthetic building debris and spiked with the surrogate organisms were operated under conditions of water infiltration and leachate recirculation
- In the leachate recirculation reactors, <10% of spiked surrogates were eluted in leachate over 4 months.

Microbial Transport - Leachate

- In the water infiltration reactors, 45% and 31% of spiked *S. marcescens* and *B. atrophaeus* spores were eluted in leachate.

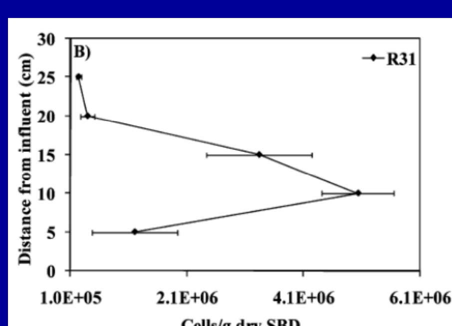




Cumulative % of S. marcescens and B. atropheus spores recoverd in leachate in water infiltration reactors

Microbial Transport - Leachate

- Less than 3% of the total spiked *S.marcescens* cells and no *B. atrophaeus* spores were detected in SBD at the termination of the experiment, suggesting that significant fractions of the spiked surrogates were strongly attached to SBD



- Concentration of attached S. marcescens cells over depth in a water infiltration reactor

Microbial Transport - Leachate

- Test represent a worst case
  - high concentrations
  - high flow
  - movement through layers of waste
- We have to assume some microbial transport in leachate if there is water movement/leachate generation in a cell.
  - Moisture content at filling?
  - Infiltration?

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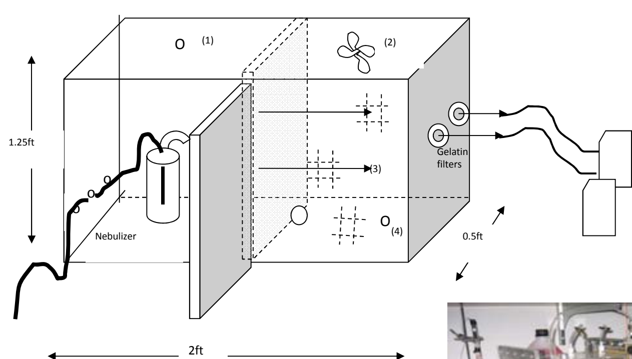
Microbial Transport – Gas Aerosol Chamber



Designed aerosol chamber using BGI nebulizer. (1) compressor air intake; (2) open fitted valve; (3) flow of the aerosol and suspended surrogates; (4) fan; (5) Closed valves; (6) sampler buttons with gelatin filters

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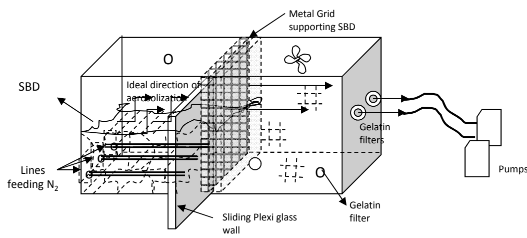
Microbial Transport - Gas



Microbial Transport - Gas

- Substantial technique development to show that we could measure microbes in the gas phase
- Even at very high velocities and high cell concentrations, B. atrophaeus cells and spores were barely detected and there was no detection of S. Marcescens
- No detection in solid phase, showing strong adherence to building debris.

Final Comments

- The mix of materials will not be know ahead of time as events are not predictable
- Expect waste to be securely buried and sealed rapidly in landfills with liners and gas and leachate control
- Models and experiments could be run after the fact to estimate long-term fate and partitioning

Acknowledgements

- Jovi Saquing, Pascal Saikaly, Rosanna Prevost, Isabella Mezzarri, Detlef Knappe, Jacky Rosati, Susan Thorneloe, Paul Lemieux

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Thermal Inactivation of Viable *Bacillus Anthracis* Surrogate Spores in a Bench-scale Landfill Gas Flare

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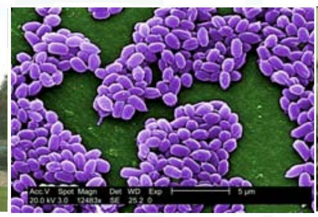
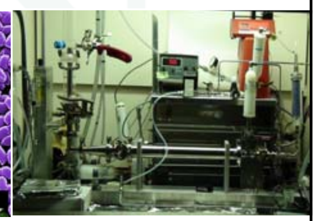
National Homeland Security Research Center
Decontamination and Consequence Management Division

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Funding and Disclaimer

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This research has been subject to Agency review but does not necessarily reflect the views of the Agency. No official endorsement should be inferred.

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1

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Outline

- Background
- Overview of MSW Landfills
- Overview of Real-World Landfill Flares
- Description of Test System
- Experimental Methods
- Results

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Decontamination Limitations

- *B.anthracis* spores very hardy, can survive for long periods under harsh conditions
- Viable spores could escape detection and decontamination
- Contaminated materials could be transported to a landfill

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Decontamination and Cleanup

2001 event produced extensive quantities of potentially contaminated wastes

Included PPE, office furniture, computers, printers, carpets, draperies, ceiling panels, and wallboard

Some debris was shipped to a RCRA Subtitle D solid waste landfill for final disposition

Critical to understand the fate and transport of *B. anthracis* spores should they survive the decontamination and landfill process

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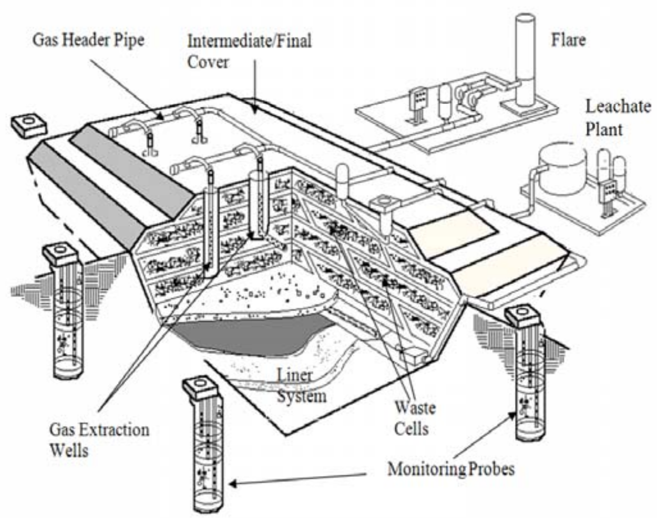
Municipal Solid Waste Landfills



3000 active landfills in US

Landfill Gas :
~ 49% CH_4
~ 49% CO_2
<1% NMOCs
<1% H_2S and other sulfur compounds

Figure source: EPA Landfill Methane Outreach Program

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Landfill Flares

Open Flare

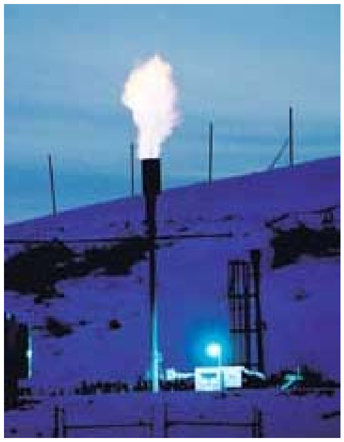

Image source: New York Power Authority
http://www.nypa.gov/ar02/annual02web/pages/pg4_1.htm

Enclosed Flare

Image source: Organics
http://organics.com/Products/21/Flare_Systems.html

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Enclosed Landfill Flares

- Federal operating requirements
  - Net heating value ≥ 11.2 MJ/scm
  - Exit velocity < 37.2 m/s
- Industry standards
  - Operating temperature of enclosed flare
    - Optimal temperature depends on LFG constituents
  - Residence time

Why is This Research Important?

The variety of materials and surface properties of cleanup waste makes the fate of land-filled spores less certain

Research investigates the fate of spores carried within landfill gas and exiting through an enclosed flare

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Research Objectives

Characterize the bench-scale landfill flare system

- Compare velocities, residence times, and system temperatures with real-world systems

Determine the viability of heat-resistant, surrogate biological spores that pass through the flare

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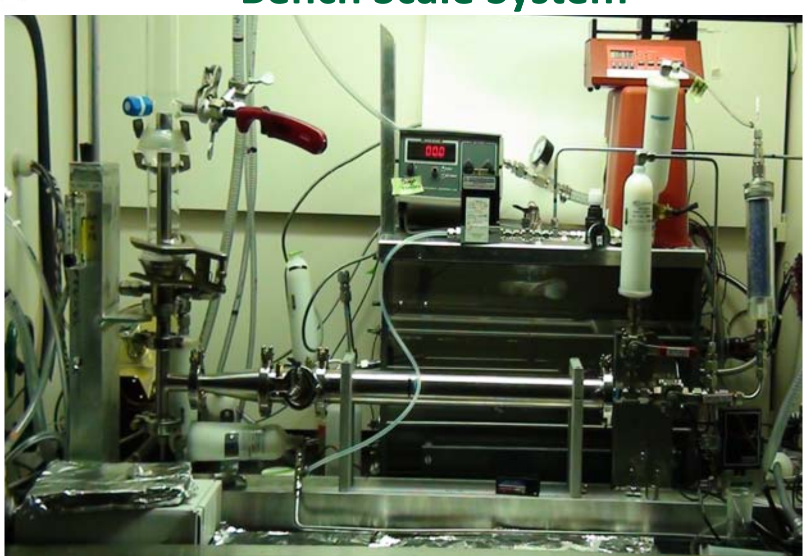
Experimental Methods
Bacteria

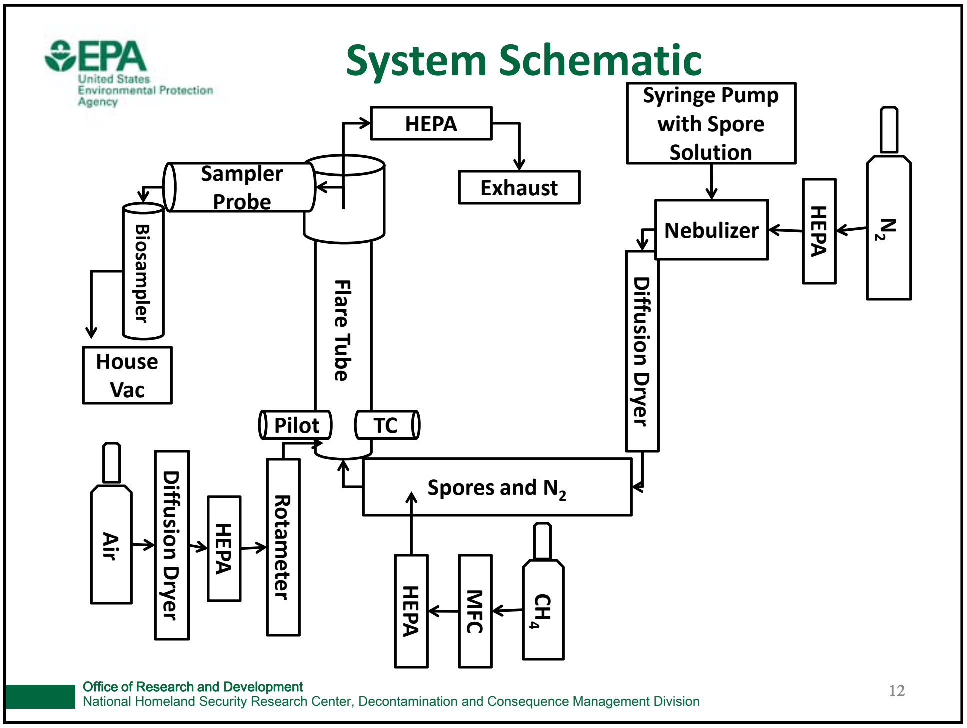
B. anthracis surrogates used

Geobacillus stearothermophilus and *Bacillus atrophaeus*

Spore Type	Gram Pos	Endospore Forming	Rod Shaped	Hardy	Size Range (μm)	
					Length	Width
B. anthracis	✓	✓	✓	✓	0.95-3.5	NR
G. stearo.	✓	✓	✓	✓	2-3.5	0.6-1
B. atrophaeus	✓	✓	✓	✓	2-3	0.7-0.8

Bench Scale System




EPA
United States Environmental Protection Agency
System Schematic
HEPA
Syringe Pump with Spore Solution
Sampler Probe
Exhaust
Biosampler
Nebulizer
HEPA
N_2
Flare Tube
Diffusion Dryer
House Vac
Pilot
TC
Air
Diffusion Dryer
HEPA
Rotameter
Spores and N_2
HEPA
MFC
CH_4
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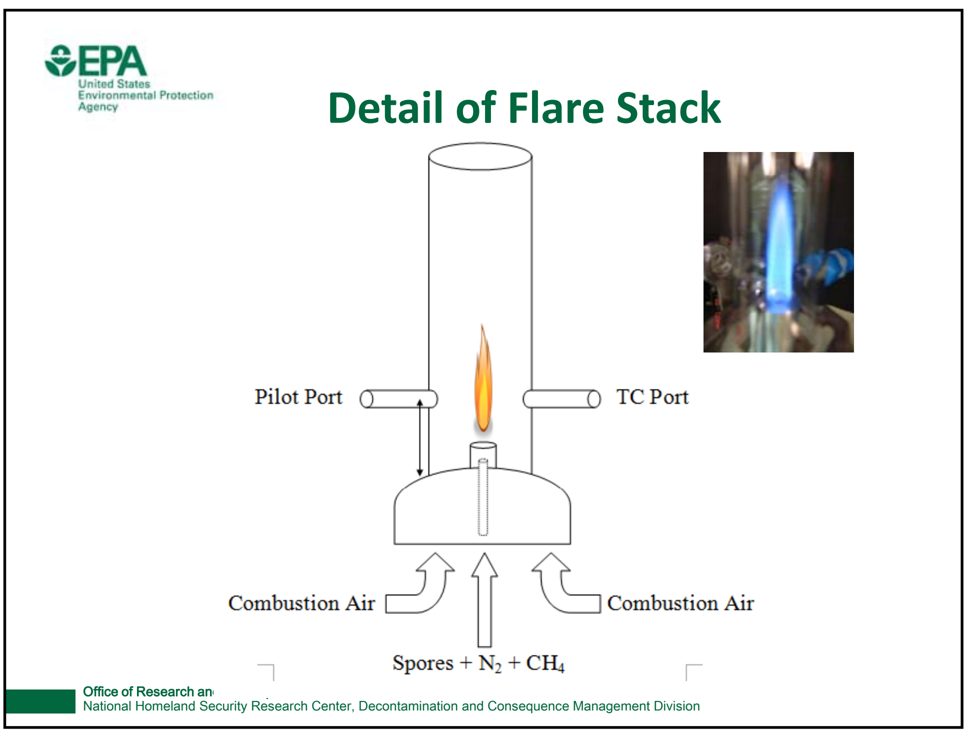
EPA
United States Environmental Protection Agency
Detail of Flare Stack
Pilot Port
TC Port
Combustion Air
Combustion Air
Spores + N_2 + CH_4
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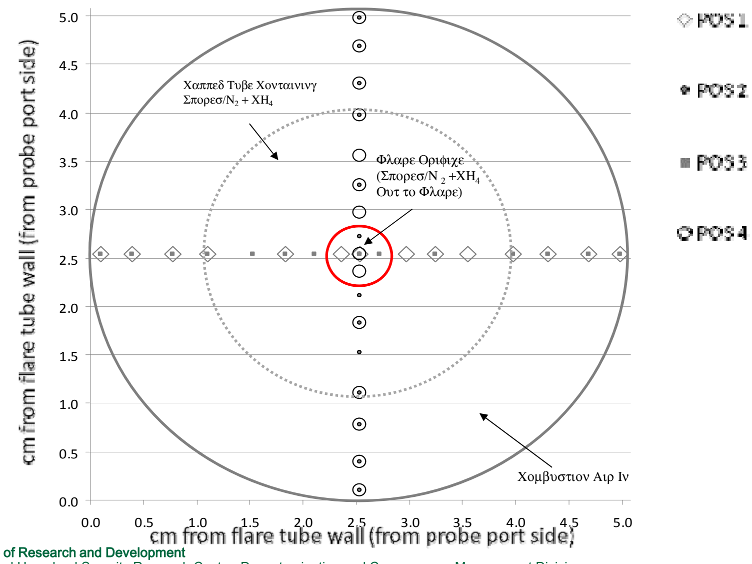
Temperature Profile



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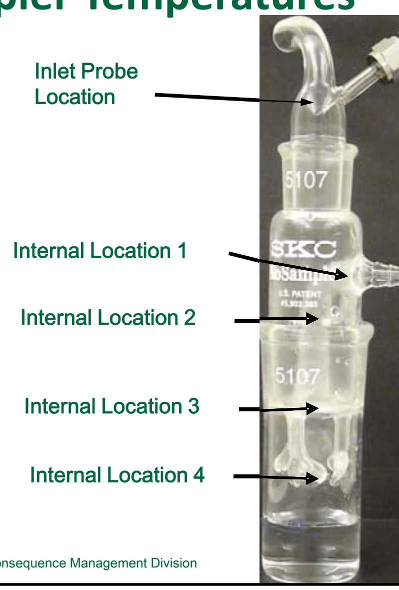
Exhaust & BioSampler Temperatures

Stack exhaust temperature

- Measured at the top of the stack in the center at the BioSampler probe inlet

BioSampler temperatures

- Inlet and four internal locations



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Residence Time and Turbulence Estimates

- Flare residence time
  - Stack height/stack velocity
- Spore residence time in the flare
  - Flare height/flare exit velocity
- Reynolds number calculated for the stack at 1000 ° C

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Spore Inactivation Experiments

- Sterile test constituents
- Seven tests conducted with each organism
  - 5 with the flare on
  - 2 control runs with flare off
- Spore suspensions concentrated
- Solution concentrations optimized

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Spore Inactivation Experiments

Spore Type	Test Solution Conc'n, Spores/mL	% of Drops Containing Spores	Estimated Spores per Test	
			From Nebulizer	Collected by BioSampler
G. Stearo	$1.52x10^8$	10	$3.81\ x10^7$	$1.89\ x10^7$
B. Atro.	$1.26\ x10^8$	7	$3.15\ x10^7$	$1.56\ x10^7$

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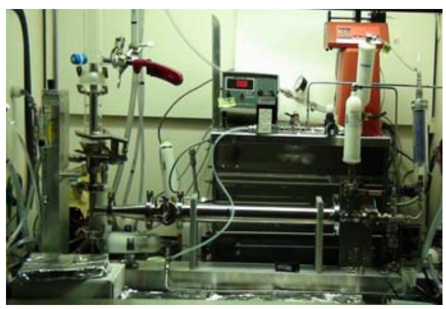
Spore Inactivation Experiments

Testing Overview

Sample Preparation



Nutritive broth

used to culture the samples because it could promote growth of spores that were injured but still viable

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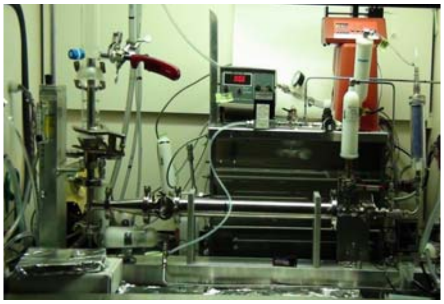
Spore Inactivation Experiments

Control Samples

11 Negative

23 Positive



Ensured aseptic techniques were used

Verified spore test solutions were viable

Used for comparison to test samples

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BioSampler Spike Tests

Tested that spores inactivation did not occur in BioSamplers from the heat of the sample stream

Spiked BioSamplers installed on sampling port

Sampled with flare on for duration of other tests

Negative and positive controls

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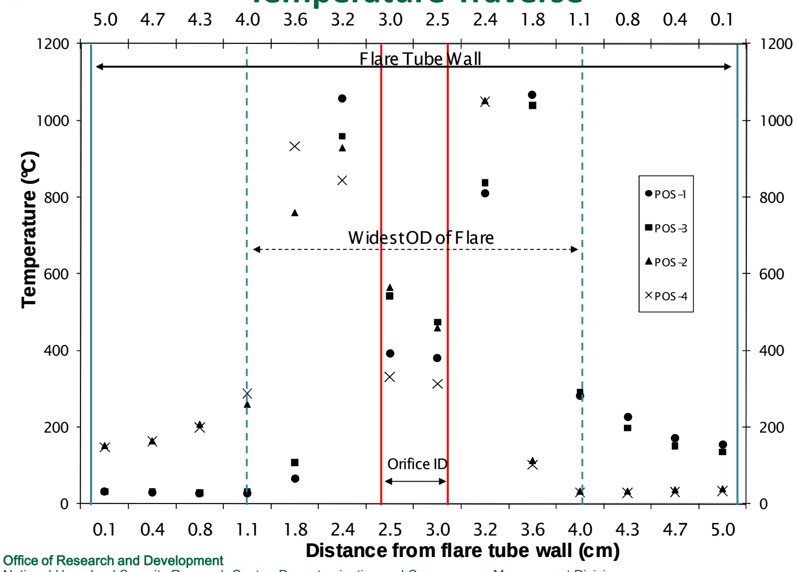
Results

Temperature Traverse



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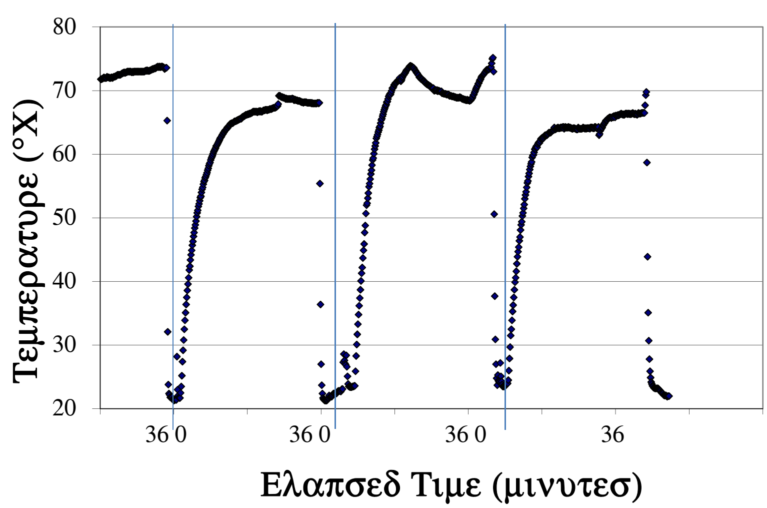
Internal BioSampler Temperatures



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Bench Scale System: Similarities to Full-Scale Flares

- Conformance with Federal Regulations
  - Net heating value ~ 34 MJ/scm
    - Meets ≥ 11.2 MJ/scm requirement
  - Exit velocity ~ 0.43 m/s
    - Meets < 37.2 m/s requirement
- Operating temperature ~ 1000 ° C at flare edges
  - Within typical operating temp (870 ° C – 1037 ° C)
- Residence time ~ 0.2 (flare) and 0.6 s (stack)
  - Within standard 0.6 to 1 s range

Results of Spore Activation Experiments

- For all *G. stearothermophilus* and *B. ατροπηαευσ* tests with flare on
  - No positive results were observed by the plating or broth methods

Summary

System flare comparable to real-world operating conditions

Both *B. anthracis* surrogates inactivated in the flare

Dissemination of results

- Manuscript in preparation
- Abstract submitted to AAAR

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EPA CBR Workshop

June 15, 2011

PA's Regulations and Guidance for Dealing with Radioactivity in Solid Waste

David J. Allard, CHP, Director

PA DEP, Bureau of Radiation Protection

(Rev. 6/14/2011)

1

Disclaimer -

Any products or manufacturers mentioned or shown in photographs or text of this presentation, does not represent an endorsement by the author or the Department of Environmental Protection.

2

Objective of this Presentation

- Intro to rad in SW and management in PA
- Interface PaDEP, public and SW industry
- Use of RCRA D landfills for emergencies
- Agencies, Orgs, Ref. Material and URLs
- Open Discussion

BRIDGING THE GAPS:

3

Legislative Authority

- Solid Waste Management Act (Act 1980-97)
- Radiation Protection Act (Act 1984-147)
- Appalachian States LLRW Compact Act (Act 1985-120)
- LLRW Disposal Act (Act 1988-12)
- LLRW Disposal Regional Facility Act (Act 1990-107)

4

PENNSYLVANIA CODE

- Title 25 Environmental Protection
  > Article VIII and IX Municipal and Residual Waste
  - 271. Municipal Waste Management – General Provisions
  - 273. Municipal Waste Landfills
  - 277. Construction/Demolition Waste Landfills
  - 279. Transfer Facilities
  - 281. Composting Facilities
  - 283. Resource Recovery Facilities (RRF)

5

PENNSYLVANIA and SW

- Traditionally the state has had low transport and “tipping” fees for solid waste (SW)
- Millions of tons of solid waste are imported annually into PA for disposal
- SW import is controlled by federal statutes as “interstate commerce”
- Not within the control of the Commonwealth or local host communities
- DEP does issue SW operating permits

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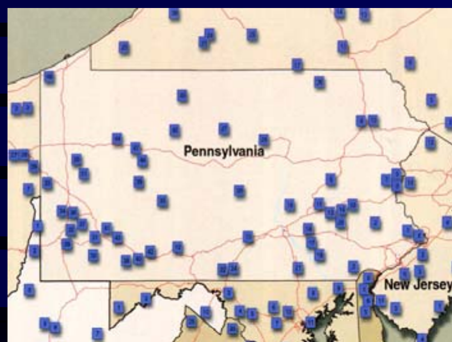
LANDFILLS



TRANSFER STATIONS

(There are also six RRFs in Central and SE PA.)

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Landfill Under Construction

EPA RCRA "D" LF with liner and leachate collection

8

Why did we need regulations and guidance for rad. in solid waste?

- Permits at SW facilities said no "radioactivity"
- Some SW facilities had installed radiation / radioactive materials (RAM) monitors
- Differences between monitors, policies, alarm set point, sensitivity, modes of use, etc.
- Alarms required response by facilities and BRP
- BRP staff responding to several alarms a week
- A "quagmire" of national regulations and standards regarding RAM involved and follow-up
- Nuclear medicine (NM) major cause of alarms

9

Why regs and guidance? (cont.)

- Most of the alarms are of little or no radiological significance (i.e., NM RAM)
- High costs of response if not NM RAM and T½ is > 65 days
- If an "orphan" source and classified as low-level rad waste (LLRW) who pays?
- Hauler or SW Facility may have to pay if originator can't be identified
- The entity in possession of the source or RAM contaminated solid waste is responsible to act

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Why do we have this problem?

- Almost everything in the world contains some radioactivity, mostly of natural origins; BUT
- There is no accepted *legal* definition of what may be detectable as “radioactive,” but of such a low public dose impact (i.e., health risk) as having little need for regulatory control
- NAS Report and NRC tabled action on “clearance” issue
- Some SW facilities had monitors, others didn’t
- Now SW facility permit holders have to install radiation monitors and develop an “Action Plan” for alarm detection response

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PA DEP RP Program Experiences

- 4.2 Ci Ir-192 source left in a patient / waste!
- Am-241 GL source shredded w/ “auto-fluff”
- (2) Ra-Be neutron sources found in trash
- (4) 3 mCi Cs-137 sources incinerated at a Resource Recovery Facility (RRF)
- (100s) Ra-226 luminescent devices in SW
- (1) c1940 Ra-226 therapy needle in SW
- (2) c1950 Ra-226 industrial sources in SW
- (5) yellow bags Co-60 LLRW in ‘cold’ SW from nuclear power plant in PA!

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RP Program Experiences (cont.)

- 150 mCi Am-241 GL source, w/ open shutter
- Cyclotron component activated with Co-56
- (83) Ra-226 check sources in a mason jar
- (2) glass test tubes with 5 mCi Ra-226 each
- (~12) Ra-226 military deck markers
- Sludge from nuclear laundry with Co-60
- Many alarms with NORM / TENORM
- K-40 in potassium permanganate for odors
- I-131 re-concentrated in biosolids from STPs
- Vast majority of the SW alarms I-131, Tc-99m

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Ra-226 Sources Found

Fall 2010 - Radium Round-up No. 3 !!

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Sources of Radioactivity – Nuclear Medicine Procedures

- Short-lived NM radioisotopes w/ T1/2 < 65 days
- NM diagnostic or therapy procedures w/ I-131
- No longer controlled to 30 mCi, use dose limit
- Once in the patient, now dose based to determine if patient leaves facility
- Excreta to sanitary sewer - biosolids with NM RAM, or contaminated “household waste”
- While in licensed facility, contaminated items are to be controlled, but may get in trash accidentally
- Patients can be human or animal

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One of four 3 mCi Cs-137 sources that were incinerated in PA or MD

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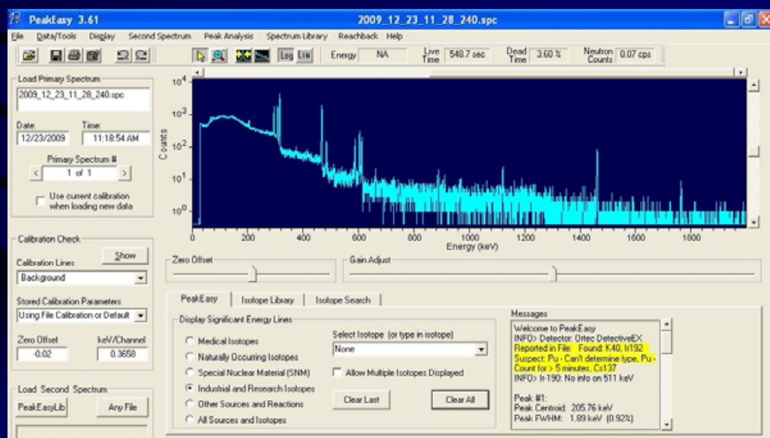
December 2009 Ir-192 Tracer Proppant Detected at a PA Landfill



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Sources of Radiation – Items containing NORM or Technologically Enhanced (TENORM)

- Coke slags
- Metal processing slags
- Media from water purification – U & Rn
- Fire brick – w/ zircon
- Mineral Sands
- Soils
- K compounds
- Rocks
- Minerals
- Fertilizer
- Gypsum
- Sheet rock
- Oil & gas brines and frac sludges
- Coal fly ash

18

“Consumer products”

ASTSWMO petition to NRC to rev regs on tritium EXIT signs!

< GL tritium EXIT sign

19

Regulations Applicable to Nuclear Medicine Procedures

- NRC regulations in 10CFR35.75
  Release of individuals containing radiopharmaceuticals or permanent implants.
- Reg Guide 8.39 Release of patients administered radioactive materials
- NRC regulations in 10CFR20.2003
  Disposal by release to sanitary sewerage

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Objectives of PA Regs and Guidance on RAM in SW

- To protect environment, public and workers from unnecessary exposure
- To protect SW facility property from RAM contamination and costly decontamination
- To help prevent unlawful disposal of specific or generally licensed RAM
- To assist facility operators in complying with revised regulations and permits
- To conserve PA DEP / RP Program resources by reducing unnecessary response activity

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SW Regulations – Basic Limitations

The following radioactive material controlled under specific or general license or order authorized by any federal, state or other government agency shall not be processed at the facility, unless specifically exempted from disposal restrictions by an applicable Pennsylvania or federal statute or regulation:

- NARM
- Byproduct material
- Source material
- Special nuclear material
- Transuranic radioactive material
- Low-level radioactive waste

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SW Regulations – Basic Limitations (cont.)

- The following radioactive material shall not be disposed / processed at the facility, unless approved in writing by the department and the disposal / processing does not endanger the health and safety of the public and the environment:

  - Short lived radioactive material from a patient having undergone a medical procedure
  - TENORM
  - Consumer products containing radioactive material

- The limitations in subsections ( ) and ( ) shall not apply to radioactive material as found in the undisturbed natural environment of the Commonwealth.

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General Guidance for Action Plans

Definitions (RAM, NARM, NORM, TENORM, etc.)

- Background; reg drivers, sources, past events
- General Considerations
  - Personnel Training
  - Monitoring and detection of radiation
  - Awareness of items containing RAM
  - Initial response to detection
  - Notifications; internal/external (PA DEP)
  - Characterization
  - Disposition; reject, dispose / process onsite
  - Record keeping

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Action Plans

- SW Facility must have a RP Action Plan
- Can have a disposal option for NM RAM, and small quantity of TENORM and consumer products
- Plan summary posted for facility personnel
- Facility personnel trained to Action Plan
- Monitoring equipment in place
- Proper response if monitors alarm
- Customer and waste hauler awareness
- Ensure that at least one trained person on duty

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Trucks Being Monitored

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SW Regs - Action Levels

- Below, average background* + 10 mR h^{-1} (max) NO ACTION REQUIRED - treat waste in normal manner.

ACTION LEVEL 1

- Above average background + 10 mR h^{-1} (alarm set point) shall cause an alarm, facility INVESTIGATES!

ACTION LEVEL 2

- Above 2 mR h^{-1} in vehicle cab, 50 mR h^{-1} on any other surface, or contamination – NOTIFY PaDEP / BRP and isolate waste and / or vehicle.

*Note: 10 mR h^{-1} limit on instrument background.

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Guidance - Detection and Initial Response

- System must alarm with 10 mR h^{-1} radiation field at detector element, with Cs-137
- Must detect 50 keV and above gamma rays
- Having a set point no higher than average instrument background + 10 mR h^{-1} - maximize sensitivity, minimize false alarms
- Background is instrument response AT THAT LOCATION; may need to shield to get < 10 mR h^{-1}
- If vehicle exceeds alarm set point, test again
- Still above alarm set point – survey driver & truck

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Guidance
Detection & Initial Response

- Facility must have a site-specific Action Plan
- Initial measurements below Action Level 2, T½ < 65 days and NM RAM, facility may have PaDEP blanket approval for a disposal or process option
- If > 2 mR h^{-1} cab, > 50 mR h^{-1} on surface, or > 22 dpm/cm^2 removable contamination - isolate and call PaDEP / BRP
- DO NOT send driver back on road until proper action determined, and if needed, DOT Exemption obtained from PaDEP/BRP
- If waste is to be rejected, PaDEP will need to know destination to notify other state agencies

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DOT Exemption

- MoU between CRCPD and U.S. DOT
- DOT- E11406 for shipment of solid waste with low-levels of external radiation (expired April 2010)
- Approved by state radiation control official
- One-way transport exemption from certain DOT regs on packaging and labeling
- No contamination, < 50 mrem/hr on side
- In PA, add < 2 mrem/hr in vehicle cab
- If NM RAM and "household waste" no DOT Exemption needed, just a PA Transport Exemption Form

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Guidance –
Characterization

- Identification of radioisotope – use portable multi-channel analyzer (MCA) for gamma spectroscopy
- T1/2 < 65 days and NM RAM, see guidance
- T1/2 > 65 days, see guidance
- May have to unload or hold onsite in the "Designated Area"

  - Isolate vehicle, bag, or container

  - STOP, isolate vehicle from people, call PaDEP if Action Level 2 exceeded

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Guidance – Disposal Option

Examples of Common Nuclear Medicine RAM *

Isotope	T-1/2
I-131	8 days
Tc-99m	6 hours
Tl-201	3.0 days
Ga-67	3.3 days

* Over 90% of alarms to date are from NM RAM and patient contaminated solid waste

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MCAs Used For Characterization

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Guidance - Disposition

- **Ok to dispose or process NM RAM with half life less than 65 days (if determined by DEP not to endanger health and safety of site staff, public and environment)**
- **Small quantity TENORM and consumer products can be pre-approved too**
- **Most SW facilities wanted blanket approval for NM RAM in Action Plan**
- **PaDEP can approve TENORM case by case**
- **RAM disposed of as LLRW at a licensed facility**
- **New DEP Fact Sheet on LLRW disposal options**
- **RAM returned to point of origin (with DOT Exemption manifest from PaDEP / BRP)**

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Guidance - Disposition

T½ > 65 days, except NORM / TENORM

- Above ACTION LEVEL 1 - reject and return to point of origin (with DOT Exemption Form from BRP), or arrange for proper recovery and disposal as LLRW
- Above ACTION LEVEL 2 - respond in consultation with PaDEP / BRP, and perhaps U.S. NRC or EPA
- DEP Fact Sheet noting LLRW brokers
- PA / CRCPD orphan source disposal Agreement may provide funding

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Guidance - Disposal Option (cont.)

TENORM

- TENORM, surface dose rate < 50 mR h^{-1}

  @ 5 cm, combined radium activity < 5.0 pCi/g, and below 1 m^3 - facility can dispose / process without DEP approval

- Higher levels permitted with BRP Director approval, if pathways analysis demonstrates dose to maximum exposed person is less than 25 mrem yr^{-1} from all exposure pathways (i.e., using “resident farmer” and RESRAD code)

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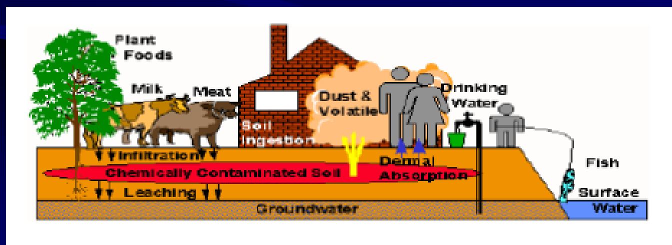
Guidance - Disposal Option (cont.)

TENORM -

RESRAD Code: "resident farmer" evaluation, public dose limit 25 mrem/yr, all pathways (i.e., radon, ground shine and drinking water), looking out 1000 years.



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Final Rev. 12-6-2010

Pennsylvania DEP Standard RESRAD Model Input Parameters / Assumptions for TENORM Landfill Disposal

Use the "Resident Farmer" exposure scenario on top of the landfill, with all pathways turned on [including radon], the dose must be less than 25 millirem per year (mrem/yr) for 1,000 years post TENORM waste placement.

1) Vertical profile:

Standard Landfill and RESRAD Assumptions

Zone	Depth inches	Depth meters	Media	Density (g/cm^3)	Hydraulic Conductivity (m/yr)
Cover	24	0.6096	Soil	1.50	-
Intermediate Cover	12	0.3048	Soil	1.50	-
Total Cover	36	0.9144	Soil	1.50	-
Contaminated Zone*	-	variable	-	1.50	10-300
Unsaturated Zone 1	96	2.438	Soil	1.50	10
Unsaturated Zone 2	6	0.1524	Clay	1.20	40.5
Unsaturated Zone 3	12	0.3050	Sand	1.50	1600
Unsaturated Zone 4	24	0.6100	Soil	1.50	10
Total Unsaturated Zone	138	3.505	-	-	-

* The Contaminated Zone may vary from 3-10 meters in thickness for most intermediate to large volume TENORM disposals; but model it in contact with the Cover and Unsaturated Zone.

2) For intermediate to large volume TENORM disposals, assumptions regarding the Horizontal Profile of the landfill will depend on the area of Disposal Cell(s) used and volume of contaminated material. Area of the Contaminated Zone should not exceed 61 by 61 meters as a typical Cell.

3) Use element-specific default Kd values dependent on soil type, i.e., soil for Unsat. Zone 1 and 4, clay for Unsat. Zone 2, and sand for Unsat. Zone 3.

4) For intermediate to large volume TENORM disposals, the source term Dilution Factor may vary depending upon volume of TENORM contaminated material; limit to no greater than 3:1 without prior DEP approval.

5) All other input parameters shall be default values, unless site specific values are approved prior to use and/or the landfill's Operational Plan is modified appropriately.

The RESRAD family of codes home page: http://web.ead.anl.gov/resrad/home2/

Guidance

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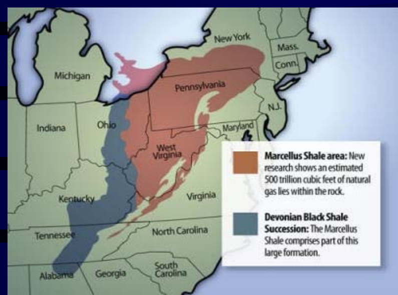
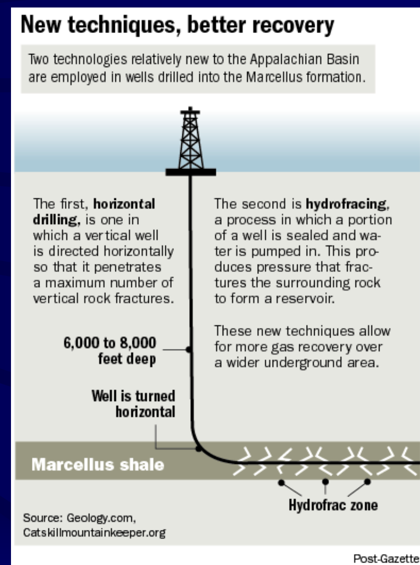
Marcellus Shale





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SW Facility Guidance – Records & Notification

- Daily Operational Records
  - Date / time / location w/ brief narrative
  - Any info on origin
  - Isotope ID if known
  - Name, address, tel.# of hauler / supplier / driver ID
  - Final deposition (dispose / reject)

- DEP Notification
  - For DOT Exemption
  - For disposal NM RAM w/ T½ < 65 days
  - If identify RAM w/ T½ > 65 days
  - Immediate if Action Level 2 exceeded
  - Annual report of detected RAM

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Implementation Update

- Over 170 SW facility permit modifications for RP Action Plans
- Over 140 initial onsite inspections
- Annual Reports being reviewed
- Hundreds of DOT Exemptions issued
- Official DOT "interpretation" on RAM in "household waste" in 2004 - not subject to hazmat regs in 49CFR
- RP Action Plans for POTWs / STPs / CWTs

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Implementation Update (cont.)

- Hundreds of onsite radiation alarm responses
  - ~ 90% NM RAM in household waste
  - ~ 9% NORM or TENORM
  - ~ 1% NM RAM in driver
  - < 1% Regulated or controlled RAM
- DEP Fact Sheets on tritium and "orphan source" / LLRW disposal

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Landfill Leachate Study

- Base-line landfill leachate radiological survey
- Sampled 54 active landfills in 2004
- Initially had ~ 1050 samples
- Gross alpha, beta, gamma spec., and tritium
- Had to do ~ 60 follow-up samples, for
- Total uranium and radium-226 / -228
- Most data could be related to NORM, but,
- Tritium (H-3) found well above background in > 90% of the leachate samples; over 50% of the landfills had > 20,000 pCi/L (i.e., EPA DW standard)
- Follow-up tritium sampling 2005, 2008, present

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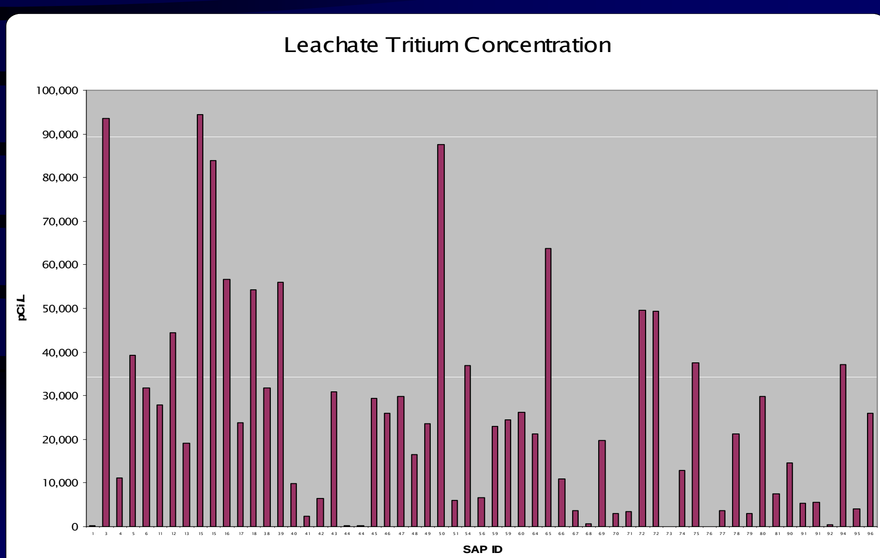
Landfill Leachate Study - Tritium



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ASTSWMO Radiation Focus Group / Board Actions

- **Letter to the Health Physics Society, requesting a related ANSI N13 Standard be developed**
- **Letter to the Conference of Radiation Control Program Directors, requesting related model [SSR] regulations be developed**

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LibRadEx - *"The Week That Was!"*

- Liberty RadEx Agencies and Organizations
- Liberty RadEx Exercise Scenario
- Liberty RadEx Venue Maps

EPA Mobile Command Post

Cleanup and assessment

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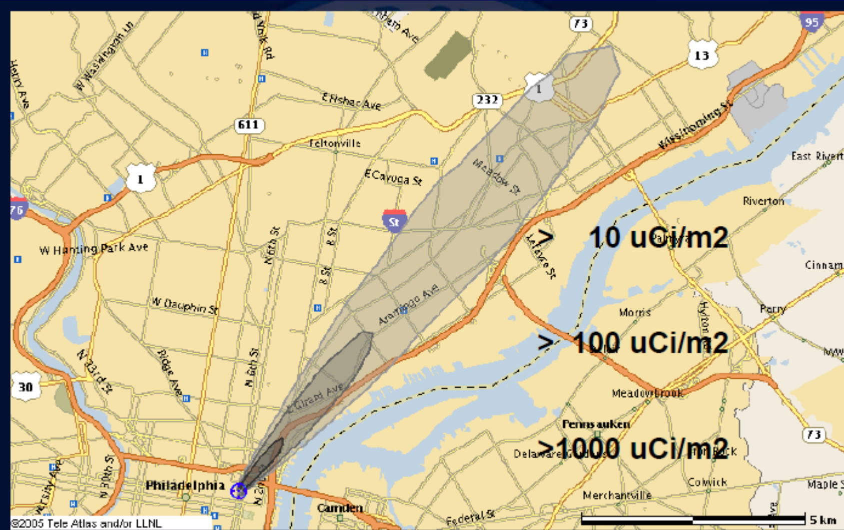
LibRadEx: *Cs-137 Deposition*



Liberty RadEx

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LibRadEx: After-action Report

Lessons learned relate to:

- PAGs, 1^{st} year, EPA vs PA
- Secondary limits: dpm/100 cm^2, pCi/g
- Radioactive Waste, LLRW?, volume, cost $!
- City Government & community involvement
- Communications within responders
- Logistics of a large scale cleanup response

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- DEP's HP consultants (Andy Lombardo, CHP, Anita Mucha and staff)

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Reference URLs

- BRP http://www.dep.state.pa.us/dep/deputate/airwaste/rp/rp.htm
- CRCPD http://www.crcpd.org/
- CDC http://www.bt.cdc.gov/radiation/index.asp
- HPS http://www.hps.org/ http://hps.org/publicinformation/ate/
- AAPM http://www.aapm.org/
- ACR http://www.acr.org/departments/educ/disaster_prep/dp_primer.html
- SNM http://interactive.snm.org/index.cfm?pageid=10&rpid=1977
- NCRP http://www.ncrp.com/
- ANS http://www.ans.org/
- FEMA http://www.fema.gov/hazards/nuclear/
- NRC http://www.nrc.gov/
- EPA http://www.epa.gov/
- IAEA http://www-pub.iaea.org/MTCD/publications/PDF/P074_scr.pdf

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“radiation”

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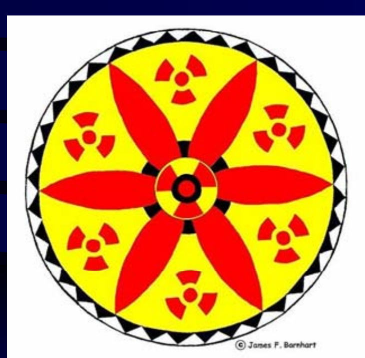
Thank you!

Questions?



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