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Technologies to Improve Efficiency of Waste Management and Cleanup After a Radiological Dispersal Device Incident

Standard Operational Guideline

Office of Research and Development
National Homeland Security Research Center

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U.S. Environmental Protection Agency

Technologies to Improve Efficiency of Waste Management and Cleanup After a Radiological Dispersal Device Incident

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The cleanup process described in this guidance does not rely on and does not affect authority under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), 42 U.S.C. 9601 et seq., and the National Contingency Plan (NCP), 40 CFR Part 300. This document is intended to provide information and suggestions that may be helpful for implementation efforts and should be considered advisory. The guidelines in this document are not required elements of any rule. Therefore, this document does not substitute for any statutory provisions or regulations, nor is it a regulation itself, so it does not impose legally-binding requirements on EPA, states, or the regulated community. The recommendations herein may not be applicable to each and every situation.

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^{137}Cs	cesium-137
ASPECT	Airborne Spectral Photometric Environmental Collection Technology
BAT	Best Available Technology
CDC	Centers for Disease Control and Prevention
CDPHE	Colorado Department of Public Health and Environment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CI/KR	critical infrastructure/key resources
COTS	commercial off-the-shelf
cm	centimeter(s)
CST	crystalline silicotitanate
DHS	U.S. Department of Homeland Security
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
EBCT	empty bed contact time
ED/EDR	Electrodialysis/Electrodialysis Reversal
EPA	U.S. Environmental Protection Agency
ESF	Emergency Support Function
FAST	FIELDS Analysis and Sampling Tools
FEMA	Federal Emergency Management Agency
FIELDS	**Fi**eld **E**nvironmenta**L** **D**ecision **S**upport
FR	Federal Register
FRMAC	Federal Radiological Monitoring and Assessment Center
GAC	granular activated carbon
GIS	geographic information system
GPS	global positioning system
HazMat	hazardous material
Hazus-MH	Hazards U.S. Multi-Hazard (modeling tool)
HEPA	high efficiency particulate air
HHS	U.S. Department of Health and Human Services
HMO	Hydrous Manganese Oxide
HPGe	high-purity germanium
HVAC	heating, ventilation, and air conditioning
I-WASTE	Incident Waste Assessment and Tonnage Estimator
ICS	Incident Command System
IX	ion exchange
keV	kiloelectron volt(s)
LLRW	low-level radioactive waste
MARLAP	Multi-Agency Radiological Laboratory Analytical Protocols
MeV	megaelectron volt(s)
mm	millimeter(s)
NCP	National Contingency Plan
NDRF	National Disaster Recovery Framework
NHSRC	National Homeland Security Research Center (EPA)
NIMS	National Incident Management System

nm	nanometer
NRC	Nuclear Regulatory Commission
NRF	National Response Framework
NRIA	Nuclear/Radiological Incident Annex
OEM	Office of Emergency Management (EPA)
OHS	Office of Homeland Security (EPA)
ORCR	Office of Resource Conservation and Recovery (EPA)
ORD	Office of Research and Development (EPA)
ORIA	Office of Radiation and Indoor Air (EPA)
OSC	On-Scene Coordinator
OW	Office of Water (EPA)
PPE	personal protective equipment
PSI	pounds per square inch
QA/QC	Quality Assurance/Quality Control
RCRA	Resource Conservation and Recovery Act
RDD	radiological dispersal device
RID	radionuclide identifier
RO	reverse osmosis
RSF	recovery support function
S/S	stabilization/solidification
SGS	Segmented Gate System
SME	Subject Matter Expert
SOG	Standard Operational Guideline
SPC	sulfur polymer cement
SSCT	Small System Compliance Technology
UASI	Urban Area Security Initiative
UC	Unified Command
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plans
USDA	U.S. Department of Agriculture
WAC	Waste Acceptance Criteria
WARRP	Wide Area Recovery and Resiliency Program
WCIT	Water Contaminant Information Tool
WEST	Waste Estimation Support Tool

Glossary

The following terms are defined for purposes of this document.

Agency – A division of government with a specific function, or a non-governmental organization (e.g., private contractor, business, etc.) that offers a particular kind of assistance. In the incident command system (ICS), agencies are defined as jurisdictional (having a statutory role in incident mitigation) or assisting and/or cooperating (providing resources and/or assistance).

Clearance – The process of determining that a cleanup goal has been met for a specific contaminant in or on a specific site or item. Generally occurs after decontamination and before reoccupancy.

Code of Federal Regulations (CFR) – The codification of the federal regulations published in the Federal Register by the executive departments and agencies of the federal government. Each volume of the CFR is updated once each calendar year and is issued on a quarterly basis. See http://www.gpoaccess.gov/cfr/index.html.

Critical Infrastructure (CI) – Systems and assets, whether physical or virtual, so vital that the incapacity or destruction of such may have a debilitating impact on the security, economy, public health or safety, environment, or any combination of these matters, across any federal, state, regional, territorial, or local jurisdiction.

Decontamination – The inactivation or removal of contaminants from surfaces by physical, chemical, or other methods to meet a cleanup goal. For the purposes of this document, decontamination does not include treatment of contaminated water or wastewater, or other wastes.

Emergency – Any incident, whether natural or man-made, that requires responsive action within hours to protect life or property. As defined in the Stafford Act, any occasion or instance for which, in the determination of the President, federal assistance is needed to supplement state and local efforts and capabilities to save lives and to protect property and public health and safety, or to lessen or avert the threat of a catastrophe in any part of the United States (Per 42 U.S.C. 5122).

Federal On-Scene Coordinator (OSC) – The federal official responsible for coordinating and directing federal responses under subpart D, or the government official designated by the lead agency to coordinate and direct removal actions under subpart E, of the National Contingency Plan (NCP) (per 40 CFR 300.5). The specific duties of the OSC are provided in 40 CFR 300.120. The federal OSC is predesignated by the U.S. Environmental Protection Agency (EPA), U.S. Coast Guard, U.S. Department of Energy (DOE), or U.S. Department of Defense (DoD) depending on the location and/or source of the release and may be designated by other federal agencies under certain circumstances.

Federal Radiological Monitoring and Assessment Center (FRMAC) – A multi-agency response asset to assist state and local officials with monitoring, assessment, and health guidance for nuclear/radiological incidents. The mission of the FRMAC is to coordinate and manage all federal radiological environmental monitoring and assessment activities during a nuclear or radiological incident, within the United States.

Federal Register (FR) – The official weekday publication for rules, proposed rules, and notices of federal agencies and organizations, as well as executive orders and other presidential documents. See http://www.gpo.gov/fdsys/browse/collection.action?collectionCode=FR.

Hazardous Waste – For the purposes of this guidance, a solid waste that may cause an increase in mortality or serious illness or pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, disposed of, or otherwise managed. See **Solid Waste** for the definition of a solid waste for the purposes of this guidance.

Incident – An occurrence, caused by either human action or natural phenomena, that may cause harm and may require action. Incidents can include major disasters, emergencies, terrorist attacks, terrorist threats, wild and urban fires, floods, hazardous materials spills, nuclear accidents, aircraft accidents, earthquakes, hurricanes, tornadoes, tropical storms, war-related disasters, public health and medical emergencies, and other occurrences requiring an emergency response.

Incident Command System (ICS) – A standardized on-scene emergency management construct specifically designed to provide for the adoption of an integrated organizational structure that reflects the complexity and demands of single or multiple incidents, without being hindered by jurisdictional boundaries. ICS is a management system designed to enable effective incident management by integrating a combination of facilities, equipment, personnel, procedures, and communications operating within a common organizational structure, designed to aid in the management of resources during incidents. It is used for all kinds of emergencies and is applicable to small as well as large and complex incidents. ICS is used by various jurisdictions and functional agencies, both public and private, to organize field-level incident management operations. (From U.S. Department of Homeland Security, *National Response Framework*, 2008, FEMA Publication P-692.)

Initial Response – Actions taken immediately following notification of a contamination incident or release. In addition to search and rescue, scene control, and law enforcement activities, initial response may include initial site containment, environmental sampling and analysis, and public health activities, such as treatment of potentially exposed persons.

Key Resources (KR) – As defined in the Homeland Security Act, publicly or privately controlled resources essential to the minimal operations of the economy and government.

Low-Level Radioactive Waste (LLRW) – Radioactive waste not classified as high-level radioactive waste, transuranic waste, spent nuclear fuel, or by-product material as defined in paragraphs (2), (3) or (4) of the definition of by-product material set forth in 10 CFR 20.1003 (per 10 CFR 61.2). LLRW may contain either high or low concentrations of radioactivity. In general practice, LLRW does not include naturally occurring radioactive material but does include man-made material.

Mixed Waste – For the purposes of this guidance, waste that contains both hazardous waste and source, special nuclear, or by-product material subject to the Atomic Energy Act of 1954.

National Contingency Plan (NCP) – Also called the National Oil and Hazardous Substances Pollution Contingency Plan, the plan (40 CFR Part 300) that generally provides a blueprint for carrying out response actions under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and section 311 of the Clean Water Act. The NCP is designed to provide for efficient, coordinated, and effective response to discharges of oil and releases of hazardous substances, pollutants, and contaminants. The NCP describes the organizational structure and procedures for preparing for and responding to discharges of oil and releases of hazardous substances, pollutants, and contaminants.

Radiological Dispersal Device (RDD) – Any device that causes the purposeful dissemination of radioactive material across an area with the intent to cause harm, without a nuclear detonation occurring.

Recovery – Those capabilities necessary to assist communities affected by an incident to recover effectively, including, but not limited to, rebuilding infrastructure systems; providing adequate interim and long-term housing for survivors; restoring health, social, and community services; promoting economic development; and restoring natural and cultural resources. (From U.S. Department of Homeland Security, *National Disaster Recovery Framework*, FEMA publication, September 2011).

Remediation – For the purposes of this guidance, when used in connection with hazardous waste, all solid and hazardous wastes, and all media (including ground water, surface water, soils, and sediments) and debris, that are managed for implementing cleanup. The cleanup process described in this guidance does not rely on and does not affect authority under CERCLA, 42 U.S.C. 9601 et seq., and the NCP, 40 CFR Part 300.

Resource Conservation and Recovery Act (RCRA) – A 1976 federal law (42 U.S.C. §6901 et seq.) that gives the U.S. Environmental Protection Agency (EPA) the authority to control hazardous waste from the "cradle-to-grave." This includes the generation, transportation, treatment, storage, and disposal of hazardous waste. RCRA also set forth a framework for the management of non-hazardous solid wastes. The 1986 amendments to RCRA enabled EPA to address environmental problems that could result from underground tanks storing petroleum and other hazardous substances.

Response – Immediate actions taken to save lives, protect property and the environment, and meet basic human needs (see also **Initial Response**). Response includes the execution of emergency plans and actions to support short-term recovery (see **Recovery**). (From U.S. Department of Homeland Security, *National Response Framework*, FEMA Publication January 2008).

Solid Waste – For the purposes of this guidance, any garbage, refuse, or sludge from waste treatment, water supply treatment, and air pollution control and other discarded materials from industrial, commercial, mining, and agricultural operations and from community activities.

Treatment – For the purposes of this guidance, when used in connection with hazardous waste, any method, technique, or process, including neutralization, designed to change the physical, chemical, or biological character or composition of any hazardous waste so as to neutralize such waste, or so as to recover energy or material resources from the waste, or so as to render such waste non-hazardous, or less hazardous; safer to transport, store, or dispose of; or amenable for recovery, amenable for storage, or reduced in volume. Treatment is not the same as "decontamination." (See **Decontamination**).

Treatment technology – For the purposes of this guidance, any unit operation or series of unit operations that alters the composition of a hazardous substance or pollutant or contaminant through chemical, biological, or physical means so as to reduce toxicity, mobility, or volume of the contaminated materials being treated. Treatment technologies are an alternative to land disposal of hazardous wastes without treatment. (See 55 FR 8819, March 8, 1990.) The definition of treatment technology as defined in the NCP can be found at 40 CFR 300.5.

Waste Management – For the purposes of this guidance, the administration of activities that include, but are not limited to, source reduction, waste minimization, waste segregation, decontamination, recycling, transport, staging, storage, treatment, and disposal.

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1. INTRODUCTION

The U.S. Department of Homeland Security (DHS), in close coordination with the U.S. Environmental Protection Agency (EPA), the U.S. Department of Defense (DoD), the U.S. Department of Energy (DOE), the U.S. Department of Health and Human Services (HHS), and the Denver Urban Area Security Initiative (UASI), has initiated the Wide Area Recovery and Resiliency Program (WARRP).[1] WARRP is designed to develop guidance to reduce the time and resources required to recover a wide urban area (specifically, Denver) following a chemical, biological, or radiological incident, including meeting public health requirements and restoring critical infrastructure (CI), and key resources (KR) (both civilian and military) and high-traffic areas. WARRP planning documents generated for the Denver UASI could potentially be used as templates and adapted by other urban areas to plan for recovery from wide-area, all-hazards incidents.

This Standard Operational Guideline (SOG) describes technologies that may be employed for decontamination and cleanup in the aftermath of a radiological dispersal device (RDD) ("dirty bomb" attack). Responding to such an incident may involve waste staging, screening, segregation, treatment, transportation, and disposal. This document focuses on the application of technologies to minimize the generation of waste and segregate waste by type and level of contamination, which will facilitate further treatment and ultimate disposal. The Annex to this document provides detailed information on each technology, including a qualitative ranking of attributes significant to implementation, that will assist decision-makers in selecting the appropriate technology(ies) for a given situation.

It is important to recognize that these or other technologies are likely to be selected within the framework of an overall integrated decontamination strategy and waste management plan for the response. Strategies and plans will depend on factors such as the exact nature of the contaminant and the size of the contaminated area, the statutory and regulatory framework governing the response, the timeline within which the response is operating, the resources available to implement the response, cleanup goals, and decisions on final disposal locations. RDD waste disposal decisions must protect public health and the environment, and the community potentially receiving the waste must be provided with an opportunity to provide meaningful input on receiving radioactive waste.[2] These and other factors affecting the response involve important policy considerations, which are beyond the scope of this document to address.

This document relies in part on previously published information by EPA and other federal agencies, as well as institutional knowledge gained from existing programs such as EPA's

[1] More information about WARRP planning objectives, guidance documents, and exercises and workshops among end users/interagency partners can be found at http://www.warrp.org. The WARRP program was based around developing planning documents for the Denver UASI.

[2] See Statement of Michael Shapiro, then - Principal Deputy Assistant Administrator, Office of Solid Waste and Emergency Response, before the U.S. Senate Committee on Environment and Public Works (July 25, 2000). Also see related letter from Robert Perciasepe, then-EPA Assistant Administrator of the Office of Air and Radiation, and Timothy Fields, Jr., then-Assistant Administrator of the Office of Solid Waste and Emergency Response, to The Honorable Clint Stennett, Minority Leader, Idaho State Senate, June 26, 2000.

Superfund program and from recent large-scale incidents (Hurricane Katrina, Deepwater Horizon, Fukushima, etc.). State and local officials also have access to online guidance and handbooks that may be considered for use when responding to a radiological incident. The intent of this document is to provide information to any decision-maker, emergency management planning organization, qualified radiological cleanup contractor, or recovery personnel involved in waste management/minimization activities. For instance, Section 5 of this document provides some basic information on preparing waste management plans that can be adapted to RDD incidents.[3]

This SOG provides multi-level (federal, state, territorial, tribal, and local) response and recovery information for a wide urban area (in this case, Denver) that could potentially be leveraged and transitioned to other parts of the United States and internationally. The cleanup process described in this document does not rely on and does not affect authority under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the National Contingency Plan (NCP).

1.1 Purpose of the Standard Operational Guideline

The purpose of this SOG is to provide information on existing technologies and methodologies that have the potential to enhance cleanup and reduce waste and/or waste management costs. Appropriate use of cleanup technologies and tactics and effective field survey and screening will improve the removal and management of contaminated materials and reduce radiation exposure. Together, these technologies and methodologies may help to minimize wastes, segregate waste streams, keep higher activity wastes separate from lower activity wastes, and ultimately maximize the efficiency of the cleanup process.[4]

The information provided in this SOG is not an endorsement or recommendation of any specific technology by any agency or individual. Appropriate technologies will be selected by the involved decision-makers according to the needs of the specific incident. Many of the technologies and methodologies described in this document have very specific or limited application. Others have had only limited testing or have been tested for applications other than an RDD attack. Some may be effective for one radionuclide and not for another. A wide-area RDD cleanup would likely employ many or all of these technologies and methodologies in different locations or at different times to achieve the overall cleanup goals. Many of the technologies and methodologies also would have to be field-tested during a response to fully evaluate their effectiveness and application. All of the technologies impact in some way the waste management of the response and recovery to the RDD.

1.2 Scope of the SOG

The SOG is intended to provide decision-makers with a summary of cleanup and waste management technologies that may be applicable in response to an RDD incident. However,

[3] For the purposes of this SOG, waste management includes, but is not limited to, the following activities: source reduction, waste minimization, waste segregation, decontamination, recycling, transport, staging, storage, treatment, and disposal.
[4] Waste management costs are likely to represent a significant proportion of the cost of facility decommissioning and may be a significant consideration in responding to an RDD attack. This document discusses waste management approaches that may improve cost-effectiveness while achieving an appropriate level of public health protection, thereby allowing additional resources to be dedicated to decontamination and remediation.

cleanup and waste management decisions are expected to be made within the scope of the overall response. Section 1.3 identifies general cleanup and waste management methods. Sections 2 through 8 of the SOG provide a general summary of other factors and considerations that decision-makers should consider in selecting cleanup and waste management technologies. These sections are deliberately general in nature so that responding organizations can insert or reference more detail or local, incident-specific operational information. Section 9 lists references cited in this SOG. Annex A provides detailed descriptions of technologies for decision-makers to consider when planning and implementing waste management activities as part of a radiological incident.[5]

Annex A also lists a set of criteria (e.g., time to implement, availability) to be considered when evaluating these technologies. The criteria can be subjective or objective and can be impacted by several factors, including (1) type of radionuclide; (2) type of surface or bulk media (building, soil, road, trees, water or other liquids); and (3) desired cleanup level goal. As stated earlier, many of the technologies and methodologies would also have to be field-tested during a response to fully evaluate their effectiveness and application.

During the WARRP Decon-13 Subject Matter Expert (SME) Meeting held on August 14 – 15, 2012, several technologies listed in the Annex were scored against each criterion and assigned a low/not advantageous (red), medium/neutral (yellow), or high/advantageous (green) designation. Data have been presented consistently in a standard format to facilitate comparisons between technology options. These results are being carried forward in this SOG; however, the ranking of the technology options should be considered only the opinion of the SMEs attending the meeting and are not prescriptive in nature.

Wastewater cleanup/waste minimization technologies were identified as an element of the overall project after the SME meeting; hence, their color coding was not developed until later. The criteria and discussion from the other types of technologies from the SME Meeting were used to prepare the color coding in the Annex.

1.3 General Cleanup and Waste Management Methods

The following general methods and options were considered during the development of the SOG to enable the segregation, separation, and reduction of waste. The technologies listed in Annex A are consistent with one or more of these methods:

- ***Enhanced surveying***. RDD plume maps tend to be deceptive because they indicate uniform and declining concentrations over distance. Topography, structures, and vegetation are expected to result in localized areas of higher or lower concentration of radioactive material within the overall pattern of radioactive material distribution. Improved surveying may enable focused cleanup of specific areas where contamination is greater, which allows areas with little or no contamination to be addressed at a later time.

- ***Hot spot removal***. An RDD attack will likely result in a small area of higher-concentration/higher-activity wastes (hot zone) immediately surrounding and immediately downwind of the blast. These higher-activity wastes may be contaminated with radionuclides at levels consistent with Class B or C low-level radioactive waste (LLRW).[6] Beyond this area of higher-activity waste, it is anticipated that the remaining

[5] Waste minimization is defined as the minimization of the generation of radioactively contaminated waste through action such as segregating waste types and controlling the spread of radioactivity.

[6] The U.S. Nuclear Regulatory Commission (NRC) defines classes of low-level radioactive waste at 10 CFR 61.55.

contaminated materials will be significantly less concentrated. Hot spot removal also has applications outside the hot zone. Air deposition may result in uneven contamination (e.g., back yards may have significant contamination, while front yards may not be impacted and drainage channels may be more impacted than the surrounding property). In some cases, cleaning up only the areas of higher contamination may achieve cleanup goals. In other cases, focusing on hot spots may be sufficient to allow continued occupancy until final cleanup is completed, or it may allow critical infrastructure (CI) to be quickly reopened or key resources (KR) to be accessed.

- ***Dig and haul, demolition, and removal of contaminated materials for disposal***. These techniques are proven, effective methods for removing radioactive material and cleaning an area for reoccupancy. In addition, when done properly, these methods assist waste segregation efforts. They are also labor-intensive, are relatively costly, and generate large volumes of waste.
- ***Thin-layer soil surface removal***. Under certain circumstances, significant radioactive material may exist only in the top few inches or centimeters of soil. Soil removal technologies and methodologies that remove a thin layer of topsoil may significantly reduce contamination while limiting waste volume, cleanup time, cost, and restoration effort. Removal may be accomplished by employing manual techniques such as sod cutting and hand digging or by using modified excavation equipment operated by highly skilled operators.
- ***Foliage removal***. Foliage may collect significant concentrations of contamination. Early removal of foliage may reduce radioactive material and immediate exposure while generating a homogeneous waste stream that can be handled and treated separately. Foliage removal may also be considered periodically after initial cleanup. If trees remain in the area, it is possible for them to take up residual radioactivity, so the leaves in subsequent years may also need to be analyzed.
- ***Physical cleaning of hard surfaces***. Vacuuming, high-pressure washing, and similar techniques may reduce (possibly significantly) contamination without damaging or destroying the surface. Vacuuming may collect small particles or dust; if coupled with a filter, care should be taken during filter removal to avoid exposure to radioactive material. Aqueous cleanup is expected to generate aqueous waste streams that may need to be addressed subsequently through treatment and/or disposal.
- ***Physical removal of surface layer of material from hard surfaces***. Scabbling, grinding, scarification, grit blasting, and other similar techniques, which remove a thin layer of the surface of objects, may remove significant amounts of radioactive contamination while generating less radioactive waste than demolition.
- ***Chemical cleaning or other treatments of hard surfaces***. Foams, acids, chelating agents, fixatives, and strippable coatings may remove or control some (usually not all) surface contamination, but these treatments have some potentially important applications for reopening CI and mobilizing KR pending completion of final cleanup and subsequent clearance. Surface treatments may also be used in applications where contamination is already low or where exposure is low.

- ***Waste volume reduction***. The use of waste volume reduction technologies, including incineration, may reduce waste handling and disposal demands.
- ***Waste stabilization***. Waste stabilization technologies, such as *in situ* vitrification, generally result in a reduction of hazardous constituent mobility. Depending on the technology used, wastes that have been stabilized in place may pose lower health risks, particularly when shielding of radioactive contamination is also employed.
- ***Soil burial***. Burying contaminated surface soils deeper in the soil (e.g., through plowing) or covering them with a layer of clean soil or concrete may reduce human and animal exposure to radioactivity. Soil burial needs to consider the implications for possible movement of contamination in the subsurface.
- ***Composting***. Composting is a methodology for turning organic wastes, possibly contaminated with low-level radionuclides (foliage, but mainly animal carcasses), into wastes that can then be buried or placed into a landfill. Subsurface transport of contaminants needs to be considered.[7]
- ***Wastewater cleanup or volume reduction***. Cleanup, particularly aqueous-based cleanup techniques, may generate large volumes of water that present treatment, storage, and disposal issues. Techniques such as ion exchange, filtration, reverse osmosis, and evaporation may potentially separate, concentrate, or remove the specific radiological contaminant or its daughter product from wastewater that is produced as a secondary waste.
- ***Other technologies***. Other technologies were considered which may potentially have application to RDD incidents. These other technologies include soil washing and the "segmented gate system."
- ***No Action***. Performing no action may be an option in the near term. Generally, no action should be considered where (1) contaminant concentrations are too high to allow timely, cost-effective cleanup and the area is temporarily evacuated or permanently abandoned; (2) concentrations are so low that they do not pose an unacceptable risk; (3) exposures are very low, cleanup is very costly, and higher-concentration areas are a higher priority; (4) contaminated historical structures may be destroyed if cleanup is undertaken; or (5) other management or engineering controls can be applied until the need for future action can be assessed.

Generally, physical damage outside the blast zone is expected to be minimal; the amount of blast-related debris is likely to be relatively small compared to the amount of undamaged contaminated materials. It may be possible to systematically segregate contaminated waste, which includes debris, from uncontaminated waste from an RDD incident.[8]

[7] Burial options for large quantities of animal carcasses are extremely limited.
[8] The terms "contaminated" and "uncontaminated" will be decided by the cleanup goals and waste acceptance criteria (WAC) of the disposal facilities.

2. PLANNING ASSUMPTIONS

This SOG is based on several planning assumptions related to the appropriate and effective use of existing waste cleanup, reduction, and management technologies and methodologies in the event of a radiological incident. It is important to understand the basic nature of a radiological incident and the factors that guide cleanup and recovery following the incident. It is also important to understand that as part of the WARRP program, this document is based on the scenarios specifically developed for the Denver UASI, with the intent of potentially being adapted more broadly for use in other urban areas.

2.1 Nature and Consequences of an RDD Attack

> Radioactive materials are widely used in medicine, agriculture, industry, and research; there are also sources that are not secure or are not accounted for. For these reasons, it is generally easier to obtain materials for dirty bombs than materials used to construct a nuclear explosive device. Furthermore, far less technical knowledge is needed to build and deploy an RDD compared to a nuclear device (FEMA, 2012).

DHS National Planning Scenario 11 describes a hypothetical radiological attack with an RDD in a moderate-to-large U.S. city (DHS, 2006).

An RDD ("dirty bomb") consists of radioactive material combined with conventional explosives. Cesium-137 (^{137}Cs) is a radioactive source that could be used in the construction of an RDD. [9] These devices are designed to use explosive force to disperse the radionuclide over a large area, such as multiple city blocks. The explosive effect of the RDD is likely to kill more people in the immediate area of the blast than would the radiological effect of the device, and such attacks are intended primarily to produce psychological, economic, and political harm rather than physical harm by inducing panic and terror in the target population and denying use of an area because of radioactive contamination. Most injuries from an RDD incident are likely to occur from the explosion of the bomb (heat, debris, and force); such attacks immediately affect individuals close to the site of the explosion and contaminate nearby areas with large amounts of radioactive particles. Health risks from an RDD attack include the trauma associated with being caught in the explosion itself and the potential for increased risk of cancers attributable to (1) long-term exposure to increased amounts of residual radiation and (2) acute inhalation of high concentrations of contaminated particles.

2.2 Estimated Waste Quantities and Radioactivity Levels Under the WARRP RDD Scenario

The RDD scenario described for the Denver urban area involves two RDD attacks: one at the U.S. Mint in downtown Denver, Colorado, and another at the Anschutz Medical Campus in Aurora, Colorado. The scenario assumes that tens of thousands of people are exposed at various levels and that hundreds immediately die from blast-related trauma. The primary fallout area is within tens of miles of the blast, although some of the radiological agent may be carried hundreds of miles. The downtown release scenario potentially impacts more than 20 square miles and 32,000 buildings (which include 82 million square feet of indoor space), while the Aurora release scenario impacts fewer buildings and people but contaminates a much larger area (DHS, 2012a). Both bombs were identical in explosive power and amount of radioactivity, but the

[9] A DHS fact sheet on RDDs is available at: http://www.dhs.gov/xlibrary/assets/prep_radiological_fact_sheet.pdf

difference in the plumes is due to the entrainment of contamination by the high-rise downtown Denver buildings.

The scenario discussion presented focuses on the U.S. Mint (downtown Denver) scenario. In this scenario, higher concentrations of ^{137}Cs were deposited immediately around and downwind of the blast. Figure 1 shows the release scenario and levels of contamination at the U.S. Mint. (In the Aurora scenario, the cesium was spread out over a far larger area.)

Based on this scenario, some tools that EPA has been developing to assist in wide-area remediation activities were used to estimate the quantity and residual activity of the waste generated from the hypothetical RDD incident at the U.S. Mint as described above. The Incident Waste Assessment and Tonnage Estimator (I-WASTE) tool (EPA, 2011a) was used to estimate the building contents, and the Waste Estimation Support Tool (WEST) (EPA, 2012a) was used to estimate building stock, building composition and square footages, and the makeup of the outdoor areas. WEST makes extensive use of the Federal Emergency Management Agency's (FEMA's) Hazards U.S. Multi-Hazard (Hazus-MH) loss estimation model (FEMA, 2010). Information on personal protective equipment (PPE) waste generated from response operations was based on information derived from the Bio-response Operational Testing and Evaluation program (Lemieux et al., 2011).

In the discussion on the following pages, the estimated contamination levels are used solely for development of the discussions on the quantity, makeup, and residual radioactivity of the waste. The estimated contamination levels should not be construed to be cleanup levels. For example, the 15-millirem-per-year dose level used to determine what is contaminated is not specified as a cleanup level by any federal program. In this scenario, there may be extensive contamination beyond the drawn plumes, and areas outside the drawn plumes may require decontamination as well.

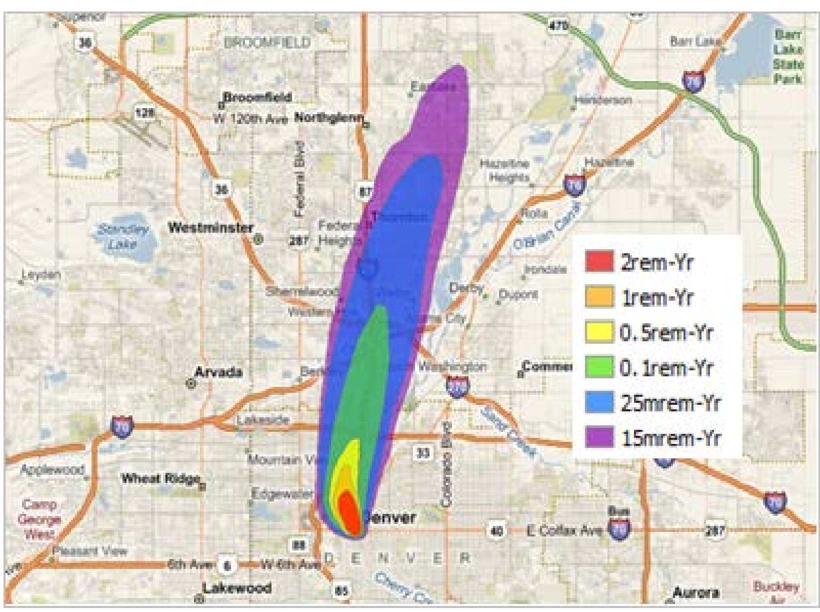


Figure 1. WARRP RDD scenario releases at U.S. Mint.

A major wastewater treatment plant that serves approximately 1 million people in Denver and the surrounding area is situated within the plume impact zone shown in Figure 1.[10] Contamination in this area may impact the ability to receive and treat wastewater. For combined systems, rain water runoff could transport the contaminant to the wastewater treatment plant; while, for separate systems, storm drains could also disperse the contaminant outside the area impacted by the plume. If wastewater treatment is compromised, downstream water intakes for drinking water systems could be more highly contaminated than the facility is able to handle. This might necessitate implementing a temporary pre-treatment step or even shutting down the downstream water intakes and providing drinking water from another source.

Figure 2 shows the estimated number of affected structures in the primary contaminated area, by building use. The following assumptions about the affected infrastructure were used: (1) the number of schools and hospitals was determined from the Hazus-MH model output; (2) all small wood buildings and mobile homes were assumed to be residences; (3) the rest of the general building stock was assumed to be offices (99%) and hotels (1%); and (4) percentage breakdowns of building size were assumed to be small (50%), medium (30%), and large (20%) (FEMA, 2010).

Based on these assumptions, two different hypothetical remediation scenarios were developed using WEST to investigate the impact of different decontamination and demolition strategies on the total amount and characteristics of the waste. Both scenarios assume that all affected areas at 15 millirem or higher were remediated. It is likely that areas contaminated at levels below 15 millirem will also be remediated, but for the purposes of this hypothetical waste estimate, they were not included. The “Extensive Decontamination” option included a significant amount of demolition and washing of outdoor areas, coupled with extensive interior decontamination. The “Limited Decontamination” option included less demolition, washing, and interior decontamination than the “Extensive Decontamination” option. Some of the following figures demonstrate the impact of these two hypothetical scenarios.

Figure 3 shows the estimated quantities and sources of waste from the affected areas. Figure 4 shows the estimated composition of the waste from the affected areas. Figure 5 shows the estimated average activity of the waste generated from the cleanup. Figures 3 through 5 also illustrate the differences between the “Extensive” and “Limited” decontamination strategies. It must be noted that due to the overwhelming quantities of certain categories of waste materials potentially generated from the outlying regions of the plume, the differences between the two decontamination strategies chosen for this example may not appear to be significant for some categories of waste generated closer to the blast point. In addition, it must be noted that the WEST tool, in its current incarnation, assumes that whatever cleanup process is used achieves the stated cleanup goals, which may not be the case, particularly when comparing disparate cleanup approaches.

Note that the upper end estimate (“Extensive Decontamination” option) of 3 billion gallons of liquid waste from demolition and decontamination operations shown in Figure 3 represents roughly 4% of Denver’s annual water usage, suggesting that delivery of wash water in quantities necessary for the cleanup may be problematic, and that finding ways to reuse wash water and

[10] The wastewater treatment plant is just south of the intersection of I-76 and I-270.

minimize its discharge as wastewater may be a critical aspect of the response. In addition, the waste estimate suggests that most solid waste was generated from only a few streams, with soil, concrete, ceiling tile, carpet, electronics, furniture, and paper constituting a significant fraction of the waste.

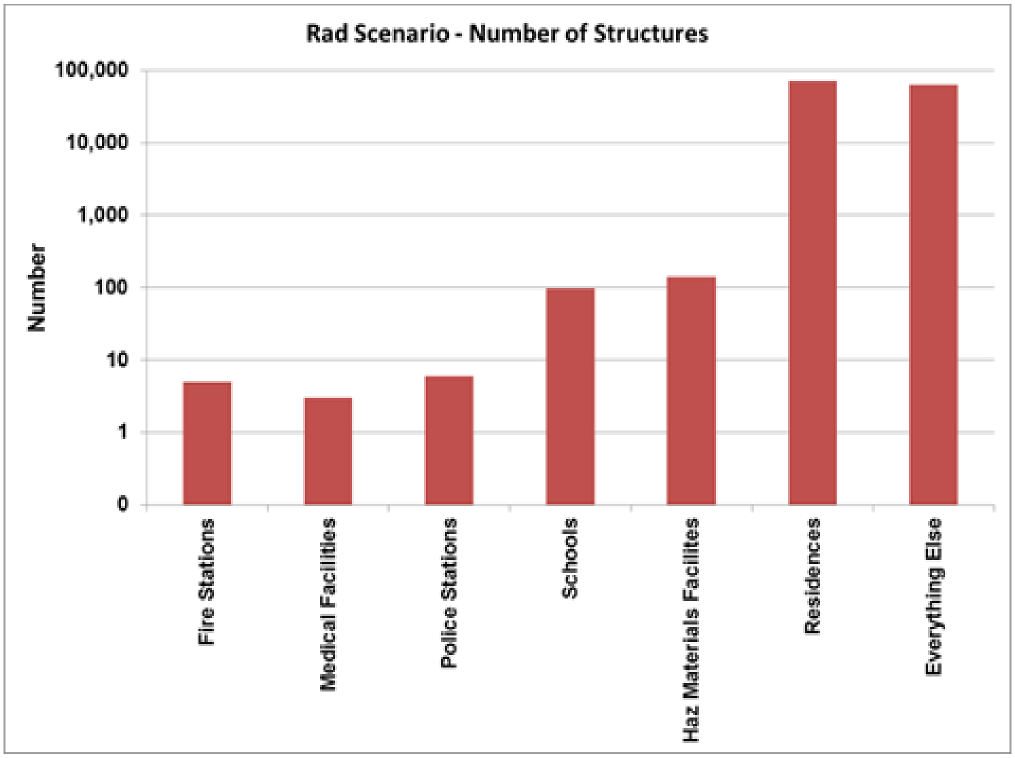


Figure 2. WARRP RDD scenario – estimated number of contaminated structures in area bounded by <15-millirem contamination zone.

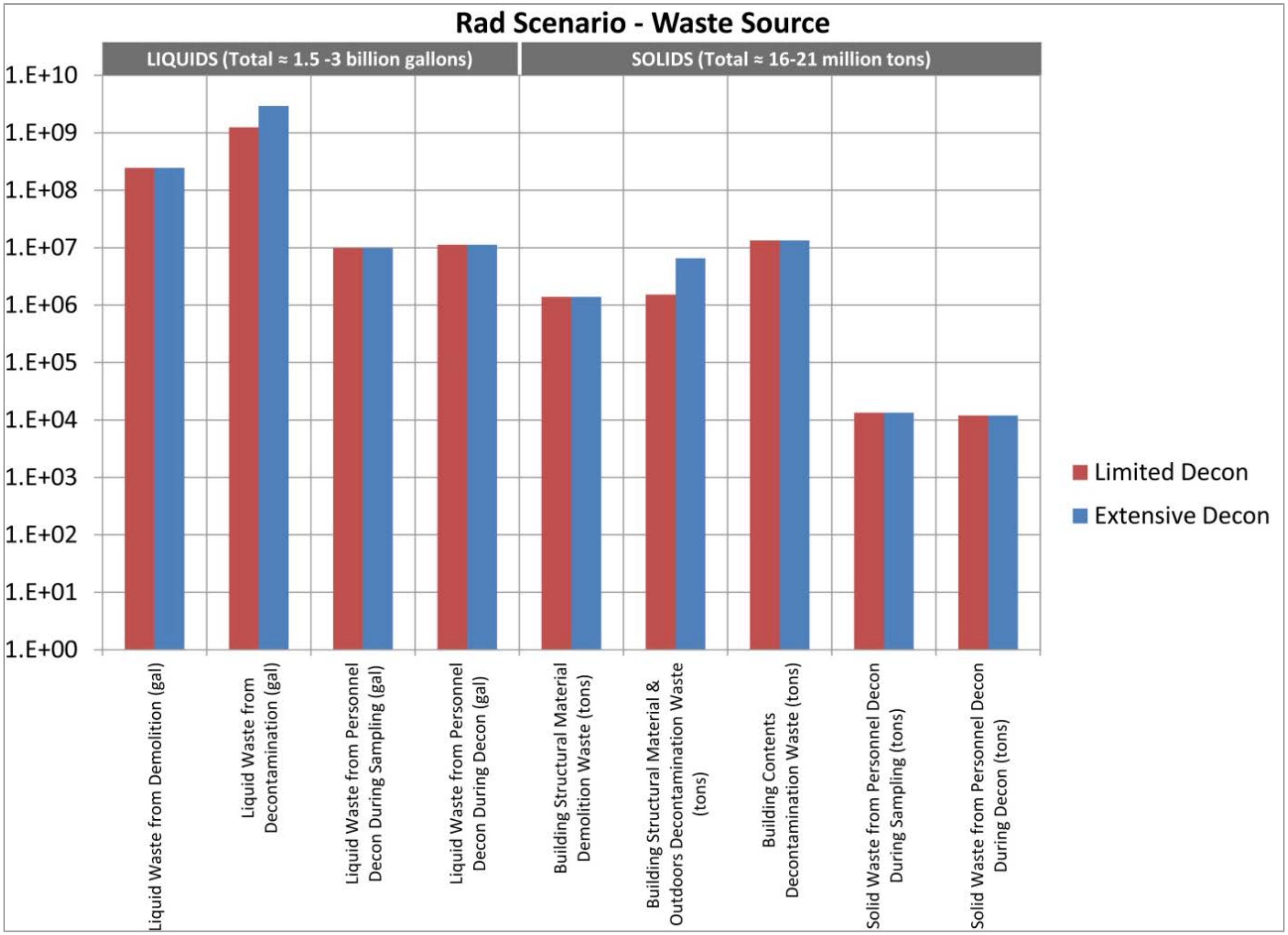


Figure 3. Estimated quantities and sources of waste from WARRP RDD scenario in area bounded by <15-millirem contamination zone.

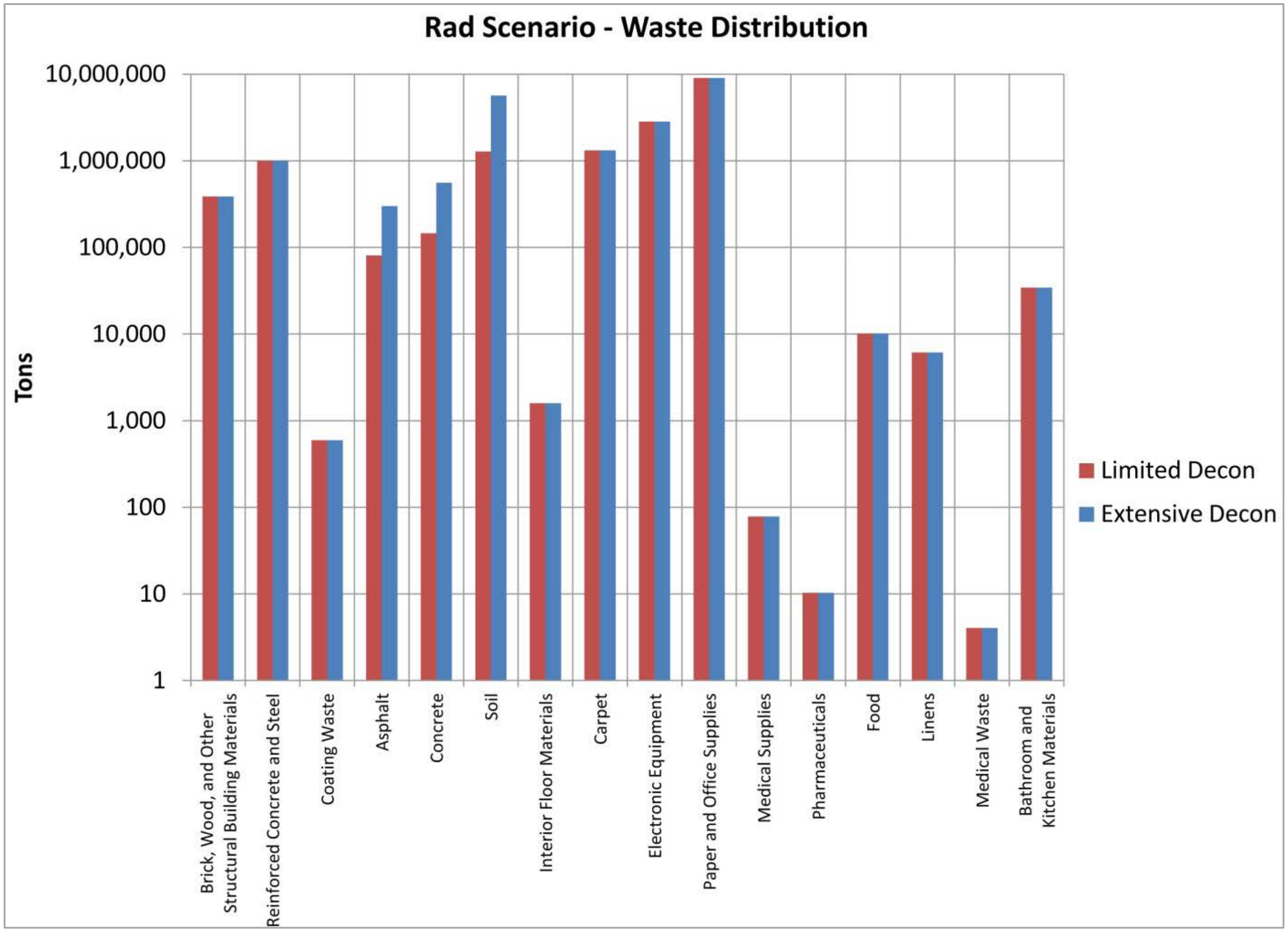


Figure 4. Estimated breakdown of solid waste from WARRP RDD scenario in area bounded by <15-millirem contamination zone.

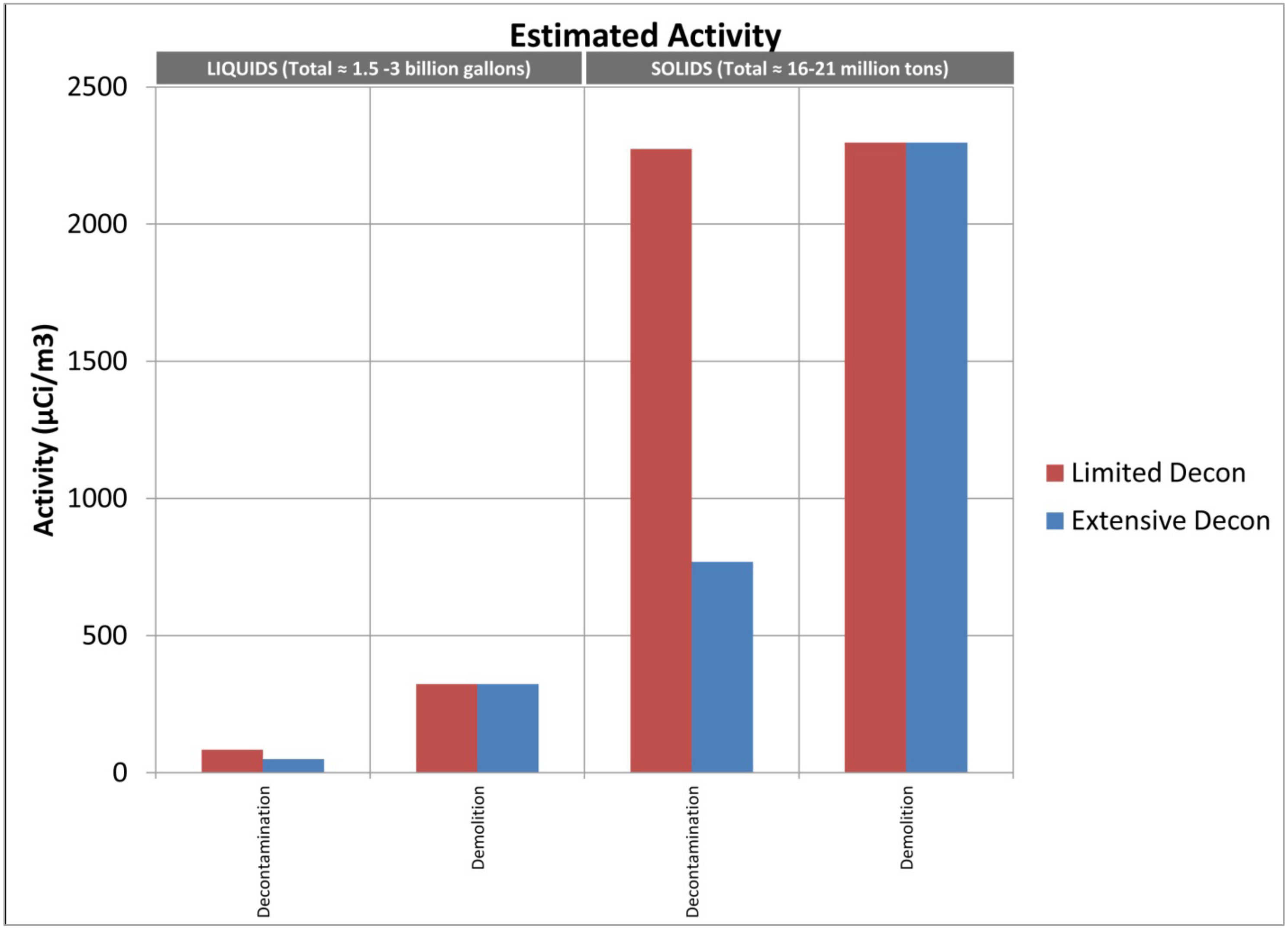


Figure 5. Average estimated activity concentration of waste from WARRP RDD scenario in area bounded by <15-millirem contamination zone.

2.3 Focus on Recovery

Recovery requires timely and cost-effective cleanup approaches, including waste management and minimization. The cleanup and waste management decisions made by decision-makers can expedite or delay recovery. Therefore, decision-makers should begin to plan for the long-term recovery almost immediately.

The National Response Framework (NRF) provides guidance for response functions immediately following a disaster. Federal disaster recovery efforts are guided by the National Disaster Recovery Framework (NDRF). The NDRF complements the NRF because it supports the transition from response to recovery.[11] The NDRF provides six scalable recovery support functions (RSFs) that facilitate a community recovery effort by linking local, state, tribal, and federal governments; the private sector; and voluntary, faith-based, and community organizations in a long-term recovery plan.

To support national recovery planning, the jurisdictions comprising the Denver urban area partnered with the State of Colorado, the military, the private sector, non-governmental organizations, the DHS, and other federal agencies to develop a disaster recovery framework known as the Denver UASI All-Hazards Regional Recovery Framework (DHS, 2012b). The development of the framework came about through WARRP and was aimed at enhancing the wide-area recovery capabilities of the Denver UASI. This framework lays the foundation for a regional and collaborative recovery approach and is intended to align with the NDRF. The Denver UASI identified 11 RSFs, which help guide the recovery process.

Table 1 lists the RSFs for the federal recovery and the Denver UASI frameworks.

Table 1. Federal and Denver UASI Recovery Support Functions

NDRF RSF	Denver UASI RSF[12]
1. Community Planning and Capacity Building	1. Cultural and Natural Resources
2. Economic Development	2. Debris Management
3. Health and Social Services	3. Economic Development
4. Housing	4. Fatality Management
5. Infrastructure Systems	5. Identify, Stabilize, and Maintain Infrastructure and Property
6. Natural and Cultural Resources	6. Post-Disaster Housing
	7. Prioritization of Cleanup
	8. Public Health and Medical Services
	9. Public Information and Messaging
	10. Public Safety
	11. Volunteer and Donation Management

[11] The NDRF is consistent with the vision set forth in the Presidential Policy Directive-8, National Preparedness, which directs FEMA to work with interagency partners to publish a recovery framework.

[12] The Denver UASI includes Prioritization of Cleanup as RSF No. 7; however, at the federal level, cleanup is part of the NRF, not the NDRF.

For each RSF, the framework lays out the scope; roles and responsibilities of local, state, tribal, and federal partners; and key assumptions and considerations that should be addressed in the short term, intermediate term, and long term for successful recovery. In the Denver UASI, most jurisdictions have comprehensive emergency operations plans outlining the actions that will be taken during the response phase of any emergency. Recovery planning is in its infancy across the Denver UASI and in the nation, but coordinating with other emergency disaster plans will facilitate effective recovery.

Within the Denver UASI framework, a number of existing state and regional plans support the RSFs (DHS, 2012b). Regional plans address mass fatalities, natural hazard mitigation, and public health. At the state level, emergency plans address disaster housing, natural hazard mitigation, emergency operations, and disaster recovery. The expectation is that federal and state agencies and other organizations in Denver will consult this framework to guide the development of recovery plans for their areas of responsibility.

3. RESPONSE MANAGEMENT AND AGENCY ROLES/RESPONSIBILITIES

In the United States, all levels of government - federal, state, territorial, tribal, and local - respond to disasters. Incident management refers to how incidents are managed by government officials, between multiple agencies and jurisdictions, and between phases of response (i.e., prevention, protection, and response and recovery. This SOG addresses the response and recovery phases.) Federal agencies provide critical assistance to state, tribal, and local response organizations in the event of a disaster that overwhelms state and local capabilities. For RDD incidents, the roles and responsibilities of local, tribal, territorial, state, and federal governments and private entities are set out in the NRF, Nuclear/Radiological Incident Annex (NRIA), and NDRF. This includes the roles of primary federal radiological response and support agencies such as DOE, the U.S. Nuclear Regulatory Commission (NRC), DoD, HHS, EPA, DHS, and the U.S. Department of Agriculture (USDA). The Federal Radiological Monitoring and Assessment Center (FRMAC) is a multi-agency response asset to assist state and local officials with monitoring, assessment, and health guidance for nuclear/radiological incidents. DOE leads the FRMAC for the initial response. EPA leads the FRMAC for long-term response.[13, 14] The NRF's Emergency Support Function (ESF) 10 supports oil and hazardous materials response, including assessment and cleanup of radiological contamination from an RDD incident and management of contaminated wastes. EPA is the coordinating agency and a primary agency, along with the U.S. Coast Guard for ESF 10. EPA also has statutory and regulatory authorities under CERCLA and the NCP for cleanup of hazardous materials, including radiation, which may also apply to RDD incidents. ESF 3 supports public works and engineering-related functions for domestic incident management. DHS is the primary agency for providing ESF 3 recovery support, which includes debris removal and disposal assistance.[15] The management of contaminated debris, including radiological contamination, will be a joint effort with ESF 10.

[13] The National Nuclear Security Administration provides more information about FRMAC at: http://www.nnsa.energy.gov/aboutus/ourprograms/emergencyoperationscounterterrorism/respondingtoemergencies/consequencemanagem-1.

[14] Coordinating agencies are listed in Table 1 of NRF's NRIA: http://www.fema.gov/sites/default/files/orig/fema_pdfs/pdf/emergency/nrf/nrf_nuclearradiologicalincidentannex.pdf

[15] Debris may include livestock or poultry carcasses and/or plant materials. For more information on ESF 3, see: http://www.fema.gov/pdf/emergency/nrf/nrf-esf-03.pdf.

Response to an RDD will be managed using the incident command system (ICS) based on the National Incident Management System (NIMS) (DHS, 2008a). ICS is a standardized, on-scene, all-hazards incident management approach allowing its users to adopt an integrated yet flexible organizational structure to match the complexities and demands of single or multiple incidents. ICS allows facilities, equipment, personnel, procedures, and communications to be integrated and operated within a common organizational structure. ICS coordinates response among various jurisdictions and public and private entities and establishes a common process for planning and managing resources. ICS includes both Command Staff and General Staff. General Staff is broken into four sections: (1) Operations, (2) Planning, (3) Logistics, and (4) Finance/Administration. A Unified Command (UC) is typically used for the command function of multi-jurisdiction ICS response; a UC consists of the appropriate local, state, and federal incident commanders representing the principal jurisdictions and lead agencies. It has proven to be a highly effective means of managing multi-jurisdictional responses. A strong, coordinated UC will be instrumental in overcoming the challenges of radiological waste management. Figure 6 shows an example of the ICS/UC structure following an RDD incident.

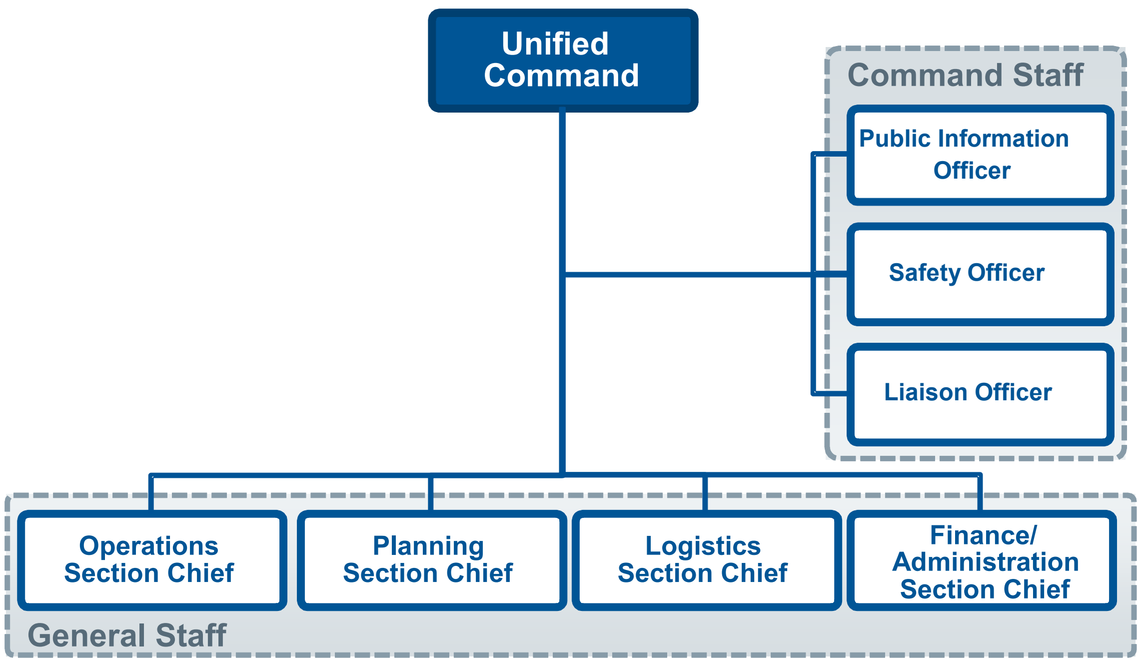


Figure 6. Example of incident command structure for RDD incident.

Because waste management is a major RDD response challenge, the ICS will have Operations and Planning Sections that are assigned waste management-related responsibilities. The ICS organizational structure may include, for example, a Disposal Division or Group in the Waste Management Branch of the Operations Section and a Waste Management Group in the Environmental Unit of the Planning Section. The Operations Section Waste Management Branch is responsible for collecting, staging, characterizing, documenting, shipping, and/or treating all wastes generated or collected on-site during field activities, including radiological wastes, solid wastes, liquid wastes, and other hazardous materials generated by such activities. Waste management can also include on-site disposal and design and fabrication of temporary or permanent storage/disposal facilities. The Planning Section Waste Management Group is responsible for conducting waste planning, identifying waste treatment and disposal options, obtaining appropriate waste disposal approvals, etc.

In responding to a radiological incident, the Environmental Unit should include or consult with state waste regulators, federal waste regulators (including the EPA Office of Resource Conservation and Recovery [ORCR] and NRC waste personnel), private waste stakeholders (including local officials), and private disposal facilities in waste planning. Cleanup and waste planning discussions should also include state water regulators and local wastewater and drinking water treatment facility operators.

4. OPERATIONAL CONCEPTS

Unlike chemical and biological agents, which can usually be altered or destroyed to eliminate or reduce toxicity and infectivity, radiological materials cannot be destroyed. Like chemical contamination that poses a carcinogenic risk, radionuclides are also carcinogenic. The carcinogenic risk posed is related to concentration and exposure. Limiting one or the other to levels that do not pose an unacceptable risk may be achieved through a number of mechanisms. Minimizing exposure through radiological decay over time, increasing the distance of contamination to the receptor, or increasing the shielding of radionuclides are accepted practices for reducing exposure and risk from radiation and may potentially be used in this situation.

While the focus for response and recovery after an RDD attack will be on cleanup, effective strategies for waste management will also be required. These strategies include screening, source reduction, decontamination, recycling, segregation, storage, treatment, and handling. Implementing these strategies will expedite and minimize cleanup by improving cleanup efficiency, reducing waste volume, maximizing the segregation of waste into homogeneous waste streams, and separating higher-activity materials from lower-activity materials. Waste management is an integral part of cleanup planning and response operations during all phases of response and recovery, from notification to reoccupancy. Table 2 provides an overview of a response and recovery effort across several phases of activity after a wide-area RDD incident.

The selection of cleanup and waste management technologies will depend on radionuclide, indoor contamination versus outdoor contamination, contaminated surface, substrate, the extent and concentration of contamination, public risk and exposures, value of property, shorter versus long-term objectives, cleanup goals, and more.

Table 2. Phases of Response and Recovery Effort Following a Wide-area RDD Incident[16]

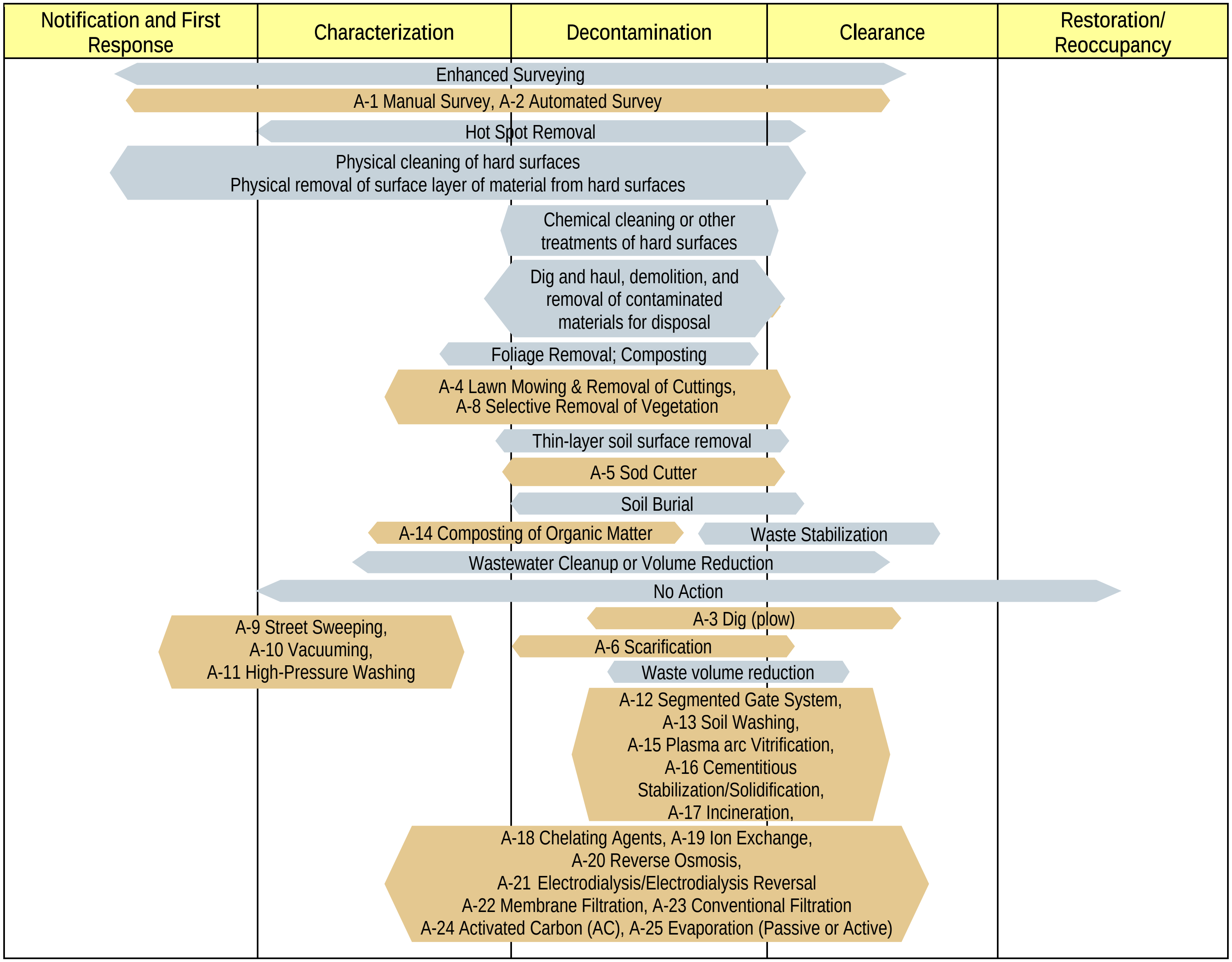
<table>
<tr><th colspan="7">Response and Recovery</th></tr>
<tr><th colspan="2">Crisis Management</th><th colspan="5">Consequence Management</th></tr>
<tr><th rowspan="2">Notification</th><th rowspan="2">First Response</th><th colspan="3">Remediation/Cleanup</th><th rowspan="2">Restoration/ Reoccupancy</th></tr>
<tr><th>Characterization</th><th>Decontamination</th><th>Clearance</th></tr>
<tr><td>Receive information on radiological incident
Identify suspect release sites
Notification of appropriate agencies</td><td>Initial threat assessment
Hazardous material (HazMat) and emergency actions
Forensic investigation
Public health actions
Screening sampling
Determine radiological contaminant
Risk communication</td><td>Characterization of marker radionuclide
Characterization of affected site(s)
Site containment
Continue risk communication
Characterization environmental sampling and analysis
Initial risk assessment
Clearance goals</td><td>Decontamination strategy
Remediation Action Plan
Worker health and safety
Site preparation
Source reduction
Waste disposal
Decontamination of sites or items
Decontamination verification</td><td>Clearance environ-mental sampling and analysis
Clearance decision</td><td>Renovation
Reoccupation decision
Long-term environmental and public health monitoring</td></tr>
</table>

Annex A contains a list of potential assessment, cleanup, and waste management technologies that may be applicable in response to an RDD incident. For a wide-area event, response personnel may use many of these technologies in different situations for different applications. These technologies are not interchangeable. Many have very specific or limited applications. These techniques may need to be modified to account for the exact incident location, local geology, and climate (weather patterns). The purpose of Annex A is to provide a general list of technologies that may be operationally useful for an RDD incident. These technologies are assessed to determine whether they are likely to achieve the desired end state, are adaptable to the situation, and are deployable.

Table 3 uses the Response and Recovery timeline from Table 2 to show when the cleanup and waste management methods and technologies listed in Section 1.3 and in Annex A may apply.

[16] Adapted from Figure 3, *Draft, "Planning Guidance for Recovery Following Biological Incidents"* (DHS/EPA. Developed by the White House Office of Science and Technology Policy's National Science and Technology Council, Subcommittee on Decontamination Standards and Technology. (DHS, 2009). The only deviation from the original table is the reference to RDD-specific details (e.g., determine radiological contaminant).

Table 3. Technologies and Methodologies to Consider During Recovery Effort



The technologies in Table 3 are grouped into three categories:

- Screening and characterization: Determining the identity, location, and physical characteristics of the radioactive material. Survey equipment will be useful throughout the characterization stage but can also be part of the clearance stage.
- Mitigation: Removing contamination from an original location, fixing it in place, or covering it. Contamination removal often requires removal of the substrate on which the contamination exists. These technologies and methodologies would generally fall under the decontamination stage.
- Segregation and waste management: Sorting and processing waste (to separate contaminated from uncontaminated material), reducing waste volumes, and ultimately treating and disposing of waste. These technologies and methodologies would generally fall under the decontamination stage and potentially into the reoccupancy stage.

It should be clarified that for the purpose of this SOG, characterization screening is an upfront activity and is not referenced as such during the clearance stage. The clearance stage is often referred to as final status or release surveys, which are performed after remediation has been conducted (the term "clearance" is used in this document for consistency with the document from which Table 2 was derived). Clearance is defined as the process of determining that a cleanup goal has been met for a specific contaminant in or on a specific site or item. Generally occurs after decontamination and before reoccupancy. Also, the distinction between mitigation and segregation and waste management is somewhat artificial. Most technologies could be listed under either and could be used at the same time during cleanup.

To develop effective and efficient cleanup strategies, a systems approach should generally address decontamination and waste management together. A number of decontamination methods have been developed for different material/contaminant systems over the past 50 years. Many are simple physical methods, such as abrasion or vacuuming, while others are advanced physical methods, such as plasma cleaning or light ablation. Many other methods use chemicals, with a few strippable coatings and chemical gels also employed. Overall, more than 100 different decontamination methods or method variations, are offered by different vendors. Table 4 presents a selection of different decontamination technologies that have been considered specifically for radiation decontamination of hard surfaces. These technologies are commercially available and most are applicable for use on various building substrates or critical infrastructure (such as roads and bridges). Many of the technologies in Table 4 have been tested by EPA's National Homeland Security Research Center (NHSRC); results from this testing provided the basis for the technology's relative effectiveness for the removal of radioactive cesium contamination from standard Portland cement substrate listed in Table 4. During these tests, every effort was made to compare different technologies on a "level playing field" and evaluate effectiveness as well as labor and equipment requirements (EPA, 2012b). Inclusion of any commercial products, companies, or vendors is for informational purposes only. EPA and its employees do not endorse any products, services, or enterprises.

When selecting technologies, decision-makers should consider operational and logistic aspects such as staging location (e.g., away from high-risk populations), equipment types, potential for exposures to workers, space requirements, the amount of material that has to be treated, waste volume generated, and coordination among utilities. The selection will also be based on the availability of specialty equipment, chemicals, and materials and the skill and training requirements for operators and other workers. Many of the technologies require specialized equipment, uncommon materials, proprietary chemicals, and/or very skilled operators in order to achieve desired results and cost savings.

Table 4. Decontamination Technologies and Relative Effectiveness

Selected Technologies Applicable to RDD Decontamination		
Decontamination Technology Category	Equipment Tested by EPA for Cesium Removal	Relative Removal on concrete
Water Blasting		ME
Abrasive Grit		VE
Grinding	CS Unitec – sanding	ME
Grinding	ICS- diamond	VE
Grinding	ICS- wire brush	LE
CO_2 (Cryogenic) Pellet Blasting	Was not tested	Not applicable
Scabbling	Was not tested	Not applicable
Scarification	Was not tested	Not applicable
Spalling	Was not tested	Not applicable
Milling	Was not tested	Not applicable
Vacuuming	Tested for "loose" type contamination only (Rivertech)	VE
Ultrasonic Cleaning	Was not tested	Not applicable
Plasma Cleaning	Was not tested	Not applicable
Light Ablation	Was not tested	Not applicable
Electrokinetic	Was not tested	Not applicable
Strippable Coating	CBI Polymers (DeconGel®)	ME
Strippable Coating	Isotron (Orion®)	VE
Strippable Coating	Bartlett (Stripcoat TLC-Free®)	LE
Chemical Gel	Argonne SuperGel®	VE
Chemical	Water	LE
Chemical	Simple Green®	LE
Chemical	Allen-Vanguard SDF®	ME
Chemical	Environment Canada UDF	ME
Chemical	EAI - Environmental Alternatives, Inc. RRII	VE
Chemical	EAI - Environmental Alternatives, Inc. RRI	VE
Chemical	Intek Technology ND-75	ME
Chemical	Intek Technology ND-600	ME
Chemical	Radiation Decontamination Solutions, LLC. (liquid)	ME
Chemical	Radiation Decontamination Solutions, LLC. (foam)	ME

VE - Very Effective (70-100%)

ME- Moderately Effective (50-69%)

LE - Less Effective (0-50%)

5. WASTE MANAGEMENT

Waste management, including storage, treatment, and final disposal, will be one of the most significant costs and greatest challenges associated with RDD incident cleanup. Millions of tons of contaminated solid and liquid waste may require staging, segregation, cleanup, and disposal. NRC and EPA guidance on radioactive waste may assist in the development and implementation of appropriate waste management strategies after an RDD incident.

This section addresses the general challenges associated with waste management following an RDD incident. Because of these challenges, it is critical that decision-makers begin waste planning immediately and establish a site-specific waste plan before an incident occurs. The first step is to engage state waste regulators, federal waste regulators, private waste stakeholders (including local officials, waste transporters, and private disposal facilities), state water regulators, and local wastewater and drinking water treatment facility operators. Decision-makers should also contact licensed LLRW disposal facilities, especially the facility nearest the incident, and local and state regulators for those facilities. While this SOG identifies cleanup and waste management technologies and methodologies, it is not intended to help responders write a site-specific waste plan; the EPA Office of Solid Waste and Emergency Response can assist decision-makers in developing such a plan.

Effective waste management planning will reduce overall costs, expedite cleanup, and reduce public exposure and risk. RDD wastes must be managed consistent with relevant local, state, tribal, and federal regulations. Currently, options for the disposal of LLRW in the United States are limited. In the event of a wide-area RDD, other disposal options, including in-state disposal options, may need to be considered and/or developed to handle the huge quantities of wastes. Planners should be aware of provisions in their state regulations that allow for expedited regulatory approval in the event of an emergency.

There are three overarching objectives for waste management to help manage RDD cleanup costs: (1) waste minimization, (2) waste segregation by material and radiation "activity," and (3) cost-effective treatment and disposal of each waste stream. Given the expected volume of wastes, RDD wastes need to be managed quickly and safely, and management efforts must be consistent with relevant local, tribal, territorial, state, and federal laws.

- ***Waste minimization***. Examples of waste minimization are: (1) removing 2 inches of soil rather 5 inches when ^{137}Cs contamination resides mainly in the top 2 inches (sod cutting); (2) composting organic wastes and vegetative wastes to reduce waste volume; and, (3) employing surface scarification techniques to remove surface contamination without removing the whole substrate.
- ***Waste segregation***. Examples of waste segregation are: (1) removing and managing vegetation, soils, and contaminated structures separately; and, (2) handling and staging waste from cleanup of the hot zone separately from lower-activity wastes (separate by activity). Segregation will minimize wastes and enable alternate disposal pathways to be used for the lightly contaminated materials. Waste segregation has the potential to achieve significant efficiencies in time and cost while at the same time ensuring long-term protectiveness of the waste managed.

- ***Treatment and disposal***. Examples of potentially cost-effective treatment or disposal options are: (1) developing in-state disposal options for lower-activity contaminated materials; and (2) employing effective techniques for separating, concentrating, or removing the specific radiological contaminant from wastewater.

Fortunately, in the event of an RDD incident, it should be possible to systematically and cost-effectively remove and segregate wastes (except in the immediate area of the blast zone, where collapsed buildings, damaged streets, and the debris field tend to make segregation more difficult.) A typical soil cleanup involves tree and shrub removal, building demolition as needed, and soil removal. Other steps for building contents, siding and roofing, asphalt and cement, etc., can be added. Not only does this allow for waste segregation, it has proven to be generally more efficient.

All waste and debris removal activities (e.g., staging area management and coordination) will be conducted by the UC (state and local agencies, as well as other federal agencies) and will be consistent with or coordinated with waste management plans developed as part of the RDD incident preparation.[17] Plans developed before the incident may need to be modified to meet the needs of the specific incident. In some cases, RDD waste planning may involve developing new permitting procedures and new disposal facilities. In all cases, RDD waste management will involve creating nearby temporary staging and storage locations. Regulations and permitting procedures for these activities may need to take advantage of state authorities that allow for emergency approvals. Most state regulations allow for such emergency approvals.

In response to a large-scale RDD incident, resources such as equipment and personnel are expected to be assigned to various staging areas to join teams or to be deployed. Some limiting factors for scaling this type of deployment include the availability of resources, the number and size of staging areas, and physical constraints such as the actual size of the site. Engineering controls, monitoring, and area and space requirements also should be considered as part of the effort.

Waste is expected to be generated as soon as the first responders arrive at the site; therefore, interim sites where contaminated waste and debris can be temporarily staged should be quickly identified. During the early phase, waste management should consist of supporting first responders by removing debris that could cause an immediate threat to public safety (e.g., unstable structures), clearing roadways, and removing fallen limbs and curbside debris that may hinder emergency vehicle movement along access pathways and egress routes. Disposable PPE waste will also be generated during the early, intermediate, and late phases of the response.[18] Handling, treating, and disposing of decontamination water and other contaminated water will be an immediate challenge.

It will also be important to identify and determine, early on, available waste management facilities and to determine and establish waste acceptance criteria (WAC) for those facilities. If site personnel know the WAC ahead of time, field surveys could create a site model that

[17] As part of the Liberty RadEx exercise, a comprehensive waste management plan was developed for RDD wastes, including options for waste staging and disposal for all waste streams.
[18] Despite the waste minimization focus, it is not likely that responders will reuse PPE that is potentially contaminated.

correlates portions of the site with the WAC for the various disposal facilities and level of hazard associated with the waste (low, very low, etc.). Furthermore, waste screening technologies could also be tied to the WAC levels. From there, facility-specific WAC information may be used to plan for waste sampling/characterization, packaging, and transportation.[19] WAC should take into account the radiological, physical, and hazardous (if present) characteristics of the waste. For example, free liquids could be an issue in the case of sludges and with soil/debris where water was used for dust suppression. Because of the potentially massive amount of waste that may be generated, WAC for municipal solid waste landfills (regulated under Subtitle D of the Resource Conservation and Recovery Act [RCRA]) may be considered because not all waste may be classified as contaminated material that needs to be shipped to a low-level waste facility.

Contaminated waste and debris volumes from an RDD incident could be significantly larger than the volumes of LLRW typically generated annually in the United States from decommissioning activities, DOE cleanup activities, and nuclear power production by the public and private sectors combined. This further emphasizes the importance of segregating waste by radiological content and knowledge of available disposal options. Not all of the waste from an incident will need to be handled as LLRW. However, the concentrations may be high enough that it would be prudent to either dispose of the higher-level contamination in a LLRW licensed facility, even if it is not determined to be LLRW, or design and build a local unit that will provide for long-term waste management. Given that much of the waste will be only slightly contaminated, local disposal options that can provide the necessary level of protection should be considered or developed (in-state and, preferably, in the contaminated area.) This approach may be a more efficient use of resources and expedite cleanup. Other challenges include inadequate on-site space for water storage and for treatment and storage of secondary waste (e.g., sludges, loaded zeolite, filter media) produced from cleanup activities.

Other potential factors affecting waste management decisions are: (1) incident location and distance to a disposal facility, (2) transportation modes serving the site and disposal facility (rail, truck, vessel), (3) types of waste, (4) volume of the waste, (5) properties of the waste (physical characteristics, hazardous/nonhazardous characteristics), (6) status of appropriate permits and/or licenses that would allow facilities to accept the waste, (7) design of the disposal facility receiving the waste, (8) performance of the treatment or disposal facility (a history of leaking contaminants, etc.), (9) capacity, (10) proximity to populations, including populations that may be disproportionately impacted by contamination, (11) timing for state, local, territorial, tribal, and disposal facility approval, and (12) public acceptance, including acceptance in the impacted area, acceptance at waste receiving facility (perhaps in another state), and acceptance along the transportation routes. The first five factors generally drive transportation and disposal costs, while the remaining factors would be considered in determining whether waste would be shipped to a given facility (Beckman et al., 2011).

6. RDD INCIDENT RESPONSE PLANNING

A critical element of the response is that data acquired be of sufficient quality to support the decision being made. Federal agencies have now agreed to use the Uniform Federal Policy for

[19] An example of facility-specific WAC information is available at: http://energysolutions.com/customer-portal/clive/waste-acceptance-criteria

Quality Assurance Project Plans (UFP-QAPP) Workbook.[20] This Workbook may be used by decision-makers to assist with the preparation of QAPPs for environmental data gathering activities.

Standard good management procedures should be used to demonstrate implementation of an effective quality assurance/quality control (QA/QC) program, including personnel training and qualification, document control, records management, work processes, design control, procurement, inspection and acceptance testing, and management and independent assessments. The data quality objectives process is routinely used for developing a project specific QA/QC program (EPA, 2000). QA/QC is needed for waste management/waste minimization activities performed after an RDD incident. If a waste management plan has been implemented, a QA/QC component should be set up as part of that plan.

7. AVAILABLE RESOURCES

The following additional resources are available to help coordinate waste management/minimization efforts:

- **Worker health and safety** considerations will be accounted for in the Health and Safety Plan that will be written in the first few days following the RDD incident. The Health and Safety Plan will contain health and safety information (such as appropriate PPE to be worn) for personnel working on waste management activities to ensure that all work conducted during cleanup and disposal is performed as safely as possible with full consideration and awareness of potential risks. Because waste management personnel will be working with radioactive materials, a personnel decontamination plan will be part of the Health and Safety Plan.
- **Environmental sampling and monitoring** of radioactive wastes and debris should be integrated into the Planning Section. FRMAC monitoring and sampling procedures (DOE, 2012a and 2012b) will be used during the early and intermediate phases of the response. Use of these methods may be continued through the late phase, if appropriate. Several guidance documents such as the EPA RCRA sample and analysis protocol or the Environmental Response Laboratory Network protocol may potentially apply to this sampling (EPA, 2011b). Field instrumentation is expected to be used during many of the waste management activities, including waste segregation, contamination control, personnel monitoring, and transportation surveys. Laboratory analysis should be done to support waste management/minimization, storage, and shipping activities. The Multi-Agency Radiological Laboratory Analytical Protocols (MARLAP) Manual (EPA et al., 2004) presents an approach to producing radioanalytical laboratory data that meet a project's data requirements.[21] EPA has also published "Selected Analytical Methods for Environmental Remediation and Recovery (SAM)" (EPA et al., 2012c).
- **Training** should be an essential component of waste management associated with an RDD response. Training should be one of the sub-units already established as part of the ICS, under the umbrella area of Planning. Specific types of training should be provided

[20] This Workbook can be accessed at: http://www.epa.gov/fedfac/pdf/ufp_wbk_0305.pdf.
[21] MARLAP is the radioanalytical laboratory counterpart to the Multi-Agency Radiation Survey and Site Investigation Manual.

by EPA on-scene coordinators (OSCs) or other federal, state, tribal, or local emergency response staff.[22] In addition, EPA and the Occupational Safety and Health Administration have examples of procedures that local, tribal, territorial, state, and federal agencies could follow to manage and minimize waste and to help train waste management personnel. These procedures focus on the type of screening/surveys to be conducted with specific technologies and on safety precautions to be taken.

8. PUBLIC INVOLVEMENT

Emergency managers across the country are keenly aware of the need for public involvement and public acceptance, regardless of the type of disaster. Radiation adds an additional level of public concern. Most people do not know what to expect if radioactive source material is released into the environment, but they will fear and assume the worst. The risks, even small risks, may be exaggerated due to the public's lack of familiarity with radiation. Engaging, educating, and listening to the public is critical to public acceptance of cleanup and disposal decisions and will be one of the biggest challenges. Successful recovery following an RDD incident hinges on public acceptance of cleanup and waste decisions. As part of the Liberty RadEx exercise, a committee of Philadelphia citizens was able to reach consensus on their own cleanup prioritization, local storage, and disposal (DHS, 2012a). Public acceptance also depends on the involvement and ownership of the outcome; if waste is being shipped across the country, a larger public audience and sphere of private-sector stakeholders should be taken into account.

The disposal of waste following an urban RDD incident is expected to be a critical component of the overall response and recovery effort. An ongoing community involvement program is appropriate to solicit public input for the decisions that are being made. The public should be kept informed and their input sought related to planning and decision-making about waste management, including transportation and disposal considerations.

It can be assumed that an RDD incident will receive intense media attention, with both national and local media reporting live within hours of its onset. Once a response is initiated, the local community should be notified that there will be ongoing monitoring to maintain a state of awareness of the extent of the contamination. This notification may involve public announcements via radio, television, website, newspaper, and signage announcing that a radiological incident has occurred and outlining what safety precautions or voluntary measures should be taken as part of the response.

The Centers for Disease Control and Prevention (CDC) Crisis & Emergency Risk Communication program provides guidance on messaging and public information during a radiation disaster (CDC, 2011). FEMA has also published communications guidance for emergency responders and federal, state, local, tribal, and territorial officials communicating with the public in the immediate aftermath of an improvised nuclear device detonation or a nuclear power plant incident in the United States (FEMA, 2013a, 2013b).

[22] The recovery team of the Colorado OEM ensures that state and federal support are provided in an efficient and timely manner throughout the disaster recovery process.

More guidance on communications, messaging plans, and outreach strategies for disaster response and recovery can be found in DHS's *Emergency Support Function (ESF) 15 Standard Operating Procedures* (DHS, 2008b). During the recovery phase, all public information and communications are coordinated through ESF #15 External Affairs (which supports all RSFs during the transition to recovery). In general, waste management personnel should be trained to refer any press or other project-specific inquiries to the Public Information Officer within the UC designated for the response. Safety is a primary issue, as are mental and physical well-being. Knowing how to access assistance makes the process faster and less stressful.

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ANNEX A

Technology Descriptions

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This Annex describes assessment, cleanup, and waste management technologies that enable the segregation, separation, or reduction of waste and may be applicable in response to a Radiological Dispersal Device (RDD) incident. These technologies, methodologies, and options are also assessed against the following criteria, which were selected with the ultimate goal of protecting public health while making most efficient use of resources:

- Safety, health, and environment: If the technology were implemented, could the health and safety of workers and the public be put at risk (e.g., would workers be required to operate heavy equipment, or would workers or the public be exposed to hazardous or combustible materials)? If implemented, could the technology compromise environmental resources at the site and in the surrounding area? Would protective equipment be required to keep humans safe or to protect natural resources?
- Time to implement: How quickly could the technology be set up and operational after an RDD attack?
- Technical performance: How effective is the technology at meeting its goal (waste characterization, waste cleanup, etc.)? Is it more (or less) effective under certain circumstances or for certain contaminants? Even if the technology were effective, would its implementation lead to any adverse effects?
- Availability: How readily available are the necessary equipment, materials, and workforce? Is the equipment commercially available or easy to adapt, or is it nonstandard, custom-built equipment? How skilled would the workforce have to be?
- Costs: Relatively speaking, how costly would it be to implement the technology? Would expensive equipment and/or a trained, highly skilled workforce be required? Would the technology need to be conducted for a long period of time to meet its goal? (Any dollar amounts provided are estimates and are not intended to be definitive totals.)
- Process waste: Does the technology produce any residual solid, liquid, or airborne pollutants, other than the waste form, that may require treatment or disposal?
- Throughput: What is the relative rate at which a process or technique is performed, and how quickly can the technology achieve its desired goal?

During the Wide Area Recovery and Resiliency Program (WARRP) Decon-13 Subject Matter Expert (SME) Meeting held on August 14 – 15, 2012, several technologies listed in this Annex were scored against each criterion and assigned a low/not advantageous (red), medium/neutral (yellow), or high/advantageous (green) designation. Data have been presented consistently in a standard format to facilitate comparisons between technology options (see Table A-1). These results are being carried forward in this Annex; however, these designations should only be considered the opinion of the SMEs attending the meeting and are not prescriptive in nature. Wastewater cleanup/waste minimization technologies were identified as an element of the overall project after the SME meeting; hence, their color coding was not developed until later. The criteria and discussion for the other types of technologies from the SME Meeting were used to prepare the color coding in this Annex.

Color coding is based on discussions with U.S Environmental Protection Agency (EPA) staff who were involved with the WARRP Decon-13 project. The colors derived from the SME Meeting were reexamined across all technology areas and were adjusted if needed. The criteria can be subjective or objective and can be impacted by several factors, including (1) type of radionuclide; (2) type of surface or bulk media (e.g., buildings, soil, roads, trees, water or other liquids); and (3) desired cleanup level endpoint. As stated in the main report of this SOG, many of the technologies and methodologies would also have to be field-tested during a response to fully evaluate effectiveness and application. The designation “A-#” in the Table of Contents directs the reader to that technology in this Annex.

Inclusion of any commercial products, companies, or vendors is for informational purposes only. EPA and its employees do not endorse any products, services, or enterprises. Similarly, exclusions or absence of specific references is merely an indication that information related to that entity was not readily available during the development of this informational document.

Annex Table of Contents

Technology A-1	Manual Survey	
Description	One of the first steps in remediation of a contaminated area is surveying the area, possibly with a portable meter. Surveying can be used to characterize the site to plan decontamination strategies and methods. Manual survey can consist of two types of configurations: the manual movement of the detector system with the manual recording of data (e.g., radiation measurement, location, etc.) and the manual movement of the detector system with automated data collection (e.g., radiation measurements, location, etc.). Manual survey provides information on the extent of radiological contaminants, the level of contamination, and other data.[1] Manual survey units are available and can detect alpha, beta, or gamma radiation. The Falcon 5000 is gamma only (radionuclide identifiers are almost always gamma detectors). Manual, gross, rate detectors like the Eberline RO2A are beta/gamma detectors. Thermo Scientific Electra units with a scintillation probe quantify alpha, beta, and gamma. Beta/gamma detectors usually have the small tubular Geiger-Mueller detector. Alpha detectors may have the large aluminized Mylar® (silver color) window. This is true only for alpha probes based on zinc sulfide, silver activated detector crystals. Plastic scintillators and gas flow alpha proportional counters do not require the same type of covering. Most of the instruments used in this methodology are of the Geiger/Mueller or Scintillation type. They are able to rapidly measure low-level quantities of radioactivity and radioactive dose rates. Other types of radiological detection include the CANBERRA Falcon 5000, a portable radionuclide identifier (RID) based on a high-purity germanium (HPGe) detector (energy range of 20 kiloelectron volts [keV] to 3.0 megaelectron volts [MeV]). The CANBERRA Falcon 5000 uses a high-purity germanium (HPGe) detector paired with a low-noise, electrical cooler using Pulse Tube cooling technology that can achieve the energy resolution needed for isotopic measurement. The unit is field-portable, does not require liquid nitrogen cooling, and covers a wide energy range.[2] Test measurements have concluded that the Falcon 5000 can be used successfully for isotopic measurements of uranium and plutonium in sealed sources such as waste drums filled with various matrix materials. The Falcon 5000 comes pre-configured with a default nuclide library, but it can be edited or loaded with a different library as the application requires. The library can be managed in the field and can be tailored to specific applications by defining the type of analysis and then adjusting the parameters of the calculation.	
Relevance to Section 1.3	Enhanced surveying; hot spot removal. Also relevant to all listed technologies.	
Effectiveness	While manual or hand-held instruments can be effective, they can put the individual holding the device at risk for contamination. However, some of the manual systems can be set up and left unattended during a data collection period. Manual surveys provide fast results, saving money and time compared to samples sent to a laboratory for analysis.	
Illustration	 **Figure A-1. Examples of manual survey in use.**[3,4]	
Safety, Health & Environment		Involves manual use of equipment in a contaminated environment; however, some manual systems can be set up to run unattended.
Time to Implement		Surveys can be mobilized quickly in radiological event.
Technical Performance		This is an accepted standard for performing surveys and may even provide superior performance to automated surveys.
Availability		Widely available. Manual instruments are dispersed to many fire and police departments.

[1] http://www.iaea.org/OurWork/ST/NE/NEFW/documents/IDN/ANL%20Course/Day_3/Characterization-Hansen.pdf
[2] Bosko, A, S. Croft, and S. Philips (2008). Plutonium Isotopic Analysis Using FALCON 5000: A Portable HPGe Based Nuclear Identifier. Institute of Nuclear Materials Management (INMM) - Annual Meeting, Nashville, Tennessee, July 2008.
[3] http://news.nationalgeographic.com/news/energy/2011/11/pictures/111111-nuclear-cleanup-struggle-at-fukushima/#/fukushima-daiichi-nuclear-reactor-remediation-baseball_43449_600x450.jpg
[4] Demmer, Rick. Waste Segregation Methodologies. US EPA WARRP Workshop. Idaho National Laboratory.

Technology A-1		Manual Survey
Costs		Uses a large amount of skilled manual labor, time to complete survey is slow, and can be costly.
Process Waste		No secondary (notably liquid) waste is generated.
Throughput		Typically not a rapid, automated process.

Technology A-2	Automated Survey
Description	Automated survey consists of a powered device or mechanically driven movement detector system with automated data collection (e.g., radiation measurement, location, etc.). Mechanically driven detector systems generally require a pilot or driver to be physically present in the vehicle. While this limits the likelihood of the individual being contaminated, it does still potentially expose the person to external radiation. An automated survey helps provide information on the extent of radiological contaminants, the level of contamination, and other data.[1] Automated survey methods typically use similar instrumentation (often thallium activated sodium iodide (NaI/Tl) gamma detectors) to manual survey techniques, but utilize unique data acquisition software and geospatial analysis to characterize large areas rapidly. An automated survey can be operated remotely, minimizing worker exposure while providing information on position and relative strength of gamma-ray radiation fields.[1] Survey tools, like Field EnvironmentaL Decision Support (FIELDS) Analysis and Sampling Tools (FAST), can perform real-time continuous field data collection and assessment, integrating data from portable hazardous material (HazMat) field instruments, global positioning system (GPS) data, geographic information system (GIS), mapping, database storage, and analysis. FAST is a Windows PC application that can map the relevant data for viewing within ArcGIS, Google Maps, or other applications for further data processing.[2] A more sophisticated technology in this field is the Airborne Spectral Photometric Environmental Collection Technology (ASPECT) system developed for the EPA. ASPECT, a remote sensing technology that employs standoff radiological (and chemical) detection, can screen the surface area for gamma and neutron sources at high speeds and return quality-assured data within minutes to the decision-makers. Based on the ASPECT system, EPA has a ground-based survey technology used to detect and measure radioactivity. The "Asphalt" system is utilized on the ground through a survey via all-terrain vehicle, pickup truck, sport utility vehicle, or other type of vehicle. The system utilizes eight 2"x4"x16" sodium iodide crystals (with ability to add four more), and up to three 3"x3" lanthanum bromide crystals. This ground-based system has greater resolution and sensitivity than other systems, including hand-held devices, due to the size of the crystals. The products are the same from either the air or the ground. However, this ground-based technology is more effective than airborne systems because samples are collected closer to the source, and the system can obtain more-sensitive readings. These systems are only as effective as the vehicle that carries them. The ground-based system must also return to base to download information before producing data products, whereas the airborne system is tied to a central computer, allowing data to be produced while the flight is still in progress. Another robust aerial measurement system is the U.S. Department of Energy (DOE) Aerial Measuring System airplane- and helicopter-based automated survey of gamma-emitting radionuclides. This system consists of five fixed-wing aircraft and three helicopters stationed at three locations in the United States. The detector systems can be mounted on other aircraft (e.g., U.S. military aircraft in Japan) or ground vehicles (Kiwi configuration.)
Relevance to Section 1.3	Enhanced surveying; hot spot removal. Also relevant to all listed technologies.
Effectiveness	EPA's FAST technology can also provide rapid, cost-effective, and high-quality decision support in remediation and contamination site cleanup. ASPECT is an efficient way of screening an area and can effectively improve the response and characterization of a large-scale event.
Illustration	 **Figure A-2. Samples of automated survey in use.**[3,4]

[1] http://www.iaea.org/OurWork/ST/NE/NEFW/documents/IDN/ANL%20Course/Day_3/Characterization-Hansen.pdf
[2] http://www.epa.gov/region5fields/
[3] http://news.nationalgeographic.com/news/energy/2011/11/pictures/111111-nuclear-cleanup-struggle-at-fukushima/#/fukushima-daiichi-nuclear-reactor-remediation-baseball_43449_600x450.jpg
[4] Demmer, Rick. Waste Segregation Methodologies. US EPA WARRP Workshop. Idaho National Laboratory.

Technology A-2		Automated Survey
Safety, Health & Environment		Automated surveys could provide "remote," operator-removed-from-direct-exposure type application. automated equipment eliminates some safety concerns for this task. Mechanically driven detector systems generally require a pilot or driver to be physically present in the vehicle; while this limits the likelihood of the individual being contaminated, it does still potentially expose the person to external radiation.
Time to Implement		May not be easily implemented. Only a few of these systems available.
Technical Performance		Generally good performance. May be less reliable than manual techniques.
Availability		Not widely available. Only a few of these systems available.
Costs		Some methods are very expensive, some use expensive robotic or other equipment.
Process Waste		No secondary (notably liquid) waste is generated.
Throughput		Can be rapid (as in the case of large area "flyovers").

Technology A-3		Dig (plow)
Description		Plowing is a remediation method for mixing or covering contaminated soil with clean soil; however, it does not remove contamination but rather moves it to a deeper layer of soil. By mixing or covering these soils, this method also reduces exposure and risk. Plowing involves a tractor-drawn trenching plow, which is used to invert a thick layer of soil, placing the top layer of soil at the bottom and moving the deeper, clean layers to the top.[1] This method puts contaminated soil deep enough into the ground that exposure is limited, including to the lower boundaries of crop root systems. Deep plowing digs down up to 90 centimeters (cm) or greater beneath the surface. A similar concept uses hand-held tools (i.e., shovels) to dig up the surface dirt and rebury it well below the surface while bringing fresh topsoil to the surface. "Triple-Digging" (practiced in areas around Chernobyl in the 1990s) involves a simple, manual (shovel)-based approach that reburies contaminated soil deeper in the ground and replaces it with uncontaminated soil. Placing contamination at depth may also result in contaminant transport to groundwater and ultimately surface water. It may also make contaminants available for plant uptake.
Relevance to Section 1.3		Soil burial.
Effectiveness		This method does not always result in perfect turnover of soil, risking some mixing of clean and contaminated soils.[1] Further study is still necessary, though it appears that the type of soil and crops grown also affect the impact of deep plowing. Effort will also increase with depth. This method can be effective in reducing the potential for direct contact with contaminated materials on the soil surface, external radiation from surface contamination, and pickup by shallow-rooted crops.[1] Deep plowing in particular may be more effective, with a report showing that uptake from deeper placements of contaminated soil was one-tenth of that from shallow placement over a period of 4 years.[1] The same report also shows that deep plowing to 50 cm in contaminated soil reduced the uptake of radiation by oats up to 60%, while plowing up to 30 cm had little effect. However, this method can be costly and ineffective in reducing the uptake of radioactivity for deep-rooted crops.[1] Many deep-plowed soils can also produce poor crops because of low fertility, high acidity, soluble salts, or poor texture, which would take years of nutrient additions and sand.[2]
Illustration		 **Figure A-3. Plowing can protect shallow rooted crops from contamination, but can also reduce soil health.[3] Plowing or digging can also be done by hand.[4]**
Safety, Health & Environment		Could cause excessive levels of airborne contamination. Burying wastes in soil profile or covering with concrete may reduce exposures.
Time to Implement		Typically not employed in the early stages of a radiological event.
Technical Performance		Does not remove contamination, but moves contamination below the surface level. This practice affects lower radiation dose, but does not decontaminate the lower soil.
Availability		Widely available (uses tractors and shovels).
Costs		Could be expensive because it is a manual labor technology with integral use of survey equipment.
Process Waste		No secondary (notably liquid) waste is expected.
Throughput		Requires significant time to perform for manual digging.

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[1] http://www-pub.iaea.org/MTCD/Publications/PDF/trs300_web.pdf
[2] http://naldc.nal.usda.gov/download/CAT87209094/PDF
[3] http://today.agrilife.org/2012/06/20/mining-cleanup-benefits-from-texas-am-expertise/
[4] Demmer, Rick. Waste Segregation Methodologies. US EPA WARRP Workshop. Idaho National Laboratory.

Technology A-4		Lawn Mowing & Removal of Cuttings
Description		One-fourth to one-half of radioactive materials are often carried on green crops. In an urban environment, much of that contamination may be removed by mowing lawns and collecting and removing grass cuttings. Directly removing biomass makes it possible to remove the majority of the contamination, depending on the density of the vegetation. This method involves cutting the grass or vegetation to remove this contaminated material. Sometimes this step is necessary before soil removal can take place.
Relevance to Section 1.3		Foliage removal; composting.
Effectiveness		Removing contaminated ground cover (such as grass) or agricultural crops is generally inadequate because contaminated material would inevitably fall to the soil.[1] Generally, no mowing or crop removal methods have removed more than 75% of fallout from a contaminated area. Sod cutting and soil removal should therefore be follow-on actions. However, mowing can be useful as it typically removes ground cover plants, which tend to carry greater amounts of radioactivity once removed.[1] Assuming soil removal is not necessary, removing contaminated crops via lawn mowing may not be as effective as removal via forage chopper or direct-cut forage harvester. Crop removal takes a significant amount of time, but necessary equipment is widely available. Removing ground cover or crops also raises the question of where to dispose of the contaminated plant material, which has not received substantial study to this point.[1] A disadvantage of using lawn mowers to remove the contaminated vegetation is the resuspension of contaminants from that vegetation that may occur. In one test, resuspension was minimized by the use of an instrumented mowing device that diverted contaminated clippings into a high efficiency particulate air (HEPA)-filtered collection system but allowed uncontaminated materials to pass into a different container.
Illustration		 **Figure A-4. Lawn mowing cuts grass or vegetation in order to remove contaminated material.**
Safety, Health & Environment	(red)	This technology has not been rigorously studied in terms of the type of filtration system that could be adapted for this application. Health and safety plans must account for adequate filtration of airborne contamination to ensure worker safety.
Time to Implement	(green)	Quick implementation will improve effectiveness; effectiveness is significantly reduced after rain has occurred or if grass has already been cut post-deposition.
Technical Performance	(red)	Only the contaminated grass blades and not even all of the vegetation can be removed. Significant contamination in the sod and soil are left behind. Resuspension of contamination could occur.
Availability	(green)	Lawn mowers and crop removal equipment are widely available.
Costs	(green)	Lawn mowing is a very inexpensive practice when compared to more sophisticated technologies.
Process Waste	(green)	No liquid waste is generated; however, some dust may be created.
Throughput	(green)	Lawn mowing is a quick and straightforward method and should be achieved quickly.

[1] http://naldc.nal.usda.gov/download/CAT87209094/PDF

Technology A-5		Sod Cutter
Description	Radioactive materials are often transported through vegetative cover and settle in the ground, making the removal of surface layer soil a potentially important endeavor and therefore making a sod cutter an important tool in remediation. A mowing machine first removes the grass. A sod cutter is then used to loosen and separate the first 4-5 cm (up to 15 cm) of soil. In this method, the thickness of the surface layer can be specifically set based on surveys of levels of radioactivity versus depth, and the amount of waste can be reduced.[1]	
Relevance to Section 1.3	Thin-layer soil surface removal.	
Effectiveness	An Agricultural Research Service study found that removing 2 inches of soil was effective in removing 80-90% of radioactive surface contamination.[2] However, individual sod cutters cannot remove huge quantities of soil/vegetation and are also dependent on the soil type and local geology characteristics such as surface unevenness, presence of rocks, soil texture, moisture content, and vegetation cover.[1,3]	
Illustration	 **Figure A-5. Sod cutter used to loosen soil, which will be removed later by larger equipment.**	
Safety, Health & Environment		This technology has not been rigorously studied in terms of the type of filtration system that could be adapted for this application. Health and safety plans must account for adequate filtration of airborne contamination to ensure worker safety.
Time to Implement		May only be used after evaluation of the contamination penetration (may take significant time).
Technical Performance		Doesn't remove all of the contamination.
Availability		Some sod cutters are available in each city, but availability is not widespread.
Costs		Labor costs may be high, units are not prohibitively expensive.
Process Waste		No liquid waste is generated; however, some dust may be created.
Throughput		Relatively slow. May require significant time to perform each pass of the cutting and retrieval of the sod.

[1] CAPT John Cardarelli II. Fukushima: Long-Term Recovery Lessons Learned. WARRP Capstone, September 13-14, 2012.
[2] http://naldc.nal.usda.gov/download/CAT87209094/PDF
[3] International Atomic Energy Agency. Technologies for remediation of radioactively contaminated sites. IAEA-TECDOC-1086, June, 1999.

Technology A-6		Scarification
Description		Scarifiers and scabblers are mechanical tools used for pummeling, scraping, and thus removing (or abrading) surface layers of contaminated concrete. They can be used either manually (by hand) or as part of a machine. As part of a machine, scarifier heads can have several carbide tips that can work on large-surface floor or wall applications. Scabblers often make use of vibrating pneumatically driven "needles" of about 1/8" diameter, carbide-tipped steel. The most common scabblers typically can remove about 1/16" of surface at a single pass.
Relevance to Section 1.3		Physical removal of surface layer of material from hard surfaces.
Effectiveness		While scarifiers and scabblers are effective in removing layers of contaminated concrete, the process is repetitious and can generate airborne contaminants.[1] One test using scabbling and cutting, completed approximately 11 years after the Chernobyl event, removed two 1-cm layers from an asphalt roadway to reduce contamination and dose in the area.[2] This technology may remove significant amounts of radioactive contamination while generating less radioactive waste than demolition. When used by hand, the labor is slow and intensive, and when done without engineering controls (shrouding or vacuums), can result in worker exposure to radiation or contamination. More modern equipment uses automated systems and vacuum retrieval for more efficient contamination control.
Illustration		 **Figure A-6. Scarification equipment can consist of large-scale equipment to smaller hand-held scabblers.**
Safety, Health & Environment		Modern equipment uses specialized shrouding and vacuum attachments to provide more efficient contamination control. HEPA vacuums collect the fine dust produced during the scarifying process. With such protection, scabbling can be done without increasing airborne exposure. Health and safety plans must account for adequate filtration of airborne contamination to ensure worker safety.
Time to Implement		Setup takes significant time on some larger scarifiers.
Technical Performance		Typical application may be repeated until contamination is removed.
Availability		Larger scarifiers could be considered specialized equipment and are not widely available; however, smaller-application scabblers, including hand-held versions, are available.
Costs		Large scarifiers can be very expensive (several $100K).
Process Waste		Dust may be generated. Does not introduce water, chemicals, or abrasives into the waste stream.
Throughput		Not as rapid as less invasive techniques but often quicker than total removal.

[1] Noyes, Robert. Nuclear Waste Cleanup Technology and Opportunities.
[2] http://www.bnl.gov/isd/documents/45491.pdf

Technology A-7		Large-scale Dig and Haul
Description		Large-scale equipment, versus the smaller-scale sod cutter, for example, can be used in larger areas in digging and hauling greater quantities of contaminated soils. This method can include equipment such as graders, bulldozers, and rotary, elevating, and pan-type scrapers.[1] The contaminated earth is then moved with earth-moving machines into piles or buried in depressions or trenches.[2] Typically, this procedure removes up to several feet of soil (and buildings above grade) versus just a few inches of localized soil. Large-scale dig/haul may be a stand-alone method or may be used with another method like the segmented gate system (SGS) (See technology A-12). If used alone, the debris is hauled directly to a landfill; this operation becomes a very expensive option with thousands of trucks (millions of highway miles) and much landfill space involved. If debris is hauled to an SGS (staged near the event), a much shorter haul can be performed and much less waste is directed to the landfill.
Relevance to Section 1.3		Dig and haul, demolition, and removal of contaminated materials for disposal.
Effectiveness		Large-scale wholesale use of this technique can be virtually 100% effective at removing contaminated structures. However, the use of this technique typically limits the opportunity for waste minimization by destroying buildings and mixing contaminated and uncontaminated debris.
Illustration		 **Figure A-7. Large-scale dig and haul equipment, versus smaller-scale equipment, removes greater amounts of soil or landmass.**[3,4]
Safety, Health & Environment	(yellow)	Could cause excessive levels of airborne contamination. Control of dust produced during demolition would be needed. Burying wastes deeper in the soil or covering them with a layer of clean soil or concrete may reduce human and animal exposure.
Time to Implement	(yellow)	Usually applied only after careful consideration. Removal may be rapid, but staging is time-consuming.
Technical Performance	(green)	Total removal of buildings and soils can be very effective at decontamination of area; not effective at reducing waste.
Availability	(yellow)	Many contractors are available to do this kind of job.
Costs	(yellow)	These types of applications can be very costly, especially in terms of waste disposal (typically a very costly part of the job).
Process Waste	(yellow)	Liquid waste generation can be a large part of this job if water sprays are used to reduce airborne contamination.
Throughput	(yellow)	Often can be a slow process removing whole facilities.

[1] http://naldc.nal.usda.gov/download/CAT87209094/PDF
[2] International Atomic Energy Agency. Technologies for remediation of radioactively contaminated sites. IAEA-TECDOC-1086, June, 1999.
[3] http://www.mma1.com/enviro/what/remDesign.php
[4] http://www.countyhire.co.uk/news.asp

Technology A-8		Selective Removal of Vegetation
Description		Certain species of plants and vegetation absorb higher concentrations of radioactivity, partly due to their physical characteristics.[1] Some contaminants that have deposited on vegetative matter may remain at least until the first precipitation event. Removing certain types of vegetation or selected parts can aid in remediation efforts. For example, lichen in the Fukushima area was found to contain higher radioactive concentrations and therefore needed to be removed from tree bark by high-pressure washing.[2] Lichens containing cesium were also found in gutter systems. In housing areas, garden trees may also need to be trimmed or removed. Much of the contamination is located in the leaves, as they are a predominant cover for the tree or bush and much more likely to concentrate the contaminants.
Relevance to Section 1.3		Foliage removal; composting.
Effectiveness		Removing contaminated mulches or vegetation varies by type, but can be quite effective overall. For example, when contaminated wheat-straw mulch was removed, over 90% of the contamination was removed with the mulch.[1] As part of the same study, the removal of contaminated Bermuda grass mulch removed 30% of the contamination when 2 tons per acre of mulch were removed and 60% when 5 tons per acre were removed.
Illustration		 **Figure A-8. Workers remove contaminated leaves and select vegetation.**[3,4]
Safety, Health & Environment		Health and safety plans must account for adequate filtration of airborne contamination to ensure worker safety.
Time to Implement		Typically performed later, not earlier, in decontamination approach (more selective and not gross decontamination method).
Technical Performance		Only removes contamination left in leaves or bushes. This may not remove significant dose levels.
Availability		May be performed with commonly available tools.
Costs		Does not use expensive tools or highly skilled labor.
Process Waste		Liquid waste may be generated if vegetation is washed or if suppression spray is used to control airborne resuspension.
Throughput		Selective removal implies slow and deliberate actions; selecting and removing pieces is typically more time-consuming than taking out whole trees/forests.

[1] http://naldc.nal.usda.gov/download/CAT87209094/PDF
[2] CAPT John Cardarelli II. Fukushima: Long-Term Recovery Lessons Learned. WARRP Capstone, September 13-14, 2012.
[3] http://e360.yale.edu/feature/as_fukushima_cleanup_begins_long-term_impacts_are_weighed/2482/
[4] http://www.phillyburbs.com/my_town/palisades/widespread-power-outages-in-bucks-montco/article_9d843abe-1aea-5404-9cc5-30ac12ecd649.html

Technology A-9		Street Sweeping
Description	Street sweeping may be used after a contamination event to begin the decontamination process. Street sweeping is a practical method for cleaning widespread contamination because it uses equipment that is already available, and it does not damage the surface.[1] Unskilled personnel can deploy this technique as well without extensive planning.[2] Often, a high-powered sprayer or individuals with brushes will clean sidewalks and roads after radiological or contaminated substances are swept clean.[3] Minimization of reaerosolization of contaminants would be an important operational consideration for using this technology.	
Relevance to Section 1.3	Physical cleaning of hard surfaces.	
Effectiveness	This method of remediation must also involve attention to dust and effluents as a result of sweepers disturbing potentially radioactive particles. Street sweeping can leave the majority of radioactive particles behind, unless vacuuming or washing occurs simultaneously.[2] Sweeper dust can have a high concentration of radioactivity.[4] This high concentration of radioactivity causes a significant issue from the resuspension of contamination. The benefit of using the street sweeper must be carefully weighed against the spread of contamination. Incorporating vacuum brush techniques can make this a more effective technique.[2] More intensive procedures, such as sandblasting or abrasive blasting, have been proven to be more effective than street sweeping alone. Another study used a sweeper on soil, with its steel bristles removing 75% of the contamination from moist soil with a thin layer of contamination. Another sweep removed up to 90% of the contamination. The same sweep with plastic bristles would have been less effective because the plastic bristles could not cut as well through vegetation.[5] This technique becomes much less effective after a rain event or after months of delay in cleanup.	
Illustration	 **Figure A-9. A street sweeper cleans the street surface without breaking the concrete.**	
Safety, Health & Environment	(yellow)	This type of equipment has not been widely deployed with adequate filtration to protect workers from airborne contamination. Shielding workers from the concentrated contaminant in the collection vessel (when coupled with a vacuum) also should be considered.
Time to Implement	(yellow)	Equipping existing sweepers could take months.
Technical Performance	(yellow)	In some cases, street sweeping has been shown to be only marginally effective at removing contamination.
Availability	(green)	Generally widely available (municipally and commercially).
Costs	(yellow)	Does not require highly skilled labor. Cost of units may be expensive, but may be lower if a government agency is supporting recovery.
Process Waste	(yellow)	May generate significant dust and wastewater during implementation.
Throughput	(green)	Relatively rapid to operate. Should be able to cover a lot of area.

[1] Paajanen, A., and Lehto, J. 1992. Disposal of Radioactive Wastes from the Cleanup of Large Areas Contaminated in Nuclear Accidents. Nordic Nuclear Safety Research Program 1990-93. Project KAN-2.
[2] http://www-pub.iaea.org/MTCD/Publications/PDF/trs300_web.pdf
[3] http://factsanddetails.com/japan.php?itemid=1856&catid=26&subcatid=162
[4] Lehto, J. Cleanup of Large Radioactive-Contaminated Areas of Disposal of Generated Waste. Final Report of the KAN2 Project. TemaNord 1994:567. February, 2004.
[5] http://naldc.nal.usda.gov/download/CAT87209094/PDF

Technology A-10		Vacuuming
Description	Vacuuming is often used to remove the debris left behind by high-pressure washing and street sweeping.[1] Other vacuums can be incorporated into street-sweeping vehicles. Vacuuming is usually recommended for the final cleanup of remediation areas after materials have been dried and contaminated materials removed. In situations like this, some vacuums can also incorporate HEPA filters. HEPA vacuums are especially recommended for cleanup of dust that may have settled in other areas outside the remediation area.[2] Using *certified* HEPA-filtered vacuum cleaners is a proven method of removing contamination without spreading it via resuspension. However, most vacuum cleaners available at retail outlets are not certified to reduce resuspension.	
Relevance to Section 1.3	Physical removal of surface layer of material from hard surfaces.	
Effectiveness	Vacuuming is an effective way to clean up small particles or dust in the final stages of remediation. However, if using a HEPA filter, care must be taken to ensure that the filter is installed correctly, so that air passes through the filter when in use. Remediation personnel must also take care when removing the filter, using proper gear to avoid exposure to the contaminated materials captured. Disposal of the filter requires further care, using well-sealed, impervious plastic bags.[2] In one case, a small vacuum street sweeper was used to remove contamination from a clipped meadow, resulting in the removal of about half the contamination (after sweeping twice). After the initial two sweeps, further sweeping/vacuuming was ineffective.[3]	
Illustration	 **Figure A-10. Street sweepers with vacuum attachments[4] allow contaminated dust and debris to be collected.**	
Safety, Health & Environment		Health and safety plans must account for adequate filtration of airborne contamination to ensure worker safety. Shielding workers from the concentrated contaminant in the collection vessel also should be considered.
Time to Implement		Equipping existing sweepers with vacuum attachments and HEPA filtration systems could take months.
Technical Performance		In some cases, where contamination has moved into concrete and asphalt, vacuuming has been shown to be only marginally effective at removing contamination. Vacuum or sweeping machines might be useful unless the contaminant had been frozen into the surface.
Availability		Generally widely available (municipally and commercially).
Costs		Does not require highly skilled labor. Cost of units may be expensive, but may be lower if a government agency is supporting recovery.
Process Waste		Contaminated filters. May generate significant dust and wastewater during implementation.
Throughput		Vacuum cleaning of "hot spots" can be a slow process.

[1] CAPT John Cardarelli II. Fukushima: Long-Term Recovery Lessons Learned. WARRP Capstone, September 13-14, 2012.
[2] http://www.epa.gov/mold/i-e-r.html#HEPA_Vacuum
[3] http://naldc.nal.usda.gov/download/CAT87209094/PDF
[4] http://www.maxwell.af.mil/photos/mediagallery.asp?galleryID=6&?id=-1&page=94&count=48

Technology A-11		High-Pressure Washing
Description		High-pressure washing involves washing surfaces with high-pressure water at various temperatures. This method can use hot water washers or rotating brushes in decontaminating surfaces such as roofs, walls, streets, or other affected surfaces.
Relevance to Section 1.3		Physical removal of surface layer of material from hard surfaces.
Effectiveness		High-pressure washing is largely effective in removing contamination from some surfaces, particularly those of a nonporous nature. However, high-pressure washing requires the use of prodigious amounts of water and can generate similarly prodigious amounts of contaminated wastewater, which must be effectively collected and disposed of. Methods that collect wastewater, such as spin-jet devices, are currently being assessed as a way to address this limitation.[1] Water can also be treated with zeolite to remove the radioactivity. Pressure-washing would not be effective on surfaces that are damaged, such as partially damaged roofs. These surfaces would need to be manually attended to. Water washing also has the drawback that some soluble radionuclides (particularly cesium) can be carried farther into the substrate, preventing further cleanup. While some water washing systems have proven effective at removing contamination, the effect of the water flushing should be carefully considered; soluble cesium contamination has been shown to attach more tenaciously to concrete substrate because of imbibition (driving the contamination further into the surface). Recent EPA testing of a rotating water jet technology (3-Way Decontamination System, River Technologies, LLC, Forest, VA) on concrete surfaces revealed modest removal levels (36%) of ^{137}Cs applied as an aqueous solution.[2] High pressure washing is not difficult. Collection and treatment of rinsate is the challenge.
Illustration		 **Figure A-11. Using pressure washing as a mitigation technology.**[2,3]
Safety, Health & Environment		Pressure washers may spread (resuspend) contamination or potentially drive contamination deeper into porous surfaces. Working with high-pressure, hot-water equipment can be hazardous, but mitigation with a modest amount of training on use of equipment and use of proper PPE would likely be adequate.
Time to Implement		Equipment is available for purchase at home improvement stores. Training personnel to use equipment properly should take approximately an hour.
Technical Performance		Has been shown not to be highly effective against "fixed" contamination.
Availability		Common equipment, available for purchase in every city.
Costs		May require highly skilled labor. Consider the cost of the vacuum, pressure washer, and discharge pump. Cost of units may be lower if a government agency is supporting recovery (typically under $10K).
Process Waste		Creates airborne contamination and generates a significant amount of wastewater during implementation. Requires special handling of runoff wastewater, which would require highly specialized equipment that may require engineering performed on a situation-by-situation basis.
Throughput		Could be used effectively over large surfaces with minimal resource requirements. The secondary waste concern could eliminate the benefits if the wastewater cannot be disposed of appropriately.

[1] CAPT John Cardarelli II. Fukushima: Long-Term Recovery Lessons Learned. WARRP Capstone, September 13-14, 2012.
[2] http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=232549
[3] http://www.drizit.co.za/cleanup_high_pressure.php

Technology A-12	Segmented Gate System	
Description	An SGS is a radioactive soil waste minimization system using a series of conveyer belts that pass excavated soil under radiation detectors. The conveyer is timed and instrumented so that when it detects a contaminated soil area among a large number of uncontaminated areas, it activates a "gate" at the end of the conveyer belt to remove only that area or section of the whole. The SGS is useful for radioactive soil waste and potentially could be modified for other, well-subdivided media such as asphalt or extruded concrete.	
Relevance to Section 1.3	Other technologies.	
Effectiveness	Several projects have shown that the SGS may provide a significant waste reduction, with an average soil waste reduction of 97% shown in most projects.[1] Preliminary technology assessments as part of a 1995 DOE program indicated that processing radionuclide-contaminated soils through physical separation using advanced sensors was cost-effective and could significantly reduce the volume of soil requiring either further treatment or off-site disposal. Further study demonstrated the ThermoRetec SGS unit to separate clean and contaminated soil for four different radionuclides: plutonium, uranium, thorium, and cesium.[2] The SGS provided significantly less efficiency in two cases: (1) if the soil was thoroughly contaminated (very uniform contamination throughout the section of soil removed) such as with windblown contamination on soil, and (2) if the soil contained large amounts of vegetation.[2] In some of these cases, the efficiency of segregation of contaminated from uncontaminated soil dropped to less than 50%. SGS does not have performance data available for an RDD-type application.	
Illustration	 **Figure A-12. Clean soil removed from the white building housing the SGS, and the SGS detector systems shown on a conveyer belt.**	
Safety, Health & Environment		Requires special heating, ventilation, and air conditioning (HVAC) (typically the system is within a "tent").
Time to Implement		Not readily available and takes time for skilled operators to set up.
Technical Performance		Has performed waste reduction at very high efficiencies in some applications.
Availability		Very few (fewer than five) of these units are available in the United States.
Costs		These units may cost over $1M to set up and operate.
Process Waste		Minimal liquid waste is generated, but some portions of the equipment may need periodic decontamination.
Throughput		Once operating, this equipment can process several hundred tons of soil per day.

[1]Moroney, K., J. Moroney III, J. Turney, et al. (1994). Processing plutonium-contaminated soil on Johnston Atoll. Radwaste Magazine, 1(3) July 1994.

[2] Patteson, R. (2000). The Accelerated Site Technology Deployment Program/Segmented Gate System Project. Spectrum 2000 Conference, Chattanooga, Tennessee, September 24-28, 2000. Report No. SAND2000-2285C.

Technology A-13		Soil Washing
Description		Soil washing uses a mechanical process involving water to remove pollutants and contaminants from the soil. Soil washing is considered feasible for the treatment of a wide range of contaminants, including radionuclides. Soil washing is often used in combination with other treatment technologies, as soil washing is primarily focused on reducing the contaminants found concentrated in relatively small masses of material. The more concentrated the material, the more cost-effective the soil washing will be. Soil washing separates the fine silt and clay particles from coarser sand and gravel, with contaminants adhering to the silt or clay particles. The process facilitates the transfer of chemical contaminants from the soil surface to the water, which can be separated and treated further.[1] After the process is complete, the sand and gravel are nontoxic and can be used as backfill, and the other volumes of particles that contain contaminants are disposed of according to the appropriate regulations. The wash water must be treated on- or off-site, depending on the contaminants present.
Relevance to Section 1.3		Other technologies.
Effectiveness		Soil washing is most appropriate when soils consist of less than 25 percent silt and clay and at least 50 percent sand and gravel.[2] Depending upon soil matrix characteristics, soil washing can allow for the return of clean coarse fractions of soils to the site at a very low cost.[3] Soil washing will generally not be cost effective for soils with fines (silt/clay) content in excess of 30 to 50 percent.[3] Other characteristics, such as moisture content, particle size distribution, contaminant concentrations, and solubilities, also affect the efficiency and operability of a soil-washing machine.[4] Completion of pilot-scale treatability studies for soil washing to reduce contaminated soil volumes demonstrated that this treatment process is not cost effective for *liquid* radioactive effluent sites and therefore is not considered a treatment option for soil volume reduction prior to disposal.[5] Soil washing equipment is transportable and can operate on the site if necessary.[1] Earthline Technologies operates a 10-ton-per-hour chemical extraction soil washing plant for the removal of uranium-contaminated soil. Soil treatment using chemical (carbonate) extraction reduced the volume of contaminated material requiring off-site disposal and lowered total project costs associated with soil remediation from $45 million off-site disposal to $25 million for on-site processing and treatment. This soil washing process is applicable to other radionuclide contaminants.[6] Soil washing works best in tandem with another treatment technology rather than as a stand-alone system, since it does not usually reduce contamination 100%.[1] It unproven for an RDD incident.
Illustration		 **Figure A-13. Soil washing machines can operate on-site to decontaminate soils.**[7]
Safety, Health & Environment	(yellow)	Requires special HVAC (typically the system is within a "tent").
Time to Implement	(yellow)	Not readily available and takes time for skilled operators to set up. As for any *ex-situ* technology, there are space requirements for the treatment system.
Technical Performance	(yellow)	Soil-washing systems have to be customized for specific contamination characteristics (e.g., soil size distribution, radionuclide types, and concentrations). Has some efficacy issues and may leave soil "sterile," unable to support vegetation.
Availability	(red)	Very few of these units are available in the United States.

[1] http://www.egr.msu.edu/tosc/dutchboy/factsheets/what%20is%20soil%20washing.pdf
[2] EPA. Technology Reference Guide for Radioactively Contaminated Media. EPA 402-R-07-004, October 2007 http://www.epa.gov/rpdweb00/docs/cleanup/media.pdf
[3] www.itrcweb.org/Guidance/GetDocument?documentID=50
[4] EPA. Technology Screening Guide for Radioactively Contaminated Sites. EPA 402-R-96-017, November 1996.
[5] http://nepis.epa.gov/Adobe/PDF/9100NU6W.PDF
[6] http://www.umasssoils.com/abstracts2001/tuesday/radionuclide.htm
[7] http://www.decnv.com/EN/techniques/soil_and_groundwater

Technology A-13		Soil Washing
Costs		Operation costs could be substantial. This would be an extremely expensive waste reduction method if used to treat the vast quantities of soils generated by an RDD.
Process Waste		Process generates significant quantities of liquid waste requiring disposal; however, some waste solutions could be reused after treatment.
Throughput		Once operating, this equipment can process several hundred tons of soil per day.

<table>
<tr><th colspan="2">Technology A-14</th><th>Composting of Organic Matter</th></tr>
<tr><td>Description</td><td colspan="2">Composting is a way of managing lower-activity organic wastes to prepare for ultimate disposal. A “bio-pile” must be created in such a way as to provide the conditions for microbial growth through the presence of oxygen, water, and nutrients. Pipes can be added to distribute oxygen throughout the pile. Nutrients or fertilizers can be added, while keeping the pile moist. Although the radioactive contamination is not removed or destroyed in this process, the quantity of residual organic matter may be naturally attenuated via the compost process. Application for composting in an RDD scenario is for organic wastes (foliage but particularly animal carcasses with low levels of radiological contamination), which are then reduced to a waste with much lower water content that can be disposed of in a landfill or incinerator. Composting may also be a viable alternative for some niche waste streams from an RDD incident such as food waste.[1]</td></tr>
<tr><td>Relevance to Section 1.3</td><td colspan="2">Foliage removal; composting.</td></tr>
<tr><td>Effectiveness</td><td colspan="2">Composting achieves a mass reduction of 50 percent and a volume reduction of 50 to 90 percent. Monitoring (specifically at a landfill) may be necessary to indicate levels of radioactivity at the higher end of this percentile since all radionuclides are now part of the remaining 10 percent of the former “low level” material. Composting is most effective in manageable sizes so that the conditions can be maintained. It can be carried out at commercial facilities or in situ. Composting will not remove or reduce radiation in soils, thus no experience with radiological waste exists. The U.S. military and others have found that through composting soils, some contaminants can be removed from munitions-contaminated soils, providing evidence that the composting of this type of contaminated soil is a cost-effective and environmentally sound clean-up method.[2]</td></tr>
<tr><td>Illustration</td><td colspan="2">
Figure A-14. Composting contaminated animal carcasses by mixing them with various feedstock, can create clean, remediated soils.[3]</td></tr>
<tr><td>Safety, Health & Environment</td><td></td><td>May leave materials loose and available for wind resuspension or attack from burrowing animals. Worker safety needs to be considered during the “turning of piles” as part of in situ composting.</td></tr>
<tr><td>Time to Implement</td><td></td><td>Not typically used in the early stages of decontamination.</td></tr>
<tr><td>Technical Performance</td><td></td><td>Not shown to be effective at removing radiological contamination; may reduce overall volume of primary waste form via microbial degradation.</td></tr>
<tr><td>Availability</td><td></td><td>Depending on the application (grass clippings vs. 100,000 head of cattle), composting may be performed using less skilled workers.</td></tr>
<tr><td>Costs</td><td></td><td>Does not require expensive equipment.</td></tr>
<tr><td>Process Waste</td><td></td><td>Depending on the field condition, leachate produced could be collected and disposed of or reused in the composting process.</td></tr>
<tr><td>Throughput</td><td></td><td>Does not rapidly reduce waste volumes.</td></tr>
</table>

[1] http://www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1194947372801
[2] http://www.epa.gov/compost/pubs/explosn.txt
[3] http://dhs.wifss.ucdavis.edu/headcontent/newsletter/2008October_newsletter.php

Technology A-15		Plasma arc Vitrification
Description		Plasma arc torch vitrification is a process of disposing of wastes such as soils, debris, sediment, buried waste, and metals into a relatively impervious matrix. A thermal plasma is an electrically conductive gas capable of generating temperatures up to 10,000 degrees Celsius.[1] A plasma torch is used to heat ex-situ furnaces, which are used to destroy contaminated waste.[2] The high temperatures immobilize non-volatile chemical species into a non-leachable matrix, making it appropriate for waste disposal.[1] This method can be used in *in-situ* vitrification and remediation of buried waste or contaminated soil, creating a rock-like mass that is resistant to leaching.[3]
Relevance to Section 1.3		Waste stabilization.
Effectiveness		Plasma arc vitrification is a practice that can be implemented on a production scale.[3] Plasma arc vitrification is effective because of its ability to sustain high temperatures, operate in a variety of environments, reduce waste volume, and maintain low gas throughput, as well as its flexibility to treat a variety of waste types.[1] It is also considered a permanent treatment technology, as opposed to other interim technologies. Plasma arc centrifugal treatment in particular is effective in disposing of low-level radioactive waste (LLRW) and other materials, despite the presence of heavy metals and mixtures of organic materials, oils, metals, and water.[4] However, this process does not affect radioactivity, so volatile radionuclides trapped during the process will require further treatment and/or disposal.[5] This technology would have very limited, if any, value for an RDD incident for the very small amount of mixed wastes. For the vast quantities of lower-activity waste, this waste reduction/stabilization method would be extremely expensive.
Illustration		 **Figure A-15. Plasma arc systems for waste vitrification are effective.**
Safety, Health & Environment	(yellow)	Significant concerns about melter off-gas and volatile contaminant species. Also, melters have hazards associated with ignition of organic species (and subsequent fires). Vitrification requires extensive federal and state permitting and can be subject to dangerous fires.
Time to Implement	(red)	Building and permitting a melter is very time-consuming.
Technical Performance	(green)	Waste treated by vitrification has been shown to be very resistant to leach processes.
Availability	(red)	Only a few radioactive waste melters operate within the United States.
Costs	(red)	Vitrification systems are very expensive to build and operate. Vitrification processes are usually used only for waste that has very high concentrations of radionuclides.
Process Waste	(green)	Minimal liquid waste is produced from these processes.
Throughput	(yellow)	Melters are slow processes, the feed is mixed with "frit," and the waste loading is not high.

1 http://www.dtic.mil/dtic/tr/fulltext/u2/p017705.pdf
2 http://www.aepi.army.mil/publications/sustainability/docs/plasma-arc-oct28.pdf
3 http://www.containment.fsu.edu/cd/content/pdf/132.pdf
4 http://www.tms.org/pubs/journals/jom/9910/womack-9910.html
5 EPA. Technology Screening Guide for Radioactively Contaminated Sites. EPA 402-R-96-017, November 1996.

Technology A-16	Cementitious Stabilization/Solidification
Description	Cementitious stabilization/solidification (S/S) is a widely used technique for treating and disposing of hazardous waste and LLRW. Cementitious materials may include cement, ground granulated blast furnace slag, fly ash, lime, and silica fume. Often, clays and additives are added to help immobilize contaminants or otherwise enhance the waste forms that are produced as a result of this process.[1] Commonly called "grouting," this technique uses cement-based grout systems to immobilize contaminants. The cement lowers the solubility of the contaminants. This process can take place in situ or ex situ.[2] Cement-based "grout" systems have been used for many years, in many instances for S/S radioactive waste of all levels. Cement-based systems have been used to treat low-level waste from nuclear power plants for decades.[3] This method can also be used to treat radioactive contaminated soils, sediment, or sludge. Sulfur polymer cement (SPC) is a viable, non-cementitious "grouting" material that displays superior radioactive waste stabilization. Despite its name, SPC is a thermoplastic material, not a hydraulic cement. It has a relatively low melting point (120°C) and melt viscosity (about 25 centipoise), and thus can be processed easily by a simple heated stirred mixer. Compared with hydraulic Portland cements, SPC has a number of advantages. Sulfur polymer concrete compressive and tensile strengths twice those of comparable Portland cement concretes have been attained. Full strength is reached in a matter of hours rather than several weeks. Concretes prepared using SPCs are extremely resistant to most acids and salts. Sulfates, for example, which are known to attack hydraulic cements, have little or no effect on the integrity of SPC. Because of these properties, modified SPC has been proposed for use as a paving material and for the production of tanks, pipes, and other structures where durable concretes are required.
Relevance to Section 1.3	Waste stabilization.
Effectiveness	Cementitious materials have low processing costs, are compatible with many disposal scenarios, and can meet strict processing and performance requirements. Attention must be given to characterizing the waste produced, developing methods to treat the waste, and mixing the cementitious mixtures correctly. Certain ingredients influence the volume of waste treated, which ultimately can have an effect on the lifetime disposal costs. Evaporation pretreatment may be necessary to control leachability as well. Ordinary Portland cement has been proven effective, with improved compatibility, mechanical integrity, and chemical durability in housing wastes.
Illustration	 **Figure A-16. Soils or wastewater can be solidified, locking in contaminants in low-permeability, high-strength blocks.[4]**
Safety, Health & Environment	(green) Have few safety and environmental hazards (with the notable exception of jet grouting at high pressures).
Time to Implement	(yellow) Cementation processes usually have to undergo trials for product consistency and leachability. This process typically comes after another process (like evaporation) and treats the higher-concentration "reject" solution.

[1] Center for Remediation Technology and Tools, U.S. EPA. Stabilization/Solidification Processes for Mixed Wastes. Prepared under Contract No. 2W-7520-NASA. EPA 402-R-96-014. June 1996
[2] http://www.cement.org/waste/wt_ss.asp
[3] http://www.cement.org/waste/wt_apps_radioactive.asp
[4] http://www.geo-solutions.com/what-we-do/technologies/soil-mixing/in-situ-stabilization

Technology A-16		Cementitious Stabilization/Solidification
Technical Performance		Considered a very robust waste form.
Availability		Universally available. Cement is readily available in all parts of U.S. It is economical and can be purchased in small or bulk quantities.
Costs		Grouting costs could be much higher for larger volumes because of significant labor involved and cement costs.
Process Waste		There is usually no secondary liquid waste produced in this process. The concentration of the S/S-treated wastes may impact disposal options. Options may include using monofills (dedicated landfills) or treating the waste *in situ* and leaving it in place.
Throughput		Grouting hazardous waste is typically a “small batch” process.

Technology A-17		Incineration
Description		Incineration is a common method of disposal of contaminated or hazardous material. Incineration is also a potential alternative for mixed hazardous/radioactive waste as well as contaminated biomass. Waste is first collected in bulk (i.e., in boxes, bags, or drums). Waste might be cut, shredded, or crushed for volume reduction. Incineration works by destroying hazardous materials and breaking them down into simpler chemical forms, eliminating liquids in the wastes that could otherwise complicate waste management, decreasing waste volume, and even generating usable energy.[1] Throughout the process, ash is collected and handled remotely, then packaged in containers to await storage or disposal
Relevance to Section 1.3		Waste volume reduction.
Effectiveness		Incineration can allow up to 80% or more of solid radioactive waste to be burned efficiently, greatly reducing the volume of waste.[2] Incineration has become a largely effective and efficient process at nuclear power plants, but further improvements still need to be made for other applications.[2] The incineration process requires extensive permitting and it may not be cost-effective to construct units specifically for an incident. Though commonly used, incineration can result in contamination through airborne radionuclide emissions, necessitating elaborate air pollution control equipment. Few established incineration sites accept radioactive waste, so the capacity is limited.[3] This technology would have very limited, if any, value for an RDD incident for the very small amount of mixed wastes. For the vast quantities of lower-activity waste, this waste reduction/stabilization method would be extremely expensive.
Illustration		 **Figure A-17. Waste is collected in bags or drums before being incinerated.[4,5]**
Safety, Health & Environment		Significant concerns about incinerator off-gas and volatile contaminant species; requires special permits.
Time to Implement		Incinerators are difficult to site because of off-gas issues and public acceptance. May require extensive permitting and not be cost-effective to build specifically for an incident.
Technical Performance		Only combustible waste can be handled in this manner.
Availability		Few radioactive waste incinerators operate within the United States.
Costs		Costs are not as high as vitrification but are still significant. Capacity limitations are a much more severe inhibition than cost.
Process Waste		Dry waste (ash) is collected and handled remotely, then packaged in containers to await storage or disposal. Liquid waste may potentially be generated from operations associated with the technology, which may require subsequent treatment and disposal.
Throughput		Most incinerators require manual sorting of items, which slows the process.

[1] http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=000005FP.txt
[2] http://www.iaea.org/Publications/Magazines/Bulletin/Bull314/31404683742.pdf
[3] http://www.uwgb.edu/safety/envpolicies/
[4] http://news.nationalgeographic.com/news/energy/2011/11/pictures/111111-nuclear-cleanup-struggle-at-fukushima/#/fukushima-daiichi-nuclear-reactor-remediation-waste_43457_600x450.jpg
[5] http://blogs.knoxnews.com/munger/2008/03/

Technology A-18	Chelating Agents
Description	Chelating agents include zeolites, various types of clays, and other sorts of engineered materials. Some engineered materials are quite novel and can have unique application in certain situations.[1] Zeolites are a well-established technology that removes radioactive components from aqueous waste streams. Zeolites are crystalline aluminosilicates, compositionally similar to clay minerals, but differing in their well-defined three-dimensional nano- and micro-porous structure. The selectivity of non-ionic adsorption mechanisms is related to this porous structure. Ion exchange (IX) and non-ionic adsorption properties often occur simultaneously and are linked since the porous structure controls the size of the radionuclide that can enter the pores and engage in IX. Considerable research and some implementations have taken place using zeolites for radioactive waste site remediation and decontamination of waters containing radionuclides.[1] Misaelides et al. (1999) presented information with general environmental applications for zeolites, but also contained information on the use of zeolites as radionuclide sorbents, including investigation of natural zeolites and nuclear waste management in the case of Yucca Mountain, Nevada, and the sorption of heavy metals and radionuclides on zeolites and clays.[2] In another evaluation, the inorganic IX media IE-96 (synthetic zeolite) was chosen for cesium recovery because of its high sorption rate, high decontamination factor, and IX capacity.[3] Clays are a popular choice for decontamination because they are inexpensive and widely available. Clays are ideal chelating agents for this purpose because cations with low hydration energy undergo dehydration in the interlayer and promote layer collapse, and are thus fixed in the clay's interlayers.[4]
Relevance to Section 1.3	Wastewater cleanup, volume reduction, or waste stabilization.
Effectiveness	*General note.* Chelating agents have a variety of applications, two of which are discussed below. Regardless of application, it is important to note that the properties of natural zeolite and clays can vary considerably depending on the specific deposit from which they were quarried, both as a result of mineralogy and the presence of naturally occurring substances that affect, through a variety of mechanisms, the adsorption properties for the radionuclide. *Wastewater applications.* Natural zeolites (e.g., clinoptilolite) can remove radioactive cations such as cesium from low-level radioactive liquid waste. One study adapted natural zeolite sorbents and chemical precipitation to decontaminate liquid low-level waste. Clinoptilolite was shown to have a high selectivity for ^{137}Cs. In the absence of potassium ions, native clinoptilolite removed other radionuclides very effectively from the liquid waste.[5] Another discussion of clinoptilolite, along with potential shortcomings of this zeolite including mineralogical variability even in the same deposit, has been documented in the literature. This discussion also cited that clinoptilolite was used to remove cesium and strontium from radioactive wastewater at the Sellafield plant in Great Britain.[6] Just as the ability of zeolites to remove radionuclides varies with the specific zeolite, it is well known that the characteristics of clays vary with type of clay and the locality from which it comes.[7] For instance, bentonite, in particular, has been considered an ideal material for a deep geological repository for its high swelling ability, low hydraulic conductivity, high cationic sorption capacity, and long-term stability.[8] In other applications, vermiculite, illite, kaolinite, and maylonite have been investigated. *In-place immobilization of soils.* Regarding efficacy, though zeolites have had limited uses in environmental remediation outside of their use in the nuclear industry for liquid radioactive waste management, they are seen as having significant potential for environmental remediation.[1] Campbell and Davies (1997) investigated plant uptake of cesium from soils amended with clinoptilolite and calcium carbonate, based on the observation that ^{137}Cs from the Chernobyl accident remained in a bioavailable form in soils of Great Britain. As a potential remedial measure, the

[1] EPA (2009). Potential Nano-Enabled Environmental Applications for Radionuclides. U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C. Document No. EPA 402-R-09-002. January. Available at: http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P1005GR1.txt

[2] Misaelides, P., F. Macasek, T.J. Pinnavaia, C. Colella (Eds.). 1999. Natural Microporous Materials in Environmental Applications. Kluwer Academic Publishers, The Netherlands.

[3] http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=6309190

[4] Oscarson, D. W., Watson, R. L., & Miller, H. G. (1987). The interaction of trace levels of cesium with montmorillonitic and illitic clays. Applied Clay Science, 2(1), 29-39.

[5] http://www.ncbi.nlm.nih.gov/pubmed/16563616

[6] Rajec, P., & Domianová, K. (2008). Cesium exchange reaction on natural and modified clinoptilolite zeolites. Journal of Radioanalytical and Nuclear Chemistry, 275(3), 503-508.

[7] Ugur, F. A., Sahan, H., & Tel, E. (2011). Sorption Studies of Cs+ on Illite.

[8] Galamboš, M., Kufčáková, J., & Rajec, P. (2009). Adsorption of cesium on domestic bentonites. Journal of Radioanalytical and Nuclear Chemistry, 281(3), 485-492.

Technology A-18		Chelating Agents
		zeolite clinoptilolite was tested in a greenhouse pot experiment for its effectiveness in selectively taking up cesium from two British soils: a lowland loam and an upland peat.[9] Batch and dynamic leaching methods were used to evaluate the effectiveness of hydroxyapatite (HA), illite, and zeolite, alone and in combination, as soil additives for reducing the migration of ^{137}Cs and uranium (U) from contaminated sediments. The current results demonstrate the effectiveness of soil amendments in reducing the mobility of U and ^{137}Cs, which makes in-place immobilization an effective remediation alternative.[10]
Illustration		 **Figure A-18. Zeolites and clays are quarried in very large quantities.**
Safety, Health & Environment	(green)	Most zeolites and clays, particularly those with current widespread uses, are regarded as a safe material. If zeolite is in sodium form, sodium toxicity risk to soil and plants increases as cation exchange proceeds. Alternatively, soil quality could easily be monitored and appropriate amendments made.
Time to Implement	(yellow)	Some technical development is usually required to demonstrate efficacy to meet desired criteria. Prior to treatment for disposal, two pre-treatments—dewatering and size reduction—may be needed.
Technical Performance	(green)	Most chelation processes can be engineered to achieve high efficiency. Zeolites and clays are a mature, long-established technology. They are widely used for the treatment of radioactive waste streams and are under ongoing development.
Availability	(green)	Zeolites and clays are a bulk commodity and might be available in large quantities following a contamination incident.
Costs	(green)	Some zeolites and engineered chelation agents are expensive (radionuclide-specific synthetics), while others can be relatively cheap. Overall, the use of zeolites or clays can be less expensive than other treatments.
Process Waste	(yellow)	Residuals from aqueous treatment using chelating agents may be radioactive waste and should be disposed of appropriately. The residual generated by chelating agent processes is the spent regenerant. Disposal of the spent regenerant most frequently will require discharge to a wastewater treatment facility. Depending on the contaminant concentrations in the spent regenerant, it may be necessary to evaluate the impacts on wastewater treatment plant discharges and disposal requirements. Radionuclides may become so concentrated in the brine and the resin that they may require special handling and disposal procedures. Systems may use disposable media that can be removed by a waste broker, and use the resin to exhaustion (rather than regenerating), especially if disposal of liquid residuals to a wastewater treatment plant is not an option.
Throughput	(green)	A well-engineered zeolite or clay process can have a high throughput.

[9] Campbell, L.S., and B.E. Davies. 1997. Plant and Soil. 189(1):65-74.
[10] Seaman, J.C., T. Meehan, and P.M. Bertsch (2001). Immobilization of cesium-137 and uranium in contaminated sediments using soil amendments. J Environ Qual, 30(4):1206-13. July-August. Available at: http://www.ncbi.nlm.nih.gov/pubmed/11476497

Technology A-19	Ion Exchange (IX)
Description	IX in general is one of the most well-developed, common, and effective treatment methods for removing radioactive ions from contaminated wastewater. As noted in the description of chelating agents, IX mechanisms can be significant for these materials. IX in this description refers to materials for which the primary removal mechanism is ion exchange, often achieved through engineered resins. Some engineered materials are quite novel and can have unique application in certain situations.[1] Engineered resins can have more reproducible physical characteristics such as pore size than naturally occurring chelating agents such as zeolites and clays, but can be more expensive. IX can remove low levels of radionuclides from drinking water. During IX treatment, water is passed through a resin containing exchangeable ions. There are two types of IX: anion exchange and cation exchange. Anion exchange resins generally exchange chloride for anionic contaminants, like uranium. Cation exchange resins generally exchange sodium or potassium for cationic contaminants, such as radium and cesium. Mixed bed resins with cation and anion exchange media in two layers are available for systems that need to remove both radioactive cations and anions. IX is also effective for the removal of radionuclides that yield beta particles and photon emitters. In the Radionuclides Rule, EPA has listed Best Available Technologies (BATs) and Small System Compliance Technologies (SSCTs) for radionuclide treatment based on their efficiency at removing radionuclides from drinking water. EPA has identified IX as a BAT and SSCT for radium, uranium, gross alpha, and beta particle (e.g., ^{90}Sr) and photon emitters. It can remove up to 99 percent of these contaminants depending on the resin type, regeneration frequency, pH, initial concentration, and competing ions.[1] IX resins are regenerated by a series of steps, including backwashing, brining, and rinsing, but removal efficiency and resin lifetime can be affected by regeneration.
Relevance to Section 1.3	Wastewater cleanup or volume reduction.
Effectiveness	The effectiveness of IX processes can be affected by scaling of minerals, chemical precipitants, and surface clogging, all of which leads to resin fouling. In order to reduce such occurrences, appropriate pretreatment measures such as filtration of suspended solids or addition of chemicals to reduce scaling may be practiced. Competition by other ions (such as sulfate and ions associated with water hardness) can reduce the service capacity of the resin bed for the target radionuclide.[1] Wastewater treatment processes exist that effectively remove radioactive ^{137}Cs. An IX system assembled at the Fukushima Daiichi Nuclear Power Plant site reported to achieve a cesium removal goal of 99.9 percent and be responsible for 70 percent of the radioactivity removed from the wastewater, although details of the exact process and IX resin are not provided.[2] Such effectiveness is not unexpected because IX was used to clean up legacy nuclear waste from an old reactor at the DOE's Savannah River Site with removal efficiencies up to 99 percent.[3] Removal of uranium from water (contamination levels vary) by IX can be very effective (greater than 99 percent removal in most cases). The most common resin used for uranium removal was an anionic resin (Dowex or Purolite). Based on another study involving bench-scale isotherm tests using groundwater, removal of ^{90}Sr was found to be very effective (greater than 99 percent removal in one case). Finally, removal of radium from water by IX can be very effective (62 percent to greater than 99 percent removal). The most common resin used was a cationic, polystyrene-based zeolite resin which performed equally well in the calcium, sodium, and hydrogen form. Another IX medium commonly used was manganese greensand, which was equally effective (84 percent to 98 percent removal).[4]
Illustration	 **Figure A-19. IX can be used for the removal of radioactive ions from contaminated wastewater.**

[1] http://cfpub.epa.gov/safewater/radionuclides/radionuclides.cfm?action=Rad_Ion Exchange
[2] http://www.kurion.com/applications/separation/fukushima
[3] http://www.wmsym.org/archives/2002/Proceedings/19/208.pdf
[4] Drinking Water Treatability Database: http://iaspub.epa.gov/tdb/pages/general/home.do

Technology A-19		Ion Exchange (IX)
Safety, Health & Environment	Green	IX systems have few safety and environmental hazards (perhaps only moderate pressure, no real hazardous chemicals, etc).
Time to Implement	Yellow	Systems can be assembled quickly, but verification for the exact waste stream, often performed in the laboratory, may take time.
Technical Performance	Green	Some IX systems have been proven to be highly efficient and are an industry standard for wastewater cleanup and drinking water treatment.
Availability	Green	May not be commercial off-the-shelf (COTS), but often can be quickly assembled. Many public water treatment systems have some IX capability, although different resins may be required to address the radionuclide of interest.
Costs	Green	IX systems are typically not expensive (though crystalline silicotitanate [CST], cesium-specific resin is very expensive); they are relatively simple to operate and may pose fewer long-lead permitting requirements.
Process Waste	Yellow	Residuals from aqueous treatment using IX may be radioactive waste and should be disposed of appropriately. The residual generated by IX processes is the spent regenerant. Disposal of the spent regenerant most frequently will require discharge to a wastewater treatment facility. Depending on the contaminant concentrations in the spent regenerant, it may be necessary to evaluate the impacts on wastewater treatment plant discharges and disposal requirements. Radionuclides may become so concentrated in the brine and the resin that they may require special handling and disposal procedures. Systems may use disposable media that can be removed by a waste broker, and use the resin to exhaustion (rather than regenerating), especially if disposal of liquid residuals to a wastewater treatment plant is not an option.
Throughput	Green	An individual column could be slow, but many columns can be grouped together for large throughput.

Technology A-20	Reverse Osmosis
Description	Reverse osmosis (RO) is a pressure-driven membrane separation process. Water is forced through a membrane with small pores by pressures ranging from 100 to 150 pounds per square inch (psi). RO removes many types of large molecules and ions from solutions by applying pressure to the solution when it is on one side of a selective membrane. To be selective, this membrane should not allow large molecules or ions through the membrane's pores, but should allow smaller components of the solution to pass freely. RO can remove low levels of radionuclides, including cesium, from drinking water and wastewater. The membrane is essentially non-permeable to the contaminants, while treated water is collected on the other side. In the Radionuclides Rule, EPA has listed BATs and SSCTs for radionuclide treatment based on their efficiency at removing radionuclides from drinking water. EPA has identified RO as a BAT and SSCT for uranium, radium, gross alpha, and beta particles and photon emitters. It can remove up to 99 percent of these radionuclides, depending on the membrane type, pH, recovery, and initial contaminant concentration.
Relevance to Section 1.3	Wastewater cleanup or volume reduction.
Effectiveness	Membrane failure, which can allow contaminants to pass through to the finished water, is a key concern. For this reason, systems will need to test the membrane for integrity. Direct methods measure the integrity of the membrane and its housing through either pressure drop or markers and usually require taking the unit offline. Another significant issue with RO is membrane fouling and scaling. Hardness components such as calcium and magnesium can precipitate scales and silica, which will decrease membrane efficiency. Colloids and bacteria can also foul the membranes. Both fouling and scaling will increase the pressure drop, decreasing membrane life and increasing energy costs.[1] Some type of pretreatment is generally required to obtain acceptable membrane run times. RO is an effective treatment method for the removal of cesium from contaminated wastewater and nuclear liquid wastes.[2] Another study found that RO membrane removal performance of cesium reduced the concentration of cesium, strontium, and iodine by less than one hundredth in high-salinity water.[3] Removal of radium from water by RO can be very effective (87 percent to greater than 99 percent removal), while RO in most cases can effectively remove greater than 90 percent of uranium from water. There are a number of commercially available products employing RO for control of strontium in drinking water. Four were tested in USEPA's Environmental Technology Verification program.[4] Natural strontium was effectively removed (97 to greater than 99 percent). RO has also been found to be effective in decontamination processes with a large number of radioisotopes.[5]
Illustration	 **Figure A-20. RO can remove radionuclides from a variety of waste streams.**
Safety, Health & Environment	Few safety and environmental hazards (perhaps only moderate pressure, no real hazardous chemicals, etc.).
Time to Implement	Can be assembled quickly, but verification for the exact waste stream, often performed in the laboratory, may take time. RO can be considered an advanced technology to operate, requiring skilled operator labor.[6] RO units can be automated and compact, making them appropriate for small systems.

[1] http://cfpub.epa.gov/safewater/radionuclides/radionuclides.cfm?action=Rad_Treatment
[2] Water Contaminant Information Tool (WCIT): http://water.epa.gov/scitech/datait/databases/wcit/index.cfm
[3] Cesium (Cs) and strontium (Sr) removal as model materials in radioactive water by advanced reverse osmosis membrane Takao Sasaki, Jun Okabe, Masahiro Henmi, Hiromasa Hayashi, Yutaka Iida Desalination and Water Treatment Vol. 51, Iss. 7-9, 2013.
[4] http://www.epa.gov/etv
[5] Bond, W.H. (1982). Ultrafiltration/Reverse Osmosis (Liquid Treatment Systems). Annual DOE LLWMP Participants Information Meeting, Denver, CO, August 31, 1982.
[6] http://cfpub.epa.gov/safewater/radionuclides/radionuclides.cfm?action=Rad_Treatment

Technology A-20		Reverse Osmosis
Technical Performance		Often has limited effectiveness for completely removing some radionuclides. Depending on various factors (e.g., contaminant type, concentration, pH, etc.), supplemental treatment technologies may be necessary.
Availability		RO systems may not be COTS but often are able to be assembled quickly.
Costs		The high pressure required for RO means higher energy and capital costs for the membrane units. This can be significant compared to other technologies, making RO one of the more expensive treatment options. May pose fewer long-lead permitting requirements.
Process Waste		Residuals from aqueous treatment using RO may be radioactive waste and should be disposed of appropriately. The residual generated by RO is the spent/used membrane. Most frequently, the spent membrane will need to be disposed of in an appropriate class of landfill. Other treatment residuals generated by RO may include "concentrated reject" from the concentrated side of the membrane. Liquid disposal options may include direct discharge, discharge to a sewer system, discharge to a wastewater treatment plant, and disposal to an underground injection control well. The concentration of radionuclides in the liquid residual may impact disposal options due to the very high level of concentrated contaminants (including radionuclides) removed from the water. This concentration will depend on the efficiency of the RO unit.
Throughput		Can be configured to have a high throughput. RO units can be automated and compact, making them appropriate for small systems.

Technology A-21		Electrodialysis/Electrodialysis Reversal
Description		Electrodialysis/Electrodialysis Reversal (ED/EDR) uses an IX membrane to separate ionic contaminants. ED is an electrochemical separation process in which ions are transferred through membranes from a less concentrated to a more concentrated solution as a result of the flow of direct electric current. Contaminants are removed from the solvent (water, in this case) through the membrane, as opposed to other membrane processes where the solvent passes through the membrane and the contaminants are rejected by the membranes. In the EDR process, the electrical polarity (anode and cathode) are periodically reversed to control membrane scaling and fouling. Polarity reversal typically occurs two to four times per hour. When the electrical polarity is reversed, the product and concentrate streams are also reversed. This prevents any of the flow compartments from seeing streams with high dissolved solids for extended periods of time and aids in controlling fouling of the membranes. EDR consists of stacks of EDR membranes arranged in lines and thus, make up the stages in an EDR system. Unlike the nanofiltration and RO processes, the product from the prior stage is further treated in subsequent stages. The concentrate from each stage is blended and wasted. ED/EDR has been identified by EPA as a SSCT for radium, and may also be effective in removing uranium.[1] ED/EDR has also been identified as an option for ^{137}Cs removal.[2,3]
Relevance to Section 1.3		Wastewater cleanup or volume reduction.
Effectiveness		The units can be highly automated and require only monitoring of operational parameters and periodic maintenance. ED/EDR may be an effective alternative for small systems that have multiple contaminants. ED/EDR membrane systems frequently require some type of pretreatment to: (1) condition the water for optimum membrane effectiveness, (2) modify the feed water to prevent membrane fouling and plugging, and (3) maximize the time between cleanings and prolong membrane life. The type of pretreatment required depends on the feed water quality and membrane type.
Illustration		 **Figure A-21. ED/EDR uses an IX membrane to separate ionic contaminants.**
Safety, Health & Environment		Few safety and environmental hazards (perhaps only moderate pressure, no real hazardous chemicals, etc.).
Time to Implement		Can be assembled quickly, but verification for the exact waste stream, often performed in the laboratory, may take time. ED/EDR can be considered an advanced technology to operate, requiring skilled operator labor.[4] ED/EDR units can be automated and compact, making them appropriate for small systems.
Technical Performance		Often has limited effectiveness for completely removing some radionuclides. Depending on various factors (e.g., contaminant type, concentration, water temperature, etc.), supplemental treatment technologies may be necessary.
Availability		Systems are generally available and can be quickly assembled.
Costs		The costs of these systems are relatively high compared to other radionuclide treatment options. Capital costs are high and operating costs are increased by required acid washes for radionuclides and by disposal costs.

[1] http://cfpub.epa.gov/safewater/radionuclides/radionuclides.cfm?action=Rad_Electrodialysis
[2] Containment and Disposal of Large Amounts of Contaminated Water: A Support Guide for Water Utilities: http://water.epa.gov/infrastructure/watersecurity/emerplan/upload/epa817b12002.pdf
[3] http://www.dtic.mil/dtic/tr/fulltext/u2/626210.pdf
[4] http://cfpub.epa.gov/safewater/radionuclides/radionuclides.cfm?action=Rad_Treatment

Technology A-21		Electrodialysis/Electrodialysis Reversal
Process Waste		Residuals from aqueous treatment using ED/EDR may be radioactive waste and should be disposed of appropriately. The residual generated by ED/EDR is the spent/used membrane. Most frequently, the spent membrane will need to be disposed of in an appropriate class of landfill. Other treatment residuals generated by ED/EDR may include "concentrated reject" from the concentrated side of the membrane. Liquid disposal options may include direct discharge, discharge to a sewer system, discharge to a wastewater treatment plant, and disposal to an underground injection control well. The concentration of radionuclides in the liquid residual may impact disposal options due to the very high level of concentrated contaminants (including radionuclides) removed from the water. This concentration will depend on the efficiency of the ED/EDR unit.
Throughput		Can be configured to have a high throughput. ED/EDR units can be automated and compact, making them appropriate for small systems.

Technology A-22	Membrane Filtration
Description	Nanofiltration, ultrafiltration, and microfiltration are all membrane processes commonly used in water treatment to remove small particles or soluble species. Similar to RO (see Technology A-20), they operate under the same principle as regular particle filtration, but the distinguishing feature between them is their effective pore size, and thus, the minimum size of particle that will be rejected by the membrane. Another distinction between these types of membrane processes and RO is that RO membranes reject almost all materials with the exception of small soluble organic species that are not otherwise considered even to be "particles", while other types of filtration allow larger particles to pass through. [1] Thus, these types of membranes may be more applicable when the radionuclide is bound to a particle, as may be the case when some types of chelating agents are employed first.
Relevance to Section 1.3	Wastewater cleanup or volume reduction.
Effectiveness	A number of types of filtration methods are effective in removing contaminants from wastewater through membranes. Nanofiltration and ultrafiltration have been investigated for the removal of radioactive species from aqueous waste streams as an ultra low-level analytical tool to separate actinides from other ionic species in high-level radioactive waste solutions, and as a possible treatment option for waste streams from the Los Alamos National Laboratory Plutonium Treatment Facility.[2] In these applications, the nanofiltration and ultrafiltration membranes were coupled with water-soluble chelating polymers (such as IX resins), but did not have the disadvantage of using organic solvent-based extractants.[3] A small study was undertaken in order to evaluate the separation of ^{137}Cs from a sodium salt excess medium utilizing nanofiltration. The removal efficiency of cesium was found to be between 75 and 95 percent, depending on the concentration of a specific ligand, resorcinarene 1.[4] Semi-permeable membranes have been demonstrated to be effective in reducing the volume of wastewater containing cesium and cobalt.[5] An inorganic nanofiltration membrane was used to treat LLRW and found to be effective.[6] Membrane filtration is often used as a pretreatment for surface water, sea water, or contaminated effluent before other processes such as RO or other membrane systems. For example, membrane filtration is generally not very effective for the removal of uranium (less than 60 percent depending on the membrane type and pH). One study found 0.45-micron membrane filtration to remove 50 to 60 percent of uranium between pHs 6.5 and 9; however, membrane filtration followed coagulation/flocculation and was suspected to be responsible for most of the uranium removal. Based on another study, removal of cobalt(II) from water by ultrafiltration was very effective when combined with a sulfonated polymer (up to 98 percent removal), and suggests that ultrafiltration without the use of polymers is not effective at cobalt removal. As pH increased from 3 to 6, cobalt removal also increased.[7]
Illustration	
	Figure A-22. Filtration membranes can come in any number of forms depending on the particle size and pore size.

[1] EPA (2009). Potential Nano-Enabled Environmental Applications for Radionuclides. U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C. Document No. EPA 402-R-09-002. January. Available at: http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P1005GR1.txt

[2] Smith B.F. 1993. Actinide separations for advanced processing of nuclear waste: Annual Report 1993. Report LA-UR-93-4017, Los Alamos National Laboratory.

[3] Smith, B.F., T.W. Robinson, J.W. Gohdes. 1995. Water-Soluble Polymers and Composition Thereof. U.S. Patent DOE No. S-78, 350.

[4] Water Contaminant Information Tool (WCIT): http://water.epa.gov/scitech/datait/databases/wcit/index.cfm

[5] Svittsov, A.A., Khubetsov, S.B., and Volchek, K. (2011). Membrane treatment of liquid wastes from radiological decontamination operations. Water Science and Technology, 64 (4): 854-860.

[6] Choo, K.H., Kwon, D.J., Lee, K.W., and Choi, S.J. (2002). Selective removal of cobalt species using nanofiltration membranes. Environmental Science and Technology, 26(6)1330-1336.

[7] Drinking Water Treatability Database: http://iaspub.epa.gov/tdb/pages/general/home.do

Technology A-22		Membrane Filtration
Safety, Health & Environment		Few safety and environmental hazards (perhaps only moderate pressure, no real hazardous chemicals, etc.).
Time to Implement		Can be assembled quickly, but verification for the exact waste stream, often performed in the laboratory, may take time. Membrane filtration technologies can be considered an advanced technology to operate, requiring skilled operator labor.[8]
Technical Performance		High efficiency, but may have limited effectiveness for completely removing some radionuclides. Depending on various factors (e.g., contaminant type, concentration, pH, etc.), supplemental treatment technologies may be necessary.
Availability		Most membranes are typically specially built.
Costs		Filtration membranes are low cost and excellent chemical resistance. May pose fewer long-lead permitting requirements.
Process Waste		Residuals from aqueous treatment using membrane filtration may be radioactive waste and should be disposed of appropriately. The residual generated is the spent/used filters and filter materials. Most frequently, the spent filters will need to be disposed of in an appropriate class of landfill. Other treatment residuals may include "concentrated reject" from the concentrated side of the membrane. Liquid disposal options may include direct discharge, discharge to a sewer system, discharge to a wastewater treatment plant, and disposal to an underground injection control well. The concentration of radionuclides in the liquid residual may impact disposal options due to the very high level of concentrated contaminants (including radionuclides) removed from the water. This concentration will depend on the efficiency of the membrane
Throughput		Can be configured to have a high throughput.

[8] http://cfpub.epa.gov/safewater/radionuclides/radionuclides.cfm?action=Rad_Treatment

Technology A-23	Conventional Filtration
Description	Coagulation/filtration is one of the most common water treatment techniques used by larger water systems, used for removing particulates and turbidity from surface water. A coagulant, typically either iron or aluminum salts (e.g., activated alumina, with polymeric materials) is added and mixed with the influent water. The larger particles formed by coagulation are then removed from the water by filtration (typically sand, anthracite coal, or a combination of the two). Regular particle filtration will reject particles down to about the one micron (1,000 nanometer [nm]) size range. If filtration to reject particles smaller than this limit is required, membrane separation should be considered. Membrane filtration processes (see Technology A-22) are frequently used as an alternative to rapid sand filtration in conventional treatment applications. In the Radionuclides Rule, EPA has listed BATs and SSCTs for radionuclide treatment based on their efficiency at removing radionuclides from drinking water. EPA has identified coagulation/filtration as a BAT and SSCT for uranium. It may remove up to 90 percent of uranium at pH 10 and may be an attractive option for systems that already have a filtration process in place. This technology will likely be considered only for surface water systems, and there are very few surface water supplies that have uranium. For radium, conventional treatment alone may be suitable for applications where influent concentrations are slightly above the maximum contaminant limit and minimal removal is required. Radium removal is dependent on the initial concentration, filtration/media type, coagulant used, and filter treatments. Another filtration option is pre-formed Hydrous Manganese Oxide (HMO) filtration. Pre-formed HMO filtration has been identified by EPA as a SSCT for radium. This technique adds a pre-formed manganese oxide to water to adsorb radium, which is then removed by filtration. Pre-formed HMO filtration can remove up to 90 percent of radium and may be a good choice for systems with existing filtration plants that can easily add HMO. Pre-formed HMO filtration has also been identified as an option for removing ^{137}Cs.[1]
Relevance to Section 1.3	Wastewater cleanup or volume reduction.
Effectiveness	Standard coagulation/flocculation was found to be an ineffective treatment technique for the removal of ^{137}Cs from water; however, sequential precipitation, using copper ferrocyanide, was found to be an effective treatment method for removing ^{137}Cs and other radionuclides from liquid wastes. This small-scale study was undertaken to treat low to intermediate-level nuclear liquid wastes in India by means of sequential precipitation using a copper ferrocyanide solution (created by adding potassium ferrocyanide, copper sulfate, and ferric nitrate together). The experiment used samples of contaminated groundwater, contaminated deionized water, and also synthetic alkaline water.[2] Note that copper salts may present ecotoxicity concerns and deactivate wastewater treatment plant sludge. Coagulation/filtration for uranium removal efficiency will depend on water quality parameters, especially pH, and also on choosing the most suitable coagulant. While uranium removal is more efficient at a higher pH, turbidity removal is not. At pH levels typically used in treatment plants, removal efficiencies are generally between 50 and 80 percent. Based on one full-scale study examining both alum and ferric chloride, removal of ^{90}Sr from water by conventional treatment was not effective (0 percent removal). Removal of radium from water by conventional treatment alone is not very effective (less than 44 percent).
Illustration	 **Figure A-23. Coagulation/filtration is used to remove particulates and turbidity from surface water.**
Safety, Health & Environment	Few safety and environmental hazards (perhaps only moderate pressure, no real hazardous chemicals, etc.).

[1] Containment and Disposal of Large Amounts of Contaminated Water: A Support Guide for Water Utilities: http://water.epa.gov/infrastructure/watersecurity/emerplan/upload/epa817b12002.pdf

[2] Water Contaminant Information Tool (WCIT): http://water.epa.gov/scitech/datait/databases/wcit/index.cfm

Technology A-23		Conventional Filtration
Time to Implement		Systems can be assembled quickly, but verification for the exact waste stream, often performed in the laboratory, may take time. Using this technology may require a highly skilled system operator.
Technical Performance		High efficiency, but may have limited effectiveness for completely removing some radionuclides, like cesium. Depending on various factors (e.g., contaminant type, concentration, pH, etc.), supplemental treatment technologies may be necessary for radionuclide removal.
Availability		May not be readily available because they are typically specially built.
Costs		For systems that do not have existing filtration, the capital costs and advanced operator skill level required may make the process impractical.
Process Waste		Treatment residuals generated by coagulation/filtration will include backwash water, coagulation solids (sludge), and aged/ineffective filtration media. Liquid disposal options may include discharge to a wastewater treatment plant or disposal to an underground injection well. Direct discharge may be possible if the backwash water can be blended to significantly reduce radionuclide concentrations and total dissolved solids. Aged/ineffective media may require disposal in an appropriate class of landfill.
Throughput		Does not typically have a high throughput, but can be configured to have a high throughput.

Technology A-24		Activated Carbon (AC)
Description	AC is commonly used to adsorb natural organic compounds, taste and odor compounds, and synthetic organic chemicals during drinking water treatment. AC is an effective adsorbent because it is a highly porous material and provides a large surface area to which contaminants may adsorb.[1] AC is available in a variety of particle sizes, with a common form being powdered activated carbon (PAC) that has smaller particle sizes than granular activated carbon (GAC). GAC typically has a diameter ranging between 1.2 to 1.6 millimeters (mm) and is utilized in dedicated GAC filtration units. PAC is added directly to treatment units to adsorb contaminants, often when a target contaminant is only present occasionally (e.g., when indicated by external factors). The two most common options for locating a GAC treatment unit in water treatment plants are: (1) post-filtration adsorption, where the GAC unit is located after the conventional filtration process (post-filter contactors or adsorbers); and (2) filtration-adsorption, in which some or all of the filter media in a granular media filter is replaced with GAC. Existing rapid sand filters can frequently be retrofitted for filtration-adsorption by replacing all or a portion of the granular media with GAC. Retrofitting existing high-rate granular media filters can significantly reduce capital costs since no additional filter boxes, underdrains, and backwashing systems may be required. Primary factors in determining the required GAC contactor volume are the (1) breakthrough, (2) empty bed contact time (EBCT), and (3) design flow rate. The breakthrough time is the time when the concentration of a contaminant in the effluent of the GAC unit exceeds the treatment requirement.	
Relevance to Section 1.3	Wastewater cleanup or volume reduction.	
Effectiveness	AC is made from organic materials with high carbon contents such as wood, coconut, lignite, and coal, and the type of source material significantly impacts the adsorptive properties of the resulting AC. In applying AC for contaminant removal, it is important to consider the properties of carbon utilized in preliminary testing and in actual operation. As many radionuclides are ionic, their potential for removal by many ACs can be limited unless the radionuclides are complexed to an appropriate organic substance. However, some AC, based on their source, may have some IX character, and AC may be pretreated to enhance its ability to remove ionic compounds. Based on limited bench-scale and isotherm tests, GAC was found to be effective for cobalt removal (up to 99 percent, but at pHs below typical drinking water treatment and at 2-hour EBCTs). The studies did not provide sufficient data to indicate whether GAC would be feasible on a full-scale level. Based on study findings, cobalt removal by GAC is dependent on contaminant concentration, EBCT, and media type. Based on another article, removal of radium from water by GAC alone is not very effective (approximately 1 to 23 percent). The article suggests that radium was not adsorbed onto the GAC. As a filter medium, like for conventional filtration, it would not be expected to be effective. Finally, based on isotherm studies, adsorption of uranium in water by GAC can be very effective. One study showed that treating the GAC with hydrophobic aerogels would enhance GAC adsorption. The type of GAC used in the studies was not mentioned, so no conclusions could be drawn about the effectiveness of the GAC material type.	
Illustration	 **Figure A-24. AC is made from organic materials with high carbon contents such as wood, lignite, and coal, and can be used in water treatment applications.**	
Safety, Health & Environment		AC has few safety and environmental hazards (perhaps only moderate pressure, no real hazardous chemicals, etc).
Time to Implement		Systems can be assembled quickly, but verification for the exact waste stream, often performed in the laboratory, may take time. Using this technology may require a highly skilled system operator.
Technical Performance		High efficiency, but may have limited effectiveness for completely removing some radionuclides, like cesium. Depending on various factors (e.g., contaminant type, concentration, pH, etc.), supplemental treatment technologies may be necessary for radionuclide removal. As a filter medium, like for conventional filtration, it would not be expected to be effective.

[1] Drinking Water Treatability Database: http://iaspub.epa.gov/tdb/pages/treatment/treatmentOverview.do?treatmentProcessId=2074826383

Technology A-24		Activated Carbon (AC)
Availability	(green)	Many public water treatment systems have some AC capability (more often PAC), although different materials may be required to address the radionuclide of interest.
Costs	(yellow)	PAC is applied to existing treatment units, so application costs are related to the quantity of material. For GAC, the optimum bed depth and volume are typically selected after carefully evaluating capital and operating costs associated with reactivation frequency and contactor construction costs. Depending on the economics, facilities may have on-site or off-site regeneration systems or may waste spent GAC and replace it with new. For systems that do not have existing GAC systems, the capital costs and advanced operator skill level required may make the process impractical.
Process Waste	(yellow)	Residuals from aqueous treatment using AC may be radioactive waste and should be disposed of appropriately. Spent PAC is removed by other treatment process units, and media within those units should be disposed of appropriately. Spent GAC must be disposed of recognizing that contaminants can be desorbed, which can potentially result in leaching of contaminants from the spent GAC when exposed to percolating water, contaminating soils or groundwater. Due to contamination concerns, spent GAC regeneration is typically favored over disposal. The three most common GAC regeneration methods are steam, thermal, and chemical, of which thermal regeneration is the most common method used. Available thermal regeneration technologies used to remove adsorbed organics from AC include: (1) electric infrared ovens, (2) fluidized bed furnaces, (3) multiple hearth furnaces, and (4) rotary kilns.
Throughput	(green)	Does not typically have a high throughput, but can be configured to have a high throughput. The carbon usage rate determines the rate at which carbon will be exhausted and how often carbon must be replaced/regenerated. Carbon treatment effectiveness improves with increasing contact times.

Technology A-25		Evaporation (Passive or Active)
Description		Evaporation has been considered a potentially viable technology for concentrating water contaminated with radionuclides. There are two primary types of evaporation technologies: passive and active. "Passive" evaporation draws its energy source to vaporize water from a natural source, such as solar or wind. For example, an evaporation pond will be warmed by solar radiation, and unsaturated air blowing over the pond surface may speed the evaporation. "Active" evaporation employs an engineered source of energy, such as fossil fuel or nuclear power. Common thermal evaporation systems can include vacuum distillation or spray-drying. Evaporation could be used to achieve two different endpoints. First, non-volatile solute contaminants (metals and most radionuclides) could be greatly concentrated (e.g., 100:1), and the low-volume concentrate could be combined with other liquid radioactive wastes in the separations area for subsequent treatment and disposal. The condensate stream, comprising 99% of the feed stream, would be clean except for volatile radionuclides. Thus, the bulk of the extracted groundwater could likely be more easily disposed. Second, the concentrated waste stream could be reduced to dry solids and disposed of as solid radioactive waste.[1]
Relevance to Section 1.3		Wastewater cleanup or volume reduction.
Effectiveness		Evaporation is highly effective at reducing the volume of wastewater, particularly dilute wastewater. Technologies range from expensive and complex active systems (like spray drying or thin film evaporators) to simple, passive methods (like evaporation ponds). They can provide high throughput and allow the effective segregation of non-volatile radionuclides from decontamination wastes. Throughput of passive evaporation system can be high, depending on their size and construction.
Illustration		 **Figure A-25. Passive and active wastewater evaporation systems have been proven to remove radionuclides from wastewater.**
Safety, Health & Environment		For passive evaporation, the significant environmental concern is that if radioactive material is concentrated, a large contaminated pond will result as the pond volume lessens. Monitoring this volume reduction in the evaporation pond prior to actual treatment (i.e., supplemental treatment technologies) may reduce this concern.
Time to Implement		Air permitting may be an issue with active evaporation and could delay startup. For passive evaporation, the land requirements are large, and evaporation ponds must be appropriately constructed to avoid subsurface contamination via leaching.
Technical Performance		Compared to pre-packaged passive/solar evaporation pond systems, active evaporation technologies are well developed and readily available from commercial vendors. Technical feasibility is not an issue. Certain passive technologies appear to be technically viable, but adequate performance cannot be guaranteed with high confidence.
Availability		Active evaporation technologies are readily available from commercial vendors.
Costs		For either alternative, both capital and operating costs must be considered. This immediately puts evaporation technologies at a financial disadvantage, as capital costs are significant for these alternatives. Active evaporation is an energy-intensive process, due to the large heat of vaporization of water. Can also mean high utility (heating) and maintenance costs.
Process Waste		Subsequent stabilization or treatment and disposal of the sludge. Significant reductions in solid waste disposal volumes could be achieved.
Throughput		Can provide high throughput and allow the effective segregation of non-volatile radionuclides from decontamination wastes.

[1] http://sti.srs.gov/fulltext/tr2002432/tr2002432.pdf

Table A-1. Technology Summary of Color Coding Against Each Criterion

Criterion	Technology																								
	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9	A-10	A-11	A-12	A-13	A-14	A-15	A-16	A-17	A-18	A-19	A-20	A-21	A-22	A-23	A-24	A-25
Safety, health & environment	Yellow	Yellow	Yellow	Red	Red	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Green	Yellow	Green	Green	Green	Green	Green	Green	Green	Yellow
Time to implement	Green	Yellow	Red	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Green	Yellow	Yellow	Yellow	Red	Yellow	Red	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Technical performance	Green	Yellow	Red	Red	Yellow	Green	Green	Yellow	Yellow	Yellow	Yellow	Green	Yellow	Yellow	Green	Green	Yellow	Green	Green	Yellow	Yellow	Green	Yellow	Yellow	Green
Availability	Green	Yellow	Green	Green	Yellow	Yellow	Yellow	Green	Green	Green	Green	Red	Red	Green	Red	Green	Yellow	Green	Green	Green	Green	Yellow	Yellow	Green	Green
Costs	Yellow	Yellow	Yellow	Green	Yellow	Yellow	Yellow	Green	Yellow	Yellow	Yellow	Red	Red	Green	Red	Yellow	Yellow	Green	Green	Yellow	Red	Green	Yellow	Yellow	Yellow
Process waste	Green	Green	Green	Green	Green	Green	Yellow	Yellow	Yellow	Yellow	Red	Yellow	Red	Yellow	Green	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Throughput	Yellow	Green	Yellow	Green	Yellow	Yellow	Yellow	Yellow	Green	Yellow	Yellow	Green	Green	Yellow	Yellow	Yellow	Yellow	Green	Green	Green	Yellow	Green	Green	Green	Green

Note: Color coding designations: Green = high/advantageous; Yellow = medium/neutral; Red = low/not advantageous

Enhanced surveying:
A-1. Manual Survey
A-2. Automated Survey

Soil burial:
A-3. Dig (Plow)

Foliage removal; composting:
A-4. Lawn Mowing
A-8. Selected Removal of Vegetation
A-14. Composting of Organic Matter

Thin-layer soil surface removal:
A-5. Sod Cutter

Dig and haul, demolition, and removal of contaminated materials for disposal:
A-7. Large-Scale Dig and Haul

Physical removal of surface layer of material from hard surfaces:
A-6. Scarification
A-10. Vacuuming
A-11. High-Pressure Washing

Physical cleaning of hard surfaces:
A-9. Street Sweeping

Waste volume reduction:
A-12. Segmented Gate System
A-13. Soil Washing
A-17. Incineration

Waste stabilization:
A-15. Plasma Arc Vitrification
A-16. Cementitious Stabilization/Solidification

Wastewater Cleanup or Volume Reduction:
A-18. Chelating Agents
A-19. Ion Exchange (IX)
A-20. Reverse Osmosis
A-21. Electrodialysis/Electrodialysis Reversal (ED/EDR)
A-22. Membrane Filtration
A-23. Conventional Filtration
A-24. Activated Carbon (AC).
A-25. Evaporation (Passive or Active)

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