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DRAFT FINAL REPORT

PRELIMINARY REMEDIAL ACTION OBJECTIVES AND REMEDIATION TECHNOLOGIES FOR THE SUBSURFACE DISPOSAL AREA

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EXECUTIVE SUMMARY

The EG&G Buried Waste Program (BWP) is conducting site investigations and engineering studies at the Radioactive Waste Management Complex (RWMC) to obtain pertinent site characterization data and to determine potential remedial corrective actions in response to detected migration of hazardous chemical and radioactive constituents. The area of evaluation is the Subsurface Disposal Area (SDA), an 88 acre landfill used from the 1950s to 1970s for the burial of transuranic and other radioactive waste co-contaminated with hazardous chemical substances.

The purpose of this report is to supplement the cleanup technology scoping process following the process set forth in the EPA guidance on conducting remedial investigations (RI) and feasibility studies (FS) under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The end result of the analyses is the identification and screening of potentially applicable remedial action technologies. The screened technologies can then be used by EG&G to formulate comprehensive remedial action alternatives for further evaluation.

Contaminants at the Subsurface Disposal Area

Identification of the contaminants present in each environmental medium at the SDA is critical to the identification of applicable or relevant and appropriate requirements (ARARs) that must be considered in each potential remedial action and to the identification and evaluation of appropriate remedial action technologies for cleanup of the SDA. Available environmental and analytical reports were reviewed to determine what contaminants have been detected at the SDA in the following environmental media: soil, bedrock, interbeds, surface water runoff, groundwater, and air. Table ES-1 summarizes the organic, inorganic, and radioactive substances found in each of these media and the highest reported concentration. Organic contaminants have been found in the soils, interbed sediments, groundwater, and air. Metals and other inorganic contaminants have been detected in groundwater and in two interbeds (110 ft and 240 ft). Radionuclides have been detected in soil, bedrock, interbeds, surface water runoff, groundwater, and air. Only carbon tetrachloride has been detected above a regulatory limit and this has occurred only once in groundwater.

Identification of Potential ARARs

EPA guidance on compliance with other laws indicates that remedial actions taken under the CERCLA process must comply with (1) ambient or chemical-specific requirements, (2) location-specific requirements, and (3) action-specific requirements. Action-specific requirements are generally established after remedial action alternatives have been developed, therefore, this report addressed the identification of chemical-specific and location-specific ARARs. ARARs can only be identified on a site-specific basis, i.e., established in connection with the characteristics of the particular site and the chemicals present at the site.

Federal and Idaho laws and regulations were reviewed to determine ARARs potentially applicable to the location and contamination problems at the SDA and the following ARARs were identified:

Chemical-Specific ARARs

Federal Drinking Water Regulations
Federal Ambient Water Quality Criteria
Idaho State Water Quality Standards
Federal Air Quality Standards
Idaho State Air Quality Standards
10 CFR 20

Location-Specific ARARs

Floodplains
Activities Proximate to Drinking Water Wells
  (Idaho Drinking Water Regulations)
Archaeological Resources and Antiquities

It was determined that ARARs do not exist for all chemicals and that ARARs do not exist for every medium. There are no ARARs for soil or basalt.

Other requirements such as those outlined in DOE-ID policies and procedures as well as EG&G procedures are additional guidance "to be considered" (TBC) and will need to be identified and evaluated after the

TABLE ES-1. CONTAMINANTS BY ENVIRONMENTAL MEDIUM AT THE SDA

MEDIUM	ORGANIC	CONC.	INORGANIC (See Note 3 below)	CONC.	RADIONUCLIDE	CONC.
GROUNDWATER (see Note 2 below)	Carbon tetrachloride (16)	6.6 ppb	Arsenic (42)	3 ppb	Sr-90 (7)	
	1,1,1-Trichloroethane (7)	0.9 ppb	Barium (42)	49 ppb	H-3 (7)	2.3+/-0.3E-08 uCi/ml
	Trichloroethylene (16)	1.4 ppb	Chromium (42)	50 ppb		1.3+/-0.4E-06 uCi/ml
	Chloroform	1.0 ppb	Selenium (42)	3 ppb		
	Tetrachloroethylene (42)	0.2 ppb	Silver (42)	1 ppb		
	Dichlorofluoromethane (42)	0.4 ppb	Chloride (7)	104+/-10 ppm		
	1,1-Dichloroethane (42)	0.8 ppb				
	Toluene (30)	1.2 ppb	Sodium (7)	100 +/-10 ppm		
SOIL (see Note 4 below)	Carbon tetrachloride (30)	1400 ug/l			Am-241 (8)	1.54+/-0.03E-04 uCi/g
	1,1,1-Trichloroethane (30)	310 ug/l			Eu-154 (8)	3.1+/-1.9E-08 uCi/g
	Trichloroethylene (30)	530 ug/l			Cs-137 (8)	1.8+/-7E-08 uCi/g
	Tetrachloroethylene (30)	40 ug/l			Pu-238 (8)	3.8+/-0.4E-07 uCi/g
	Tetrachloroethene (30)	40 ug/l			Pu-239,240 (8) in soil	3.34+/-0.06E-08 uCi/g
					in soil water	8+/-7E-11 uCi/ml
					Pu-238 and/or Am-241 (8) in soil water	5.3+/-1.3E-10 uCi/ml
					Sr-90 (8)	1.28+/-0.04E-06 uCi/g
					Co-60 (8)	
AIR	Carbon Tetrachloride (9)*	5800 mg/M3			Cs-137 (7)	0.7+/-0.2E-15 uCi/ml
	Chloroform (9)*	320 mg/M3			Sb-125 (7)	7.27+/-0.15E-14 uCi/ml
	Trichloroethene (30)*	380 mg/M3			Am-241 (7)	3.5+/-0.7E-17 uCi/ml
	Tetrachloroethene (30)*	62 mg/M3			Sr-90 (7)	3.2+/-0.6E-16 uCi/ml
	Trichlorotrifluoroethane (9)*	24 mg/M3			Pu-238 (7)	1.6+/-0.2E-17 uCi/ml
	1,1,1-Trichloroethane (30)*	120 mg/M3			Pu-239,240 (7)	7.2+/-0.6E-16 uCi/ml
	1,1,2-Trichlorotrifluoroethane (30)*	65 mg/M3				
	** borehole vapor grab sample					
BEDROCK						
SURFACE WATER						
110' INTERBED			Copper (13)	30.3 mg/kg	Am-241 (8)	4.7+/-0.2E-07 uCi/g
			Mercury (13)	0.6 mg/kg	Pu-238 (8)	1.18+/-0.17E-07 uCi/g
			Vanadium (13)	53.3 mg/kg	Pu-239 (11)	9.4x10E-08 uCi/g
			Sulfide (13)	200 mg/kg	Pu-239,240 (8)	7.4+/-0.4E-07 uCi/g
					Sr-90 (8)	5+/-4E-08 uCi/g
240' INTERBED	Carbon Tetrachloride (42)*	1400 ppb	Arsenic (12)	14.3 mg/kg	Cs-137 (8)	3+/-1.6E-08 uCi/g
	Chloroform (42)*	940 ppb	Barium (12)	392 mg/kg	Pu-239,240 (8)	5.8+/-0.2E-08 uCi/g
	1,1,1-Trichloroethane (42)*	250 ppb	Beryllium (12)	1.4 mg/kg	Pu-239 (11)	8.1x10E-09 uCi/g
	Trichloroethlyene (42)*	1,100 ppb	Cadmium (12)	8.4 mg/kg	Pu-238 (8)	3.22+/-0.17E-08 uCi/g
	Tetrachloroethylene (42)*	120 ppb	Chromium (12)	40.0 mg/kg	Am-241 (11)	8.0x10E-09 uCi/g
	Dichlorodifluoromethane (42)*	0.3 ppb	Cobalt (12)	14.4 mg/kg	Sr-90 (8)	8+/-3E-08 uCi/g
	Toluene (42)*	0.3 ppb	Lead (12)	18.1 mg/kg		
	1,1-Dichloroethane (42)*	22 ppb	Nickel (12)	34.4 mg/kg		
	1,1-Dichloroethylene (42)*	2.6 ppb	Selenium (12)	1.0 mg/kg		
	1,2-Dichloropropane (16)*	5.9 ppb	Silver (12)	2.4 mg/kg		
	1,1,2,2-Tetrachloroethane (7)*	1.0 ppb	Thallium (12)	2.4 mg/kg		
			Zinc (12)	81.6 mg/kg		
	** Well No. 92- perched water zone		Cyanide (12)	1.25 mg/kg		
			Tin (12)	244 mg/kg		
	Methylene chloride (14)	42 ug/kg				
	Acetone (14)	11 ug/kg				
	Chloroform (14)	120 ug/kg				
	Trichloroethene (14)	81 ug/kg				

NOTES:

1) Concentration values provided in this table are the highest observed values per medium as reported in the literature provided for this effort. Limited monitoring data was available for this review and therefore the contaminants and concentration reported in this table are not necessarily all-inclusive and such be used as a general indicator of the range of contamination at the RWMC. The list provides data only on compounds found above stated detection limits (i.e., estimated values are not included).
2) Results are for the RWMC general area which is assumed to include the following wells: #'s 87, 88, 89, 90, 92, 117, 119, 120, and the RWMC production well. Well 92 samples the 240 ft. interbed, see results below.
3) Comparable background concentrations were not available for review and therefore it can not be determined whether these levels are elevated.
4) Includes results from soil gas analyses

()'s = reference number

remedial action alternatives are developed and are therefore not included in this report.

Preliminary Remedial Action Objectives

General, chemical-specific, and location-specific remedial action objectives were identified for the SDA. The general objectives include:

- Control originating waste constituent source (buried waste) if not removed
- Minimize or eliminate precipitation or run-off infiltration at the SDA
- Control secondary sources of contaminants (contaminated soil, basalt bedrock, sedimentary interbeds) to protect the Snake River Plain Aquifer
- Minimize contaminant migration off the SDA
- Prevent contaminant migration off the INEL
- Minimize on-site worker exposure to chemical and radiological waste constituents
- Provide the RWMC and off-site users (if necessary) with sufficient, dependable, and safe potable water
- Provide a water supply at the RWMC that can meet potable water demand and fire flow requirements
- Comply with all applicable Federal and State of Idaho requirements.

Because ARARs do not exist for every compound in every environmental medium, a risk-based approach was used to back-calculate concentrations in soil and groundwater so that a specified target risk level was achieved after remediation. In other words, after site cleanup activities have been completed, the residual quantities of contaminants remaining would results in an acceptable level of risk to an exposed individual or population. Table ES-2 presents a summary of the preliminary concentrations calculated for soil and groundwater using this method. The methodology used involved numerous assumptions regarding exposure pathways and the allocation of risk among pathways and between chemicals and radionuclides. As a result, the methodology in its current form is extremely conservative and this conservatism is reflected in the low concentrations calculated. The major assumptions in the methodology are as follows:

- The target risk is 10^{-6} (1 additional case of cancer in a population of 1,000,000) - EPA's CERCLA program uses a range of 10^{-4} to 10^{-7} with 10^{-6} as the goal or point of departure in a risk analysis.

- The target risk is equally divided between nonradioactive compounds ($0.5x10^{-6}$) and radioactive compounds ($0.5x10^{-6}$).

- Four exposure pathways are assumed:

    1. Ingestion of contaminated groundwater through drinking water
    2. Inhalation of volatile substances during showering with contaminated groundwater
    3. Incidental ingestion of contaminated soil dust
    4. Inhalation of contaminated soil dust

- The target risk within a category of compounds (chemical or radioactive) is equally allocated between the groundwater exposure pathway (pathways 1 and 2 above) and the soil exposure pathway (pathways 3 and 4 above). Within a given exposure route within a given category of compounds, the risk is further equally allocated between each compound present in the medium of interest.

- The population at risk are the workers at the RWMC.

The analysis focused only on carcinogens present in either soil or groundwater. Noncarcinogenic effects were not considered.

TABLE ES-2. PRELIMINARY CHEMICAL-SPECIFIC REMEDIAL ACTION OBJECTIVES

Carcinogenic Compound	Preliminary Remedial Action Objective In Soil	Preliminary Remedial Action Objective In Groundwater
Arsenic	--	$2.83\text{x}10^{-3}$ ug/l
Carbon Tetrachloride	2.26 mg/kg	$2.37\text{x}10^{-2}$ug/l
Chloroform	--	$3.81\text{x}10^{-2}$ ug/l
Tetrachloroethylene	5.83 mg/kg	$1.81\text{x}10^{-1}$ ug/l
Trichloroethylene	26.9 mg/kg	$4.68\text{x}10^{-1}$ ug/l
Americium-241	$7.0\text{x}10^{-9}$ uCi/g	--
Cesium-137	$2.0\text{x}10^{-6}$ uCi/g	--
Cobalt-60	$3.67\text{x}10^{-6}$ uCi/g	--
Europium-154	$8.62\text{x}10^{-6}$ uCi/g	--
Plutonium-238	$2.02\text{x}10^{-9}$ uCi/g	--
Plutonium-239	$1.82\text{x}10^{-9}$ uCi/g	--
Plutonium-240	$1.82\text{x}10^{-9}$ uCi/g	--
Tritium	--	$1.33\text{x}10^{-4}$ uCi/l
Strontium-90	$7.05\text{x}10^{-7}$ uCi/g	$1.03\text{x}10^{-7}$ uCi/l

The following location-specific remedial action objectives were formulated for the SDA:

1. Floodplains

   Goal: Environmental/Facility Protection

   Objective: Site any new waste management facilities outside the 100-year floodplain in accordance with RCRA and State of Idaho hazardous waste management regulations. [It is reasonable to expect that new waste management facilities will have to be constructed at the SDA, which is within the 100-year floodplain. However, potential flooding is controlled by the diversion system to the west of the SDA; therefore, facilities in the SDA may be considered to be "outside" the 100-year floodplain as long as the diversion system is adequate to control a 100-year flood on the Big Lost River with no impact on the SDA. Runon/runoff controls would be action-specific requirements.]

2. Proximity of Drinking Water Wells

   Goal: Human Health Protection

   Objective: When in the proximity of a drinking water well, construct any sewer lines, canals, ditches and other specified structures in accordance with the minimum distances required by the Idaho Drinking Water Regulations (IDAPA 16.01.8900,07). Specified minimum distances from a well for applicable structures include:

Sewer line	50 feet
Canals, streams, ditches, lakes	50 feet

   Any new drinking water wells constructed at the SDA must also comply with these minimum distance requirements.

3. Archaeological Resources and Antiquities

Goal: Resource Protection

Objective: Actions should not cause irreparable harm, loss, or destruction of archaeological artifacts and antiquities. If such resources are encountered during remedial activities, appropriate procedures should be followed and actions taken to evaluate and protect this material.

General Response Action Identification and Preliminary Remedial Technology Screening

General response actions represent categories of remedial action technologies that may be used to mitigate environmental contamination problems. Based on a preliminary listing of potential SDA problems, the following general response actions were identified as applicable:

- Air pollution controls
- Leachate and groundwater controls
- Contaminated soil and sediments containment
- Land disposal and temporary storage
- Institutional controls
- Surface water controls
- Gas migration control
- Soil excavation and removal
- In-situ treatment
- Direct waste treatment
- Contaminated water and sewer line controls

The remedial action technologies within each of these categories were evaluated and screened to eliminate potentially inapplicable technologies. Three screening factors were used: effectiveness, implementability, and cost. No technologies were eliminated solely on cost.

Thirty-six (36) technologies involving 90 different process options were screened. A total of 31 technologies involving 48 process options passed the screening effort. Table ES-3 summarizes the technologies and process options that passed the preliminary screening.

TABLE ES-3. REMEDIAL TECHNOLOGIES THAT PASSED SCREENING

NO ACTION

WASTE OR CONTAMINATED SOIL IN-SITU TREATMENT

Institutional Controls
- Access Restriction

Treatment
- In-Situ
  - In-Situ Vitrification
  - Vapor Flushing

CONTAMINATED SOIL REMOVAL AND TREATMENT

Institutional Controls
- Access Restriction

Removal/Treatment/Disposal
- Complete Removal
  - Backhoes
  - Cranes
  - Dozers
  - Loaders
  - Scrapers
- Onsite Disposal
  - RCRA Permitted Landfill (mixed waste)
- Offsite Disposal
  - RCRA Permitted Landfill (mixed waste)
- In-Situ
  - In-Situ Vitrification
  - Vapor Flushing
- Treatment of Removed Soil
  - Handling
  - Solidification (cement/asphalt)
  - Encapsulation
  - Vitrification
  - Incineration
  - Chemical Separation/Fixation

SURFACE WATER CONTROL

Institutional Controls
- Access Restriction
- Monitoring

Collection/Treatment/Discharge
- Capping
  - Multi-media
  - Soil
- Grading
- Revegetation

TABLE ES-3. REMEDIAL TECHNOLOGIES THAT PASSED SCREENING (continued)

- Diversion/Collection
  - Dikes/Berms
  - Channels
  - Terraces

LEACHATE AND GROUNDWATER CONTROL

Institutional Controls
- Access Restriction
- Alternate Water Supply
  - Surface Pipeline
  - Bottled Water
- Monitoring
- Treatment of Water Supply
  - Adsorption
  - Air Stripping

Containment
- Capping
  - Multi-Media
  - Soil
- Near-Surface Vertical Barriers
  - Slurry Walls

Collection/Treatment/Usage/Discharge
- Pumping
  - Extraction Wells
  - Extraction/Injection Wells
- Biological Treatment
  - Activated Sludge
  - Trickling Filter
  - Rotating Biological Disk
- Chemical Treatment
  - Precipitation/Coagulation/Flocculation
  - Neutralization
  - Oxidation/Reduction
  - UV/Ozonation
- Physical Treatment
  - Sedimentation/Clarification/Gravity Thickening
  - Carbon Adsorption
  - Ion Exchange
  - Air Stripping
  - Steam Stripping
  - Reverse Osmosis
- In-Situ Treatment
  - Biodegradation
- On-Site Disposal
  - Surface Water
  - Reinjection

TABLE ES-3. REMEDIAL TECHNOLOGIES THAT PASSED SCREENING (continued)

GAS MIGRATION CONTROL

- Institutional Controls
    - Access Restriction
    - Monitoring
- Collection/Treatment/Discharge
    - Active Extraction (Vapor Vacuum Extraction)
    - Gas Treatment
        - Carbon Adsorption

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1. INTRODUCTION

The EG&G Buried Waste Program (BWP) is conducting site investigations and engineering studies at the Idaho National Engineering Laboratory (INEL) to obtain pertinent site characterization data and to determine necessary remedial corrective actions in response to detected migration of hazardous chemical and radioactive constituents from the Subsurface Disposal Area (SDA) of the Radioactive Waste Management Complex (RWMC). To date, chlorinated organic chemicals have been detected, on one occasion, above applicable regulatory standards in the groundwater. The RCRA Facility Investigation (RFI) studies related to the migration of organic chemicals at the SDA are being performed under the existing Consent Order and Compliance Agreement (COCA) between the U.S. Environmental Protection Agency (EPA) Region X and DOE-ID for the INEL. The ongoing mission of Buried Waste Program (BWP) has been to address the removal of previously disposed transuranic and mixed chemical and radioactive waste at the SDA; the migration of radionuclides; and other measures necessary to resolve any remaining environmental contamination issues. The BWP mission does not address ongoing disposal of low-level waste in the currently operating low-level waste disposal pits. The development of preliminary remedial action objectives and technologies follows the CERCLA/SARA guidelines for conducting remedial investigation (RI)/feasibility study (FS) corrective action investigations and engineering studies under the COCA.

The following sections present an overview of the CERCLA/SARA feasibility study process, the purpose and scope of this report, and the organization of this report.

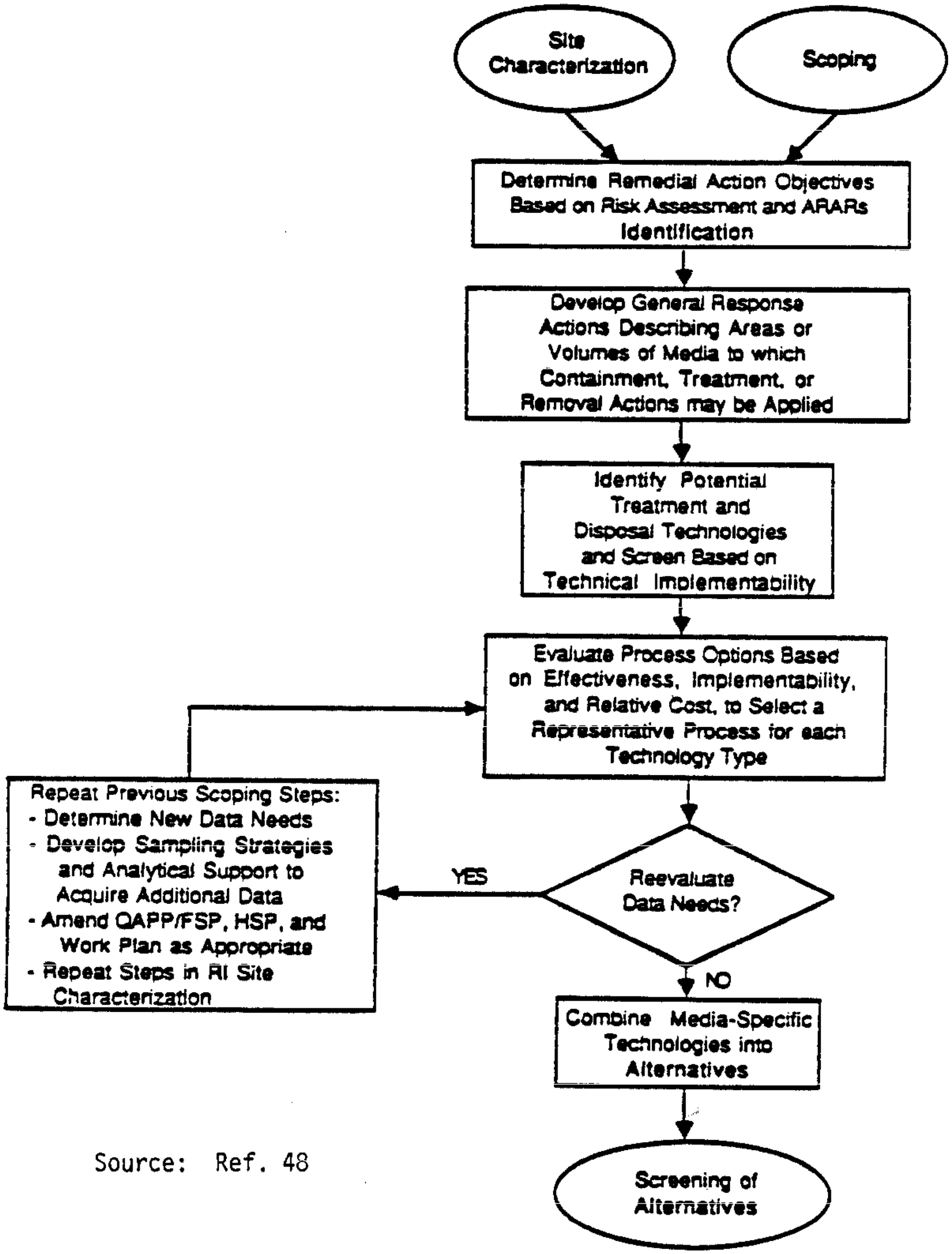
1.1 OVERVIEW OF THE CERCLA/SARA FEASIBILITY STUDY PROCESS

The CERCLA process includes two components: the RI and the FS. The RI is the data collection mechanism for the FS and is conducted concurrently. The FS is the mechanism for the development, screening, and detailed evaluation of potential remedial action alternatives to remedy site contamination. The analyses performed in the FS lead to selection of the remedy to be implemented, a Record of Decision (ROD) on the remedy selected, remedial action design, and performance of the remedial action.

The FS process includes scoping activities, development of remedial action alternatives, screening of remedial action alternatives, and detailed analysis of remedial action alternatives. The scoping effort is the initial planning phase. The analyses conducted in the scoping effort are further refined in later FS analyses. The scoping process involves the development of a conceptual site model that addresses a preliminary understanding of the contaminants at the site, the environmental media that are contaminated, potential contaminant transport pathways, human and environmental receptors, and potential exposure pathways. This "model" is then used to establish a preliminary list of potentially applicable or relevant and appropriate requirements (ARARs), and preliminary remedial action objectives. The focus of the analysis is a determination, if it can be made at this time, whether (and to what extent) a threat to human health or the environment exists. Remedial action alternatives are developed and evaluated in relation to this defined threat. Figure 1-1 presents an overview of the alternatives development process in the FS.

A preliminary Site Management Strategy can also be developed at this point in the process. This strategy serves to identify: (1) types of actions that may be considered in site cleanup or mitigation; (2) interim actions necessary to mitigate pressing site problems; (3) timing and optimal sequence of remedial actions; and (4) streamlining of the FS focus or process based on site-specific considerations (i.e., waste types, volume of waste or area to be addressed, geologic barriers, etc.). Operable units may also be established at this time on a preliminary basis. The operable unit may be a step in the remediation process, a geographic portion of the site, a specific problem at the site, or an interim action (in support of a later final action).

Three types of ARARs are identified in the FS process: contaminant- or chemical-specific; location-specific; and action-specific. Contaminant- or chemical-specific ARARs are used to define acceptable exposure levels and to establish preliminary cleanup goals in specific environmental media (e.g., concentration of a specific chemical or chemicals in groundwater). Location-specific ARARs are requirements that in practice restrict activities in certain areas (e.g., location or floodplain requirements). Action-specific ARARs are used to set controls or restrictions for treatment



Source: Ref. 48

FIGURE 1-1. REMEDIATION ALTERNATIVES DEVELOPMENT PROCESS and disposal activities. Location-specific ARARs may also result in action-specific engineering requirements that can be implemented in lieu of restricting an activity in a certain location (e.g., system design to meet seismic requirements in a seismically active area). In addition, some action-specific ARARs are chemical-specific in nature; for example, restrictions on air releases of specific compounds.

The ARAR identification process is iterative. It continues throughout the FS process as better understanding is achieved regarding site conditions, site contaminants, and potential remedial action technologies to be implemented. In the scoping process and prior to the development of alternatives, contaminant-specific and location-specific ARARs are the requirements primarily developed. Action-specific ARARs can only be identified in general terms based on a range of potential actions. Action-specific ARARs can be developed after the remedial action alternatives are developed; the action-specific ARARs are further refined during the screening and detailed analysis of the remedial action alternatives.

Throughout the FS process, ARARs are established on a preliminary basis. The actual ARARs required to be included in the analysis and the cleanup or action levels established based on the ARARs must be negotiated with the cognizant regulatory and lead agencies. Otherwise, the ARARs and cleanup levels identified are only "working" numbers to focus the analyses.

The ARARs identified serve as the basis for developing remedial action objectives. These objectives initially define the cleanup levels or other requirements that remedial action alternatives must meet. The objectives identification process is also iterative. As remedial action alternatives become better developed, the ability of the individual technologies to treat or contain specific contaminants can be further assessed and used to make "tradeoffs" in establishing chemical-specific cleanup objectives without necessarily changing exposure goals. The detailed evaluation of remedial action alternatives will also consider how well each alternative can meet chemical-, location-, and action-specific objectives which are based on ARARs.

To develop remedial action alternatives, general response actions are identified. These actions represent categories of technologies that can generally address particular site problems and may also be able to be combined to address multiple problems or several aspects of one particular problem. Potential remedial action technologies in each response action category are identified and screened based on potential effectiveness, implementability, and cost. Technology process options are also considered in this analysis. These options represent specific technologies within a technology group and may be representative of the group as a whole. These options are also screened to eliminate any that are impractical or otherwise inapplicable to site problems and remediation objectives, and to identify possible options that may be representative.

Once the technologies and technology process options are screened, they may be assembled into a range of alternatives. The alternatives can focus on a particular medium, specific area(s) of the site, or the site as a whole. However, the detailed analysis of alternatives must address alternatives that comprehensively resolve site contamination problems. The primary objective of the alternatives developed is to protect human health and the environment. The range of alternatives developed should represent a range of waste management options: (1) no action; (2) eliminate the hazardous substances; (3) reduce the hazardous substances present to acceptable levels (defined based on exposure and risk analyses); (4) prevention of exposure (e.g., replacement of water supply thereby eliminating exposure); and (5) a combination of (2), (3), and (4). The range may also be expressed in terms of no action, treatment to reduce/eliminate hazard, and containment with little to no treatment.

Once the remedial action alternatives are developed, they are screened based on effectiveness, implementability, and cost. The screening effort involves more detailed analyses than performed during scoping and addresses each alternative rather than only a specific technology. The purpose of this screening process is to minimize the number of alternatives to be considered for detailed analysis. ARARs are further developed at this stage and action-specific ARARs can be defined. Remedial action objectives are further developed at this stage as well, based on refinment of the ARARs.

Following the screening step, the remaining alternatives undergo a detailed evaluation based on nine criteria: (1) short-term effectiveness; (2) long-term effectiveness and permanence; (3) reduction of toxicity, mobility, or volume; (4) implementability; (5) cost; (6) compliance with ARARs; (7) overall protection of human health and the environment; (8) State acceptance; and (9) community acceptance. The outcome of this detailed analysis is a comparative analysis presenting the relative strengths and weaknesses of the remedial action alternatives considered. This comparative analysis forms the basis for final selection of the preferred remedy.

The above discussions represent a summary of information presented in the EPA Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA, March 1988 (Ref. 48).

1.2 PURPOSE AND SCOPE OF REPORT

The purpose of this report is to supplement the scoping process and continue the ARAR analyses and technology analyses to support the development of remedial action alternatives by EG&G. Data received from EG&G regarding contaminant concentrations, past technology assessments, and preliminary evaluations of environmental characteristics and disposal history at the SDA has been used to perform the following analyses:

- Identification of SDA contaminants by medium
- Development of a conceptual "working" model of contaminant transport pathways, affected receptors, and exposure pathways
- Preliminary identification of chemical-specific and location-specific ARARs
- Identification of generally applicable action-specific ARARs
- Development of preliminary chemical-based action levels by medium
- Development of preliminary remediation objectives (general, chemical-specific, and location-specific)
- Identification of general response actions

- Identification and screening of potentially applicable remedial action technology types for the SDA.

Figure 1-2 presents the relationship of these analyses.

The effort has been performed in conformance with the EPA Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA, March 1988 (Ref. 48). As previously shown in Figure 1-1, the activities noted above lead to the development of remedial action alternatives. The combination of screened technologies from this report into remedial action alternatives will be performed by the EG&G Buried Waste Program and is outside the current scope of this report.

Two remediation scenarios are considered in the development of remediation objectives, target action levels, and remedial action technology types: (1) remediation of environmental contamination remaining after buried waste is retrieved; and (2) remediation of the buried waste (in situ) and other environmental contamination should the waste not be retrieved. Technologies for retrieval of the buried waste and the management of such retrieved waste are outside the scope of this effort as those technologies and related alternatives are being addressed separately within the EG&G Buried Waste Program. "No action" is a remediation option retained throughout the analyses. It should be noted that "no action" can include institutional controls such as monitoring, fencing, limiting site access, etc.

1.3 REPORT ORGANIZATION

Section 2 identifies the contaminants of potential concern at the SDA by medium and presents a conceptual "model" of the environmental contamination problems, transport mechanisms, and exposure routes used in this report. Section 3 identifies ARARs that may need to be considered in evaluating potential remediation solutions. The ARARs identified include chemical-specific and location-specific requirements. Section 4 presents remedial action objectives including general response objectives, potential action or cleanup levels for chemicals and radionuclides at the SDA, and

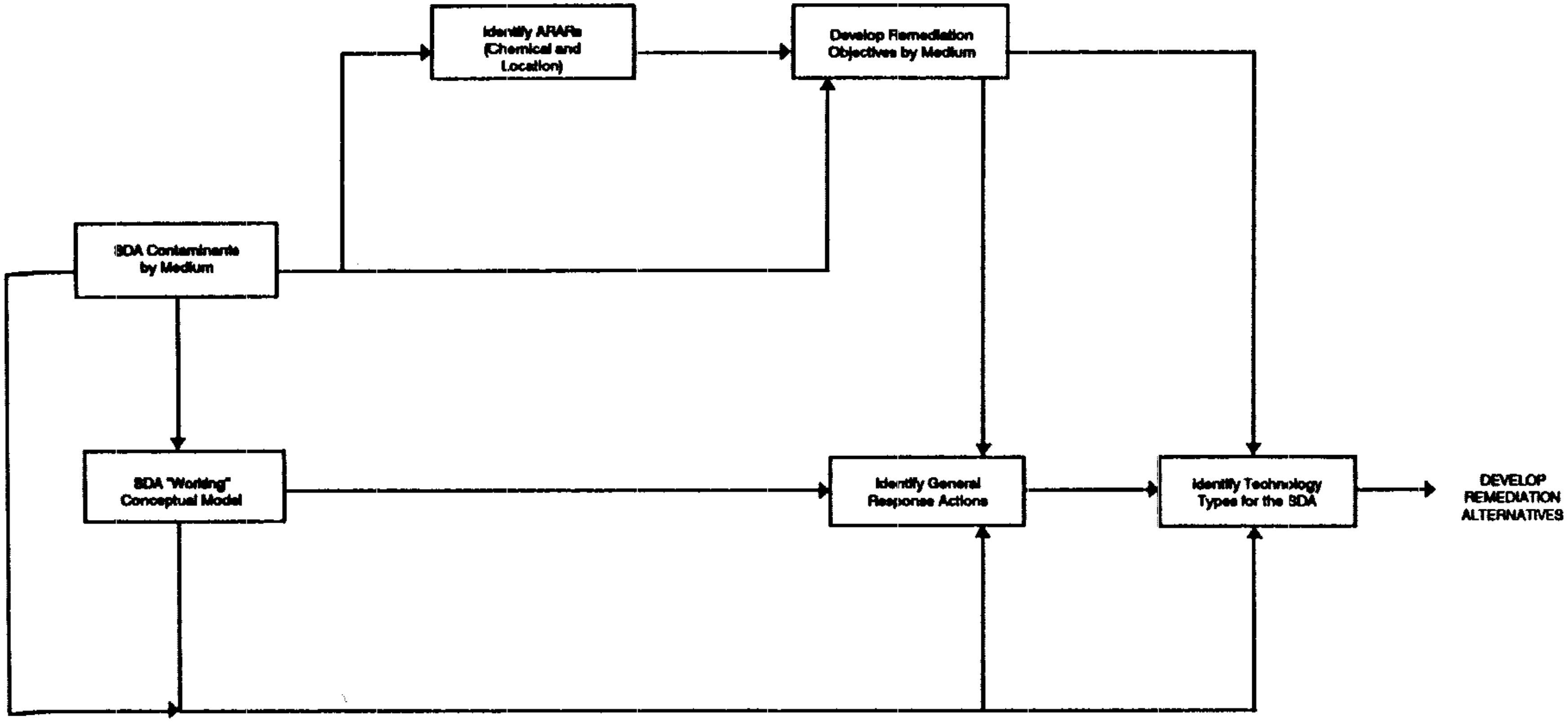


FIGURE 1-2. RELATIONSHIP OF ANALYSES IN THIS REPORT

location-specific objectives. Section 5 identifies potential general response actions and categories of technologies that may be applicable to environmental contamination at the SDA. Section 6 identifies preliminary remedial action technologies and screens the technologies based on effectiveness, implementability, and cost. Section 7 presents recommendations for additional data, analyses, and other issues pertinent to the FS process. Section 8 presents the bibliography of information and references used in this report. Appendix A provides the derivation of equations used to develop risk-based chemical-specific cleanup objectives in Section 4. Appendix B provides short, summary descriptions of remediation technologies screened in Section 6.

2. CONTAMINANTS AT THE SUBSURFACE DISPOSAL AREA

Identification of the contaminants present at the Subsurface Disposal Area (SDA) is critical to the identification of applicable or relevant and appropriate requirements (ARARs) and to the identification and evaluation of appropriate remedial technology(s) for cleanup of this site. Environmental studies at the SDA continue in an effort to better characterize the SDA in terms of its natural geology/hydrogeology, wastes disposed, and the migration of contaminants from the buried waste. These activities include sampling of the various media at the site (i.e., surface and subsurface soil, bedrock, groundwater) for the presence of contaminants.

Available environmental and analytical reports were reviewed to determine what contaminants have been detected at the SDA in each environmental medium. A summary list of contaminants by medium was then developed.

Section 2.1 presents a general discussion of the environmental media at the SDA, the contaminants reported to be found in those media, and the corresponding highest observed concentrations of those contaminants. Section 2.2 presents a conceptual "working" model of contaminant transport, receptors, and exposure routes at the site.

2.1 IDENTIFICATION OF CONTAMINANTS BY ENVIRONMENTAL MEDIUM

As a first step in the process of identifying contaminants by medium at the SDA, literature related to the site was reviewed to determine the actual media of relevance at the site. Geological and hydrological studies performed to date have established a limited characterization of the subsurface environment and the nature and extent of contaminants in the area of the SDA.

Section 2.1.1 presents a general description of the media of concern at the SDA. Section 2.1.2 discusses the contaminants that have been detected in the various media at the SDA.

2.1.1 Media of Concern at the SDA

For purposes of this report, the following media of concern at the SDA were identified:

- Soil
- Bedrock
- Interbeds
- Surface water runoff
- Groundwater
- Air.

Soils as a medium are an important consideration due to the potential for direct contact with contaminants by workers and animals, surface water runoff further spreading contaminated soil particles, and wind dispersal of contaminants adsorbed to soil particles. Soils at the SDA are characterized as alluvial sediments of Quarternary age that range from zero to 25 feet in depth above the basalt bedrock although they are typically shallow (Ref. 44). Deposited originally by eolian and/or fluvial processes, the alluvial sediments consist primarily of silt-sized particles, with varying amounts of clay-sized materials, and grain size distribution ranging from silt to gravels. In addition, gravels and layered sands are also found in the local area (Ref. 44). However, the soils within the SDA have been greatly disturbed by the waste management activities at the site through the construction of pits, trenches, soil vaults, and an aboveground pad; applying cover to the waste management areas; and through periodic recontouring.

The majority of the remaining original soil at the site occurs between the SDA waste management units since excavations for waste pits were generally made to bedrock. For purposes of this study, no distinction has been made between "surface soils" and "subsurface soil" since the soils at the SDA have been greatly disturbed by the waste management and grading activities at the site. Contaminants found in the SDA soils include organic vapors and radionuclides.

Beneath the soil horizon at the SDA are extensive flows of fractured tholeiitic olivine basalts interlain with breccia zones and clastic interbeds (Ref. 44). This basalt bedrock is usually found at approximately 25 feet below the ground surface and consists of multiple flows that may have different flow orientations. The basalt is heavily factured and is also vesiculated (Ref. 44). Therefore, it serves as a conduit for contaminants to reach the groundwater. Chemical characterization of the basalt at the SDA is not presently available.

Geological investigations at the SDA have established the existence of several interbeds within the basalt formation. Three of these interbeds occur in the basalt at approximately 30 feet, 110 feet, and 240 feet below the ground surface. The interbeds vary in thickness and are composed of silts, sands, and gravels (Ref. 44). Other discontinuous interbeds have been encountered throughout the subsurface beneath the SDA. Analyses of the interbed sedimentary materials and vapors have determined the presence of organic contaminants and radionuclides. A discontinuous perched water zone has been found in association with the interbed which lies 240 feet below one area of the SDA. Analysis of water samples taken from this zone indicates high levels of organic constituents (Ref. 42).

Surface water is located in the vicinity of the SDA. The SDA is approximately two miles southeast of the Big Lost River. The Big Lost River flows to the northeast. The Big Lost River and the INEL are located within the Pioneer Basin, a closed drainage basin with no surface water outflow (Ref. 44). The SDA is located within the 100 year floodplain of the Big Lost River but dikes and other engineered flood control structures have been constructed to the west and northwest of the SDA to prevent flooding of the site and the INEL. Spreading areas are found a mile to the west of the SDA that are used to divert and dissipate high waters of the Big Lost River. These areas are not affected by the SDA although periodic infiltration of water into the subsurface is suspected to influence contaminant migration and groundwater flow in the area.

During periods of precipitation, ponding of water has occurred within the SDA. In addition, three flooding events have occurred in the past at the SDA as a result of rapid local snowmelt. These flooding events may be a cause of contaminant mobilization and migration at the site. SDA runoff is monitored for radionuclides in the northeast corner of the SDA, then released to the RWMC drainage channel which runs to the northeast and ultimately leads to the Big Lost River. Characterization of SDA surface water runoff was not available for this review.

Groundwater at the INEL is part of the Snake River Plain Aquifer which serves as the source of drinking water and shower water at the RWMC and as a drinking water and irrigation water source for eastern Idaho. Regional groundwater flow in the area is to the southwest with an average flow velocity of approximately 13 feet per day (Ref. 44). However, a local reversal in flow direction to the northeast is suspected in the area of the SDA due to the influence of the Big Lost River and the spreading areas. Groundwater at the SDA is found at approximately 600 feet below the ground surface although areas of perched water have been found closer to the surface (240 feet). Contamination of the groundwater by chlorinated organics at the SDA has been detected. It should be noted that upgradient groundwater in the vicinity of the CFA (3 to 4 miles to the northeast) has also been found to be contaminated with chlorinated organic chemicals (Ref. 15). Plumes of contamination from the Idaho Chemical Processing Plant (ICPP) also extend to the vicinity of the SDA. The impact of these sources of contamination on groundwater quality at the SDA is not known at this time. However, the potential exists that some of the contaminants observed in the groundwater at the SDA may be from other sources.

Emissions to the air from the SDA occur from the volatilization of organic compounds and dispersal of contaminated soils. Monitoring of borehole gases has been conducted and ambient air monitoring has also been performed at the SDA. While borehole gases are generated in the subsurface, they are released to the atmosphere during drilling and sampling and, therefore, are a health and safety concern. Organic contaminants have been detected in borehole gases during drilling.

2.1.2 Contaminants at the SDA

Various EG&G Idaho and DOE-Idaho technical reports, annual environmental summary reports, and miscellaneous sample analysis reports received from EG&G Idaho were reviewed in an effort to identify the universe of contaminants that have been detected at the SDA to date. For each medium described in Section 2.1.1., a list of detected contaminants was prepared and the highest reported concentration of that contaminant in that medium was noted. Contaminants were placed into three categories: organics, inorganics, and radionuclides. Table 2-1 presents the results of this data review. The sources of all data presented in Table 2-1 are cited and can be found in the reference list.

Table 2-1 illustrates that organic compounds and radionuclides have been detected at the SDA in a number of media. While the information reviewed to develop this table was not all inclusive, the table does indicate the types of contaminants that are being detected and the maximum concentrations that have been observed. It should be noted that the absence of information for a particular medium or class of compounds does not necessarily mean that no contaminants are present, but may reflect that the medium in question has not been sampled.

Organic contaminants have been found in the soils, interbed sediments, groundwater, and the air at the SDA. Carbon tetrachloride is the organic contaminant found in the highest concentrations in these media. Reported maximum concentrations include: 1400 ppb in collected soil gases; 1400 ppb in perched water; 6.6 ppb in groundwater; and 5800 mg/m^3 in borehole vapors. The carbon tetrachloride concentration of 6.6 ppb observed in groundwater exceeds EPA's maximum contaminant level (MCL) of 5.0 ppb. The other organic compounds detected most frequently at high concentrations include: 1,1,1-trichloroethane, trichloroethylene, tetrachloroethylene, and chloroform. Concentrations of tetrachloroethylene and trichloroethylene have been detected above the federal drinking water maximum contaminant level goals (MCLG). Metals and other inorganics have been detected in groundwater and the 110 ft. and 240 ft. interbeds. Inorganics detected include: chloride, sodium, and sulfide. Metals detected include: chromium, barium, arsenic, selenium, silver, vanadium, copper, mercury, tin, zinc, nickel, lead, cobalt, cadmium, thallium, and beryllium. Radionuclides have been detected in all media sampled at the SDA and include isotopes of the following elements: americium, antimony, cesium, cobalt, europium, plutonium, and strontium, as well as tritium.

Several limitations exist concerning the data presented in Table 2-1. The reviewed analytical data were limited to that received from EG&G Idaho and such data were not available for all media or types of contaminants

TABLE 2-1. CONTAMINANTS BY ENVIRONMENTAL MEDIUM AT THE SDA

MEDIUM	ORGANIC	CONC.	INORGANIC (See Note 3 below)	CONC.	RADIONUCLIDE	CONC.
GROUNDWATER (see Note 2 below)	Carbon tetrachloride (16)	6.6 ppb	Arsenic (42)	3 ppb	Sr-90 (7)	
	1,1,1-Trichloroethane (7)	0.9 ppb	Barium (42)	49 ppb	H-3 (7)	2.3+/-0.3E-08 uCi/ml
	Trichloroethylene (15)	1.4 ppb	Chromium (42)	50 ppb		1.9+/-0.4E-06 uCi/ml
	Chloroform	1.0 ppb	Selenium (42)	3 ppb		
	Tetrachloroethylene (42)	0.2 ppb	Silver (42)	1 ppb		
	Dichlorofluoromethane (42)	0.4 ppb	Chloride (7)	104+/-10 ppm		
	1,1-Dichloroethane (42)	0.8 ppb				
	Toluene (30)	1.2 ppb	Sodium (7)	100 +/-10 ppm		
SOIL (see Note 4 below)	Carbon tetrachloride (30)	1400 ug/l			Am-241 (8)	1.54+/-0.03E-04 uCi/g
	1,1,1-Trichloroethane (30)	310 ug/l			Eu-154 (8)	3.1+/-1.9E-08 uCi/g
	Trichloroethylene (30)	690 ug/l			Cs-137 (8)	1.8+/-7E-08 uCi/g
	Tetrachloroethylene (30)	40 ug/l			Pu-238 (8)	3.8+/-0.4E-07 uCi/g
	Tetrachloroethene (30)	40 ug/l			Pu-239,240 (8) in soil	3.34+/-0.06E-05 uCi/g
					in soil water	8+/-7E-11 uCi/ml
					Pu-238 and/or Am-241 (8) in soil water	5.3+/-1.3E-10 uCi/ml
					Sr-90 (8)	1.28+/-0.04E-06 uCi/g
					Co-60 (8)	
AIR	Carbon Tetrachloride (9)*	5800 mg/M3			Cs-137 (7)	0.7+/-0.2E-15 uCi/ml
	Chloroform (9)*	320 mg/M3			Sb-125 (7)	7.27+/-0.15E-14 uCi/ml
	Trichloroethene (30)*	380 mg/M3			Am-241 (7)	3.5+/-0.7E-17 uCi/ml
	Tetrachloroethene (30)*	62 mg/M3			Sr-90 (7)	3.2+/-0.6E-16 uCi/ml
	Trichlorotrifluoroethane (9)*	24 mg/M3			Pu-238 (7)	1.6+/-0.2E-17 uCi/ml
	1,1,1-Trichloroethane (30)*	120 mg/M3			Pu-239,240 (7)	7.2+/-0.6E-16 uCi/ml
	1,1,2-Trichlorotrifluoroethane (30)*	65 mg/M3				
	** borehole vapor grab sample					
BEDROCK						
SURFACE WATER						
110' INTERBED			Copper (13)	30.3 mg/kg	Am-241 (8)	4.7+/-0.2E-07 uCi/g
			Mercury (13)	0.6 mg/kg	Pu-238 (8)	1.18+/-0.17E-07 uCi/g
			Vanadium (13)	53.3 mg/kg	Pu-239 (11)	9.4x10E-08 uCi/g
			Sulfide (13)	200 mg/kg	Pu-239,240 (8)	7.4+/-0.4E-07 uCi/g
					Sr-90 (8)	5+/-4E-08 uCi/g
240' INTERBED	Carbon Tetrachloride (42)*	1400 ppb	Arsenic (12)	14.3 mg/kg	Cs-137 (8)	3+/-1.6E-08 uCi/g
	Chloroform (42)*	940 ppb	Barium (12)	392 mg/kg	Pu-239,240 (8)	5.8+/-0.2E-08 uCi/g
	1,1,1-Trichloroethane (42)*	250 ppb	Beryllium (12)	1.4 mg/kg	Pu-239 (11)	8.1x10E-09 uCi/g
	Trichloroethlyene (42)*	1,100 ppb	Cadmium (12)	8.4 mg/kg	Pu-238 (8)	3.22+/-0.17E-08 uCi/g
	Tetrachloroethylene (42)*	120 ppb	Chromium (12)	40.0 mg/kg	Am-241 (11)	8.0x10E-09 uCi/g
	Dichlorodifluoromethane (42)*	0.3 ppb	Cobalt (12)	14.4 mg/kg	Sr-90 (8)	6+/-3E-08 uCi/g
	Toluene (42)*	0.3 ppb	Lead (12)	16.1 mg/kg		
	1,1-Dichloroethane (42)*	22 ppb	Nickel (12)	34.4 mg/kg		
	1,1-Dichloroethylene (42)*	2.6 ppb	Selenium (12)	1.0 mg/kg		
	1,2-Dichloropropane (16)*	5.9 ppb	Silver (12)	2.4 mg/kg		
	1,1,2,2-Tetrachloroethane (7)*	1.0 ppb	Thallium (12)	2.4 mg/kg		
			Zinc (12)	81.6 mg/kg		
	** Well No. 92- perched water zone		Cyanide (12)	1.25 mg/kg		
			Tin (12)	244 mg/kg		
	Methylene chloride (14)	42 ug/kg				
	Acetone (14)	11 ug/kg				
	Chloroform (14)	120 ug/kg				
	Trichloroethene (14)	81 ug/kg				

NOTES:

1) Concentration values provided in this table are the highest observed values per medium as reported in the literature provided for this effort. Limited monitoring data was available for this review and therefore the contaminants and concentration reported in this table are not necessarily all-inclusive and such be used as a general indicator of the range of contamination at the RWMC. The list provides data only on compounds found above stated detection limits (i.e., estimated values are not included).

2) Results are for the RWMC general area which is assumed to include the following wells: #'s 87, 88, 89, 90, 92, 117, 119, 120, and the RWMC production well. Well 92 samples the 240 ft. interbed, see results below.

3) Comparable background concentrations were not available for review and therefore it can not be determined whether these levels are elevated.

4) Includes results from soil gas analyses

()'s = reference number

(e.g., organic analyses were not performed or available for review on bedrock samples). In addition, some of the monitoring results that were reviewed had not received a QA review. Therefore, this table should be regarded as preliminary, particularly since characterization of the SDA is on-going and some of the media have not been characterized for all contaminant types. In addition, characterization of background conditions for inorganics in soils and other media was not available and therefore it cannot be determined at this time if the reported concentrations are elevated or not. The table can be amended as additional information on detected contaminants becomes available. In addition, Table 2-1 lists only contaminants that have been detected above the detection limit for the analytical method used. Estimated values were not included.

2.2 CONCEPTUAL SITE MODEL

The SDA has been used for the burial of various radioactive, hazardous, and other wastes in pits and trenches from the 1950s to the 1970s. Contamination of various environmental media by organic constituents, inorganic constituents, and radionuclides from these wastes has been documented at the SDA, as discussed in the previous sections. To determine the magnitude and consequences of this contamination one must consider the pathways of migration, the routes of exposure, and the receptors that will ultimately come in contact with the contaminants. This section discusses a "conceptual site model" of the contaminant transport mechanisms and the affected receptors that are present at the SDA and establishes the environmental media of most and least concern for purposes of this report. The various media and the mechanisms for exposure of given receptors to contaminants in those media are discussed below. This discussion is summarized in Table 2-2.

The SDA is located in a topographic depression that is approximately two miles to the southeast of the Big Lost River and one mile to the east of the diversion ponds that have been constructed to dissipate high waters of the Big Lost River. Alluvial sediments comprise the soil at the SDA and are found up to a depth of 25 feet. The soil horizon at the SDA is underlain by an extensive basalt bedrock formation that is comprised of multiple flows. The basalt is heavily fractured and vesiculated and is interlain with breccia zones and clastic interbeds. The major interbeds beneath the SDA

TABLE 2-2. SUMMARY OF SDA ENVIRONMENTAL MEDIA, CONTAMINANT MIGRATION PROCESSES, AND EXPOSURE PATHWAYS

Environmental Medium	Suspected Migration Pathway	Suspected Transport Mechanism/ Process	Suspected Exposure Pathway	Receptors	Comments
Soil (incl. Air)	Vapors to air (O)	Vapor	Inhalation (Air)	SDA workers	Offsite exposure is possible but high dilution decreases risk.
	Soil particulates to air (O, R, I?)	Entrainment	Inhalation (Air) Dermal contact Ingestion (Air)	SDA workers SDA workers SDA workers	Offsite exposure is possible but high dilution decreases risk.
	Soil contam. uptake (O, R, I)	Uptake	Plants Animal ingestion	Animal in food chain (wildlife)	Minor pathway. Limited access to site. Difficult to differentiate SDA exposure from INEL exposure. Range fires are short-term effect - focus is long-term risk and maximum exposure. Soil considered to be limited source of contamination to groundwater.
Basalt & Interbeds	Organics to groundwater (O)	Vapor transport Liquid transport	None	Groundwater	
	Inorganics to groundwater (I)	Mobilization	None	Groundwater	
	Radionuclides to groundwater (R)	Mobilization	None	Groundwater	
Groundwater	Migration (O)	Movement in groundwater (advection)	Consumption (ingestion) Inhalation (showers) Dermal contact (showers)	SDA workers SDA workers SDA workers	Off-site - possible exposure but most population is > 25 mi. regionally downgradient (<50 people within 50 mi.); also, current <u>low</u> conc. at SDA of organics. Radionuclides not yet in groundwater.
Surface Water	Precipitation run-off (R, O?, I?)	Liquid transport	Dermal contact Ingestion	Humans (theoretical) Wildlife	Monitored and released. May contaminate soils in channel but difficult to differentiate SDA contamination from RWMC as a whole.
Food	O, I?, R?		Consumption of contaminated plants	Humans (off-site) Animals (off-site)	No dairy cattle regionally downgradient.
			Consumption of contaminated animal flesh	Humans (off-site) Animals (off-site)	Minimal pathway.

O = organic; R = radionuclide; I = inorganic are found at depths of 30, 110, and 240 feet and average 13 feet in thickness. A discontinuous perched water zone is associated with the interbed that is 240 feet below the surface. The soils and basalt bedrock comprise the vadose zone at the SDA which is approximately 600 feet in depth where groundwater is found. Groundwater at the SDA is part of the Snake River Plain Aquifer which serves as the regional drinking water source as well as the source of drinking and shower water at the RWMC. While the regional groundwater flow is generally toward the southwest, it is subject to local reversals in the vicinity of the SDA due to the recharge from the Big Lost River and the diversion ponds (Ref. 35).

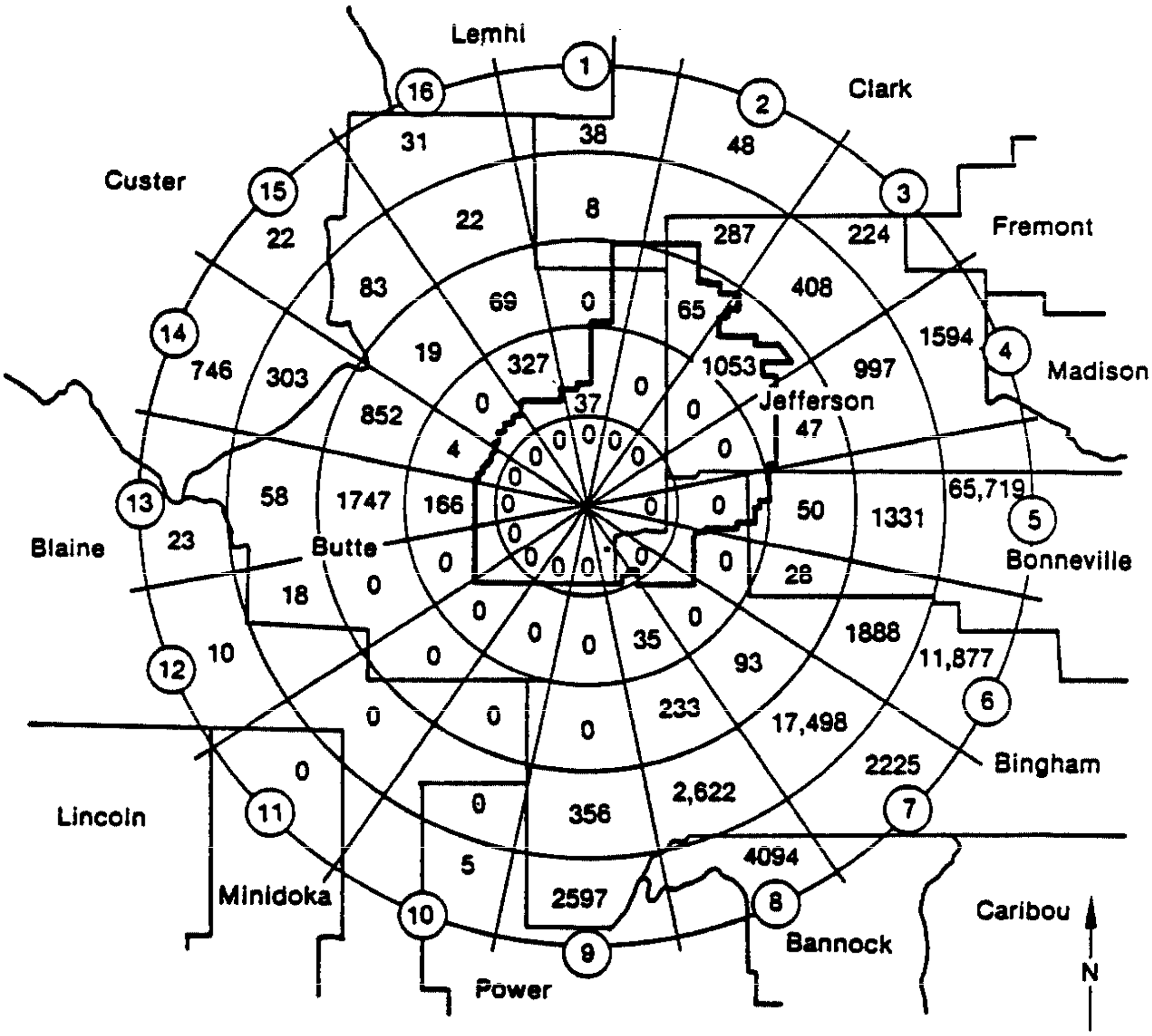
A wide variety of wastes were disposed at the SDA in pits and trenches dug into the soil layer, often to the bedrock. Table 2-3 presents a brief summary of the wastes deposited at the SDA. The wastes were typically placed just above the bedrock and covered with soil. Migration of waste constituents at the site has been attributed to the disposal of non-containerized wastes, breached containers, and several flooding events. While migration of some waste constituents can be expected in the shallow soil, the majority of contaminant migration is expected to be downward into the basalt rather than in the soil. Volatilization of organic compounds has been documented and the presence of a "vapor plume" is suspected as a major contributor to the migration of contaminants at the site. The extent and magnitude of soil contamination is difficult to determine from the existing data. It is also difficult to distinguish between the natural soils and the disturbed soils at the site. It is assumed that all soils beneath the wastes are disturbed and therefore would have properties different from the natural soil or soil cover.

The regionally downgradient, off-site population is quite small and distant from the RWMC. Figure 2-1 identifies population densities in and around the Idaho National Engineering Laboratory (INEL); Sectors 10-12 on Figure 2-1 are the regionally downgradient population. Individuals can be exposed to contaminants in the soil through the following: breathing organic vapors volatilized from the soil; inhaling suspended, contaminated soil particles; direct contact with contaminated soils; and accidental ingestion of contaminated soils through contact with windblown particulates. Soil contaminants can also be taken up by vegetation and enter the food chain. Wildlife have been able to access the SDA in the past; however,

TABLE 2-3. SUMMARY OF POTENTIAL WASTES AT THE SDA

CATEGORY	SPECIFIC WASTES OR WASTE MATERIALS		
Metals	Lead (metal and batteries)	Sodium	
	NAK piping (small quantity)	Beryllium	
	Zirconium	Paint Chips, Cans, Waste (As, Pb, Cr, etc.)	
	Cadmium	Thallium (oxide)	
	Uranium	Scrap steel and vehicles	
	Plutonium (weapons grade)	Radium sources	
	Mercury (metal, solutions, batteries)	Lithium (batteries)	
	Chromium		
Inorganics	Acids (some on absorbent) - HCl, HF, HNO_3	Perchloric filters	
	Caustic (some on absorbent) - NaOH	Ammonia (bottles)	
	Nitrates	Tritium	
	Cyanide (very small quantity)	Asbestos	
Organics	PCBs (>500 ppm in oil with TRU)	Trichloroethylene[a]	
	Oils (machining, motor, lubricating)	Perchloroethylene[a]	
	Polyethylene glycol (Carbo Wax)	Ether[b]	
	Ethylene glycol	Benzene[b]	
	Chloroform	Gasoline (in absorbent or in vehicles)	
	Alcohols[b]	Toluene	
	Scintillation cocktails	Kerosene	
	Carbon tetrachloride	Xylene (?)	
	Trichloroethane[a]		
Other	Raffinate	Biological Waste:	
	Sludges:	Animal carcasses	Hospital waste
	Sewage	Feces	
	Evaporation	Meat with botulinus	University waste
	Grinding/polishing	Organic resins exposed to acids from	
	Tank bottoms	regeneration	Radioisotope source manufacturers
	Cooling tower	Gas cylinders (CO_2, fire extinguishers)	
	Sump pit		Santo Wax
	Oil		
	Basin cleanup		

[a] Present as constituents in disposed oils
[b] Reported as "other organics"



*The computer listing of six persons living in this area is erroneous, because of the program's assumption that persons within a given mi² section are uniformly distributed in that area. No persons reside in this area.

INEL 4 4892

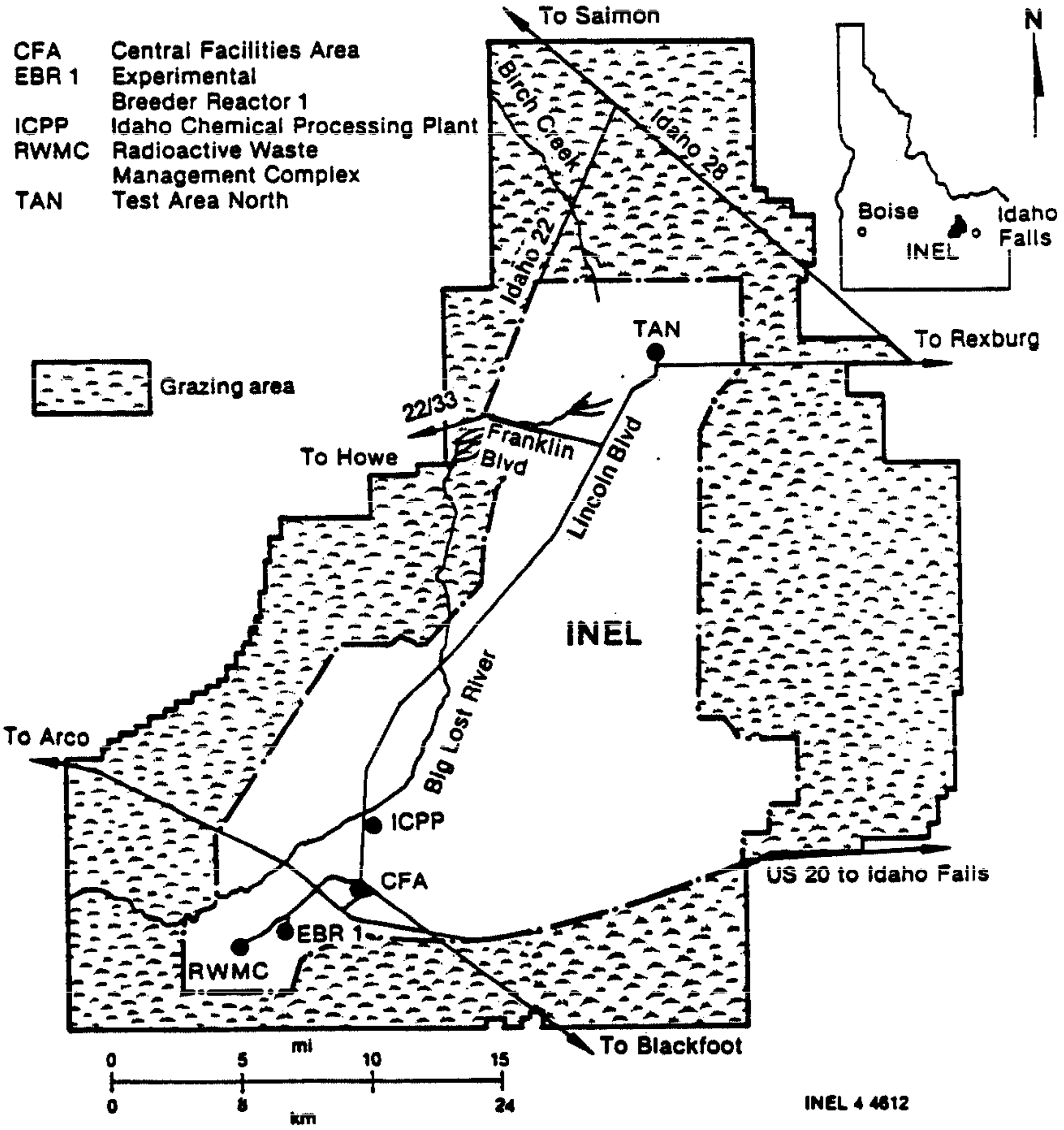
(outer circle represents 50 mile radius from CFA)

Source: Ref. 58

FIGURE 2-1. MAP OF POPULATIONS SURROUNDING INEL fencing has been installed that could limit present and future contact. Also food crops are not grown in the area. Figure 2-2 indicates those areas where the grazing of animals is permitted in the INEL area. Vaporization of organic constituents in soil peaked in 1970 according to current EG&G modeling results. In addition, the contaminants currently present in the soil are not suspected as being major contributors to the groundwater contamination. Thus, all of these pathways are considered minor for off-site exposures due to the low levels of present contamination and the extent of natural dilution that would occur before off-site populations would be exposed to soil and air contaminants. In addition, the contribution of the SDA contaminants would be masked by the contribution of the entire INEL. However, the exposure could be significant for on-site workers, especially during remedial activities. However, based on present data, it is difficult to determine whether the soil should be remediated and if so to what extent.

No published information on the chemical characterization of the basalt at the SDA was available for this review. However, sampling of the interbeds has shown that both organic constituents and radionuclides exist in these media. As a result of its fractured and vesiculated nature, the basalt formation at the SDA serves as a pathway for contaminant migration to the groundwater either through vapor transport, infiltration, and/or contaminant mobilization. The exact nature of this transport is not well established at this time and multiple mechanisms are believed to be occuring. The past disposal of liquid organic compounds and dissolution of wastes by flood waters may have resulted in significant liquid transport in this medium. For organic compounds, vapor transport has been assumed to be the current and future predominant migration process. The basalt and the interbeds within the basalt must be considered as sources of contaminants to the groundwater but not a medium to which humans are exposed. Thus, the basalt should only be considered for remediation, where cost-effective, as a means to protect the aquifer since it is not a direct exposure route.

The groundwater at the SDA is contaminated with a variety of organic compounds and a number of inorganics and radionuclides have also been detected (the contribution of radionuclides from the SDA as opposed to upgradient sources is not known at this time). The groundwater, located approximately 600 feet below the ground surface, serves as a source of drinking water and shower water for the workers at the RWMC. It is also a



Source: Ref. 58

FIGURE 2-2. MAP OF PERMITTED GRAZING AREAS AT THE INEL source of water for livestock and wildlife and the aquifer itself is the major source of drinking water in the region. There are five off-site drinking water wells within 20 miles and only 33 people live within 50 miles downgradient of the SDA (see Sectors 10-12 on Figure 2-1) (Ref. 30). Current modeling of organic transport indicates that the concentrations of organics in the groundwater at the SDA should increase to a maximum in 2015 and reach a maximum at the INEL boundary in the year 2020. Upgradient contamination of the groundwater may also be a contributing factor and this possibility needs to be investigated further (Ref. 30). The groundwater itself is the primary medium of concern at the SDA since the federal drinking water standards and guidances have been exceeded and are expected to be exceeded in the future. While this is not expected at this time to have an adverse impact on off-site populations, due to the distances involved and the extent of expected natural dilution, the contaminated groundwater poses a risk to the SDA workers who use it both for drinking and showering and therefore are exposed to the contaminants by ingestion, inhalation (i.e., volatilization of organics), and dermal contact.

Other pathways of potential concern are surface water runoff and the ingestion of contaminated food. The SDA is located in a topographic depression and is protected from flooding by a variety of engineered flood control measures. Surface water runoff from the SDA is collected onsite and monitored for radionuclides prior to release and therefore it is not expected to be an exposure pathway for off-site animal and human populations. Dermal contact with potentially contaminated surface water runoff could pose a risk to on-site workers but this is considered a minor pathway in comparison with other exposure pathways at the SDA. Similarly, the potential exists for the off-site consumption of contaminated plant and animal tissues by both animals and humans via the food chain. This pathway is also considered minor or nonexistent since there are no dairy cattle downgradient in proximity of the SDA, food chain crops are not grown on-site or in the immediate vicinity of the SDA, nor are many animals expected to come into contact with contaminated materials at or from the SDA.

3. IDENTIFICATION OF POTENTIALLY APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

The Comprehensive Environmental Response Compensation and Liability Act of 1980 (CERCLA) as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986 requires the selection of remedial actions at Superfund hazardous waste sites that are protective of human health and the environment, cost-effective, and technologically and administratively feasible. Section 121 of CERCLA specifies that response action must be undertaken in compliance with applicable or relevant and appropriate requirements (ARARs) established in Federal and state environmental laws.

The revised National Contingency Plan (NCP) (53 FR 51394) clearly states that compliance with ARARs is one of the statutory requirements for remedy selection. Prior to the CERCLA amendments of 1986, the U.S. Environmental Protection Agency (EPA) required compliance with all Federal ARARs, but only consideration of state criteria and standards. The revised NCP incorporates the new statutory requirement that in addition to Federal ARARs, remedies must comply with state environmental requirements and facility siting laws that are more stringent than corresponding Federal standards. In addition, the importance of non-promulgated criteria, or other advisory information "to be considered" (TBC), is formally recognized in the NCP in the development of remediation goals or cleanup levels.

In the interim guidance published by EPA on compliance with ARARs (52 FR 32496-32499), and the more recently published guidance document <u>CERCLA Compliance with Other Laws</u> (Ref. 56), several different types of requirements are identified with which CERCLA remedial actions must comply: (1) ambient or chemical-specific requirements, (2) location-specific requirements, and (3) action-specific requirements. Because situations at CERCLA sites vary widely, EPA cannot categorically specify requirements that will be ARARs for every site. ARARs can only be identified on a site-specific basis (i.e., established in connection with the characteristics of the particular site, the chemicals present at the site, and the remedial action alternatives suggested by the circumstances of the site).

EPA has specified that the different ARARs that may apply to a site and its remediation should be identified and considered at several points in the remediation planning process (52 FR 32496), as delineated below:

- During scoping of the RI/FS, chemical- and location-specific ARARs may be identified on a preliminary basis
- During the site characterization phase of the RI when the baseline public health evaluation is conducted to assess risk at a given site, the chemical-specific ARARs and advisories and location-specific ARARs are identified more comprehensively and used to help determine preliminary cleanup objectives
- During the development of remedial action alternatives in the FS, action-specific ARARs are identified for each proposed remedial action alternative and are considered along with other ARARs and advisories
- During the detailed analysis of alternatives, all ARARs for each proposed remedial action must be examined to establish the appropriate level of protection and to comply with other environmental laws
- In selecting the most appropriate alternative, the remedial action chosen must be able to attain all ARARs, unless one of the six statutory waivers is invoked
- During remedial design, the technical specifications of construction must comply with appropriate ARARs (primarily action-specific).

This section presents the scoping-level ARAR evaluation. Section 3.1 addresses chemical-specific ARARs for the SDA. Section 3.2 addresses location-specific ARARs for the SDA. Section 3.3 provides a preliminary overview of action-specific ARARs.

3.1 CHEMICAL-SPECIFIC ARARs

This section identifies a preliminary set of chemical-specific ARARs that may apply to remedial actions at the SDA and are used later in this report (Section 4) to develop potential cleanup levels. Section 3.1.1 provides an overview of the role of chemical-specific ARARs in the FS process and associated risk assessments. Section 3.1.2 identifies chemical-specific ARARs for radioactive and nonradioactive compounds present at the SDA.

3.1.1 Use of Chemical-Specific ARARs in the FS Process

The screening and detailed analysis of remedial action alternatives must consider effectiveness, implementability, and cost. Within the context of the effectiveness evaluation, chemical-specific ARARs assume major significance as each alternative is evaluated with regard to its effectiveness in protecting human health and the environment.

The ability to protect human health and the environment is the primary requirement that CERCLA remedial actions must meet (53 FR 51394). EPA considers a remedy protective if it "adequately eliminates, reduces, or controls all current and potential risks posed through each [exposure] pathway [at] the site." In accomplishing this, a given remediation alternative must meet or exceed ARARs or other risk-based levels established through a risk assessment when ARARs do not exist or are waived.

In the revised NCP (53 FR 51394) and in the recently published draft guidance manual CERCLA Compliance With Other Laws (Ref. 56), EPA specifies that when ARARs are not available for a given chemical, or where such chemical-specific ARARs are not sufficient to be protective, health advisory levels should be identified or developed in order to ensure that a remedy is protective. Carcinogenic and non-carcinogenic effects are both considered in determining ARARs and evaluating protectiveness. For carcinogenic effects, the health advisory or risk-based levels are selected such that the total lifetime risk to the exposed population of all contaminants falls within the acceptable range of 10^{-4} to 10^{-7}. The 10^{-6} risk level is specified by EPA as a goal for remediation. For noncarcinogenic effects, cleanup levels should be based on acceptable levels of exposure as determined by the EPA reference doses (RfDs), taking into account the effects of other contaminants at the site.

Therefore, chemical-specific ARARs serve two primary purposes: (1) requirements that _must_ be met as a minimum by a selected remedial action alternative (unless a waiver is obtained), and (2) a basis for establishing appropriate cleanup levels. The public health risk assessment of a given remedial action alternative characterizes the actual risk of exposure of human receptors to contaminants under investigation.

For carcinogenic effects, risk characterization yields a probabilistic estimate of the additional lifetime risk of cancer in the exposed individual or the incidence of new cases of cancer in populations. For noncarcinogenic effects, as noted above, exposure levels or doses for all subject compounds are evaluated to determine levels or doses if these exceed EPA RfDs. When a chemical-specific ARAR is available for all subject compounds of concern and the chemical-specific ARARs are determined to be protective, these requirements become the chemical-specific cleanup goals. However, as noted above, when ARARs are found not to be protective or are not available, the results of the risk assessment (i.e., health advisory levels) are used to establish the more stringent target cleanup goals.

Thus, the requirement that a remedial action alternative meet chemical-specific ARARs does not ensure that the proposed alternative is protective, and thereby potentially acceptable. This can be determined only by:

1. Evaluating the combined carcinogenic risk associated with the ARAR limits for all chemicals at a given site (assuming additivity of effect in the absence of data on synergism or antagonism);

2. Establishing that ARARs do not exceed EPA RfDs for noncarcinogenic effects, and are sufficiently protective when multiple chemicals are present;

3. Determining whether environmental effects (in addition to human health considerations) are adequately addressed by the ARARs; _and_

4. Evaluating whether the chemical-specific ARARs adequately cover all significant pathways of human exposure identified in a baseline risk assessment.

The EPA Superfund Public Health Evaluation Manual (Ref. 47) provides guidance on evaluating multiple exposure to chemicals (both carcinogenic and noncarcinogenic effects) and on establishing acceptable exposure levels when no chemical-specific ARARs exist.

3.1.2 Identification of Chemical-Specific ARARs for Nonradioactive and Radioactive Compounds at the SDA

Table 3-1 is a listing of available Federal and Idaho chemical-specific ARARs for the metals, inorganic compounds, organic compounds, and radionuclides identified at the SDA. The compounds listed in Table 3-1 have been identified based on the constituents identified in the wastes (Table 2-3) and the compounds detected in various environmental media (Table 2-1). Provided in Table 3-1 is a listing of: (1) the EPA primary drinking water standards (MCLs); (2) EPA drinking water maximum contaminant level goals (MCLGs); (3) EPA (Federal) ambient water quality criteria for the protection of human health (FWQC) for consumption of aquatic organisms and water adjusted for drinking water only; (4) Idaho State drinking water standards; (5) Idaho ambient water quality standards; (6) EPA national ambient air quality standards (NAAQS); (7) EPA national emission standards for hazardous air pollutants (NESHAPS); (8) the Idaho State Air Quality Regulations; and (9) 10 CFR 20.

Given the exposure pathways of concern at the SDA identified in Section 2 (soil, groundwater), the chemical-specific ARARs of primary importance are the Federal and Idaho water quality criteria and standards. These are briefly discussed below. Note that neither Federal nor Idaho ARARs are available for soil.

MCLs are enforceable EPA standards and represent the allowable lifetime exposure to a contaminant in public drinking water supplies. The MCL is established taking into consideration potential health effects and incorporates a safety factor to provide adequate protection for sensitive subpopulations. In establishing MCLs, EPA also considers the feasibility of

TABLE 3-1. POTENTIAL ARARs FOR CONTAMINANTS IDENTIFIED AT THE SDA

CHEMICAL COMPOUND	Federal Drinking Water Regulations		Federal Ambient Water Quality Criteria		Idaho State Water Quality Standards		Federal Air Quality Standards		Idaho State State Air Quality Standards
	Primary Drinking Water Standards MCLs (mg/L)	Drinking Water Maximum Contaminant Level Goals MCLGs (mg/L)	Human Health: Adjusted for Drinking Water Only (mg/L)	Human Health: Consumption of Water and Aquatic Organisms (mg/L)	Idaho Drinking Water Standards (mg/L)	Idaho Ambient Water Quality Standards	National Ambient Air Quality Standards -NAAQS- (ug/m3)	National Emission Standards for Hazardous Air Pollutants -NESHAPS-	Idaho Air Quality Regulations
NONRADIOACTIVE CHEMICALS						SEE FOOTNOTE g BELOW			SEE FOOTNOTE i BELOW
METALS									
Arsenic	0.05	0.05 a	(0.000025) j	(.0000022)					
Barium	1.00	1.50 a							
Beryllium			(0.0000039)	(0.0000037)				10 g (24 HR.)	
Cadmium	0.01	0.005 a	0.01	0.01	0.01				
Chromium (+3)			179	170	(TOTAL Cr) .05				
Chromium (+6)	0.05	0.12 a	0.05	0.05					
Cobalt									
Copper	1.00 m	1.3 a	1 n	1 n					
Lead	0.05	0.02	0.05	0.05	0.05		1.5 (90 DAY AVER.)		
Mercury	0.002	0.003	0.01	0.000144	0.002			3200 g (24 HR.)	
Nickel			0.0154	0.0134					
Selenium	0.01	0.045 a	0.01	0.01					
Silver	0.05		0.05	0.05					
Thallium			0.0178	0.013					
Tin									
Vanadium									
Zinc	5.00 m		5 n	5 n					

a: Proposed MCL or MCLG

b: Radionuclides in drinking water are limited to activity levels corresponding to a total body dose, or any internal organ dose of 4 millirem/year, summed over all radionuclides present.

c: Total trihalomethanes refers to the sum concentration of chloroform, bromodichloromethane, dibromochloromethane, and bromoform.

d: No maximum - 20.mg/L is suggested by the state as an optimum

e: Gross alpha particle activity shall not exceed this value. Includes radium-266 but excludes radon and uranium.

f: The average annual concentration of beta particle and photon radioactivity from man-made radionuclides in drinking water of the state shall not produce an annual dose equivalent to the total body or any internal organ greater than four millirem per year. Calculated on the basis of a two-liter per day drinking water intake.

g: No numerical criteria have been proposed by the state for toxic chemicals in surface waters. Narative guidelines: Waters of the state must not contain "Hazardous materials in concentrations found to be of public health significance or to adversely affect designated or protected beneficial uses".

h: Radionuclides from DOE facilities: Emission of radionuclides shall not exceed those amounts that cause a dose equivalent of 25 mrem/yr whole body, or 75 mrem/yr to the critical organ.

i: No numerical state ambient air quality guidelines are available for the chemicals listed. Narrative criteria for toxic chemicals in air: "Contaminants toxic to human or animal life or vegetation shall not be emitted in such quantities or concentrations alone or in combination with other, as to injure or unreasonably affect human or animal life or vegetation".

j: Numbers in parenthesis are federal ambient water quality criteria for potential carcinogens corresponding to the 10-6 per year risk level.

k: Use values in 10 CFR 20, Appendix B, Table II for the appropriate isotope of Plutonium.

l: Use values in 10 CFR 20, Appendix B, Table II for the appropriate isotope of Uranium.

m. Secondary Maximum Contaminant Level (SMCL). Not an ARAR.

n. Ambient water quality criterion based on organoleptic properties, not toxicity.

o. Ambient water quality criterion for halomethanes as a class of compounds: includes chloromethane, bromomethane, dichloromethane (methylene chloride), bromodichloromethane, tribromomethane, dichlordifluoromethane, trichlorofluoromethane, or combinations of these chemicals.

p. National ambient air quality standard for sulfur oxides.

TABLE 3-1. POTENTIAL ARARs FOR CONTAMINANTS IDENTIFIED AT THE SDA (Continued)

CHEMICAL COMPOUND	Federal Drinking Water Regulations: Primary Drinking Water Standards MCLs (mg/L)	Federal Drinking Water Regulations: Drinking Water Maximum Contaminant Level Goals MCLGs (mg/L)	Federal Ambient Water Quality Criteria: Human Health: Adjusted for Drinking Water Only (mg/L)	Federal Ambient Water Quality Criteria: Human Health: Consumption of Water and Aquatic Organisms (mg/L)	Idaho State Water Quality Standards: Idaho Drinking Water Standards (mg/L)	Idaho State Water Quality Standards: Idaho Ambient Water Quality Standards	Federal Air Quality Standards: National Ambient Air Quality Standards -NAAQS- (ug/m3)	Federal Air Quality Standards: National Emission Standards for Hazardous Air Pollutants -NESHAPS-	Idaho State State Air Quality Standards: Idaho Air Quality Regulations
OTHER INORGANIC CHEMICALS									
Chloride									
Cyanide			0.2	0.2	0.2				
Sodium					20 d				
Sulfide							365 (24-hour) p 80 (1-year)		
ORGANIC CHEMICALS									
Acetone									
Carbon Tetrachloride	0.005	0	(.00042)	(.0004)					
Chloroform	0.1 c		(.00019)	(.00019)					
Dichlorofluoromethane									
Dichlorodifluoromethane									
1,1-Dichloroethane									
1,1-Dichloroethylene	0.007	0.007	(.000033)	(.000033)					
1,2-Dichloropropane	0.006 a								
Methylene Chloride			(.00019) o	(.00019) o					
1,1,2,2-Tetrachloroethane									
Tetrachloroethylene		0 a	(.00088)	(.0008)					
Toluene		2 a	15	14.3					
1,1,1-Trichloroethane	0.2		19	18.4					
Trichlorotrifluoroethane									
Trichloroethylene	0.005	0	(.0028)	(.0027)					

a: Proposed MCL or MCLG

b: Radionuclides in drinking water are limited to activity levels corresponding to a total body dose, or any internal organ dose of 4 millirem/year, summed over all radionuclides present.

c: Total trihalomethanes refers to the sum concentration of chloroform, bromodichloromethane, dibromochloromethane, and bromoform.

d: No maximum - 20.mg/L is suggested by the state as an optimum

e: Gross alpha particle activity shall not exceed this value. Includes radium-266 but excludes radon and uranium.

f: The average annual concentration of beta particle and photon radioactivity from man-made radionuclides in drinking water of the state shall not produce an annual dose equivalent to the total body or any internal organ greater than four millirem per year. Calculated on the basis of a two-liter per day drinking water intake.

g: No numerical criteria have been proposed by the state for toxic chemicals in surface waters. Narative guidelines: Waters of the state must not contain "Hazardous materials in concentrations found to be of public health significance or to adversely affect designated or protected beneficial uses".

h: Radionuclides from DOE facilities: Emission of radionuclides shall not exceed those amounts that cause a dose equivalent of 25 mrem/yr whole body, or 75 mrem/yr to the critical organ.

i: No numerical state ambient air quality guidelines are available for the chemicals listed. Narrative criteria for toxic chemicals in air: "Contaminants toxic to human or animal life or vegetation shall not be emitted in such quantities or concentrations alone or in combination with other, as to injure or unreasonably affect human or animal life or vegetation".

j: Numbers in parenthesis are federal ambient water quality criteria for potential carcinogens corresponding to the 10-6 per year risk level.

k: Use values in 10 CFR 20, Appendix B, Table II for the appropriate isotope of Plutonium.

l: Use values in 10 CFR 20, Appendix B, Table II for the appropriate isotope of Uranium.

m. Secondary Maximum Contaminant Level (SMCL). Not an ARAR.

n. Ambient water quality criterion based on organoleptic properties, not toxicity.

o. Ambient water quality criterion for halomethanes as a class of compounds: includes chloromethane, bromomethane, dichloromethane (methylene chloride), bromodichloromethane, tribromomethane, dichlordifluoromethane, trichlorofluoromethane, or combinations of these chemicals.

p. National ambient air quality standard for sulfur oxides.

TABLE 3-1. POTENTIAL ARARs FOR CONTAMINANTS IDENTIFIED AT THE SDA (Continued)

	Federal Drinking Water Regulations		Federal Ambient Water Quality Criteria		Idaho State Water Quality Standards		Federal Air Quality Standards		Idaho State State Air Quality Standards
CHEMICAL COMPOUND	Primary Drinking Water Standards MCLs (mg/L)	Drinking Water Maximum Contaminant Level Goals MCLGs (mg/L)	Human Health: Adjusted for Drinking Water Only (mg/L)	Human Health: Consumption of Water and Aquatic Organisms (mg/L)	Idaho Drinking Water Standards (mg/L)	Idaho Ambient Water Quality Standards	National Ambient Air Quality Standards -NAAQS- (ug/m3)	National Emission Standards for Hazardous Air Pollutants -NESHAPS-	Idaho Air Quality Regulations
RADIOACTIVE CHEMICALS								h	
Americium 241									
Cesium 137									
Cobalt 57									
Cobalt 60									
Europium 154									
Sb 125									
Gross Alpha	15 pCi/L				15 pCi/L e				
Gross Beta/Man-Made Rad.	b				4 mrem/yr. f				
Plutonium-238, 239, 240	k								
Strontium-90	8 pCi/L								
Tritium	20,000 pCi/L								
Uranium	l								

a: Proposed MCL or MCLG

b: Radionuclides in drinking water are limited to activity levels corresponding to a total body dose, or any internal organ dose of 4 millirem/year, summed over all radionuclides present.

c: Total trihalomethanes refers to the sum concentration of chloroform, bromodichloromethane, dibromochloromethane, and bromoform.

d: No maximum - 20.mg/L is suggested by the state as an optimum

e: Gross alpha particle activity shall not exceed this value. Includes radium-266 but excludes radon and uranium.

f: The average annual concentration of beta particle and photon radioactivity from man-made radionuclides in drinking water of the state shall not produce an annual dose equivalent to the total body or any internal organ greater than four millirem per year. Calculated on the basis of a two-liter per day drinking water intake.

g: No numerical criteria have been proposed by the state for toxic chemicals in surface waters. Narative guidelines: Waters of the state must not contain "Hazardous materials in concentrations found to be of public health significance or to adversely affect designated or protected beneficial uses".

h: Radionuclides from DOE facilities: Emission of radionuclides shall not exceed those amounts that cause a dose equivalent of 25 mrem/yr whole body, or 75 mrem/yr to the critical organ.

i: No numerical state ambient air quality guidelines are available for the chemicals listed. Narrative criteria for toxic chemicals in air: "Contaminants toxic to human or animal life or vegetation shall not be emitted in such quantities or concentrations alone or in combination with other, as to injure or unreasonably affect human or animal life or vegetation".

j: Numbers in parenthesis are federal ambient water quality criteria for potential carcinogens corresponding to the 10-6 per year risk level.

k: Use values in 10 CFR 20, Appendix B, Table II for the appropriate isotope of Plutonium.

l: Use values in 10 CFR 20, Appendix B, Table II for the appropriate isotope of Uranium.

m. Secondary Maximum Contaminant Level (SMCL). Not an ARAR.

n. Ambient water quality criterion based on organoleptic properties, not toxicity.

o. Ambient water quality criterion for halomethanes as a class of compounds: includes chloromethane, bromomethane, dichloromethane (methylene chloride), bromodichloromethane, tribromomethane, dichlordifluoromethane, trichlorofluoromethane, or combinations of these chemicals.

p. National ambient air quality standard for sulfur oxides.

attaining such a concentration given the best available technology, treatment techniques, and cost.

As part of the process for developing a final drinking water standard (MCL), maximum contaminant level goals (MCLGs) are established at concentrations that are associated with no known or anticipated adverse health effects. MCLs are set at concentrations as close to MCLGs as is feasible.

Federal ambient water quality criteria (FWQC) are guidelines developed by the EPA Office of Water Regulations and Standards for the protection of aquatic life and human health. Although these are not enforceable standards, they represent scientific data and guidance to be used by the states in developing water quality standards. FWQC (adjusted for drinking water only) may be used in evaluating the significance of concentrations in groundwater at waste sites.

State environmental quality standards may be applicable or relevant and appropriate for evaluating remedial actions at waste sites in that state. The availability of, and numerical values for, these standards may vary widely from state to state, and may be more restrictive than Federal criteria and standards. The revised National Contingency Plan (NCP) notes that state standards, requirements, criteria, or limitations are to be considered ARARs only if these have been formally promulgated and consistently applied. Idaho's current drinking water standards and waste quality standards are not more stringent than the Federal standards, therefore, the Federal standards are used in subsequent analyses.

The revised NCP identifies MCLs as the relevant and appropriate requirements for evaluating groundwater and surface water supplies that are currently, or potentially, used as a source of drinking water. When a promulgated MCL exists, the FWQC for that chemical would <u>not</u> be relevant and appropriate (53 FR 51394). When MCLs are <u>not</u> available, the NCP specifies that the FWQC may be relevant and appropriate in water that is a potential drinking water source. The NCP states, however, that FWQCs without modification are not considered relevant and appropriate in selecting cleanup levels in groundwater, where consumption of contaminated fish is not a concern. FWQC adjusted for drinking water only would be the alternate relevant and appropriate requirement for groundwater supplies.

3.2 LOCATION-SPECIFIC ARARs

A number of statutes have requirements related to activities occurring in particular locations. For instance, waste management activities in floodplains are restricted under RCRA and critical habitats of endangered or threatened species are protected under the Endangered Species Act. Location-specific ARARs are regulatory requirements or restrictions placed on activities in specific locations that must be met by a given remedial action. These location-specific ARARs are used in conjunction with chemical-specific and action-specific ARARs to ensure that remedial actions are protective of human health and the environment by meeting the requirements of all applicable or relevant and appropriate Federal and state regulations. The location-specific ARARs are also used to establish remedial action objectives.

This section identifies a preliminary set of location-specific ARARs that may apply to remedial actions at the SDA. Section 3.2.1 identifies general location-specific regulatory requirements and Section 3.2.2 presents an analysis of the applicability of these requirements to the SDA.

3.2.1 Identification of Location-Specific Regulatory Requirements

Federal and Idaho statutes and regulations were reviewed to identify the universe of potentially applicable location-specific regulatory requirements that may apply to remedial activities and new hazardous waste activities (as a result of remediation) at the SDA. All of the requirements identified in this subsection have a location-specific orientation and restrict or prohibit certain activities at or near a location such as that occupied by the SDA. Specific characteristics of the SDA considered in this evaluation are its location in a floodplain, its location in a seismic region, the presence of endangered species in the area, the proximity of surface water, the presence of archaeological and historical sites in the area, and the presence of drinking water wells in the area.

The following regulatory requirements, with potential applicability to remedial activities at the SDA, were identified:

- Floodplains (40 CFR 270 & 264; 40 CFR 6, Appendix A [Executive Order 11988]); Fish and Wildlife Coordination Act (16 USC 661 _et seq_.; 40 CFR 6.302; Idaho Hazardous Waste Management Regulations, Title 1, Ch. 5, 01.5227,09)
- Seismic considerations (40 CFR 270 & 264; Idaho Hazardous Waste Management Regulations, Title 1, Chp. 5, 01.5227,09)
- Activities in the proximity of drinking water wells (Idaho Drinking Water Regulations, IDAPA 16.01.8900,07)
- Wetlands (10 CFR 1022; 40 CFR 230; 33 CFR Parts 320-330; 40 CFR 6, Appendix A [Executive Order 11988)
- Endangered species (50 CFR Parts 17, 200, 402; 33 CFR Parts 320-330)
- Archaeological Resources and Antiquities (Archaeological Resources Protection Act; 43 CFR 7; 36 CFR Parts 65 & 296; 25 CFR 261)
- National Historic Places (National Historic Preservation Act (16 U.S.C. 470); 36 CFR 800)
- Fish and Wildlife (40 CFR 6).

3.2.2 Determination of Preliminary Location-Specific ARARs for the SDA

A review of the eight location-specific regulatory requirements presented in Section 3.2.1 suggests that three of these requirements may be appropriate as ARARs for the SDA (floodplains, activities in the proximity of drinking water wells, archaeological resources and antiquities) and five are neither applicable nor relevant and appropriate to the SDA (wetlands, endangered species, fish and wildlife, seismic, and national historic places). A discussion of these various regulatory requirements and their applicability or relevance and appropriateness to the SDA is provided below.

3.2.2.1 Preliminary Location-Specific ARARs

The identified location-specific ARARs include: floodplains, activities in the proximity of drinking water wells, and archaeological resources and antiquities. The requirements of these location-specific ARARs are presented in Table 3-2.

The SDA is located in the floodplain of the Big Lost River, an intermittent stream that passes approximately two miles to the north of the site. The SDA is actually situated in a basin that is 30 to 40 feet below the elevation of the river. Flow in the river is variable with snowmelt and rains contributing to high flows in late spring/early summer. In order to protect the SDA as well as other INEL areas, an extensive flood control system has been built at the INEL which utilizes a diversion gate and a series of spreading areas. The spreading areas are located approximately one mile to the west of the SDA (Ref. 30). Dikes have also been constructed near and around the SDA to prevent flooding of the site from runoff or the spreading areas. Regulatory requirements that apply to activities in floodplains include RCRA and State of Idaho requirements that restrict hazardous waste management activities in such areas.

A number of archaeological surveys have been conducted at the INEL in the past and the locating and surveying of sites and the preservation of antiquities continue. Several sites are located in the vicinity of the SDA. However, no material of archaeological or historical value has been found at the SDA itself which has been extensively disturbed for over 20 years. Remedial activities within the SDA are not anticipated to encounter such materials either. Therefore, the regulatory requirements associated with the preservation of antiquities and archaeological materials/sites will only serve as ARARs for any activities conducted in the vicinity of the SDA but not within it.

The State of Idaho Drinking Water Regulations include specified minimum distances from drinking water wells that certain waste management units and associated activities must maintain. Such facilities include sewer lines, canals, and ditches. If a new production well was to be built at the SDA, the specified distances must be maintained. Also, if in the course of

TABLE 3-2. SUMMARY OF PRELIMINARY LOCATION-SPECIFIC ARARs

LOCATION-SPECIFIC ARAR	REGULATORY CITATION	LOCATION REQUIREMENTS	APPLICABILITY TO SDA
Floodplains	40 CFR Part 270 40 CFR Part 264 40 CFR Part 6 Idaho H.W. Mgmt. Regs. (01.5227,09)	• If within 100 year floodplain, a new facility must be able to withstand washout from a 100 year flood • Facilities must demonstrate capability to either: (1) withstand washout; (2) remove wastes prior to flooding; or demonstrate that no adverse impacts will result from a washout	• SDA located in 100 year floodplain
Activities in the Proximity of Drinking Water Wells	Idaho Drinking Water Regs., IDAPA 16.01.8900,07	• Specifies minimum distances between drinking water wells and various sanitary waste management units or other structures	• The RWMC has an on-site drinking water well; relocation of the RWMC water supply well is a potential action • Sewer lines, septic tanks and fields, ditches, etc. must be a specified minimum distance from the drinking water well
Archaeological Resources and Antiquities	43 CFR 7 36 CFR 65 36 CFR 296 25 CFR 261	• Establishes conditions for permits authorizing the excavation and/or removal of archaeological resources and antiquities from public and Indian lands • Establishes conditions to prevent disturbance of archaelogical resources and antiquities on public and Indian lands	• Several archaeological sites exist in the vicinity of the SDA

remediation, new ditches or other such structures were to be constructed, the specified distances would have to be maintained against the existing production well.

3.2.2.2 Location-Specific Regulatory Requirements Inappropriate to the SDA

A number of the previously identified location-specific regulatory requirements do not qualify as being either applicable or relevant and appropriate to the SDA, including those addressing:

- Wetlands
- Endangered species
- Fish and wildlife
- Seismic
- Historic places.

The flood control diversion ponds that are located one mile to the west of the SDA provide wetlands during wet seasons of the year. When these areas contain water, they are visited by a number of animal and bird species, particularly waterfowl. The SDA is isolated from the diversion ponds by a series of dikes and other engineered structures. Any anticipated activities at the SDA are not expected to have any impacts on the diversion ponds.

The SDA is not known to be located within a critical habitat of an endangered or threatened species nor are such species known to frequent the SDA. However, the bald eagle and the American peregrine falcon have been observed at the INEL. In addition, eight species of concern to the Idaho Department of Fish and Game and the Bureau of Land Management have been observed at the INEL (Ref. 30). Remedial activities at the SDA are not expected to affect any endangered species because activities are anticipated to be restricted to the immediate area of the SDA itself.

No fish or wildlife addressed by the Fish and Wildlife Coordination Act are found at the SDA. Neither do the planned activities at the SDA involve the modification of a stream as no streams are located on the site and surface runoff is controlled. Unless significant water discharges along the RWMC drainage channel to the Big Lost River occur as part of a remedial action, the regulatory requirements associated with the protection of fish and wildlife would not apply.

The seismic standards contained in the RCRA and Idaho regulations are only applicable in certain counties specified in the regulations themselves. The SDA is located in Butte County which is not listed in Appendix VI to 40 CFR Part 264 nor the Idaho regulations and is therefore exempt from demonstrating compliance with the seismic standard.

There are no historic sites at the SDA. The Experimental Breeder Reactor No. 1, located approximately two miles to the northeast of the SDA, is a National Historic Landmark and the only historic site at the INEL.

3.3 ACTION-SPECIFIC ARARs

Action-specific ARARs are performance, design, or other action-specific requirements that apply as a result of a specific technology or activity or that are limitations on certain actions involving hazardous or mixed waste. Action-specific ARARs are identified during the development of remedial alternatives in the FS, which is outside the current scope of this report. Specific requirements are triggered by the particular remedial activities within each alternative. This section presents a preliminary list of laws and regulations to be considered in a later effort to develop action-specific ARARs.

The buried wastes at the SDA include chemicals and other wastes that would be considered hazardous wastes or radioactive mixed wastes under today's regulatory definitions. Migration of chemical constituents from the waste constitutes migration of the waste; therefore, any treatment actions applied to the waste or to soil, air, or groundwater contaminated by migrated contaminants may constitute management of hazardous or mixed wastes or may generate wastes (e.g., treatment residuals) to be managed as hazardous or mixed wastes. Applicable regulations would include the Resource Conservation and Recovery Act regulations (RCRA, 40 CFR 260-264, 268, and 270) and the Idaho Hazardous Waste Management Regulations (Title 1, Ch. 5). Other guidance to be considered (TBC) include DOE Orders 5480.1A, 5480.1B, and 5820.2.

Treatment activities resulting in discharges to air, surface water, or the groundwater may need to comply with:

- Rules and Regulations for the Control of Air Pollution in Idaho
- Federal Clean Air Act
- Idaho Water Quality Standards and Wastewater Treatment Requirements (Title 1, Ch. 2)
- Licensing Requirements for Land Disposal of Radioactive Waste (10 CFR 61)
- Federal Clean Water Act
- Federal and State of Idaho Underground Injection Control Regulations.

Treatment of drinking water or replacement of the existing potable water system would need to comply with Idaho Drinking Water Regulations and the Federal Safe Drinking Water Act.

Other requirements can be identified based on specific remedial action alternatives or technologies being considered for the SDA. This would include all pertinent DOE-ID and EG&G Idaho requirements for design standards (seismic, tornado, etc.), operating requirements, and discharge/exposure limitations as well as compliance with the National Environmental Policy Act (NEPA).

4. DEVELOPMENT OF PRELIMINARY REMEDIAL ACTION OBJECTIVES

Remedial action objectives are established based on identified contaminants of concern, exposure routes, receptors (human and environmental), acceptable contaminant levels or range of levels for each exposure route, and other requirements that must be met in mitigating environmental contamination problems (i.e., ARARs). The remedial action objectives established throughout the FS process serve as goals that various remedial action technologies or alternatives must achieve. Preliminary remedial action objectives can be developed based on chemical- or location-specific requirements and preliminary site characterization information. These objectives are then refined in the development of alternatives at which time action-specific remedial action objectives can be established.

This section presents preliminary remedial action objectives for the SDA developed from information reviewed for this report and the analyses presented in Sections 2 and 3. Section 4.1 presents general remedial action objectives for the Subsurface Disposal Area (SDA). Section 4.2 presents the methodology for establishing preliminary chemical-specific cleanup levels or remedial action objectives. The methodology presented is a risk-based approach, and uses a spreadsheet program to calculate remedial action cleanup levels and to facilitate sensitivity analysis. Section 4.3 identifies location-specific remedial action objectives. Action-specific remedial action objectives are established in the development of remedial actions and are not addressed in this report.

4.1 GENERAL REMEDIAL ACTION OBJECTIVES

General remedial action objectives can be established that provide a framework for future analyses. These objectives are based on the nature of contamination problems and anticipated migration and exposure routes as well as services or operations that cannot be disrupted or must be supplied to on-going activities in the area. Based on the analyses in Section 2, the major concerns regarding contaminants at this time are risks to RWMC workers, the continuing need for a water supply at the RWMC, and continued migration of organics, inorganics, and radionuclides from the buried waste.

The following preliminary general objectives have been identified to address those concerns:

- Control originating waste constituent source (buried waste) if it is not removed
- Minimize or eliminate precipitation or run-off infiltration at the SDA
- Control secondary sources of contaminants (contaminated soil, basalt bedrock, sedimentary interbeds) to protect the Snake River Plain Aquifer
- Minimize contaminant migration off the SDA
- Prevent contaminant migration off the INEL
- Minimize on-site worker exposure to chemical and radiological waste constituents
- Provide the RWMC and off-site users (if necessary) with sufficient, dependable, and safe potable water
- Provide a water supply at the RWMC that can meet potable water demand and fire flow requirements
- Comply with all applicable Federal and State of Idaho requirements.

4.2 CHEMICAL-SPECIFIC REMEDIAL ACTION OBJECTIVES

EPA has identified nine criteria to be applied in evaluating and selecting remedial action alternatives. Of these, overall protection of human health and the environment and compliance with ARARs are considered the two "threshold criteria" that must be satisfied in order for an alternative to be eligible for selection (Ref. 57). These two "threshold criteria" are the basis for developing cleanup levels for site remediation. These remedial action goals are chemical-specific levels established for each chemical in each exposure route of concern and serve as the foundation for developing and evaluating remedial action alternatives and for estimating associated costs.

The establishment of chemical-specific remedial action objectives typically begins during project scoping or concurrent with preliminary RI activities. Because these preliminary objectives are first established prior to completion of the baseline risk assessment, they are initially equated with chemical-specific ARARs or other readily available environmental- or health-based limits. As the FS process progresses, the results of risk assessment and the subsequent identification of additional chemical-specific ARARs serve to modify the preliminary chemical remedial action objectives. Ultimately, remedial action objectives are derived that ensure that remedial action alternatives both comply with ARARs and are protective of human health.

Protectiveness of an action or residual contamination is evaluated with respect to potential for noncarcinogenic and carcinogenic effects. For carcinogenic effects, remedies resulting in excess lifetime cancer risks within the range 10^{-4} to 10^{-7} are considered protective (Ref. 57). An excess risk of 10^{-6} may be established as the remediation goal. For noncarcinogenic effects, remediation goals must meet acceptable levels for each subject chemical, e.g., Reference Doses (RfDs) developed by EPA, and must be protective for combined exposure.

ARARs do not comprise a uniformly derived set of standards. Chemical-specific ARARs are developed by the state or Federal government and often by varying methods and for different environmental media. These ARARs establish health-based or risk-based limits on the amount of a given chemical that may be discharged to, or be present in, the environment or a specific medium. These chemical-specific ARARs are set for a single compound or closely related group of compounds. Typically, these requirements do not incorporate consideration of the effects of combined exposure to mixtures of chemicals, or the implications of multiple exposure pathways. In site-specific situations where multiple chemicals or multiple exposure routes exist, a remedial action alternative may comply with the chemical-specific ARARs established for the remedial action yet may result in an exposure or risk that does not adequately protect human health or the environment.

Guidance on the development of remedial action goals is provided by EPA in several key documents: (1) The Superfund Public Health Evaluation Manual (Ref. 47); (2) the draft Guidance on Conducting Remedial Investigations and Feasibility Studies under CERCLA (Ref. 48); (3) a recent article by two senior EPA analysts (Ref. 51); and (4) the revised National Contingency Plan (NCP). The RI/FS Guidance Document specifies that if a chemical-specific ARAR is determined to be protective, it should be used to establish acceptable exposure levels, i.e., remedial action objectives. If a chemical-specific ARAR is not protective or does not exist for the specific chemical or pathway of concern <u>or</u> if multiple contaminants may result in an unacceptable cumulative risk, acceptable exposure levels would be identified through the risk assessment process. The revised NCP reiterates that in instances where human or nonhuman receptors are exposed to multiple chemicals and multiple pathways, remedial action goals may be set below the chemical-specific ARARs (i.e., at more stringent levels) in order to obtain a remedy that is protective.

4.2.1 Methodology for Derivation of Chemical-Specific Remedial Action Objectives

Currently, the Superfund Public Health Evaluation Manual (Ref. 47) provides the most detailed overview of methods for derivation of cleanup levels for site remediation. Based on this document and the additional guidance presented in the FS Guidance and the revised NCP, an outline has been developed of the general approach used in this report to develop preliminary remedial action goals. The basic steps are as follows:

- Identify subject/indicator chemicals of concern.
- Assemble a listing of all available ARARs.
- Identify potential exposure pathways and receptors at risk.

- Develop exposure scenarios and characterize environmental concentrations at the points of exposure using available monitoring data and/or the results of environmental fate modeling.

- If chemical-specific ARARs are available for all subject chemicals, evaluate the overall protectiveness to human health of exposure to the chemicals at ARAR levels. Take into consideration combined exposure across chemicals and multiple pathways.

- If the chemical-specific ARAR levels are found to be protective, adopt these as remedial action goals (cleanup levels).

- If chemical-specific ARARs are not available for all subject chemicals, or are not found to be protective of human health, derive cleanup levels based upon the results of risk assessment.

In the following sections, a detailed discussion is presented of all methods employed and the results of the assessment.

It is important to recognize that the derivation of cleanup goals becomes a complex process for any site such as the SDA with numerous contaminants, multiple exposure pathways, and contaminants for which ARARs are not available or are not protective of human health. Under these circumstances, the development of cleanup levels must incorporate all elements of a comprehensive risk assessment. In essence, an acceptable target risk level is first established for combined exposure across all chemicals and all environmental media. Using the risk assessment methods established by EPA, corresponding acceptable levels of each subject chemical are then back-calculated for the affected environmental media.

The chemical-specific cleanup levels derived by the risk assessment method cannot be considered absolute targets for site remediation. Rather, these risk-based guidelines are used in conjunction with the results of analysis of remedial action alternatives (engineering feasibility and costs) to refine the preliminary cleanup goals. Tradeoffs can be developed between the cleanup goals for specific chemicals based on the ease or difficulty of their cleanup by different technologies. The overriding objective is to develop cleanup levels that are protective of human health, technically sound, and cost-effective. Thus, the establishment of cleanup levels is iterative and ultimately requires negotiation with cognizant regulatory or lead agencies. As noted above, a target risk range must be established and achieved for selected remedial action alternatives. However, there is considerable latitude allowed in apportioning risk across chemicals and exposure pathways in the FS process and in establishing the target risk. For example, the cleanup levels could vary among remedial action alternatives by taking advantage of different technology capabilities to address specific contaminants.

In order to facilitate the process of apportioning risk and deriving target limits for each affected environmental medium, a computer-based "tool" has been developed by SAIC for the analyses in this report. An integrated LOTUS 1-2-3 spreadsheet has been created ultimately for use by EG&G in establishing cleanup levels for radioactive and nonradioactive substances in soil and groundwater at the SDA and to evaluate variations in the exposure scenarios in relation to engineered actions. Maximum flexibility in conducting sensitivity or "what if" analyses has been built into this spreadsheet by linking exposure assumptions, intake factors, toxicity measures, target risk levels, and remedial action goals. The spreadsheet has been constructed such that the influence of changes in target cleanup levels (or any other key parameters) on overall risk may be immediately examined. Sections 4.2.2 through 4.2.5 present further background on the methodology and Section 4.2.6 presents the spreadsheet analysis.

4.2.2 Risk Assessment Process

To understand the utility of the risk allocation and cleanup goal calculation spreadsheets developed by SAIC, it is necessary to review the methods for risk assessment incorporated into the program. These risk assessment methods closely follow the guidelines developed by EPA and incorporate the most recent toxicity measures available for evaluating the radioactive and nonradioactive chemicals present at SDA. An understanding of the measures and algorithms used is important in defining the potential applications of the spreadsheet and in clarifying the inherent uncertainties in its use.

The following sections provide a brief discussion of relevant risk assessment methods for nonradioactive and radioactive chemicals pertinent to the development of cleanup levels for the SDA. Section 4.2.5 provides a detailed discussion of all variables and assumptions.

4.2.2.1 Nonradioactive Chemicals

The risk assessment process for nonradioactive chemicals involves integrating the results of exposure and toxicity assessments, i.e., comparing estimates of dose with appropriate toxicological endpoints to determine the likelihood of adverse effects in exposed populations. It is common practice to consider risk characterization separately for carcinogenic and noncarcinogenic effects. This is due to a fundamental difference in the way organisms typically respond following exposure to carcinogenic or noncarcinogenic agents. For noncarcinogenic effects, toxicologists recognize the existence of a threshold of exposure below which there is only a very small likelihood of adverse health impacts in an exposed individual. Exposure to carcinogenic compounds is not thought to be characterized by the existence of a threshold. Rather, all levels of exposure are considered to carry a risk of adverse effect.

Carcinogenic Risk

The procedure for calculating risk associated with exposure to nonradioactive carcinogenic compounds has been established by EPA (Refs. 47, 53, 54). A linear non-threshold, dose-response model is used to calculate a carcinogenic potency factor. This potency factor mathematically is the slope of the dose-response curve for each chemical. To derive an estimate of risk, the carcinogenic potency factor (q_1^*) is then multiplied by the estimated chronic daily dose experienced by the exposed individual as shown below:

$$R = D \times q_1^* \qquad (1)$$

where

R = excess lifetime risk of cancer from chronic exposure to a specific chemical

D = chronic daily dose (mg/kg body weight/day)

q_1^* = 95% upper-bound estimate of the slope of the dose-response curve [(mg/kg body weight/day)$^{-1}$] for the chemical

Equation (1) provides an explicit estimate of excess lifetime risk for a given chemical and has a value between 0 and 1. It expresses the additional probability that an individual will develop cancer over a lifetime of exposure at the specified dose level. In evaluating risk of exposure to more than one carcinogenic chemical, the risk measure (R) for each compound considered may be summed (in the absence of information on antagonistic or synergistic effects) to provide an overall estimate of total carcinogenic risk (Refs. 47, 53). The risk is calculated for each source of environmental release, associated exposure pathway, and receptor group at risk of exposure. Population risks may be derived by multiplying the overall risk level (summed for all chemicals considered) by the number of people exposed. This would yield a measure of the additional incidence of developing cancer (i.e., additional number of new cases) in the exposed population over a lifetime of exposure (i.e., 70 years).

Equation (1) above is recommended only for quantifying estimated carcinogenic risk levels that are less than 1×10^{-2} (Ref. 54). Where exposure/dose for carcinogens is high and the combined risk exceeds 10^{-2}, an alternate model is recommended by EPA for quantifying lifetime risk:

$$R = 1 - \exp(-D \times q_1^*) \qquad (2)$$

The analysis for the SDA uses equation (1).

Noncarcinogenic Risk

The traditionally accepted practice of evaluating exposure to noncarcinogenic compounds has been to experimentally determine a No Adverse Exposure Level (NOAEL) and to divide this by a safety factor to establish an acceptable human dose, for example, acceptable daily intake or Reference Dose (RfD) (Ref. 50). The RfD is then compared to the average daily dose experienced by the exposed population to obtain a measure of concern for adverse noncarcinogenic effects for a given compound as shown below:

$$HI = D/RfD \tag{3}$$

where

HI = Hazard Index (potential for adverse noncarcinogenic effects)
D = average daily dose for subchronic or chronic exposure (mg/kg body weight/day)
RfD = acceptable intake for subchronic or chronic exposure (mg/kg body weight/day)

If HI is >1, then adverse noncarcinogenic effects may be anticipated at the given exposure/dose level for the compound considered.

Evaluating exposure to mixtures of noncarcinogens involves summing the hazard indices (HI) for all chemicals under evaluation (as presented in EPA 1986b). If the sum of the hazard indices is >1, then there is the potential for adverse noncarcinogenic effects. Under these circumstances, EPA recommends segregating the compounds into groups of like or common toxicological effects and re-evaluating the potential for manifestation of the various adverse health effects identified.

4.2.2.2 Radioactive Compounds

The methods for risk characterization for radionuclides in soil and at the SDA is based on guidance provided by the International Commission for Radiological Protection (Ref. 93). The focus of the assessment is on somatic effects of exposure to the radiouclides with cancer selected as the endpoint of concern. For the purposes of developing remedial action goals, the excess or incremental lifetime risk of cancer incidence is considered.

The 50-year committed effective dose equivalent (hereafter, "dose") is calculated as follows:

$$D = (C)\ (IF)\ (DCF) \tag{4}$$

where

D = effective dose in rem (see Appendix A for details)
C = concentration of radionuclide in μCi/kg or μCi/L
IF = intake of contaminated material during the period of interest; it is the product of the daily intake (kg/day or L/day) and the period of exposure (days)
DCF = the dose conversion factor (rem/μCi) for the ingestion or inhalation routes

The incremental lifetime risk to humans associated with exposure to the radionuclides at the calculated dose (D) is determined as follows:

$$R = (D)\ (CRF) \tag{5}$$

where

R = excess or incremental lifetime risk of all cancers
D = dose (rem) as determined above in Equation 4
CRF = cancer incidence risk factor (per rem)

The cancer incidence risk factor is derived from the use of high to low dose extrapolation models. The EPA is currently using a CRF of 6.2×10^{-4} per rem for low LET radiation (Personal communication, January 1989: Paul Vollique, SAIC, Radiation Advisory Committee of the EPA Science Advisory Board). The range of cancer incidence is given as 1.9×10^{-4} to 1.9×10^{-3} per rem.

4.2.3 Identification of Chemicals for Risk Assessment

As specified by EPA, the first step in the risk assessment process is identification of the chemicals of concern. This is typically accomplished by reviewing historical records on wastes disposed at the site and by evaluating all available monitoring data. Often dozens of chemical contaminants are identified at hazardous waste sites. EPA acknowledges that it may be both impractical and unnecessarily time-consuming to assess the risk of each compound identified. Under these circumstances, EPA recommends the selection of "indicator compounds" that pose the greatest risk to human health or the environment. EPA suggests using the indicator selection process for waste sites at which more that 15 chemicals of potential concern have been identified (Ref. 47).

As presented in the EPA Superfund Public Health Evaluation Manual, the indicator selection process involves assigning a score to each chemical identified and ranking the resulting list. Briefly, scores are developed for a given chemical and environmental medium by multiplying together two factors: (1) a chemical- and route-specific toxicity measure identified specifically for this process; and (2) the quantity or concentration of the chemical present at the site (or in contaminated environmental media surrounding the site). For a particular chemical, scores may be developed for several environmental media/exposure routes (i.e., air, soil, and water). The overall indicator score for a compound would then be the sum of the products (toxicity measure times concentration) for all affected environmental media. EPA recommends the development of separate scores for noncarcinogenic and carcinogenic effects.

In addition to this quantitative approach to ranking chemicals of concern, EPA also recommends a more qualitative consideration of mobility and persistence in refining the selection process. In the final analysis, the use of professional judgment is advocated to modify the list of scored chemicals and to include any additional chemicals that are thought to be of significance.

At the SDA, more than 15 radioactive isotopes and nonradioactive chemicals have been found in soil, the subsurface, and groundwater. Although EPA guidance sanctions the use of the indicator chemicals selection process at this site, the analysis presented in this report does not exclude any chemicals at this time. The use of indicator chemicals facilitates the risk assessment process when dozens of compounds have been identified at a site by narrowing the list of subject chemicals to those that theoretically drive the overall magnitude of the risk. Given the limited data set currently available for the SDA, it would be premature to eliminate any compounds at this time. A much larger data set is needed regarding the specific contaminants and the magnitude of concentrations in each medium. Once a larger data set is available, selection of indictor compounds may be pursued and the cleanup objectives re-evaluated.

In developing preliminary cleanup goals for the SDA, it is believed to be most prudent to include all potentially carcinogenic compounds in the evaluation. No indicator chemicals have been selected. In this developmental phase of the process, noncarcinogenic effects have not been considered in derivation of cleanup levels. Criteria for protection against unacceptable carcinogenic risk are almost always considerably more stringent than those for noncarcinogenic effects. The development of the computer spreadsheets for this analysis incorporates consideration of all potentially carcinogenic compounds identified in the environment at SDA from Table 2-1.

Note that chromium and nickel have been found in the environment at SDA but are not included in the current evaluation of carcinogenic compounds. Hexavalent chromium (Cr +6), nickel subsulfide, and nickel carbonyl are potentially carcinogenic forms of these metals. The specific form of chromium and nickel have not been determined, but the carcinogenic form of these compounds are not anticipated to be present in the environment at the SDA. Nickel subsulfide and nickel carbonyl are produced primarily in association with pyrometallurgical processing. Trivalent chromium (Cr+3) is the predominant form of chromium under typical environmental conditions.

4.2.4 Identification of Potential Exposure Pathways

As shown in Section 2.2, there are a wide variety of potential exposure pathways by which people at the SDA might be exposed to hazardous constituents from the buried waste at the site. The waste at the SDA contains potentially harmful organic chemicals, heavy metals, and radionuclides. These waste constituents have been spreading through the various environmental media since being disposed at the SDA, or since their containers were first breached. The environmental media receiving these waste constituents include the following:

- Soil
- Air
- Surface water runoff
- Vadose zone (basaltic bedrock and sedimentary interbeds)
- Groundwater.

Organic vapor is present in the soil pore space at the SDA. This vapor has diffused from the source waste, or vaporized from organics that may have flowed in concentrated form or been transported in aqueous solution from the source waste. The soil also contains organic chemicals, heavy metals, and radionuclides that may have migrated in solution in infiltrating precipitation or snow melt. These species exist adsorbed to the surface of soil particles or in solution in the soil moisture. Insoluble particulate waste constituents may be carried in suspension in runoff or may be carried (if small enough) through the soil pores in liquid waste or in infiltrating water.

The environmental media receiving SDA waste constituents in dissolved or vapor form are the atmosphere, the vadose zone underlying the surface soil, and the groundwater. The atmosphere may receive volatile organics from the soil and the basaltic vadose zone and groundwater may receive volatile organics through evaporation and vapor transport through the subsurface pore space or through open wells.

Human receptors may come into intimate contact with four of the five contaminated environmental media at the SDA (soil, air, surface water, groundwater). Humans may therefore be exposed to environmentally transported waste constituents without coming in contact with the waste itself. The vadose zone is the only environmental medium to which humans are not directly exposed. Note that the focus of this assessment is the area surrounding the SDA after remediation and site closure (active and inactive pits) have been completed.

Employees at the RWMC are the only individuals likely to be exposed to high concentrations of contaminants from the SDA, and over a long enough period, to present a reasonable basis for establishing cleanup levels at the site. Visitors to the SDA are anticipated to receive an insignificant lifetime exposure. The nearest resident population is too far away to experience any significant exposure to SDA contaminants based on current concentrations. In the downgradient direction of groundwater flow, no one lives closer than 32 km (20 mi) from the SDA (Ref. 30). The towns in closest proximity to the SDA are Butte City, which is about 19 km (12 mi) to the northwest and Atomic City, which is about 19 km (12 mi) to the southeast, neither of which is regionally downgradient to groundwater flow or prevailing wind directions.

Of the potential pathways for human exposure at the SDA, four are considered significant and are used as the basis for estimating worker exposures to SDA contaminants in deriving remediation objectives or action levels:

- Ingestion of contaminated groundwater
- Inhalation of vapor released from contaminated groundwater during showering
- Ingestion of contaminated soil dust
- Inhalation of contaminated soil dust.

Chronic dose estimates for all of the above exposure pathways have been derived based on <u>reasonable maximum exposure scenarios</u> as suggested by EPA guidance (Ref. 57). Although these scenarios are based on exposure factors which are greater than the average, they result in reasonable upper-bound estimates for long-term exposure. All of the scenarios have the following assumptions in common:

- Exposed human receptors are adult workers weighing 70 kg
- Exposures occur 5 days/week
- Exposures occur 50 weeks/year

- Exposures occur for 20 years of a 70-year lifetime.

- As a simplifying assumption in this preliminary analysis, all subject chemicals and radionuclides are considered conservative in the environment, i.e., physical/chemical or biological transformation and radioactive decay do not modify observed environmental concentrations over the period of exposure.

The following subsections describe the four exposure pathways and estimate the associated contaminant intake factors.

4.2.4.1 Ingestion of Contaminated Groundwater

All water for drinking, cooking, and showering at the RWMC is obtained from the RWMC production well. Workers at the SDA/RWMC are currently using this groundwater, and are therefore directly exposed to any contaminants present in these waters. A consumption rate of two liters per day has been assumed for the purposes of this assessment.

4.2.4.2 Inhalation of Vapor from Contaminated Groundwater Used for Showering

Studies of exposure to gases and volatile organics released from contaminated tap water during showering have indicated that chronic dose estimates are equal to or greater than dose estimates resulting from only direct ingestion of 2 L/day of the water (Ref. 46). The reasonable maximum exposure scenario for SDA worker exposure to volatile organics during showering at the site is based on the work of McKone, 1987 (Ref. 46). This "upper-bound" exposure scenario is used here as a basis for estimating worker exposure during showering. The mean of McKone's upper-bound estimates for "lifetime inhalation pathway dose factors" for four chlorinated hydrocarbons was used in the exposure calculation: carbon tetrachloride, chloroform, tetrachloroethylene, and trichloroethylene. (The range of values for McKone's upper-bound estimates for the four compounds was 0.16-0.18 mg/kg-d per mg/L concentration.) These compounds are also found in groundwater at the SDA. The scenario for the analyses in this report includes the following assumptions, some of which are modified from McKone's original assumptions:

- Workers spend 20 minutes in the shower each day
- Workers spend 40 minutes in the room adjacent to the showers each day while showering is taking place or immediately after showering has ceased (an added 20 minutes exposure later in the day was not included here)
- Breathing rate is 20 L/min (McKone used 28.8 m^3/day during the active, nonresting part of the day)
- All of the volatilized chemical inhaled is also retained in the body
- The adult body weight is 70 kg (McKone used 67 kg).

McKone's estimates have been corrected appropriately for SAIC's revised scenario assumptions.

Contaminants that are non-volatile are not included in this inhalation from showering exposure route. That is, arsenic and most of the radionuclides are not expected to be volatile, and the extent of mist formation followed by inhalation is not considered significant enough to include in the exposure calculations. The showering process would be expected to quickly entrain mist as it is generated. Volatile organics and tritium (conservatively assumed to be HTO) are included in the exposure calculations.

4.2.4.3 Ingestion of Contaminated Soil Dust

The ingestion of contaminated soil dust by adults is considered completely accidental, but can routinely occur whenever handling of soil or items covered with soil occurs at the site or when working in area where windblown dust is common. The route of exposure is by way of the hands. Contaminated soil dust is transferred to the mouth when a person touches his lips or nose, smokes, eats, applies cosmetics, etc. The extent of soil ingestion in this manner is usually estimated at 0.1 g/day for adults (Ref. 47). It is assumed that the concentration of contaminants on the dust particles is the same as on the soil itself (Ref. 52). This is considered a minor pathway.

4.2.4.4 Inhalation of Contaminated Soil Dust

Another potential route of worker exposure at the RWMC is the inhalation of contaminated soil dust generated in the vicinity of the RWMC. Soil dust can be generated by moving contaminated soil, excavation, by vehicles driving over dry soil surfaces, wind entrainment, etc. It is assumed that the concentration of contaminants on the airborne dust particles is the same as in the soil itself (Ref. 52). That is, the concentration of a contaminant on airborne dust can be calculated as follows:

$$C_{air} = C_{soil} \times TSP \qquad (6)$$

where

C_{air} = concentration of a contaminant in air (mg/m^3)
C_{soil} = concentration of that contaminant in the soil (mg/kg)
TSP = total suspended particulates in air at the SDA (kg/m^3)

This calculation assumes that there is no correlation of the distribution of contaminants in the soil with particle size; small soil particles do tend to become airborne more readily than large particles. Also, the calculation assumes that the process of dust entrainment in air does not cause loss of adsorbed volatiles from the dust. The measured TSP level at the SDA has been reported to be approximately 50 ug/m^3 (Personal communication January 1989: Marilyn Case, EG&G). This is considered a minor pathway.

4.2.4.5 Potential Exposure Pathways Not Considered Significant

There are several other potential pathways for human exposure to contaminants at the SDA that were initially considered for determining cleanup levels. These pathways were subsequently concluded to present only minimal risk of exposure. That is, if the exposures were quantified, their contribution to the total risk by all exposure pathways would be negligible. These other exposure pathways include the following:

- Inhalation of volatiles released from residual soils once the wastes at the SDA have been excavated
- Ingestion of contaminated plants or animals, including animals containing contaminant chemicals via the food chain
- Skin absorption of contaminants during showering
- Skin absorption of contaminants from airborne contaminated soil dust.

As more information on the levels of environmental contamination at and near the SDA is gathered, and as contaminant transport from the SDA is evaluated further, the decision not to include these exposure routes in the determination of action levels may require reassessment.

Inhalation exposure to volatile contaminants released directly from the buried waste would be of concern to workers only if the expected atmospheric dilution rates were very slow. Baca and coworkers estimate that the bulk of the volatile waste constituents at the SDA (80 percent) have already been lost to the atmosphere (Ref. 30). However, attempts at sampling and analysis of airborne vapors of waste constituents in the human breathing zone 3-5 ft directly above boreholes D02 and D10 produced no levels above the Practical Quantitation Limit (PQL) of 5.0 mg/m^3 on September 30, 1987 (Ref. 30). (Carbon tetrachloride, chloroform, 1,1,1-trichloroethane, and trichloroethylene were detected; estimated levels were 3.0, 0.4, 0.4, and 0.5 mg/m^3, respectively.) No organics above the respective PQLs were found when air sampling was also conducted directly above the ground surface at the Pad A open hole. A control sample at the West Guard Gate on the same date showed chloroform and 1,1,1-trichloroethane detected at 0.9 and 2.0 mg/m^3, respectively (Ref. 30).

Modeling of contaminant vapor transport at the SDA has been conducted by EG&G in order to estimate human exposures to organic vapor. An extremely conservative exposure model was used in conjunction with the transport model, assuming 24 hr/day exposure, air stability class F, and 0.1 m/s wind speed (Ref. 30). The results of the modeling effort and risk evaluation projected excess lifetime risks in the acceptable range of 10^{-4} to 10^{-7} (Ref. 30). EG&G concludes that given the very conservative assumptions used in the assessment, "further evaluation of remediation concerning inhalation exposure may not be necessary" (Ref. 30).

Workers at the RWMC are not anticipated to hunt (hunting is prohibited on the INEL) and eat any significant amount of wildlife in close proximity to the SDA, nor eat any of the plants growing nearby. Cattle and sheep may graze at distances over 2 miles from the SDA. More than 20,000 animals are within a 50 mile radius of the center of INEL (Ref. 30). Exposure of these animals to airborne contaminants potentially released from the SDA has not been quantified, although it is anticipated to be minimal and, if present, would be masked by that released from the INEL as a whole. Even if exposure due to ingestion of contaminated animal tissue was a route of theoretical concern, it is unlikely to be the most appropriate basis for developing the reasonable maximum exposure scenario. In general, the use of the reasonable maximum exposure scenario results in the most meaningful estimates of cleanup goals. (Note that any intake of contaminants by grazing cattle cannot be attributed readily to release of contaminants from the SDA since one must consider the contribution of other contaminant sources at the INEL.)

Generally, the rate of absorption of contaminant chemicals across intact skin is minimal for organics in dilute solution such as the chemicals in groundwater at the SDA. Compared to inhalation of vapor from groundwater used in showering, skin absorption during showering or bathing would not be of major concern.

The contribution of inhaled contaminated soil dust to the overall human exposure burden is also relatively small. The contribution of skin absorption of contamination from soil dust on the skin, therefore, can be expected to be much smaller, and insignificant relative to the total exposure scenario.

4.2.5 Establishing Target Risk Levels and Dose for SDA Chemicals and Exposure Routes of Concern

As noted previously, the overriding objective is to develop cleanup objectives that are protective of human health and that comply with Federal and state chemical-specific ARARs. To accomplish this, it is necessary first to establish an acceptable target risk level. Concentrations of all subject chemicals are then derived such that combined exposure across all subject chemicals and all exposure rates in an aggregate health risk equivalent to the acceptable target risk level.

ARARs are not available for all chemicals identified at the SDA. Under such circumstances, EPA recommends the use of risk assessment to derive remedial action goals for eaCh chemical under evaluation. However, EPA regulations still require compliance with ARARs for those chemicals for which ARARs exist. Using the spreadsheet that has been developed, it is possible to initially evaluate cleanup levels equivalent to ARARs for those chemicals for which ARARs are available, and to derive risk-based limits for the remaining compounds. The integrated format of the spreadsheet facilitates balancing target levels for chemicals and exposure routes in order to achieve the overall target risk level. To meet an overall lifetime target risk level of 10^{-6}, it may be necessary to set remedial action goals at levels more stringent than the ARARs identified. The revised NCP clearly addresses this issue:

> "In general, chemical-specific ARARs are set for a single chemical or closely related group of chemicals. These requirements typically do not consider the mixtures of chemicals and other conditions [e.g., multiple pathways of exposure] that may be found at CERCLA sites. Therefore, due to site-specific factors, remediation goals set at the level of single chemical-specific requirements (i.e., ARARs) may not adequately protect human health or the environment at that site. In these instances, remediation goals may be set below the chemical-specific requirements (i.e., at more stringent levels) in order to obtain a remedy that is protective."

As noted earlier, EPA considers an excess lifetime risk of 10^{-4} to 10^{-7} to be acceptable for combined exposure to carcinogens. EPA recommends the 10^{-6} risk level as a first cut or "point of departure" in risk assessment and risk management of hazardous waste sites (Refs. 47, 51). The risk level may be adjusted on a site-specific basis to a higher or lower level.

Factors that are considered in adjusting the risk level include: (1) sensitivities of the population at risk or other non-site-related health risks experienced; (2) effects on nonhuman receptors; (3) weight of evidence (uncertainty) of toxicity information; (4) potential for actual exposure; and (5) the ability to detect/monitor the chemicals under evaluation. Technical feasibility and cost-effectiveness may also come into play in adjusting the target risk level. In any case, when the target risk level is adjusted, it is important that sufficient justification be provided.

The 10^{-6} excess lifetime risk level is used in this analysis to develop preliminary/example remedial action goals at SDA. The toxicity endpoint of concern is cancer incidence for both radioactive and nonradioactive compounds present at the SDA. The risk estimates in this analysis consider the excess or incremental probability that an individual will experience cancer of any type following contact with SDA contaminants. The exposure scenarios discussed in Section 4.2.4 form the basis for all dose estimates. Section 4.2.2 provided an overview of methods for risk characterization.

In this preliminary phase of the site remediation process, target cleanup levels are being established separately for radionuclides and nonradioactive chemicals. No published guidance is available from EPA or DOE and no precedent has been set in the scientific literature for combining estimates of excess lifetime risk of cancer for simultaneous exposure to these classes of carcinogens. The spreadsheet analysis designed for this report (described in SEction 4.2.6) allows the user to derive remediation goals independently for radionuclides and nonradioactive compounds and to jointly consider the contributions made by these compounds.

In order to achieve an overall excess lifetime risk level of 10^{-6}, the analysis in this report allocates one-half of this risk (i.e., 0.5×10^{-6}) for exposure to radioactive elements, and one-half of the risk for exposure to nonradioactive chemicals. For each class of compounds, this risk level (i.e., 0.5 x 10^{-6}) will again be divided, this time across related exposure pathways. Half of this risk level (i.e., 0.25 x 10^{-6}) will be apportioned to the groundwater and showering routes, and half to the soil ingestion and inhalation routes. This apportioning is arbitrary as current information is insufficient to determine the contribution of each compound and each exposure pathway to total risk. This apportioning can be adjusted once additional information on contaminant concentrations and exposure pathways is available.

There are a number of ways of apportioning the total risk level across chemicals and "translating" this into remediation goals (Ref. 47). In the Superfund Public Health Evaluation Manual, EPA offers two simple approaches for consideration. The first method (for a single exposure pathway) is simply to divide the target carcinogenic risk level by the number of subject chemicals that are potential carcinogens. Once the target risk is determined for each chemical, the target cleanup levels in the environment are back-calculated given a knowledge of the chronic daily intake and the carcinogenic potency factors. (A similar procedure could also be used for radionuclides). EPA notes that this approach is simple and conservative, ensuring that the target risk will not be exceeded if the target intakes are attained. The EPA acknowledges, however, that this may not necessarily result in the most efficient or cost-effective engineering design for a given remedial action alternative.

The second method suggested by EPA is to let one or two chemicals drive the design process. For example, one or two compounds may be particularly difficult to treat or especially toxic (i.e., highly potent carcinogens). Cleanup levels for especially toxic chemicals might need to be extremely low so that the total risk falls within the established target risk range whereas a higher level might be established for a difficult to treat compound. Thus, by designing remedial action alternatives to reduce environmental concentrations of these chemicals to within the target range, levels of other subject chemicals may become negligible by default. The FS engineers would refine the remedial action alternative's design iteratively so that combined exposures from the various routes achieve target risk levels (or fall within a target risk range). These adjustments would be made based on an understanding of the exposure pathways of greatest risk, an understanding of the exposure pathways of greatest risk, and the most cost-effective design alternatives. This effort would occur in the screening and detailed analysis of remedial alternatives.

The methods used herein for the SDA are a synthesis and expansion of the example approaches provided by EPA. In this particular approach, remediation goals are derived separately for two classes: radionuclides and nonradioactive chemicals. A target risk level of 0.25×10^{-6} is apportioned across all subject chemicals in each class (radioactive or nonradioactive) in each related exposure pathway [e.g., 0.25×10^{-6} to ingestion of groundwater and inhalation of volatiles from showering (chemicals) and 0.25×10^{-6} to soil ingestion and inhalation (radionuclides), etc.]. Using the target risk level in a given exposure route for a particular class of compounds, it is then possible to back-calculate corresponding concentration in soil and groundwater. The apportioned target risk level for a given chemical and a given exposure pathway is calculated as follows:

$$\text{Apportioned Target Risk} = \frac{0.25 \times 10^{-6}}{\text{No. of "chemical-routes"}} \tag{7}$$

As noted earlier, human receptors at the SDA are potentially exposed to contaminants in soil and groundwater via four pathways: ingestion of soil dust, inhalation of soil dust, ingestion of groundwater, and inhalation of volatiles during showering. However, as discussed in Section 4.2.4, humans are not anticipated to be exposed to all subject chemicals by all of these exposure routes. Showering will result in substantial exposure only for the volatile organic compounds found in groundwater. Radionuclides and nonradioactive inorganics are not included in the showering pathway (except for tritium).

Equation (7) above is used to apportion target risk as a function of the number of chemicals and exposure pathways. The equation should be viewed as deriving the target risk per "chemical-route." The number of "chemical-routes" is determined as the sum of the products of number of carcinogenic chemicals (with common exposure routes) times the number of exposure routes. Specifically:

- <u>Groundwater and showering</u>

  Organics: 4 chemicals x 2 exposure routes = 8 "chemical-routes"
  Inorganics: 1 chemical x 1 exposure route = 1 "chemical-route"
  TOTAL: 8 + 1 = 9 "chemical-routes"

  Radionuclides:
  1 chemical x 1 exposure route (Sr-90) = 1 "chemical-route"
  1 chemical x 2 exposure routes (Tritium) = 2 "chemical-routes"
  TOTAL: 1 + 2 = 3 "chemical-routes"

- <u>Soil ingestion and inhalation</u>

  Organics: 3 chemicals x 2 exposure routes = 6 "chemical-routes"
  TOTAL: 6 "chemical-routes"

  Radionuclides: 8 nuclides x 2 exposure routes = 16 "chemical-routes"
  TOTAL: 16 "chemical-routes"

Equation (7) is used to calculate the apportioned target risk per "chemical-route" separately for: (1) the groundwater and showering pathways; and (2) the soil ingestion and soil inhalation pathways. Using the apportioned target risk level, preliminary/example risk-based remedial action goals are then developed for each chemical. These preliminary goals, along with the spreadsheet program in Section 4.2.6, can be used to derive final remedial action goals.

The preliminary risk-based cleanup levels or remedial action objectives are calculated for nonradioactive chemicals from the apportioned target risk level using the following equations for groundwater:

$$RGNR_{GWi} = \frac{(NCR) \times \text{Apportioned Target Risk}_{(\text{chemical } i)}}{(CPF_{Oi} \times DWIF) + (CPF_{Ii} \times INSHW)} \qquad (8)$$

where

$RGNR_{GWi}$ = Preliminary remediation goal for chemical i in groundwater. Units: mg/L

NCR = Number of "chemical-routes"

CPF_{Oi} = Cancer potency factor for chemical i, oral exposure route (i.e., q_1* defined in equation 1 above). Units: $(mg/kg/day)^{-1}$

CPF_{Ii} = Cancer potency factor for chemical i, inhalation exposure route (i.e., q_1* defined in equation 1 above). Units: $(mg/kg/day)^{-1}$

DWIF = Drinking water intake factor. Units: L/kg-day

INSHW = Intake factor for showering exposure pathway. (Converts mg chemical per liter of groundwater/shower water to dose via inhalation). Units: L/kg-day.

Note that the remedial action goals for groundwater must reflect the contribution to total exposure both from direct ingestion of drinking water as well as inhalation of site-related organic chemicals during showering.

The preliminary remedial action objectives for soil (nonradioactive chemicals) are derived using a similar equation:

$$RGNR_{Si} = \frac{(NCR) \times \text{Apportioned Target Risk}_{(\text{chemical } i)}}{(CPF_{Oi} \times SIF) + (CPF_{Ii} \times INSP)} \qquad (9)$$

where

$RGNR_{Si}$ = Preliminary remediation goal for chemical i in soil. Units: mg/kg

NCR = Number of "chemical-routes"

CPF_{Oi} = Cancer potency factor for chemical i, oral exposure route (i.e., q_1* defined in equation 1 above). Units: $(mg/kg/day)^{-1}$

CPF_{Ii} = Cancer potency factor for chemical i, inhalation exposure route (i.e., q_1* defined in equation 1 above). Units: $(mg/kg/day)^{-1}$

SIP = Soil ingestion intake factor.
Units: kg/kg-day
INSP = Intake factor for inhalation of suspended soil dust.
Units: kg/kg-day.

Remedial action goals for soil must reflect the contribution to total exposure from direct ingestion of soil dust as well as inhalation of soil dust.

For radionuclides, preliminary remedial action goals are derived using the following set of equations for groundwater:

$$RGR_{GWi} = \frac{(NCR) \times \text{Apportioned Target Risk}_{(\text{radionuclide } i)}}{RCRF \times [(DWIFR \times DCF_{Oi}) + (INSHWR \times DCF_{Ii})]} \quad (10)$$

where

RGR_{GWi} = Preliminary remediation goal for radionuclide i in groundwater. Units: µCi/L
NCR = Number of "chemical-routes"
RCRF = Cancer risk factor for radionuclides (conversion from rem to excess lifetime cancer risk). Units: cancer risk per rem
DCF_{Oi} = Dose conversion factor for radionuclide i, oral exposure route. Units: rem/µCi
DCF_{Ii} = Dose conversion factor for radionuclide i, inhalation exposure route. Units: rem/µCi
DWIFR = Drinking water intake factor for radionuclide i.
Units: liters
INSHWR = Intake factor for showering exposure pathway for radionuclides (tritium). Units: liters.

For soil:

$$RGR_{GWi} = \frac{(NCR) \times \text{Apportioned Target Risk Radionuclide}_{(\text{chemical } i)}}{RCRF \times [(SIFR \times DCF_{Oi}) + (INSPR \times DCF_{Ii})]} \quad (11)$$

where

RGR_{GWi} = Preliminary remediation goal for radionuclide i in groundwater.
NCR = Number of "chemical-routes"
RCRF = Cancer risk factor for radionuclides (conversion from rem to excess lifetime cancer risk).
DCF_{Oi} = Dose conversion factor for radionuclide i, oral exposure route. Units: rem/μCi
DCF_{Ii} = Dose conversion factor for radionuclide i, inhalation exposure route. Units: rem/μCi
SIFR = Soil intake factor for radionuclides. Units: grams
INSPR = Intake factor for inhalation of suspended soil dust for radionuclides. Units: grams

A complete derivation of equations (8) through (11) is provided in Appendix A. Toxicity measures for nonradioactive chemicals and radionuclides are presented in the next section.

4.2.6 Spreadsheet Risk Analysis

A Lotus 1-2-3 spreadsheet has been developed for deriving remedial action goals at the SDA using the methodology, assumptions, and equations presented in Sections 4.2.1 through 4.2.5. The overall spreadsheet contains a number of tables and spreadsheets all of which are linked for ease of use, to facilitate estimations reflecting revised scenarios or alternate exposure target levels, and to facilitate sensitivity analysis. The basic elements of the spreadsheet are as follows:

- Table of toxicity measures for nonradioactive and radioactive materials. This includes: (1) EPA reference doses (RfDs) for noncarcinogenic effects; (2) carcinogenic potency factors for evaluating carcinogenic effects of nonradioactive materials; (3) dose conversion factors for radionuclides (rem/μCi); and (4) the radionuclide cancer incidence risk factor.

- Table of exposure assumptions for all exposure routes under investigation: (1) ingestion of groundwater; (2) inhalation of organics during showering (use of contaminated groundwater); (3) ingestion of soil dust; and (4) inhalation of soil dust.

- Two spreadsheets for allocating (apportioning) target risk levels to each chemical in exposure route of concern.

- Spreadsheet for converting the apportioned target risk for a given chemical/radionuclide and exposure route to corresponding concentrations in groundwater and soil.

- Spreadsheet for assigning and evaluating cleanup levels (remediation goals) for nonradioactive chemicals in groundwater and soil.

- Spreadsheet for assigning and evaluating cleanup levels (remediation goals) for radionuclides in groundwater and soil.

Each one of these elements is presented in the following discussions.

4.2.6.1 Database of Toxicity Measures

Table 4-1 presents the toxicity measures for compounds of concern at the SDA based on the compounds identified to be present in the environment (Table 2-1) and in the wastes (Table 2-3). As shown, EPA reference doses for noncarcinogenic effects include: (1) acceptable intake values for subchronic (short-term) oral exposure (AIS-oral); (2) acceptable intake values for chronic (long-term) oral exposure (AIC-oral); (3) acceptable intake values for subchronic inhalation exposure (AIS-inhal.); and (4) acceptable intake values for chronic inhalation exposure (AIC-inhal.). These measures were obtained from two primary sources: the EPA Integrated Risk Information System (IRIS) (Ref. 49), and the EPA Superfund Public Health Evaluation Manual (Ref. 47). IRIS is an online data base developed and maintained by EPA, and provides the most current Agency information on toxicity of chemical compounds. If data are not available on IRIS, or are currently under review, the Superfund Public Health Evaluation Manual is used as a secondary source.

Carcinogenic potency factors (q_1*) are also provided in Table 4-1 for use in projecting the excess lifetime risk of cancer associated with exposure to nonradioactive cancer-causing agents. As discussed previously, the cancer potency factors are the 95% upper-bound limit of the slope of the dose-response curve. The EPA Carcinogen Assessment Group (CAG) typically uses a linearized, multistage, low dose extrapolation model in deriving potency factors for carcinogens. Potency factors for the oral and inhalation routes are provided where available.

Table 4-1 includes a listing of dose conversion factors (DCF) required in evaluating the cancer risk of exposure to radionuclides. DCFs were computed from available information (Refs. 93, 94). These factors are specific to the radionuclides under investigation and are derived for the most soluble forms. The cancer risk factor for radionuclides (RCRF) is found at the bottom of column one in Table 4-1. This value, 6.2×10^{-4} per rem, expresses the excess lifetime probability of cancer incidence per rem dose. This is the most current risk factor used by the EPA (Personnel communication, January 1989: Paul Vollique, SAIC, Radiation Advisory Committee of the USEPA Science Advisory Board).

The focus of this present effort is the derivation of remedial action goals for carcinogenic materials. In this preliminary stage, remedial action goals have not been developed for noncarcinogenic compounds or considering noncarcinogenic effects of carcinogenic compounds. All toxicity measures provided are linked to subsequent calculations in the spreadsheet. If new or revised data become available, entry of these values into Table 4-1 in the spreadsheet will result in automatic recalculation and updating of all results that are dependent upon use of the toxicity measures.

4.2.6.2 Exposure Assumptions Spreadsheet

Table 4-2 is a spreadsheet for summarizing all exposure assumptions used in the assessment and for calculating intake factors. As noted in Section 4.2.4, four exposure pathways are considered to be of greatest importance. These are listed in Table 4-2 along with several others that have not presently been incorporated in order to account for these pathways

TABLE 4-1. TOXICITY MEASURES FOR WASTE CONSTITUENTS AND COMPOUNDS DETECTED IN ENVIRONMENTAL MEDIA AT THE SDA

	References Doses (RfD) Noncarcinogenic Effects (a) (mg/kg/day)				Carcinogenic Potency Factors (b) (mg/kg/day)-1		Dose Conversion Factors for Radionuclides	
Chemical	AIS(Oral)	AIC(Oral)	AIS(Inhal)	AIC(Inhal)	q1*(Oral)	q1*(Inhal)	Effective Whole Body Dose Conversion Factor (DCF): Ingestion Expos. (rem/uCi)	Effective Whole Body Dose Conversion Factor (DCF): Inhalation Expos. (rem/uCi)
INORGANICS								
Arsenic	- -	- -	- -	- -	1.75E+00 [A] c,e	1.75E+00 [A] c,g		
Barium	- -	5.10E-02 d	1.40E-03 d	1.40E-04 d				
Beryllium	- -	5.00E-03 c	- -	- -				
Cadmium	- -	2.90E-04 d	- -					
Chloride	- -	- -	- -					
Chromium	- -	1.00E+00 c	- -	5.10E-03 d				
Cobalt	- -	- -	- -	- -				
Copper	- -	3.70E-02 d	- -	1.00E-02 d				
Lead	- -	1.40E-03 d	- -	4.30E-04 d				
Nickel	2.00E-02 d	1.00E-02 d	- -	- -				
Nitrate	- -	1.00E+00 c	- -	- -				
Silver	- -	3.00E-03 c	- -	- -				
Sulfide	- -	- -	- -	- -				
Tin	- -	- -	- -	- -				
Thallium	- -	4.00E-04 d	- -	- -				
Vanadium	- -	2.00E-02 d	- -	- -				
Zinc	2.10E-01 d	2.10E-01 d	1.00E-01 d	1.00E-02 d				
ORGANICS								
Acetone	- -	1.00E-01 d	3.00E+01	3.00E+00 d				
Benzo(k)fluoranthene	- -	- -	- -	- -				
Benzo(a)pyrene	- -	- -	- -	- -	1.15E+01 [B2] d	1.15E+01 [B2] d,g		
Benzoic Acid	- -	- -	- -	- -				
Bis(2-ethylhexyl)phthalate	- -	- -	- -	- -	6.84E-04 [B2] d	6.84E-04 [B2] d,g		
Carbon Tetrachloride	- -	7.00E-04 c	- -	- -	1.30E-01 [B2] c	1.30E-01 [B2] c,g		
Chloroform	- -	1.00E-02 c	- -	- -	8.10E-02 [B2] d	8.10E-02 [B2] d,g		
1,2-Dichlorobenzene	- -	- -	1.38E+00 d	- -				
Dichlorodifluoromethane	- -	2.00E-01 c	- -	- -				
Dichlorofluoromethane	- -	- -	- -	- -				
1,1-Dichloroethane	1.20E+00 d	- -	1.38E+00 d	1.38E-01 d				
1,1-Dichloroethylene	- -	9.00E-03 c	- -	- -	6.00E-01 [C] c	1.16E+00 [C] d		
1,2-Dichloroethylene	- -	- -	- -	- -				
1,2-Dichloropropane	- -	- -	- -	- -				
Methylene Chloride	- -	6.00E-02 d	- -	- -	7.50E-03 [B2] d	7.50E-03 [B2] d,g		
Pentachlorophenol	3.00E-02 d	3.00E-02 d	- -	- -				
Phenol	1.00E-01 d	1.00E-01 d	1.90E-01 d	2.00E-02 d				
Tetrachloroethylene	- -	1.00E-02 c	- -	- -	5.10E-02 [B2] d	1.70E-03 [B2] d		
Toluene	4.30E-01 d	3.00E-01 d	1.50E+00 d	1.50E+00 d				
1,1,1-Trichloroethane	- -	9.00E-02 c	1.10E+01 d	6.30E+00 d				
Trichloroethylene	- -	- -	- -	- -	1.10E-02 [B2] c	4.60E-03 [B2] d		

TABLE 4-1. TOXICITY MEASURES FOR WASTE CONSTITUENTS AND COMPOUNDS DETECTED IN ENVIRONMENTAL MEDIA AT THE SDA (Continued)

	References Doses (RfD) Noncarcinogenic Effects (a) (mg/kg/day)				Carcinogenic Potency Factors (b) (mg/kg/day)-1		Dose Conversion Factors for Radionuclides	
Chemical	AIS(Oral)	AIC(Oral)	AIS(Inhal)	AIC(Inhal)	q1*(Oral)	q1*(Inhal)	Effective Whole Body Dose Conversion Factor (DCF): Ingestion Expos. (rem/uCi)	Effective Whole Body Dose Conversion Factor (DCF): Inhalation Expos. (rem/uCi)
Trichlorofluoromethane	- -	- -	- -	- -				
Trichlorotrifluoroethane	- -	3.00E-01 c	- -	- -				
RADIONUCLIDES								
Americium-241							4.4	1000
Cesium-137							0.05	0.032
Cobalt-57							0.0012	0.0074
Cobalt-60							0.026	0.15
Europium-154							0.0091	0.26
Plutonium-238							3.8	4600
Plutonium-239							4.3	5100
Plutonium-240							4.3	5100
Plutonium-241							0.087	100
Plutonium-242							4	4800
Strontium-90							0.13	1.3
Tritium							0.000063	0.000063
Uranium-233							0.27	130
Uranium-235							0.25	120
Uranium-238							4.3	5100

Cancer Risk Factor for
Radionuclides [RCRF] f:
Excess Lifetime Risk per Rem
6.20E-04 <-------

a. Acceptable intake values or Reference Doses for subchronic and chronic exposure. Evaluation of noncarcinogenic (threshold) effects.
b. Carcinogenic potency factors: 95% upper bound limit of the slope of the dose-response curve. Evaluation of excess lifetime cancer risk (nonthreshold effects).
c. EPA Integrated Risk Information System (IRIS)
d. USEPA 1986 Superfund Public Health Evaluation Manual (Ref.47)
e. Potency factor derived from unit cancer risk estimate of 5 x 10-5/(ug/l). Source: IRIS data base.
f. Cancer risk incidence for all cancers. Source: Personnel communication: Paul Vollique, SAIC, Radiation Advisory Committee, Science Advisory Board, USEPA (Jan. 1989)
g. In the absence of data, the potency factor for the oral route has been adopted for evaluating the inhalation exposure pathway.

- - = Not available

TABLE 4-2. EXPOSURE ASSUMPTIONS

Exposure Pathway	Contact Rate (a)	Units Conversion Factor (b)	Exposure Duration/ Frequency (c)	Absorption Factor/Body Wt. (d)	Intake Factor (e)
Soil Intake (nonrad.): (Long-term, adult) [SIF]	0.1 (g/day)	0.001 (to kg/day)	0.1962	0.0143 (1/70 kg)	2.80E-07 (kg/kg-day)
Soil Intake (rad.) (Long-term, adult) [SIFR]	0.1 (g/day)	1 (no conv.)	5000.00	1.0000 (ab. fctr only)	5.00E+02 (g)
Drinking Water Intake (nonrad.) (Lifetime-Ground Water) [DWIF]	2 (liters/day)	0.001 (ug to mg)	0.1962	0.0143 (1/70 kg)	5.61E-06 (l/kg-day)
Drinking Water Intake (rad.) (Lifetime-Ground Water) [DWIFR]	2 (liters/day)	1 (no conv.)	5000.00	1.0000 (ab. fctr only)	1.00E+04 (liters)
Inhalation Exposure (nonrad): (Showering-volatiles) [INSHW]	4.42 (ug/day)/(ug/L)	0.001 (ug to mg)	0.1962	0.0143 (1/70 kg)	1.24E-05 (l/kg-day)
Inhalation Exposure (rad): (Showering-volatiles) [INSHWR]	4.42 (uCi/day)/(uCi/L)	1 (no conv.)	5000.00	1.0000 (ab. fctr only)	2.21E+04 (liters)
Inhalation Exposure (nonrad): (Soil Particulates) [INSP]	20 (m3/day)	5.00E-08 (TSP in ug/m3) (to kg part./m3)	0.1962	0.0143 (1/70 kg)	2.80E-09 (kg/kg-day)
Inhalation Exposure (rad.): (Soil Particulates) [INSPR]	20 (m3/day)	5.00E-05 (TSP in ug/m3) (to g part./m3)	5000.00	1.0000 (ab. fctr only)	5.00E+00 (g)

a. Contact rate is the quantity of environmental media per unit time with which the receptors come in contact. Values presented here for showering scenarios express exposure concentrations of chemical or radionuclide in indoor shower room air as a function of concentration in shower water. See section on exposure assumption for details on derivation.

b. Units conversion factors are used in converting from environmental concentrations to appropriate units of dose. Conversion factors for inhalation of soil particulates are used in calculating ambient atmospheric levels of soil contaminants.

c. Exposure duration/frequency indicates the length of the exposure period. For nonradioactive chemicals, the exposure duration/frequency factor is defined as follows: 5 days/7 day week x 50 weeks/52 week year x 20 years/70 year lifetime. Note that this factor is a unitless fraction of a 70 year lifetime. For radionuclides, this factor is the total number of exposure days over the 20 year exposure period: 5 days/week x 50 weeks/year x 20 years.

d. Absorption factor is taken to be 100% for all routes. Specifically, it is assumed that all of the chemical in the environment is bioavailable for uptake and adsorption. Dose for nonradiactive chemicals must be expressed on a per kg body weight basis. Body weight of 70 kg is assumed for all receptors.

e. For each exposure route, the intake factor is calculated as the product of the four previous factors discussed above. These intake factors are used in subsequent spreadsheets to calculate target risk levels and remediation goals.

if later found to be important. The purpose of this worksheet is to derive intake factors for use in subsequent calculations of dose. The intake factor is generally defined by EPA as the quantity of environmental medium to which a receptor at risk of exposure may come in contact (for example, 2 liters of water per day for ingestion exposure to drinking water supplies). In this assessment of the SDA Facility, the intake factor (IF) incorporates a number of other variables.

The intake factors are calculated as the product of four components: (1) contact rate; (2) unit or media conversion factors; (3) exposure duration; and (4) absorption factor divided by body weight. The product of these four variables yields the intake factors shown in the last column. The intake factors used in calculation of dose are linked to other component spreadsheets. Dose estimates will automatically reflect any changes in exposure assumptions entered into Table 4-2.

4.2.6.3 Target Risk Level Allocation Spreadsheets

Tables 4-3 and 4-4 are small spreadsheets for calculating target risk levels for radionuclides and nonradioactive chemicals. As discussed in Section 4.2.5, the 10^{-6} risk level is taken here as the overall benchmark for acceptable excess lifetime risk of cancer. As a starting point, this risk level has been apportioned equally between nonradioactive chemicals and radionuclides. This allocated risk level (i.e., $10^{-6}/2$ or 0.5×10^{-6}) is then further divided between environmental media/exposure routes within each chemical class.

The resultant risk level (0.25×10^{-6}) is the apportionment for groundwater and showering, and for soil ingestion and inhalation pathways (see Tables 4-3 and 4-4). The target risk for each chemical is then determined by dividing this resultant risk level by the product of the number of <u>carcinogens</u> (for that particular set of exposure pathways) times the number of exposure pathways. This number is found in the last column of Tables 4-3 and 4-4. This is a somewhat simplistic approach to allocating target risk levels for each chemical. The apportionment is arbitrary given the current limited data base. However, it should only be considered a starting point and refinements can be included in subsequent analyses/iterations.

TABLE 4-3. CALCULATION OF TARGET RISK LEVEL FOR NONRADIOACTIVE COMPOUNDS

Overall Target Risk Level		Number of Carcinogens (Nonradio.) (a)	Number of Exposure Routes (b)	Target Risk for each Nonradioactive Carcinogen (c)
Ground water and showering				
2.50E-07	VOCs	4	2	2.78E-08
	Arsenic	1	1	
Soil ingestion and inhalation				
2.50E-07		3	2	4.17E-08

a. Number of nonradioactive carcinogens of concern via the designated route.
b. Number of routes by which the exposure to the chemical may occur.
c. Target risk for each chemical is calculated as the overall target risk level divided by the sum of the products of the number of carcinogens x number of exposure routes.

TABLE 4-4. CALCULATION OF TARGET RISK LEVEL FOR RADIONUCLIDES

Overall Target Risk Level		Number of Carcinogens (Radionucl.) (a)	Number of Exposure Routes (b)	Target Risk for each Radionuclide (c)
Ground water and showering				
2.50E-07	All others	8	1	2.50E-08
	Tritium	1	2	
Soil ingestion and inhalation				
2.50E-07		8	2	1.56E-08

a. Number of radioactive carcinogens of concern via the designated route.
b. Number of routes by which the exposure to the radionuclide may occur.
c. Target risk for each chemical is calculated as the overall target risk level divided by the sum of the products of the number of carcinogens x number of exposure routes.

4.2.6.4 Risk Level to Environmental Concentration Conversion Spreadsheet

In Table 4-5, the target risk levels calculated for each subject chemical (from Tables 4-3 and 4-4) are used to derive a corresponding concentration in the groundwater and soil for each carcinogenic chemical detected. The equations for derivation of these values were presented in Section 4.2.5. The concentrations developed in Table 4-5 should be considered preliminary/example estimates of cleanup levels or remedial action goals. Note that calculation of these preliminary remedial action goals are linked to the toxicity measures provided in Table 4-1, the exposure assumptions in Table 4-2, and the apportioned target risk levels derived for each chemical in Tables 4-3 and 4-4.

4.2.6.5 Action Level Spreadsheets

Tables 4-6 and 4-7 are blank examples and are the core of the overall spreadsheet system. These tables are in themselves small spreadsheets to be used in refining the preliminary remedial action goals and in deriving final target cleanup levels. The final target levels selected should incorporate consideration of technical feasibility and cost-effectiveness.

Initially, the preliminary remedial action goals derived in Table 4-5 are carried over to Tables 4-6 and 4-7 into the columns entitled "Remediation Goals for Groundwater" and "Remediation Goals for Soil." The area of the spreadsheets into which proposed cleanup levels are entered is enclosed by a box. (A "macro" has been created in the Lotus spreadsheet that will automatically transfer the risk-based values from Table 4-5 to Tables 4-6 and 4-7.) Once these values are entered into these columns, the spreadsheets (Tables 4-6 and 4-7) calculate the following measures:

- Corresponding lifetime dose from ingestion of groundwater
- Corresponding lifetime dose from showering
- Corresponding lifetime dose from ingestion of soil dust
- Corresponding lifetime dose from inhalation of soil dust

TABLE 4-5. CONVERSION OF TARGET RISK TO ENVIRONMENTAL CONCENTRATIONS FOR CARCINOGENIC NONRADIOACTIVE CHEMICALS AND RADIONUCLIDES

Chemical	Concentrations Corresponding to Target Risk Level: Ground Water (b)	Concentrations Corresponding to Target Risk Level: Soil (b)
INORGANICS (ug/L in ground water, mg/kg in soil)		
Arsenic	2.83E-03	
ORGANICS (ug/L in ground water, mg/kg in soil)		
Carbon Tetrachloride	2.37E-02	2.26E+00
Chloroform	3.81E-02	
1,1-Dichloroethylene (c)		
Methylene Chloride (c)		
Tetrachloroethylene	1.81E-01	5.83E+00
Trichloroethylene	4.68E-01	2.69E+01
RADIONUCLIDES (uCi/L in ground water, uCi/g in soil)		
Americium-241		7.00E-09
Cesium-137		2.00E-06
Cobalt-57		
Cobalt-60		3.67E-06
Europium-154		8.62E-06
Plutonium-238		2.02E-09
Plutonium-239		1.82E-09
Plutonium-240		1.82E-09
Strontium-90	1.03E-07	7.05E-07
Tritium	1.33E-04	

a. The concentrations calculated are conservatively based on equal apportionment of risk between nonradioactive chemicals and radionuclides as classes of chemicals. These calculations must be considered a starting point in the process of deriving remediation goals. These values serve primarily to illustrate the process, and may be subsequently refined based on changes in apportioned risk between classes of compounds and exposure routes under evaluation.

b. Concentration for nonradionuclides corresponding to target risk levels (i.e., derived in Table 4-3) are calculated using equations 8 and 9, Section 4.2.5. Concentrations for radionuclides corresponding to target risk levels (i.e., derived in Table 4-4) are calculated using equations 10 and 11, Section 4.2.5.

c. These potentially carcinogenic chemicals have been found in the waste but have not been detected in the environment at this time.

TABLE 4-6. EXAMPLE OF SPREADSHEET TO PROVIDE EVALUATION OF REMEDIATION GOALS FOR CARCINOGENIC NONRADIOACTIVE CHEMICALS

				Ground Water Exposure		Soil Exposure			
Chemical	Excess Lifetime Cancer Risk per Chemical: Combined Across Ingestion and Inhalation Paths (b)	Remediation Goals for Ground Water (ug/L)	Remediation Goals for Soil (mg/kg)	Corresponding Lifetime Dose from Ingestion of Ground Water (mg/kg/day) (d)	Corresponding Lifetime Dose from Showering (mg/kg/day) (e)	Corresponding Lifetime Dose from Ingestion of Soil (mg/kg/day) (f)	Corresponding Lifetime Dose from Inhalation of Soil Partic. (mg/kg/day) (g)	Excess Lifetime Cancer Risk: Ingestion Exposure (a)	Excess Lifetime Cancer Risk: Inhalation Exposure (a)
INORGANICS									
Arsenic	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ORGANICS									
Carbon Tetrachloride	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Chloroform	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,1-Dichloroethylene	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Methylene Chloride	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tetrachloroethylene	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Trichloroethylene	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Excess Lifetime Cancer Risk (c): Combined Exposure Across Chemicals and Exposure Pathways	0.00E+00								

a. Excess lifetime risk of cancer to the individual. Risk estimates calculated as product of chronic dose x the carcinogenic potency factor. See eq. 1, Section 4.2.2. Dose for ingestion exposure is the sum of doses for ground water and soil ingestion. Dose for inhalation exposure is the sum of doses for inhalation of volatiles during showering, and suspended/airborne soil particulates.

b. Combined excess lifetime risk for a given chemical is calculated as the sum of the last two columns in this table.

c. Excess lifetime risk combined across chemicals and exposure pathways is the sum of the estimates in the column above.

d. Dose estimated as the product of concentration in ground water x drinking water intake factor for nonradioactive chemicals (Table 4-2.)

e. Dose estimated as the product of concentration in ground water x intake factor for showering for nonradioactive chemicals (Table 4-2.)

f. Dose estimated as the product of concentration in soil x soil intake factor for nonradioactive chemicals (Table 4-2.)

TABLE 4-7. EXAMPLE OF SPREADSHEET TO PROVIDE EVALUATION OF REMEDIATION GOALS FOR RADIONUCLIDES

				Ground Water Exposure		Soil Exposure			
Chemical	Excess Lifetime Cancer Risk per Chemical: Combined Across Ingestion and Inhalation Paths (b)	Remediation Goals for Ground Water (uCi/L)	Remediation Goals for Soil (uCi/g)	Corresponding Lifetime Dose from Ingestion of Ground Water (rem) (d)	Corresponding Lifetime Dose from Showering (rem) (e)	Corresponding Lifetime Dose from Ingestion of Soil (rem) (f)	Corresponding Lifetime Dose from Inhalation of Soil Partic. (rem) (g)	Excess Lifetime Cancer Risk: Ingestion Exposure (a)	Excess Lifetime Cancer Risk: Inhalation Exposure (a)
Americium-241	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cesium-137	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cobalt-57	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cobalt-60	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Europium-154	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Plutonium-238	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Plutonium-239	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Plutonium-240	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Strontium-90	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tritium	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Excess Lifetime Cancer Risk (c): Combined Exposure Across Chemicals and Exposure Pathways	0.00E+00

a. Excess lifetime risk of cancer to the individual. Risk estimates calculated as product of chronic dose x the carcinogenic potency factor. See eq. 4, Section 4.2.2. Dose for ingestion exposure is the sum of doses for ground water and soil ingestion. Dose for inhalation exposure is the sum of doses for inhalation of volatiles (tritium) during showering, and suspended/airborne soil particulates.

b. Combined excess lifetime risk for a given nuclide is calculated as the sum of the last two columns in this table.

c. Excess lifetime risk combined across radionuclides and exposure pathways is the sum of the estimates in the column above.

d. Dose estimated as the product of concentration in ground water x drinking water intake factor for radionuclides (Table 4-2.)

e. Dose estimated as the product of concentration in ground water x intake factor for showering for radionuclides (Table 4-2.)

f. Dose estimated as the product of concentration in soil x soil intake factor for radionuclides (Table 4-2.)

g. Dose estimated as the product of concentration in soil x intake factor for inhalation of soil particulates for radionuclides (Table 4-2.)

- Excess lifetime cancer risk for ingestion exposure (i.e., ingestion of groundwater and soil dust)

- Excess lifetime cancer risk for inhalation exposure (i.e., inhalation of volatiles from showering and suspended soil dust)

- Excess lifetime cancer risk per chemical combined across all four ingestion and exposure pathways.

The final measure calculated, and the most important indicator of acceptability of the remedial action goals, is the excess lifetime cancer risk combined across chemicals and exposure pathways. This value is shown at the bottom of column two in both Tables 4-6 and 4-7. All elements in each of these tables are linked. By varying the magnitude of the remedial action goals (i.e., columns three and four of the tables), the effects are automatically reflected throughout the spreadsheets and, most importantly, in the combined risk estimate at the bottom of column two.

4.2.7 Derivation of Preliminary/Example Remedial Action Goals

Preliminary chemical-specific remedial action goals have been derived for nonradioactive and radioactive compounds in groundwater and soils of the SDA. In this initial effort, the focus is on demonstrating the utility of the methodology developed. At present, the cleanup levels derived must be considered preliminary/example remedial action goals and are for illustrative purposes only. The levels calculated are very stringent and reflect the conservative assumptions adopted in this initial assessment. As noted previously, only carcinogenic materials are currently included in the evaluation; inclusion of noncarcinogenic effects or additional exposure pathways will result in decreasing the concentrations of each compound.

The process for deriving remedial action goals is complex when many chemicals and exposure routes must be considered simultaneously. It was important, therefore, to establish methods that can readily accommodate changes in the many underlying assumptions. The computer spreadsheet developed by SAIC readily facilitates evaluation of changes in any of the assumptions and is a valuable tool for balancing considerations of protectiveness, cost, and technical feasibility.

Table 4-8 is the spreadsheet used in deriving remedial action goals for nonradioactive carcinogens found at SDA. The values shown in columns three and four (i.e., remediation goals for groundwater and remediation goals for soil) are the preliminary/example cleanup levels. As shown, the remediation goals for groundwater are in units of μg/L and for soil in units of mg/kg.

Table 4-9 is the component spreadsheet used in deriving remedial action goals for radionuclides present in groundwater and soils at the SDA. Again, the values shown in columns three and four are the preliminary/example cleanup levels. The remediation goals for groundwater are in units of μCi/L, and for soil in units of μCi/g.

In examining these levels it is important to review the exposure and risk apportionment assumptions used in this assessment (see Section 4.2.2.2). The key point to remember is that the cleanup levels reflect combined exposure across multiple chemicals and pathways, and <u>equal apportionment</u> of risk between nonradioactive chemicals and radionuclides (as classes of compounds).

An overall target risk level of 10^{-6} (excess lifetime risk of cancer) was established as the basis of this initial effort. Half of this risk level (5×10^{-7}) was established for exposure to the nonradioactive chemicals and half to radionuclides. Half of this amount (i.e., 2.5×10^{-7}) was then allocated to (1) the groundwater and shower inhalation routes, and half to (2) the soil ingestion and inhalation of soil particulates routes. This allocation of 2.5×10^{-7} risk was then used to apportion risk for each "chemical-route." Finally, the apportioned risk for each chemical-route was used in developing preliminary/example remedial action goals for the compounds under evaluation. Only carcinogens detected in soil or groundwater are used; noncarcinogenic effects were not considered.

Two points of importance must be noted with regard to this allocation of excess lifetime risk. First, EPA guidance specifies that the range of 10^{-4} to 10^{-7} is considered protective of human health and should serve as a basis for selecting remedial action alternatives. Because the 10^{-6} risk level is considered a "point of departure" by EPA in conducting risk assessments at waste sites, this risk level was selected as a starting point

TABLE 4-8. PRELIMINARY REMEDIATION GOALS FOR CARCINOGENIC NONRADIOACTIVE CHEMICALS

				Ground Water Exposure		Soil Exposure			
Chemical	Excess Lifetime Cancer Risk per Chemical: Combined Across Ingestion and Inhalation Paths (b)	Remediation Goals for Ground Water (ug/L)	Remediation Goals for Soil (mg/kg)	Corresponding Lifetime Dose from Ingestion of Ground Water (mg/kg/day) (d)	Corresponding Lifetime Dose from Showering (mg/kg/day) (e)	Corresponding Lifetime Dose from Ingestion of Soil (mg/kg/day) (f)	Corresponding Lifetime Dose from Inhalation of Soil Partic. (mg/kg/day) (g)	Excess Lifetime Cancer Risk: Ingestion Exposure (a)	Excess Lifetime Cancer Risk: Inhalation Exposure (a)
INORGANICS									
Arsenic	2.78E-08	2.83E-03		1.59E-08	0.00E+00	0.00E+00	0.00E+00	2.78E-08	0.00E+00
ORGANICS (h)									
Carbon Tetrachloride	1.39E-07	2.37E-02	2.26E+00	1.33E-07	2.94E-07	6.35E-07	6.35E-09	9.98E-08	3.91E-08
Chloroform	5.56E-08	3.81E-02		2.14E-07	4.72E-07	0.00E+00	0.00E+00	1.73E-08	3.82E-08
1,1-Dichloroethylene	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Methylene Chloride	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tetrachloroethylene	1.39E-07	1.81E-01	5.83E+00	1.01E-06	2.24E-06	1.63E-06	1.63E-08	1.35E-07	3.84E-09
Trichloroethylene	1.39E-07	4.68E-01	2.69E+01	2.62E-06	5.80E-06	7.54E-06	7.54E-08	1.12E-07	2.70E-08
Excess Lifetime Cancer Risk (c): Combined Exposure Across Chemicals and Exposure Pathways	5.00E-07								

a. Excess lifetime risk of cancer to the individual. Risk estimates calculated as product of chronic dose x the carcinogenic potency factor. See eq. 1, Section 4.2.2. Dose for ingestion exposure is the sum of doses for ground water and soil ingestion. Dose for inhalation exposure is the sum of doses for inhalation of volatiles during showering, and suspended/airborne soil particulates.

b. Combined excess lifetime risk for a given chemical is calculated as the sum of the last two columns in this table.

c. Excess lifetime risk combined across chemicals and exposure pathways is the sum of the estimates in the column above.

d. Dose estimated as the product of concentration in ground water x drinking water intake factor for nonradioactive chemicals (Table 4-2.)

e. Dose estimated as the product of concentration in ground water x intake factor for showering for nonradioactive chemicals (Table 4-2.)

f. Dose estimated as the product of concentration in soil x soil intake factor for nonradioactive chemicals (Table 4-2.)

g. Dose estimated as the product of concentration in soil x intake factor for inhalation of soil particulates for nonradioactive chemicals (Table 4-2.)

h. Note: 1,1-Dichloroethylene and methylene chloride are potentially carcinogenic chemicals that have been found in the waste. At this time however, these compounds have detected in the environment.

TABLE 4-9. PRELIMINARY REMEDIATION GOALS FOR RADIONUCLIDES

				Ground Water Exposure		Soil Exposure			
Chemical	Excess Lifetime Cancer Risk per Chemical: Combined Across Ingestion and Inhalation Paths (b)	Remediation Goals for Ground Water (uCi/L)	Remediation Goals for Soil (uCi/g)	Corresponding Lifetime Dose from Ingestion of Ground Water (rem) (d)	Corresponding Lifetime Dose from Showering (rem) (e)	Corresponding Lifetime Dose from Ingestion of Soil (rem) (f)	Corresponding Lifetime Dose from Inhalation of Soil Partic. (rem) (g)	Excess Lifetime Cancer Risk: Ingestion Exposure (a)	Excess Lifetime Cancer Risk: Inhalation Exposure (a)
Americium-241	3.13E-08		7.00E-09	0.00E+00	0.00E+00	1.54E-05	3.50E-05	9.55E-09	2.17E-08
Cesium-137	3.13E-08		2.00E-06	0.00E+00	0.00E+00	5.01E-05	3.21E-07	3.11E-08	1.99E-10
Cobalt-57	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cobalt-60	3.13E-08		3.67E-06	0.00E+00	0.00E+00	4.77E-05	2.75E-06	2.95E-08	1.70E-09
Europium-154	3.13E-08		8.62E-06	0.00E+00	0.00E+00	3.92E-05	1.12E-05	2.43E-08	6.94E-09
Plutonium-238	3.12E-08		2.02E-09	0.00E+00	0.00E+00	3.85E-06	4.66E-05	2.38E-09	2.89E-08
Plutonium-239	3.13E-08		1.82E-09	0.00E+00	0.00E+00	3.92E-06	4.65E-05	2.43E-09	2.88E-08
Plutonium-240	3.13E-08		1.82E-09	0.00E+00	0.00E+00	3.92E-06	4.65E-05	2.43E-09	2.88E-08
Strontium-90	1.15E-07	1.03E-07	7.05E-07	1.34E-04	0.00E+00	4.58E-05	4.58E-06	1.12E-07	2.84E-09
Tritium	1.67E-07	1.33E-04		8.37E-05	1.85E-04	0.00E+00	0.00E+00	5.19E-08	1.15E-07

Excess Lifetime Cancer Risk (c): Combined Exposure Across Chemicals and Exposure Pathways	5.00E-07

a. Excess lifetime risk of cancer to the individual. Risk estimates calculated as product of chronic dose x the carcinogenic potency factor. See eq. 4, Section 4.2.2. Dose for ingestion exposure is the sum of doses for ground water and soil ingestion. Dose for inhalation exposure is the sum of doses for inhalation of volatiles (tritium) during showering, and suspended/airborne soil particulates.
b. Combined excess lifetime risk for a given nuclide is calculated as the sum of the last two columns in this table.
c. Excess lifetime risk combined across radionuclides and exposure pathways is the sum of the estimates in the column above.
d. Dose estimated as the product of concentration in ground water x drinking water intake factor for radionuclides (Table 4-2.)
e. Dose estimated as the product of concentration in ground water x intake factor for showering for radionuclides (Table 4-2.)
f. Dose estimated as the product of concentration in soil x soil intake factor for radionuclides (Table 4-2.)
g. Dose estimated as the product of concentration in soil x intake factor for inhalation of soil particulates for radionuclides (Table 4-2.)

in the derivation of remediation goals at the SDA. However, this target risk level may be adjusted. As noted previously, factors that may influence the selection of the target risk level include: (1) potential for actual exposure; (2) uncertainty in toxicity information (e.g., weight of evidence of carcinogenicity); and (3) the ability to detect/monitor contamination. Thus, given the availability of additional information on activities and levels of contamination at SDA, it may be found appropriate to revise the target risk level (e.g., upward of 10^{-5} or 10^{-4}).

Secondly, the method used to apportion risk across classes of compounds and exposure pathways is a simplified approach that will be refined as more information becomes available. Ideally, the allocation of risk should be weighted based on several factors:

- The relative quantity of nonradioactive chemicals and radionuclides present in all environmental media at the SDA
- The relative importance of each exposure pathway
- The toxicity or relative carcinogenic potency of the contaminants under evaluation
- The mobility and persistence of the subject compounds in the environment
- The relative exposure potential for nonradioactive chemicals vs. radionuclides.

Given the limited available information, and the need to introduce and demonstrate the methods developed herein, further refinement of the risk allocation process was not considered appropriate at this time.

When sufficient data are available to address all of the above considerations, target risk levels may be apportioned more realistically. At that point, it will be meaningful to examine the available ARARs and their utility in deriving final remediation goals. Specifically, the ARARs will be entered into Tables 4-6 and 4-7. The influence of the magnitude of these values on the projected excess combined lifetime carcinogenic risk may then be evaluated. As noted previously, ARARs are not available for all chemicals and environmental media of concern at the SDA. Therefore, the water quality ARARs that are available cannot solely form the basis for final cleanup levels.

4.3 LOCATION-SPECIFIC REMEDIATION OBJECTIVES

Three location-specific ARARs are identified in Section 3.2 for remedial activities at the SDA. The identified location-specific ARARs regulate waste management and related activities occurring in or involving:

- Floodplains
- Proximity of drinking water wells
- Archaeological Resources and Antiquities.

Identifying remedial action objectives associated with these ARARs involved evaluating the requirements of each regulation and assessing how the requirements can be met. In the case of the location-specific ARARs identified for the SDA, the remedial action objectives are rather straightforward and have been derived based on the regulatory assessment in Section 3.2. These objectives are summarized below:

1. Floodplains

   Goal: Environmental/Facility Protection

   Objective: Site any new waste management facilities outside the 100-year floodplain in accordance with RCRA and State of Idaho hazardous waste management regulations.

   Note: It is reasonable to expect that new waste management facilities will have to be constructed at the SDA, which is within the 100-year floodplain. However, potential flooding is controlled by the diversion system to the west of the SDA; therefore, facilities in the SDA may be considered to be "outside" the 100-year floodplain as long as the diversion system is adequate to control a 100-year flood on the Big Lost River with no impact on the SDA. Runon/runoff controls would be action-specific requirements.

2. Proximity of Drinking Water Wells

<u>Goal</u>: Human Health Protection

<u>Objective</u>: When in the proximity of a drinking water well, construct any sewer lines, canals, ditches and other specified structures in accordance with the minimum distances required by the Idaho Drinking Water Regulations (IDAPA 16.01.8900,07). Specified minimum distances from a well for applicable structures include:

• Sewer line	50 feet
• Canals, streams, ditches, lakes	50 feet.

Any new drinking water wells constructed at the SDA must also comply with these minimum distance requirements.

3. Archaeological Resources and Antiquities

<u>Goal</u>: Resource Protection

<u>Objective</u>: Actions should not cause irreparable harm, loss, or destruction of archaeological artifacts and antiquities. If such resources are encountered during remedial activities, appropriate procedures should be followed and actions taken to evaluate and protect this material.

5. GENERAL RESPONSE ACTIONS

General response actions are media-specific treatments that address site problems and satisfy a remedial action objective. Remedial action objectives include higher level goals such as those which define protection of health and environment at the site and more specific goals such as technical and location requirements and clean-up standards for specific media. Identification of general response actions is an initial step in the process for developing remedial action alternatives and each general response action is comprised of diverse technology types. As suggested in EPA Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA (Ref. 48), the general response actions are intended to provide the decisionmaker with a range of options which protect the public health and the environment. At the Subsurface Disposal Area (SDA), identification of these actions is the first step of an iterative process which procedes from identification of broadly defined objectives and general response actions to selection of media-specific clean up levels and remedial action alternatives. Incorporation of data from ongoing site investigations is provided for in this iterative process.

The following sections describe this process and identify the general response actions identified for the SDA based on the information presented in Sections 2 through 4. Section 5.1 describes the general response actions identification process. Section 5.2 describes the remediation scenarios considered in this analysis. Section 5.3 presents the general response actions identified for the SDA.

5.1 GENERAL RESPONSE ACTIONS IDENTIFICATION PROCESS

Identification of general response actions integrates existing site hydrogeologic and contaminant data and characteristics of available treatment technologies with specific objectives which protect public health and the environment. Specific elements of this iterative process include:

- Identification of media of concern
- Identification of contaminants of concern by media
- Development of conceptual site model
- Identification of ARARs

- Identification of remedial action objectives
- Selection of actions which meet objectives.

The first three elements listed incorporate stratigraphic, hydrologic, source term, receptor, and contamination data into a conceptualization of the site problem which allows qualitative and quantitative assesment of health and environmental impacts. At the SDA, elements of the geohydrologic component of the site model remain uncertain. This is due to the high degree of disturbance of the upper soil, the large (88 acre) size of the site, the relative paucity of interpreted data, and the difficulty inherent in characterizing heterogeneous, anisotropic media such as basalt. The conceptual model includes assessment of both health and environmental risk which in turn provide the basis for identification of the protective requirements and remediation objectives which are the design basis for the potential actions. This conceptual site model is described in more detail in Section 2.2 of this report.

In this initial phase of the RI/FS process, the conceptual model is lacking in detail, therefore, the associated remedial action objectives are necessarily preliminary in nature and the identified actions are broad groupings of types of technologies. In later phases of the CERCLA RI/FS process, additional site data and preliminary screening of technologies will be integrated with site modeling projections of excess lifetime risk to assess combinations of clean-up levels and alternative technologies.

5.2 REMEDIATION SCENARIOS

The complexity of the many factors considered in the CERCLA RI/FS process at the SDA led to the development of two separate scenarios for evaluation. The first scenario takes as the starting point the SDA as it now exists and assumes no removal of buried waste. The media and contaminants of concern are described in Section 2.1 and the primary source waste is described in Section 2.2. The primary waste source is considered to be the unmobilized, non-degraded component of material in the chemical/physical state originally emplaced at the site. Secondary contaminant sources are considered to be materials derived from the primary source by mobilization, change in physical state, degradation, or chemical or biological reaction. Examples of secondary sources include radionuclide contaminated soil and organic vapor plumes migrating from the original source location. These secondary sources may be the source of continued contaminant migration should the source waste be removed.

The second scenario takes as the starting point a site (the SDA) from which the source waste material has been removed. This second scenario covers each of the media considered in the first scenario along with same exposure pathways and environmental and human receptors but deals only with the known secondary waste sources and does not address containment or in situ treatment of the source waste.

The first scenario will be referred to in this report as the waste-in-place scenario while the second scenario will be referred to as the waste removed scenario. This report does not address removal of the source waste.

5.3 GENERAL RESPONSE ACTIONS IDENTIFIED FOR THE SDA

The environmental media and contaminants of concern have been identified through site studies as discussed in Section 2 of this report. Table 5-1 summarizes this data and associated assumptions regarding contaminants present. Review of population and worker distribution on and around the site and possible modes of exposure have been incorporated with the media and contaminant data into the site model and the development of preliminary remedial action objectives. At the present time, the presence of radionuclides in the various media and of organics in soil gas and the migration of volatile organic compounds to the groundwater constitute the major site problems which have the potential for contributing to negative health effects. The primary exposure pathways presently identified in the model involve only on-site workers and not members of the public. The pathways are inhalation and ingestion of windblown radionuclides, ingestion of organic compounds in drinking water, and inhalation of organics and tritium during showering. Drinking and shower water are obtained from groundwater pumped to the surface at the RWMC. Past flooding events have contaminated surficial soil which may be entrained by wind and inhaled or ingested by workers. This consideration of source, media, contaminant, pathways, and receptors has led to the identification of SDA problems and related categories of potentially applicable general response actions listed in Table 5-2.

TABLE 5-1. SUMMARY OF CONTAMINANTS AND ENVIRONMENTAL MEDIA OF CONCERN

ENVIRONMENTAL	PRESENCE OF		
MEDIUM	ORGANICS	INORGANICS	RADIONUCLIDES
Air	X		X
Surface Water			(1)
Soil	X	(1)	X
Bedrock	(1)	(1)	(1)
Interbeds	(1)	X	X
Groundwater	X	X	X

(1) Compounds not detected but presumed to be present based on presence in other media.

TABLE 5-2. MATRIX OF GENERAL RESPONSE ACTIONS FOR SPECIFIC SITE PROBLEMS

	General Response Actions										
SDA Problem(s)	Air Pollution Controls	Surface Water Controls	Leachate and Ground-water Controls	Gas Migration Control	Soil Excavation and Removal	Contaminated Soil and Sediments Removal and Containment	In-Situ Treatment	Direct Waste Treatment	Land Disposal and Temporary Storage	Contaminated Water and Sewer Line Controls	Institutional Controls
Volatilization of chemicals into air	●			●	●						●
Hazardous particulates released to atmosphere	●					●					●
Dust generation by heavy construction or other site activities	●					●					●
Contaminated site run-off		●								●	●
Erosion of surface due to wind or water		●				●					
Flood hazard or contact of surface water body with wastes		●									
Leachate migrating vertically or horizontally			●				●				
Precipitation infiltrating into site to form leachate		●	●								
Evidence of methane or toxic gases migrating underground				●							
On-site waste materials in non-disposed form: drums, lagooned waste, waste piles							●		●		
Contaminated surface water, groundwater, or other aqueous or liquid waste		●					●	●	●	●	●
Contaminated soils					●	●	●		●		●
Toxic and/or hazardous gases which have been collected								●			
Contaminated stream banks and sediments					●	●		●	●		●
Drinking water distribution system contamination										●	

General response actions specific to each media include measures designed to control the primary and secondary sources and to limit migration of contaminants as well as institutional controls which limit exposure through administrative means or monitoring of the progress of contaminants or clean up activities. In more specific terms these actions include:

- Removal of primary or secondary sources
- Prevention of contaminant movement from primary or secondary sources
- Preferential removal or extraction of a contaminant
- Treatment and/or disposal of source or contaminant materials
- Access limitation for exposure control
- Environmental monitoring.

Each of these actions may not be appropriate for each media at a given site and an initial screening is applied at this stage to eliminate actions which are clearly not feasible for a given media. For example, radionuclides present in the basalt media constitute a secondary source but due to the low concentrations of contaminants and the large mass of bedrock, removal of this source is not feasible. Other response actions considered inappropriate for the SDA include removal of interbed solids and removal of contaminants from the air media. Site problems and related general response actions for the SDA are presented in Table 5-2. Given the similarity of the site problems and response actions for the waste-in-place and waste-removed scenarios, this table is developed to encompass both scenarios. Although not listed in this table, the no action alternative is considered for the SDA as required by CERCLA/SARA.

The applicability of identified general response actions to the complete and partial source scenarios is summarized in Table 5-3. Also included in these tables are the remedial action objectives as presently formulated and the technology types considered for the general response actions. The remedial action objectives are discussed in detail in

TABLE 5-3. SUMMARY OF REMEDIAL ACTION OBJECTIVES, RESPONSE ACTIONS, AND TECHNOLOGY TYPES

Environmental Media	Remedial Action Objective	General Response Action	Technology Type
Air	Prevent inhalation or ingestion of contaminants.	Air pollution controls	Capping Limit access Dust control
Surface Water	Prevent inhalation or ingestion of contaminants. Minimize off-SDA contaminant mitigation. Minimize precipitation or runoff infiltration.	Surface water controls	Diversion Collection/treatment Capping Grading Revegetation
Soil	Prevent inhalation or ingestion of contaminants.	Contaminated soil control	Capping Grading Revegetation
		Soil excavation and removal	Containment
		In-situ treatment	In-situ treatment Removal Direct waste treatment Disposal on/off-site
Bedrock and Interbeds	Control secondary contaminant sources to protect aquifer.	Gas migration control	Exhaust/remove vapor Treat contaminated vapor
		Leachate and groundwater control	Pump perched water Water treatment Containment Infiltration control
Groundwater	Prevent ingestion of carcinogens.	Leachate and groundwater control	Pumping Water treatment Containment
	Prevent inhalation of carcinogens.	In-situ treatment	In-situ treatment
	Provide aquifer users with sufficient, dependable, an safe potable water.	Contaminated water and sewer line controls	Alternate water supply Treat water supply
Buried Waste (Waste-In-Place Scenario Only)	Prevent further migration of contaminants.	Leachate and groundwater controls	Containment
		In-situ treatment	In-situ treatment
		Limit access	

Section 4 of this report. They are intended to define the scope of the cleanup effort and to provide criteria for assessment of effectiveness of the action.

6. PRELIMINARY IDENTIFICATION OF REMEDIAL ACTION TECHNOLOGIES

The general response actions selected as potentially applicable for remediation of the SDA include a large number of specific technologies. EPA guidance for RI/FS under CERCLA (Ref. 48) calls for preliminary screening of these technologies, combination of screened technologies into remedial action alternatives, and detailed evaluation of each alternative. This section presents the preliminary screening of technologies. The objective is to identify technologies which are protective of health and the environment and which provide a range of options for the decisionmaker. The preliminary screening involves identification of a broad range of potentially applicable technologies and broad evaluation of these technologies against quantitative or qualitative criteria. Since the site characterization and remedial alternatives development processes are proceeding in parallel for the SDA, all potentially useful data are not available for this technology screening step. Consequently, the screening presented herein does not provide a complete basis for the development and evaluation of alternatives and may identify site data which will be needed for the detailed evaluation of alternatives.

The technologies presented in this section are grouped in response action categories for purposes of evaluating remedial technologies. However, the description and evaluation portions of this chapter organizes technologies according to control strategy, that is, as applied to source or migration control. This is intended to minimize repetition and cross-referencing in these sections as individual technologies may be applied to more than one general response action. Technologies which pass the screening process may then be recombined, with due consideration to interactive effects, into preliminary remedial action alternatives.

The technologies presented are applicable to the two scenarios under evaluation at the SDA. The first scenario takes the SDA as is with a primary source term of originally emplaced waste and contaminated soil. The second scenario assumes that the original waste has been removed and is based on a primary source term comprised only of contaminated soil. Both scenarios consider secondary sources, such as migrating plumes of organics or radionuclides. The excavation of the waste is not considered in this report since this technology is being evaluated separately in the Buried Waste Program and is outside the scope of this report.

Section 6.1 presents a discussion of the identification and screening processes. Section 6.2 identifies potentially applicable technologies. Section 6.3 presents the results of the technology screening. Section 6.4 is a summary of the screening process.

6.1 TECHNOLOGY IDENTIFICATION AND SCREENING PROCESS

General response actions reflect categories of technologies which are selected based on consideration of site data, exposure pathway analysis, and site problems. Broad classes of technologies applicable in the general response actions proposed for the SDA were identified in Section 5 of this report. In the following sections, the screening methodology is presented. Section 6.1.1 describes the technology identification process. Section 6.1.2 describes the technology screening procedure.

6.1.1 Candidate Technology Identification Procedure

Initial identification of potentially applicable technologies is based upon technical experience in site remediation projects, review of literature lists of all technologies which have been categorized in each class, evaluation of case studies of past remedial actions, and assessment of surveys of innovative technologies presently under development. The identification procedure considered technologies listed in EPA guidance for screening and remediation (Ref. 59), EPA case studies reports (Ref. 60) and INEL Waste Innovative Ideas project reports (Ref. 61).

6.1.2 Screening Procedure

Preliminary screening of technologies for remediation of the SDA is comprised of a comparison of site and technology characteristics against the criteria of effectiveness, implementability, and cost. The effectiveness criteria include a measure of the protectiveness of health or environment and consideration of time factors. Protectiveness includes a measure of ability to reach a remedial action objective or other cleanup goal including reduction in contaminant toxicity, mobility, or volume. Time factors include time to implement, time to reach the selected goal, and length of useful life of the technology.

The implementability criteria are site- and technology-specific characteristics which determine the utility of a technology when applied to a particular site problem. Technical factors affecting implementability of a broad range of technologies have been published in summary form (Ref. 59), and examples include:

- Inapplicability of capping to areas with steep slope
- Vulnerability of capping to subsidence
- Degradation of clay barriers on contact with acid plumes
- Inapplicability of grout curtains in heterogeneous media
- Inefficiency of groundwater pumping in formations of low transmissivity
- Inapplicability of subsurface drains at moderate depth
- Inapplicability of in-situ flushing in low permeability soil
- Unsuitability of fluid-bed incineration for bulky materials
- Low adsorption rates of polar organics on activated carbon.

In addition to the above-mentioned technical factors, the stage of technology development, performance history, and operating and maintenance characteristics are considered in the screening process. Innovative technologies which are not fully demonstrated are considered if they offer a potential substantial advantage in cleanup effectiveness.

Reliable, relative estimates of the cost of implementing specific technologies at the SDA are not available at this early stage in the evaluation process. Consequently, the cost criterion plays a relatively minor role in this preliminary screening. Where possible, a rank/order estimate of cost based on engineering judgment and hazardous waste site remediation experience is provided for particular technologies.

6.2 POTENTIALLY APPLICABLE TECHNOLOGIES

Table 6-1 presents a listing of potentially applicable technologies based on the general response actions identified in Section 5 of this report. Summary descriptions of these technologies are presented in Appendix B.

6.3 TECHNOLOGY SCREENING

The following sections provide a preliminary screening of the technologies described in Section 6.2 and Appendix B of this report. The discussion provides an objective for application of the technology, especially as related to effectiveness; an evaluation of potential effectiveness and implementability; any known operability and maintenance constraints specific to the SDA for the technology; a rank/order estimation of cost where possible; and a preliminary identification of data needs. For this preliminary screening, primary emphasis was placed on the effectiveness and implementability criteria. Due to the early stage of this assessment, reliable cost estimates are not available and no technologies were screened out on the basis of cost. Section 6.3.1 presents the screening of source control technologies. Section 6.3.2 presents the screening of migration control technologies. Section 6.3.3 presents the screening of treatment technologies for recovered contaminated waste streams. Section 6.3.4 presents the screening of disposal technologies. Section 6.3.5 presents the screening of institutional controls.

TABLE 6-1. POTENTIALLY APPLICABLE TECHNOLOGIES

CATEGORY OF TECHNOLOGIES	TECHNOLOGY APPLICATION (Page No.)	SPECIFIC TECHNOLOGY (Page No.)
Source Control	In-situ waste or soil treatment (B-2)	Bioreclamation (B-2) In-situ vitrification (B-4) Solidification/stabilization (B-4) Soil flushing (B-10) Chemical treatment (B-6) Physical in-situ methods (B-15)
	Contaminated soil excavation (B-16)	
Migration Control	Runon/runoff control (B-19)	Capping (B-19) Covers (B-22) Diversion/collection systems (B-22) Grading (B-28) Revegetation (B-28)
	Leachate and groundwater controls (B-29)	Groundwater pumping (B-30) Subsurface drains (B-32) Subsurface barriers (vertical), using slurry walls, grouting, or piling (B-34) Barrier Walls (horizontal) (B-37) In-situ treatment (B-37)
	Fugitive dust controls (B-37)	Dust suppressant (B-37) Wind fences/screens (B-38) Water sprays (B-38) Other measures (B-38)
	Gaseous emissions controls and gas removal (B-38)	Capping (B-39) Covers (B-39) Passive perimeter gas control systems (B-39) Active perimeter control systems (B-41) Active interior collection/recovery system (B-42)
Waste Stream Treatment	Aqueous waste treatment (B-42)	Activated carbon (B-43) Biological (B-44) Precipitation/flocculation (B-44) Ion exchange and sorptive resins (B-46) Reverse osmosis (B-46) Neutralization (B-47)

TABLE 6-1. POTENTIALLY APPLICABLE TECHNOLOGIES (Continued)

CATEGORY OF TECHNOLOGIES	TECHNOLOGY APPLICATION (Page No.)	SPECIFIC TECHNOLOGY (Page No.)
	Aqueous waste treatment (B-42) (Continued)	Gravity separation (B-48) Air stripping (B-48) Oxidation (B-49) Reduction (B-49) Evaporation (B-50) Solidification/stabilization (B-50)
	Solids/water separation (B-50)	Filtration (B-51) Sedimentation (B-52) Separation using sieves and screens, hydraulic and spiral classifiers, cyclones, clarifiers, or dissolved air flotation (B-53) Dewatering using gravity thickeners or centrifuges (B-55)
	Solids treatment (B-56)	Incineration (B-56) Separation (B-60) Solidification/stabilization (B-60) Vitrification (B-66) Soils treatment (B-67)
	Gaseous waste treatment (B-68)	Flaring (B-68) Incineration (B-69) Activated carbon (B-69)
Disposal Technologies	On-site landfills (B-69) Off-site landfills (B-70) Publicly owned treatment works (B-71) Underground injection (B-71)	
Institutional Controls	Fencing (B-72) Signs (B-72) Land restriction (B-72) Bottled water (B-72) Water treatment (B-72) New production well (B-72) Pipeline from existing well (B-72)	

6.3.1 Source Control

For the purposes of this evaluation, source control technologies are grouped into in-situ waste and soil treatment and contaminated soil excavation. In this project, in-situ treatment technologies are applied for both the waste-in-place and waste-removed scenarios while soil excavation applies only to the waste-removed scenario. Source control technologies address only the originally emplaced waste and the soil media and are protective of both health and the environment through elimination of the source of contaminants entering exposure pathways. Source control technologies do not address the air, surface water runoff, bedrock and interbed, or groundwater media.

6.3.1.1 In-Situ Waste Treatment

In-situ treatment technologies include solidification or fixation of the source, biological or chemical alteration of source components for reduction in toxicity or mobility, and selective stripping of source components.

In-Situ Vitrification

The effectiveness of in-situ vitrification has been demonstrated at the laboratory (Ref. 67) and field (Ref. 68) scale in the presence of hazardous and radioactive wastes. Short term leaching tests have provided positive results. At the SDA, inorganics and radionuclides would be imobilized by the in-situ vitrification process. Organic compounds would be volatilized, combusted and collected in an off-gas removal system. Technical factors affecting selection include soil chemical and physical properties, soil moisture content, site hydrologic complexity, waste composition, containment and emplacement depth, and off-gas generation rates and clean-up characteristics. Due to the large area and complexity of waste forms at the SDA, costs would be high. Present data indicate that conditions specific to the SDA do not preclude implementation of in-situ vitrification and consequently the technology passes the preliminary screening.

Data needs for more detailed evaluation include role of soil composition and physical properties, impact of presence of organic oils and solvents, leach rates of product waste form, ability to control organic emissions, criticality control, and waste form characteristics over long time frames. Supplementary information include a more site-specific estimation of costs.

Grouting

The effectiveness of grouting in solidification of waste or soil containing organic, inorganic, and radionuclide contaminants has been demonstrated (Ref. 69) for excavated wastes. The effectiveness of grouting as an in-situ technology for long-term isolation has not been fully established. Observation of contamination of groundwater following deep-well injection of grouted waste (Ref. 70) and negative results for field testing of near surface grouting at the SDA (Ref. 17) indicate that the technology is not protective of the environment. Technical factors precluding implementation include low permeability of target soil. Factors affecting selection include chemical and physical characteristics of the waste and soil, interferences due to organics present, depth of emplacement, and ability of grout to fill available voids. Given the lack of demonstration of effectiveness in isolating toxic contaminants, in-situ grouting fails to pass the preliminary screening.

Soil Washing

In-place washing of contaminated soils with water, inorganic salts, mineral acids, and complexing agents are potentially effective means for selective removal of toxic contaminants (Ref. 71, 60). Technical factors precluding implementation include low soil permeability and geohydrologic complexity. Factors affecting selection specific to the SDA include heterogeneous, fractured nature of near surface basalt, low permeability of unsaturated soil, the diversity of contaminant species, and the present low mobility of radioactive specie. Since the above technical factors indicate that collection of flushed liquids at the SDA is problematical (see also Section 6.3.2.3) and since mobilization has an element of risk, this technology does not pass the preliminary screening.

Vapor Flushing

The effectiveness of aeration and steam stripping for removal of volatile compounds has been demonstrated in laboratory and field applications. Vacuum-assisted steam stripping of gasoline from soil has been explored on small scale (Ref. 72) and hot air and steam stripping of hydrocarbons from soil has been demonstrated on a larger scale (Ref. 73). Technical factors precluding implementation include low soil permeability and complex geohydrologic conditions. Technical factors affecting selection include the characteristics and distribution of the primary waste source, the need to collect vapors generated in the process, and the impact of the stripping media on the non-volatile fraction of the waste. Costs are estimated as moderate for this technology. Given the potential effectiveness for removal of volatile organic contaminant sources, this technology passes the preliminary screening process. However, it will not address inorganics or radionuclides.

Data needs include estimates of the quantity and distribution of volatile components, vapor-liquid distribution behavior, and the soil permeability characteristics.

Biological Degradation

The effectiveness of in-situ bioreclamation varies with the organism, the substrate material, and the geohydrologic conditions of the site. At the SDA, the low hydraulic conductivity of the soil, the complex chemical and physical character of the waste, and the spatial distribution of the waste indicate that the technology is not implementable and consequently does not pass the preliminary screening.

6.3.1.2 Soil Excavation

Soil excavation may be accomplished using backhoes, cranes, dozers, loaders, and scrapers. The effectiveness of the technology has been demonstrated at many construction and disposal sites (Ref. 63). Technical factors precluding implementation include depth of excavation greater than sixty feet, inapplicability to specific soil conditions, and high costs associated with large sites. Factors affecting selection at the SDA include the need to prevent distribution of potentially contaminated dust generated in the excavation and near surface occurrence of bedrock. Costs at the SDA would be high. Despite the potentially unfavorable cost factor the technology is applicable at the SDA and passes the preliminary screening. In addition to the above extraction technologies, dust control is considered. Specific candidates include water spray, natural and synthetic soil binders, and containment covers. Due to the need to protect on-site workers and allow minimum entrainment of radionuclide contaminated soil for extended periods of time, the effectiveness of water spray and other soil binders is considered inadequate. Water spray is effective in suppressing dust for time periods less than two hours while natural and synthetic dust suppressants are effective for time periods of a few weeks. Containment barriers, including tents and engineered structures, are considered effective and therefore pass the preliminary screening.

6.3.2 Migration Control

Migration control measures are those technologies which do not directly affect the position or chemical and physical state of the emplaced waste. Included in this category are measures which:

- Prevent or control movement of agents, for example water, which mobilize or transport contaminants
- Treat in place contaminants which have been mobilized
- Recover mobilized contaminants
- Treat recovered contaminated waste streams
- Dispose of recovered or treated waste streams.

Candidate technologies which perform the first three of these functions are evaluated in the following sections while technologies which perform the last two functions are screened in Sections 6.3.3 and 6.3.4. Migration control technologies apply to both the waste-removed and waste-in-place scenarios.

6.3.2.1 Control of Mobilizing Agents

Capping

Capping the ground surface of the SDA is a measure which affects several potential exposure pathways. Minimization of rainfall infiltration directly reduces potential liquid phase flux of contaminants downward to groundwater. Covering of contaminated surficial soils eliminates entrainment in wind and suspension in precipitation run-off. Increase in up-flow direction vapor phase diffusional path length and resistance lessens the amount of volatile organics released to the atmosphere. Each of these effects applied in combination and in proper timing with other measures, such as grading, diversion, and source extraction, indicates that capping may be an effective technology at the SDA for several media. This indication of potential effectiveness is supported by experience (Ref. 60, 62) in which capping in combination with other technologies contributed to reduction in contaminant migration. The following capping technologies are considered as candidates in this study :

- Clay
- Asphalt or concrete
- Synthetic covers
- Multi-layer system
- Soil, fly ash, or soil/fly ash mixture.

Technical factors which preclude application of each of these technologies include steep slope of land surface and likelihood of subsidence. The basin in which the SDA is located is gently sloping and characterized by near surface occurrence of bedrock and consequently neither of these factors preclude capping at this site.

Application of a single layer clay cap at the SDA is considered infeasible due to the need for a nearby large source of clay material, the emplacement of acids at the site, and the arid conditions at the site which favor dehydration and cracking of clay layers. Similiarly, the large size of the site, the hot, dry summer conditions and the vulnerability to cracking in heat and freeze-thaw cycles of asphalt or concrete argue against application of these technologies at the SDA. A single layer synthetic cover is also considered not well suited to the conditions and needs at the SDA due to size of the site and potential for actinic/oxidative degradation.

General design guidelines for multi-layer caps call for a lower layer of impermeable material overlain by a drain layer and a soil layer (Ref. 63). The large size and high potential evapotransporation at the SDA, however, while not precluding application of this type of multi-layer cap indicate that use of a capillary break may be favored over a draining barrier. Experimental studies at an arid site (Ref. 64) investigated combinations of gravel and soil designed to lessen infiltration and deter animal and root intrusion. Results indicate that combinations of coarse and fine grained material layers can be effective in infiltration and run-off control. In addition, recent studies (Ref. 65) of an engineered vegetative cover demonstrated effectiveness in infiltration and run-off control. Performance regarding erosion is also favorable and is under continuing study. Similiar considerations apply to soil and soil/fly-ash cap technology. Consequently, multi-layer and soil caps pass the preliminary screening.

Data needs associated the with capping technology include composition and mineralogy of soils readily available at the SDA, performance characteristics of cap materials and of capillary breaks, and interaction of cap design with complementary technologies, such as revegetation and gas extraction.

Grading

Grading at the SDA is intended to facilitate run-off and lessen infiltration of water which might mobilize contaminants. The effectiveness of grading is widely recognized, especially when used in combination with revegetation, diversion, or collection. No general technical factors preclude grading but requirements for large amounts of fill soil may be a negative selection factor. Slope length and gradient are important design variables which due to the large size of the SDA may require integration with diversion technology, such as terracing. Terracing would be applied in combination with grading for the long-term period when minimum active maintenance is required. Costs for grading are generally low. Consequently, grading technologies pass the preliminary screening at the SDA.

Revegetation

Revegetation diminishes infiltration through promotion of evapotranspiration and lessens erosion and entrainment through stabilization of the soil surface. Experiments (Ref. 64) show that vegetation is effective in controlling erosion and in managing infiltration (Ref. 65). Factors precluding implementation include the need for soil cover and vulnerability to toxic chemicals. Factors affecting selection include the need for application of complementary technology, such as capping, grading or diversion; the need to avoid root and burrowing mammal penetration of the waste zone; and the potential need for maintenance. Potential variants of this technology include grasses and legumes. Revegation costs are low. Since soil capping passed the preliminary screening, revegetation is not precluded and consequently passes the preliminary screening.

Data needs related to revegation include the performance of the range of candidate species in arid conditions and with the selected soil cover and design.

Surface Water Diversion and Collection Systems

Surface water diversion and collection systems act to (1) prevent run-on to a site thereby lessening infiltration and erosion rates and (2) intercept water running-off a site to lessen potential spread of contaminants. Technologies considered include dikes and berms, channels, terraces, chutes, seepage ditches and basins, sedimentation basins, and levees and floodwalls. Ample evidence exists to support the effectiveness of these technologies when properly applied (Ref. 60, 62, 63). Technical factors which preclude implementation include the applicability of dikes and berms and chutes to small areas for short time frames and the temporary nature of channels (trenches and ditches) and seepage structures. In addition, seepage ditches and basins are not appropriate for control of potentially contaminated water. Technical factors affecting selection include the need for regular maintenance and integration with other site control technologies. Application of additional flood control measures does not appear warranted at the present time due to existance of recently instituted measures. In summary, dikes and berms and channels and chutes may be applicable as short term measures in remediating the SDA while terraces may be of utility in shortening slope lengths to control erosion. Seepage ditches and basins are not applicable due to the potential presence of contaminated runoff.

Data needs related to surface water controls are uncertain due to the dependence on the overall strategy selected for remediating the site. However, a complete water balance, an estimate of net downward flux, an evaluation of subsidence, and an assessment of erosion rates are required data.

Subsurface Containment Barriers

Subsurface barriers, including slurry walls, grouting, and sheet piling, may decrease the spread of contaminants through control of water infiltration or outflow. At the SDA, the broad range of appplication of this technology includes control of near surface infiltration and control of deep groundwater. However, due to the great depth to groundwater at the SDA, the presence of bedrock throughout the entire depth of the subsurface, and the nature of installation of the technology, groundwater control through subsurface barriers is not feasible. Utility of subsurface barriers is therefore restricted to near surface applications. Experience with slurry walls at waste sites indicates that this technology can be effective in control of water influx, reduction of leachate production, and isolation of contaminants to prevent their spread in the environment (Ref. 60, 62). Experience with grouting is less promising (Ref. 63), especially in unconsolidated materials. Tests conducted at INEL indicate that presently available grouting techniques are not effective in soils found at the SDA (Ref. 17). The effectiveness of grouting in rock sealing as might be applied for bottom sealing in the fractured basalt bedrock at the SDA is not supported by available data. The effectiveness of sheet piling at rocky sites such as the SDA is also questionable due to difficulties sealing joints and in driving the piles. Technical factors precluding use of subsurface barriers include the existence of permeable bedrock which provides alternative liquid flowpaths. Since this is the case at the SDA, the utility of barriers appears limited to specialty applications where local flow conditions are well defined. Technical factors affecting selection include magnitude of the gradient driving flow; potential for presence of acidic, caustic, or organic chemicals; and the soil conditions at the site. Given the above considerations, subsurface barriers for groundwater control fail to pass the preliminary screening while near surface application of slurry walls pass with the note that only specific, shallow, local applications are likely.

Data needs associated with subsurface barrier technology include identification of paths of infiltration at the SDA, evaluation of potential for migration of acid or caustic components, and identification of moisture content of SDA soils under seasonally varying conditions.

6.3.2.2 In-Situ Treatment for Migration Control

In-situ treatment using biological or chemical agents offers the potential for protection of health and environment through reduction in either the quantity or toxicity of migrating contaminants. At the SDA, in-situ treatment for migration control is potentially applicable to control of organic and radionuclide contaminants in groundwater. Candidate bioreclamation techniques include application of bacteria or fungi, possibly in combination with aeration, while potentially applicable chemical reclamation techniques include hydrolysis, oxidation/reduction, dechlorination, or precipitation. The effectiveness of in-situ bioreclamation has been demonstrated at spill sites with successful application to waste sites yet to be demonstrated (Ref. 63). Data demonstrating the effectiveness of in-situ chemical treatment for control of migrating species are not available. Factors precluding the implementation of in-situ treatment include low media permeability and hydrogeologic complexity. Factors affecting selection include need for injection systems to distribute the agent, the potential to mobilize contaminants, temperature dependence of removal rate, and need for limited control of the geochemical environment. Classification of costs for in-situ treatment involve research and site specific elements which are not quantifiable at this stage of assessment. Given the above data, the applicability of bioreclamation is not rejected and the lack of field application of chemical treatment argues for elimination of this technology.

Data needs related to in-situ bioreclamation include identification of an organism appropriate to the specific site problem, understanding of the geohydrology of the contaminated media, and understanding of the geochemical environment affecting growth of the candidate organisms.

6.3.2.3 Recovery for Migration Control

Sediment Removal

Surface water impoundments, such as ponds and basins, and natural surface water features, such as streams and lakes, do not exist at the SDA. Engineered surface water control measures including drainage channels are not known at this time to be contaminated and consequently sediment removal technologies are not required for remediation. Applications of sedimentation technology which may be applied in treatment of recovered contaminated streams are discussed in Section 6.3.3.

Subsurface Drains

Subsurface drains may reduce migration of contaminants through collection of contaminated leachate or soil flush water. Collection system construction methods, the presence of basalt flows, and the great depth to groundwater at the SDA are such that interception of groundwater using drains is not feasible. Application of subsurface drains in conjunction with unsaturated zone flushing or washing is possible. The effectiveness of interceptor trenches and french drains has been demonstrated under field conditions (Ref. 60). Factors precluding near surface application include high permeability of surrounding media and long flow distances to french drains. Technical factors affecting selection include particle size distribution of soil, near surface occurrence of bedrock, and hydrologic flow conditions. Costs range from low for shallow trenches to high for extensive french drains. The disturbed conditions of the site and the heterogeneous flow paths asociated with fractured basalt are unfavorable for application of subsurface drains at the SDA. In addition, soil flushing introduces the undesirable potential for mobilization of a wide range of contaminants. Given the above factors, this technology is not appropriate at the SDA and fails to pass the preliminary screening.

Gas Collection

Gas collection reduces health risk and protects the environment through removal of a secondary source of contaminants which can percolate upward out of the unsaturated zone into the atmosphere or diffuse downward and dissolve into groundwater. Technologies considered in the screening include passive systems which modify gas migration paths without mechanical components and active systems which extract or flush gas from the porous solid media using pumps or fans. Passive gas systems at the SDA are not effective in that release of contaminants to the environment and to potential receptors is not prevented. The effectiveness of active gas collection systems has been demonstrated in the field at landfill sites and at spill sites (Ref. 66). There are no technical factors precluding implementation of this technology at the SDA site. Technical factors affecting selection include the permeability and heterogeneity of the solid media, the spatial extent of the contaminant plume, and the nature and quantity of contaminants present in the plume. Costs of passive collection systems are low while costs for an active system at the SDA may be high. On the basis of lack of protectiveness, passive gas collection technologies fail to pass the preliminary screening. Based on the above considerations, active collection systems, which may incorporate some passive design features, pass the preliminary screening.

Data needs related to active gas collection include the extent and nature of the vapor contamination in the unsaturated zone, characterization of the heterogeneity and permeability of the porous media, and characterization of the spatial distribution and chemical and physical properties of the primary source.

Soil/Bedrock Excavation

Evaluation of excavation of primary source waste and contaminated soil is discussed above in Section 6.3.1. This section considers removal of solids, including basalt and interbed material, which may affect migration of contaminants. The technology is effective in that flow paths are altered and secondary source terms are treated. Factors precluding implementation of the technology include inapplicability to material more than sixty feet below the ground surface without expensive, specialized equipment, low concentration of contaminants in the subsurface, the difficulty in excavating the basalt without releasing the contaminants to the atmosphere, and inapplicability to large quantities of material. Given these factors, this technology fails to pass the preliminary screening for migration control at the SDA as the depths and quantities of material involved are prohibitive given the low contaminant concentrations.

Groundwater Pumping

Groundwater pumping reduces potential health and environmental impact through removal of contaminants from a primary exposure pathway and protects the aquifer from further contamination. Technologies evaluated include combinations of extraction and injection wells using wellpoints, suction systems, ejectors, and pumps. The effectiveness of groundwater pumping for contaminant removal has been demonstrated at numerous sites presenting a range of hydrologic conditions (Ref. 60). Technical factors precluding implementation include low storativity and transmissivity of the subject formations. Technical factors affecting selection include the hydraulic conductivity and heterogeneity of the formation, the magnitude of the head resisting flow, the corrosive nature of the liquid, and the extent and level of contamination. Due to their inability to transport groundwater from the depth required at the SDA, well points, suction pumps, and ejectors fail to pass the preliminary screening. Due to the potential protectiveness and implementability, extraction wells, possibly in combination with injection wells, pass the preliminary screening.

Data needs related to groundwater pumping include nature and levels of contaminants in the groundwater, extent of the contaminant plume, spatial distribution of geohydrologic properties, and nature and rate of contaminant influx to the groundwater.

6.3.3 Treatment of Recovered Contaminated Waste Streams

Secondary waste treatment processes include systems for the treatment of solid, gaseous, and liquid streams generated in site remediation. Candidate solid streams are decontaminated, solidified, incinerated, or treated soil and solids, such as activated carbon, generated in clean-up processes. Gas streams include contaminated vapor extracted from the vadose zone and off-gas produced in waste treatment processes, such as vitrification. Liquid streams include potentially contaminated surface and groundwater and effluent from waste treatment processes.

6.3.3.1 Gas Treatment

Technologies applicable to removal of organic compounds from vadose zone vapor include condensation, absorption, combustion, and adsorption systems. The effectiveness of these technologies is demonstrated by widespread application in the petroleum industry (Ref. 83) to processing of industrial gases. The effectiveness of granular activated carbon adsorption for removal of organics from water vapor has been demonstrated (Ref. 60) as has removal of organics from air stripper streams (Ref. 84). There are no technical factors which preclude implementation of these technologies. Factors affecting selection include gas stream composition, temperature, pressure, flow rate and heating value, availability of disposal options, and regulatory constraints. Equipment requirements for the condensation and absorption technologies depends strongly on the feed gas contaminant level and product gas purity requirements. Given the expected low levels of organic contamination, sizing constraints may preclude implementation of these technologies. Combustion or flaring requirements also depend on concentration and due to low levels are not favored at the SDA. The adsorption process is effective and implementable and therefore passes the preliminary screening.

Data requirements for implementation of carbon adsorption include characterization of inlet gas conditions, determination of the equilibrium adsorption isotherm, and quantification of rate parameters, such as dispersivity and mass transfer coefficients.

In-situ, direct, and secondary waste treatment produces gas streams contaminated with volatilized organics and radioactive particulates. Equipment used in clean-up of these streams includes quenchers, wet and dry scrubbers, absorption and adsorption columns, mist eliminators, hoods, and filters. The effectiveness of gas clean-up equipment has been demonstrated in industrial (Ref. 85, 86) and nuclear (Ref. 87) applications. There are no technical factors which preclude the application of this technology at the SDA. Technical factors affecting selection include chemical and physical properties, temperature, pressure, and flow rate of feed gas; allowable exhaust gas contaminant levels; and available options for waste disposal. Although the exact nature of potential feed streams has not been identified at this stage of site remediation, the technologies are effective and implementable and therefore pass the preliminary screening.

6.3.3.2 Aqueous Waste Treatment

Groundwater pumping and secondary waste treatment at the SDA may produce aqueous streams contaminated with low levels of organics, inorganics, or radionuclides. Applicable clean-up technologies are based on biological, chemical, and physical principles. Biological processes, including activated sludge, trickling filters, and rotating disks, have demonstrated (Ref. 63) effectiveness in treating water contaminated with organics. Technical factors precluding implementation include high levels of organic contaminants and presence of poisons specific to the organism. Technical factors affecting selection of biological processes include composition and rate of feed, presence of minor components which may poison the active organism, need for auxiliary nutrients, and time dependence of feed rate. Biological processes have the potential for effective implementation at the SDA and therefore pass the preliminary screening.

Chemical processes potentially applicable at the SDA include neutralization, precipitation, oxidation/reduction, hydrolysis, chemical dechlorination, and UV/ozonation. The nature of contaminants presently identified at the SDA is such that the hydrolysis and chemical dechlorination processes would not be effective in controlling contamination. The effectiveness of neutralization has been demonstrated and implementation at the SDA is possible where pH is found to be a problem. The effectiveness of ozonation, oxidation/reduction, and precipitation and associated flocculation and sedimentation for removal of organic compounds and metals from aqueous streams has been demonstrated in drinking water treatment and industrial applications (Ref. 88). There are no general technical factors which preclude implementation of these technologies. Factors affecting implementation include the chemical and physical nature of the contaminated stream, required effluent concentration levels, ability to dispose of large volumes of liquids, and integration into an over-all clean-up process. These technologies are potentially effective and implementable and therefore pass the preliminary screening.

Physical processes potentially applicable to clean-up of contaminated water at the SDA include sedimentation and clarification, adsorption, ion exchange, membrane separations, air and steam stripping, solvent extraction, and dissolved air flotation. The effectiveness of sedimentation and clarification has been demonstrated in industrial and utility applications (Ref. 88). The effectiveness of adsorption for processing contaminated water has been demonstrated using activated carbon, resins, and molecular sieves. In particular, removal of chlorinated organics from water using activated carbon has been demonstrated for hazardous wate site remediation (Ref. 60). The effectiveness of ion exchange in removing radioactive cesium (Ref. 89) and cesium and strontium (Ref. 90) from aqueous streams has been demonstrated. Membrane separations, including reverse osmosis, are effective in concentrating solutions containing salts and macromolecules.

Implementation of reverse osmosis for concentration of aqueous streams contaminated with low levels of organics or dissolved solids is feasible at the SDA. The technology would need to be used in combination with another separation technique as high osmotic pressures preclude attaining high levels of concentrated contaminants. Ultrafiltration is most effective in separating large size molecules and is not appropriate to problems at the SDA. Electrodialysis is most effective for separations involving high dissolved salt concentrations and is not considered applicable at the very low ionic strengths expected at the SDA. Air and steam stripping of low concentrations of contaminants from aqueous streams has been widely applied (Ref. 91) and is implementable at the SDA. Solvent extraction depends upon interphase transport for separation and given the low concentrations of contaminants at the SDA, size requirements would preclude implementation. The dissolved air flotation process removes suspended solid particles from a liquid. At the present time, this type of contamination is not observed at the SDA and therefore the technology does not pass the screening.

There are no technical factors precluding the implementation of sedimentation and clarification, ion exchange, adsorption, and air and steam stripping at the SDA. Technical factors affecting selection include chemical and physical properties of the feed stream, disposal of large volumes of water, and required effluent purity. These four physical separation technologies are effective and implementable and therefore pass the preliminary screening.

6.3.3.3 Solids Treatment

Solids treatment in the scope of this project entails treatment of excavated soils which are potentially contaminated with radionuclides, metals, inorganic salts, oils, solvents, and miscellaneous organic and inorganic chemicals. It also includes treatment of residuals such as activated carbon that may be generated in the course of remediation. Applicable categories of technologies include solids handling, solidification/ stabilization, incineration, and chemical separation or fixation processes. The technologies are protective of health and the environment through reduction of the magnitudes and rates of release of contaminants.

Solids Separation or Handling

Solids handling as applied to excavated SDA soils includes conveying, size reduction and size classification. Conveying is accomplished using belt and bucket systems, trucks and trolleys, and liquid and air streams. Size reduction is accomplished using shredders, mills, and grinders while classification is accomplished using screens and sieves, cyclones, and sedimentation in liquids. The effectiveness of each of these technologies is witnessed by wide application in mining and power generation systems. Some research has been performed that indicates that contaminants may be concentrated or removed using solids separation techniques. Technical factors affecting selection of conveying technologies includes particle size distribution, particle density, moisture content, and required transfer rate. Technical factors affecting selection of size reduction and classification technologies include moisture content, particle size distribution, and particle hardness and density. Costs of these technologies range from low to moderate. Selection of specific systems for use at the SDA depends upon integration into the direct and secondary waste treatment processes, but each of the technologies passes the preliminary screening.

Solidification/Stabilization

Solidification technologies include production of monolithic waste forms using binders such as cement, silicates and bitumenous materials; encapsulation in polymers; and transformation of soil into a glass-like state (vitrification) using electrical or microwave energy. The effectiveness of incorporation of soil into cements is a common construction practice while incorporation of resins into cement and asphalt has also been demonstrated. Incorporation of liquid wastes containing dissolved salts into large scale blocks (Ref. 74) which have acceptable EP-toxicity characteristics may also be cited as evidence of effectiveness of this technology. Leach testing of waste solidified into asphaltic material (Ref. 75) has also shown positive results. Evaluation of microencapsulation using thermplastic or asphaltic materials (Ref. 76) supports the potential effectiveness of this technology. The effectiveness of microwave energy has been investigated for solidification of TRU contaminated sludges (Ref. 77) and LLW contaminated liquids (Ref. 78). Bench scale testing of the TRU waste indicated that waste containing diatomaceous earth melted easily. The effectiveness of vitrification of soil contaminated with organics and metals has been investigated at pilot scale. The vitrified product had high compressive strength, low toxicity, and reduced metal leach rates relative to source soil.

Technical factors precluding implementation of solidification technologies include potential inapplicability of solidification to large volumes of waste due to cost and inapplicability to waste having high concentrations of organic solvents. Technical factors affecting selection include composition and particle size of contaminated soil, increase of volume during solidification, equipment complexity for large-scale processing, and leach rates of product solid. Costs for solidification/stabilization of soil at the SDA would be high. Despite the potential high cost, solidification of soil is feasible and passes the preliminary screening. Solidification is also potentially applicable as a secondary waste treatment technique.

Data needs for soil solidification technologies at the SDA include site-specific soil chemical and physical properties, levels of organic and metallic contaminants in soil, ranges of composition of solidification agents which produce acceptable waste forms, acceptance criteria for waste forms, waste form physical properties and leach rates, and estimates of processing costs.

Incineration

The applicability and effectiveness of incineration technologies for treatment of large volumes of organic contaminated soils has been evaluated (Ref. 80). Twenty-four systems were considered and rotary kiln, hearth, circulating bed, and electric infrared incinerators were selected as having greatest potential applicability. The effectiveness of incineration of hazardous waste and soils has been demonstrated in RCRA trial burns (Ref. 80) while the effectiveness of incineration of low-level waste has been documented (Ref. 81). Technical factors precluding implementation of incineration includes inapplicability to destruction of inorganics and dependence of specific systems on the chemical and physical properties of the feed. Factors affecting selection include feed quantity, heat content, particle size distribution and composition of feed material, off-gas clean-up requirements, availability of auxiliary fuel, destruction and removal efficiency for contaminants, and excess air levels. Costs for soil incineration at the SDA would be high. Despite potential high cost, the incineration technologies are potentially effective and applicable at the SDA and consequently pass the preliminary screening. In addition, incineration systems may be applicable for processing waste produced in secondary treatment technologies.

Data needs include quantification of soil chemical and physical properties and contaminant levels, process destruction and removal efficiencies for specific technologies and contaminants, operating conditions, off-gas particle loadings and composition, volume reduction achieved and estimates of capital and operating cost including auxiliary fuel requirements.

Chemical Separation/Fixation

The effectiveness of chemical separation technologies for clean-up of excavated soil contaminated with radionuclides has been demonstrated on the pilot scale level (Ref. 71). Representative processes involve chemical extraction using water, inorganic salts, mineral acids, and complexing agents followed by contaminant recovery from the secondary waste stream. Examples include size screening and caustic (NaOH) stripping for removal of plutonium from contaminated soil at Rocky Flats Plant (Ref. 71). The effectiveness of chemical separation technologies for removal of oil and organic bromine compounds from soil has been demonstrated (Ref. 82) using hot water and caustic, respectively. Alternative technologies which are potentially applicable include supercritical extraction (Ref. 61) of both organics and heavy metals and bioreclamation or bioconcentration. There are no technical factors which preclude implementation of chemical separation/fixation technologies at the SDA. Technical factors affecting selection include chemical, physical, and mineralogic characteristics of the soil; contaminant levels as a function of particle size; spatial extent of contamination; solubility of contaminant in extraction agent; and requirements for secondary waste treatment. Costs of application of these technologies at the SDA would be high due to the large volumes of soil involved. Given the demonstrated effectiveness, this technology passes the preliminary screening.

Data needs include soil chemical and physical properties; characterization of nature, extent, and levels of contamination; and process-specific rate and equilibrium parameters including solubilities, reaction rate constants, and mass transfer coefficients.

Biological Treatment

Degradation or concentration of soil contaminants may be accomplished using biological treatment. The effectiveness of the process depends on the chemical properties of the substrate contaminants and has not been successfully demonstrated for soils containing the the combinations of types of organics and organics and metals expected at the SDA. Consequently, this technology does not pass the preliminary screening.

6.3.4 Disposal of Waste

The effectiveness of disposal of properly treated or stabilized solid and liquid waste has been demonstrated in many applications. Options for SDA remediation include on- and off-site disposal for both solid and aqueous waste. Solid waste disposal technologies are piling and landfilling. Technical factors precluding implementation include lack of an on-site landfill and lack of capacity outside of INEL for mixed waste. However, given the potentially large volumes and need for a long term solution, piling is not implementable on- or off-site. Factors affecting selection of landfilling are level of contamination, volume, site geohydrologic characteristics, transporation risks, and regulatory constraints. Assuming the effectiveness of treatment technologies, the lack of factors precluding design and construction of a RCRA permitted landfill at the SDA, and the existance of an off-site RCRA permitted landfill, both on- and off-site disposal of solid waste pass the preliminary screening. Costs of on-site disposal are high and costs of off-site disposal are high.

Disposal technologies for aqueous effluent potentially applicable at the SDA are release to surface water, transport to a publicly owned treatment works (POTW), and deep well injection. Given the lack of a reasonable candidate POTW and the large distance to off-site surface water, off-site disposal of treated water is not implementable at the SDA. There are no technical factors which preclude on-site surface water release or deep well injection. Assuming the effectiveness of treatment technologies and potential for obtaining an NPDES or underground injection permit, on-site disposal of treated water passes the preliminary screening.

6.3.5 Institutional Controls

Institutional controls potentially applicable at the SDA include measures which limit exposure of on-site personnel to contaminants and measures which limit access to the site. Measures which limit exposure of on-site personnel include monitoring, training, and point-of-use treatment or substitution for contaminated streams. Monitoring of potentially contaminated media is potentially effective at the SDA since identification of contamination allows implementation of protective actions. Potential routes of exposure at the SDA are inhalation and ingestion of contaminated dust, ingestion of contaminated groundwater, and inhalation of volatile contaminants during showering. Training and education programs on personal hygiene in contaminated areas are potentially effective in reducing the extent of exposure to contaminated dust.

Treatment of contaminated groundwater or substitution with an uncontaminated alternative source of water are potentially effective means for reducing exposure to waterborne contamination. Screening of technologies for treatment of contaminated water was presented in Section 6.3.3. Technologies screened as potentially effective for removing organic contaminants include air and steam stripping and carbon adsorption. Substitution candidates include installation of a new on-site well, provision of bottled or trucked water, and installation of a pipeline for pumping of water from an existing alternative well. Installation of a new on-site well, while implementable, is not considered effective as the new well is vulnerable to contamination from plumes originating from sources at the SDA or other INEL facilities. Provision of bottled or trucked water and pumping from an existing on-site well are potentially effective measures at the SDA assuming the purity of the source water.

Institutional measures for limitation of access to the SDA include installation of signs, fences and security patrols and provision of education programs for INEL employees. Limitation of access using signs, fences and security personnel are widely applied and effective techniques. Education programs are potentially effective in that thy can inform INEL employees of possible dangers and lessen the likelihood of inadvertant exposure.

6.4 SUMMARY OF PRELIMINARY SCREENING

Technologies screened for application at the SDA have been categorized as applicable to source or migration control. Source control actions considered applicable to both the waste-in-place and waste-removed scenarios utilize in-situ treatment, secondary waste stream treatment, and on- and off-site disposal technologies. Source control technologies applicable only to the waste-removed scenario include excavation and direct waste treatment. In the migration control category, all technologies are considered applicable to each scenario. The results of the preliminary screening are summarized in the following paragraphs and in Figures 6-1 through 6-5.

Among in-situ treatment technologies applied for source control, in-situ vitrification and vapor phase flushing were considered potentially effective and implementable and were passed in the preliminary screening. Grouting and liquid phase flushing for source control were considered ineffective at the SDA and did not pass this preliminary screening. For soil excavation technologies; covers for dust control, and conventional backhoes, dozers, cranes and loaders were considered effective and passed the preliminary screening.

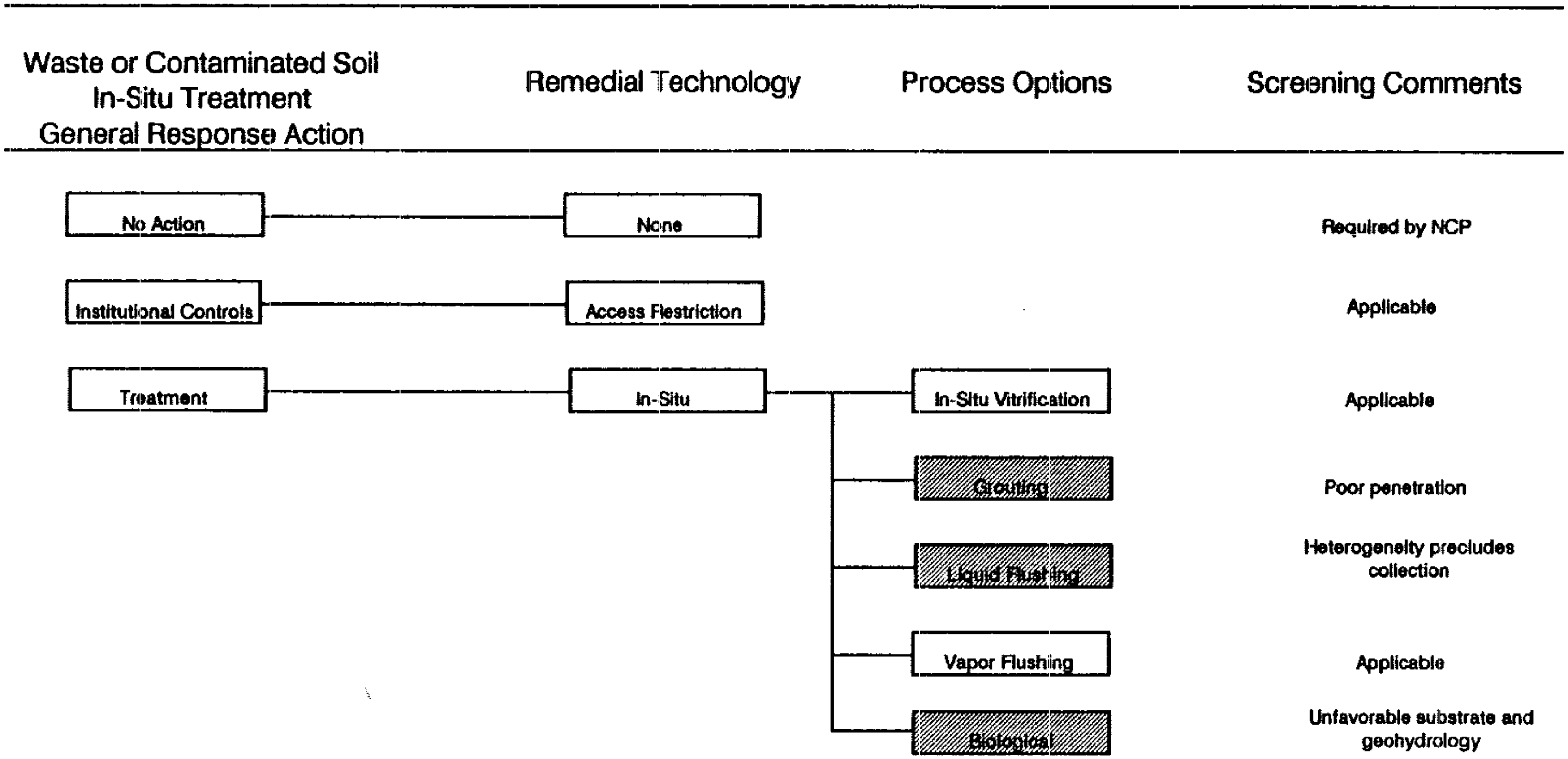


FIGURE 6-1. PRELIMINARY SCREENING OF TECHNOLOGIES WASTE-IN-PLACE SCENARIO -- IN-SITU TREATMENT

* Shading indicates technologies that are screened out

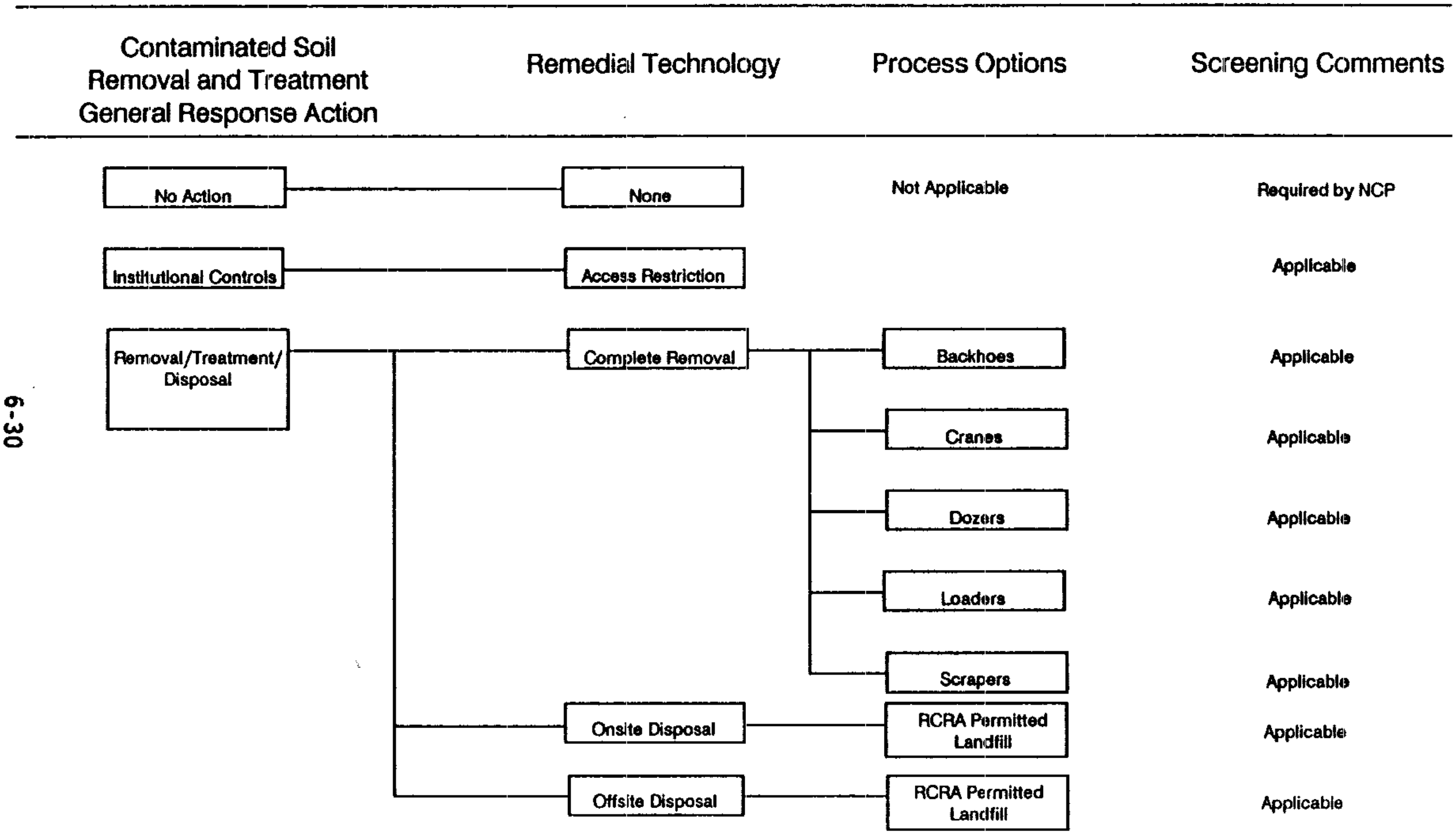


FIGURE 6-2. PRELIMINARY SCREENING OF TECHNOLOGIES WASTE-REMOVED SCENARIO -- SOIL REMOVAL

* Shading indicates technologies that are screened out

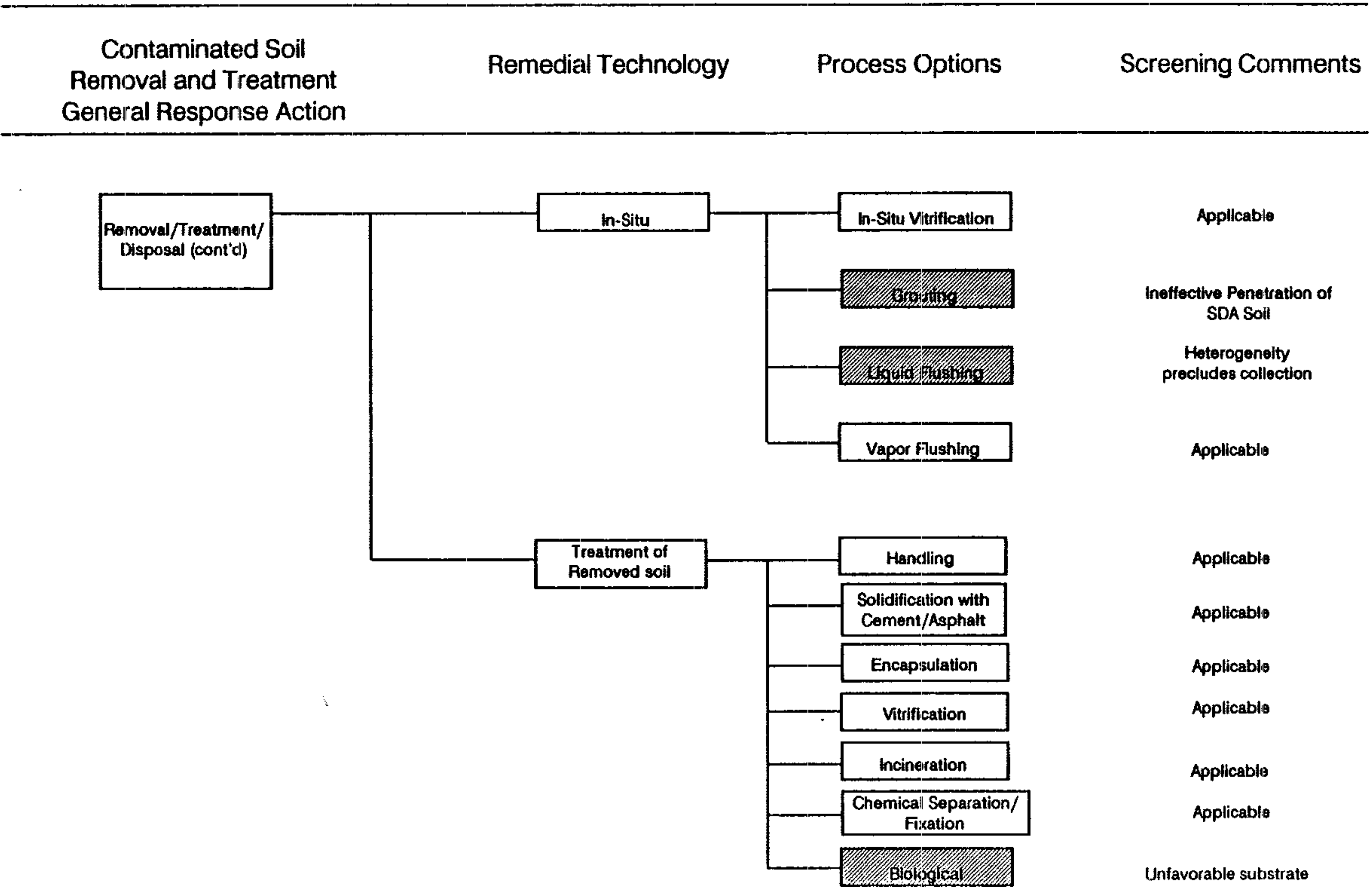


FIGURE 6-2. PRELIMINARY SCREENING OF TECHNOLOGIES WASTE-REMOVED SCENARIO -- SOIL REMOVAL (continued)

* Shading indicates technologies that are screened out

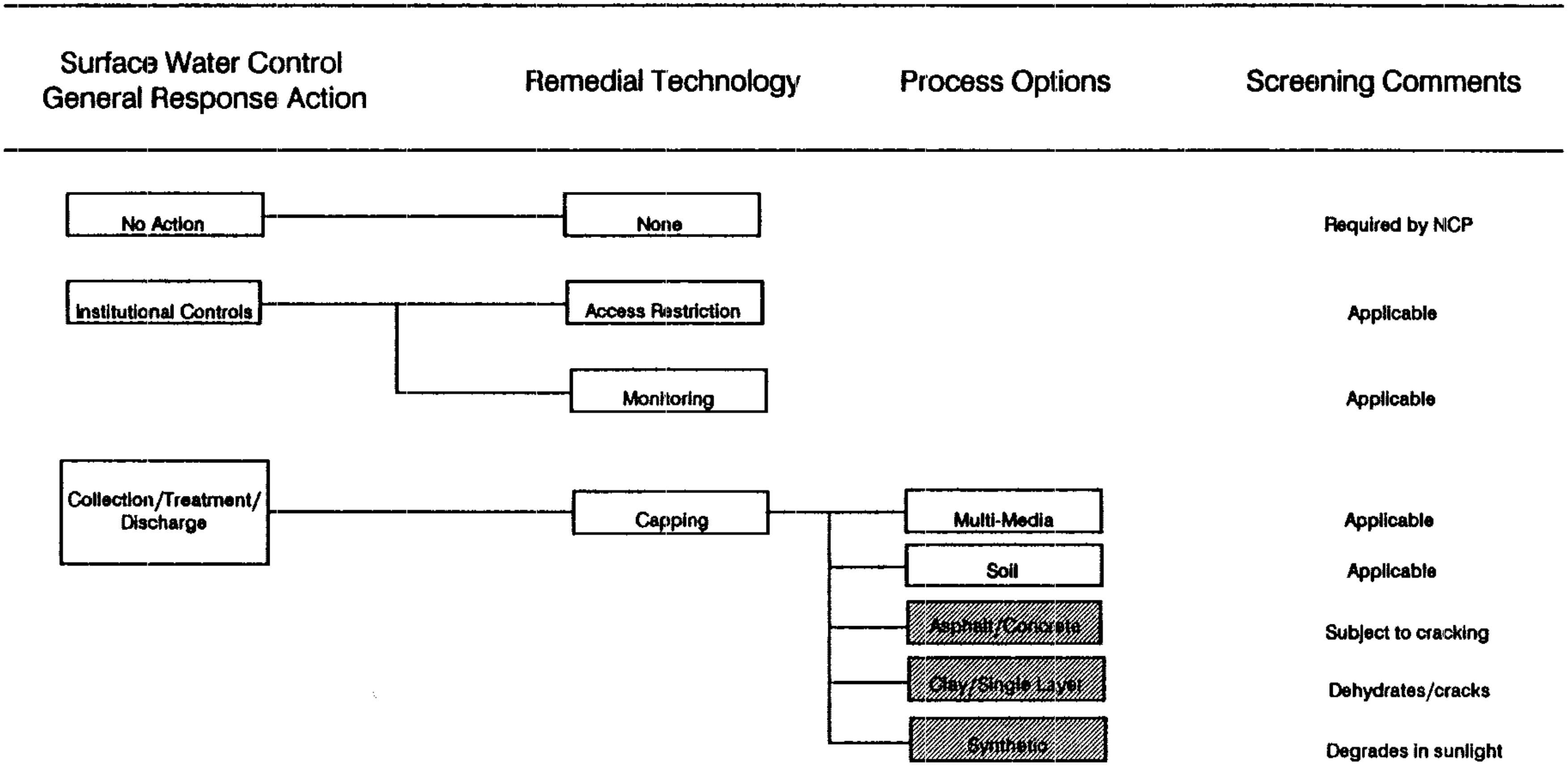


FIGURE 6-3. PRELIMINARY SCREENING OF TECHNOLOGIES MIGRATION CONTROL -- SURFACE WATER CONTROLS

* Shading indicates technologies that are screened out

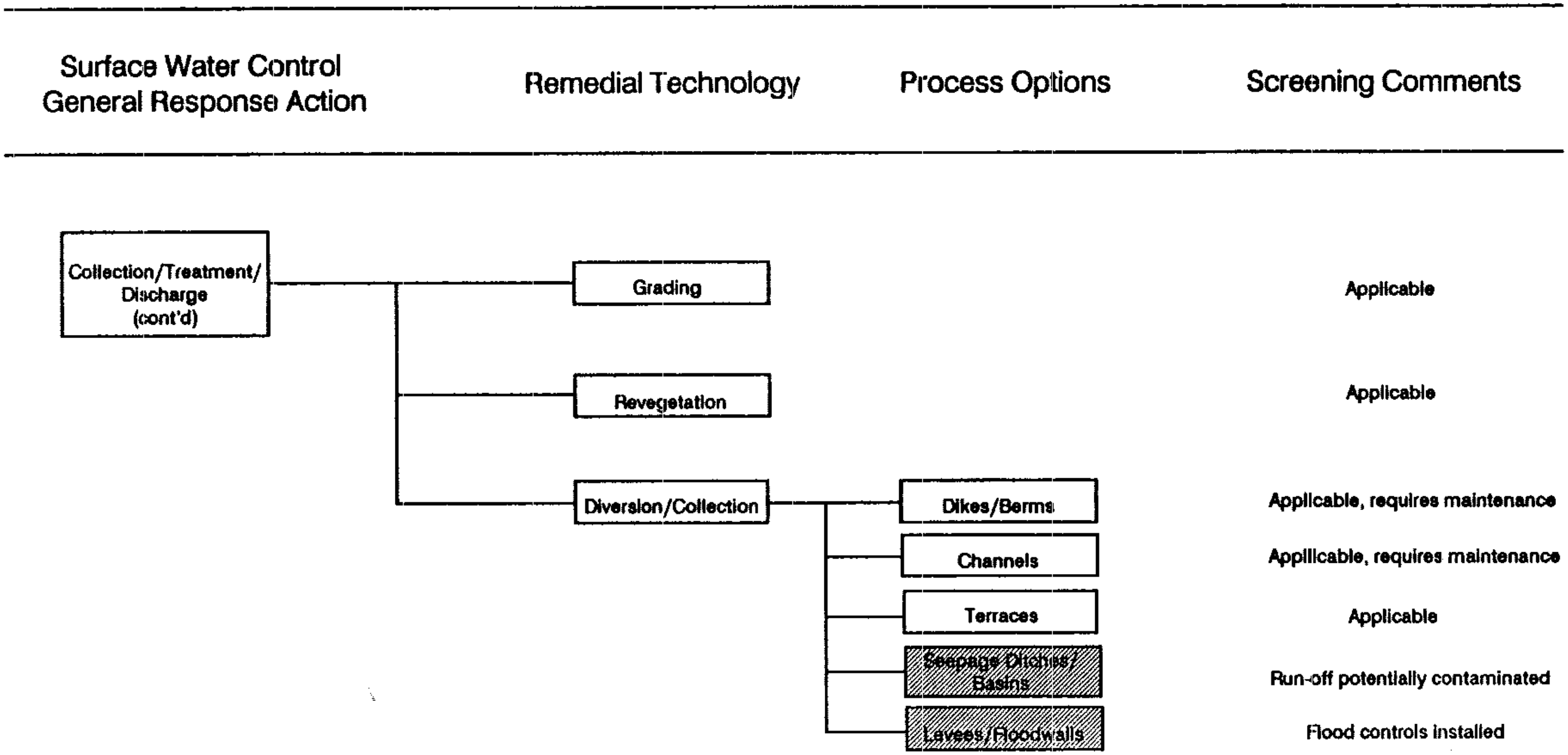


FIGURE 6-3. PRELIMINARY SCREENING OF TECHNOLOGIES MIGRATION CONTROL -- SURFACE WATER CONTROLS (continued)

* Shading indicates technologies that are screened out

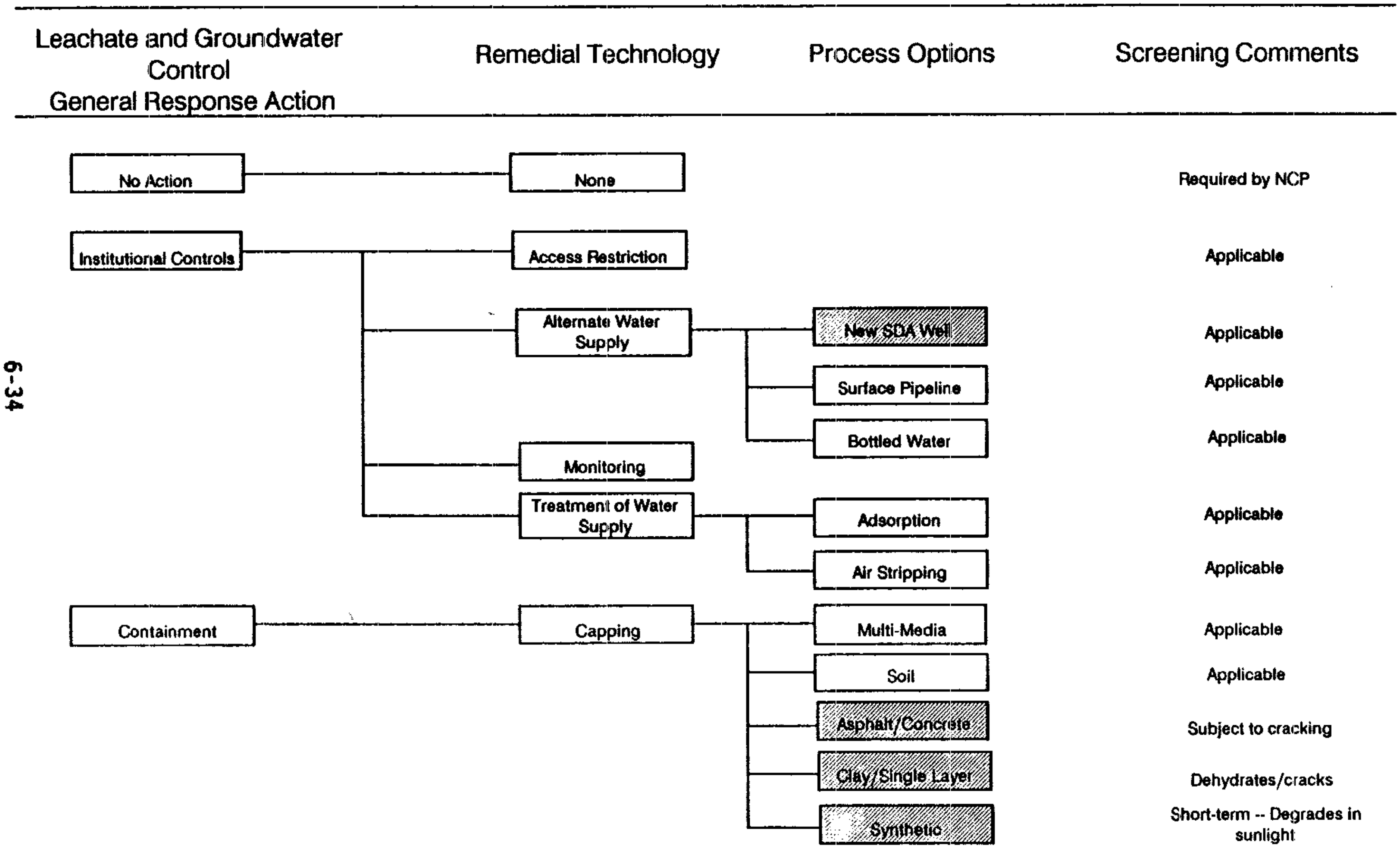


FIGURE 6-4. PRELIMINARY SCREENING OF TECHNOLOGIES MIGRATION CONTROL -- GROUNDWATER/LEACHATE CONTROLS

* Shading indicates technologies that are screened out

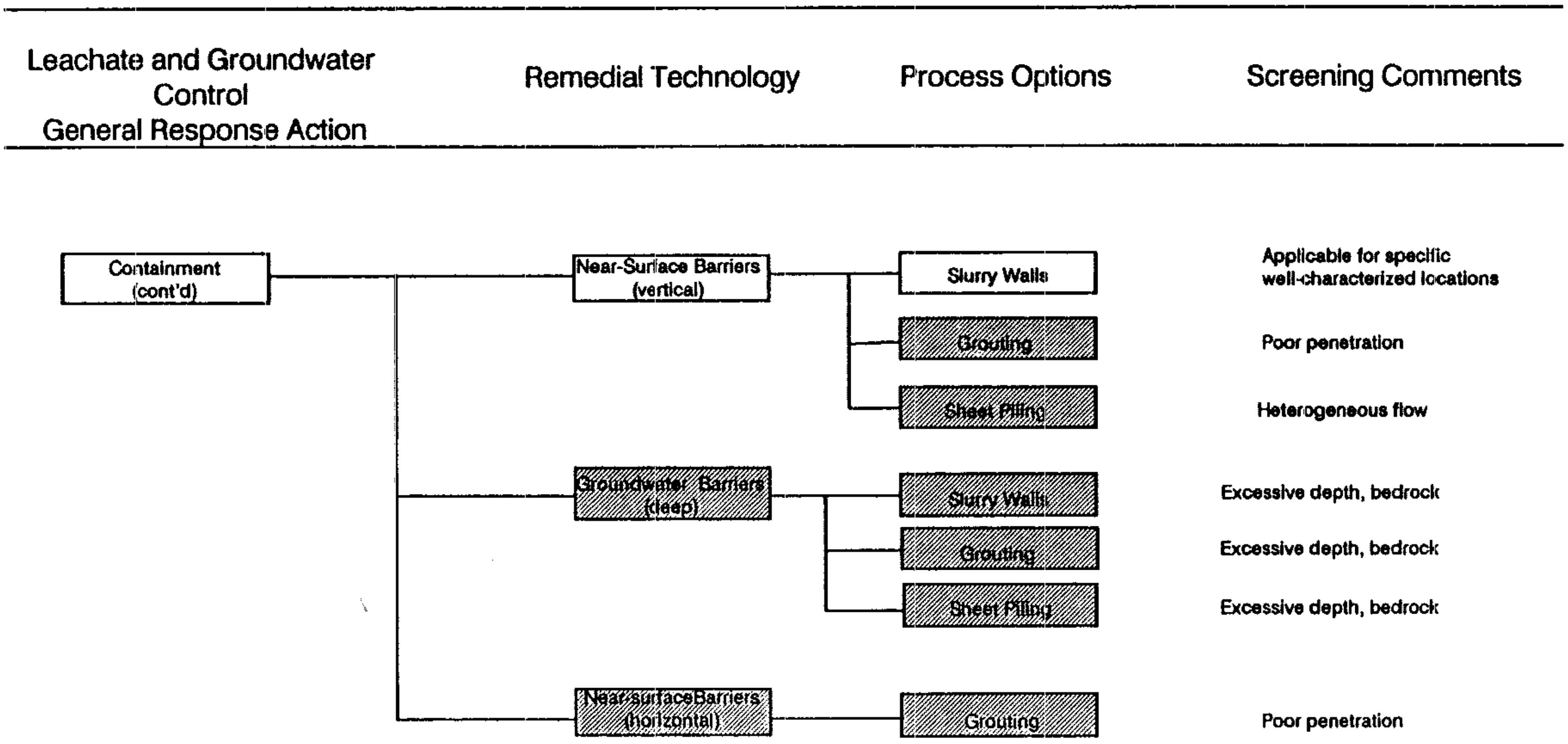
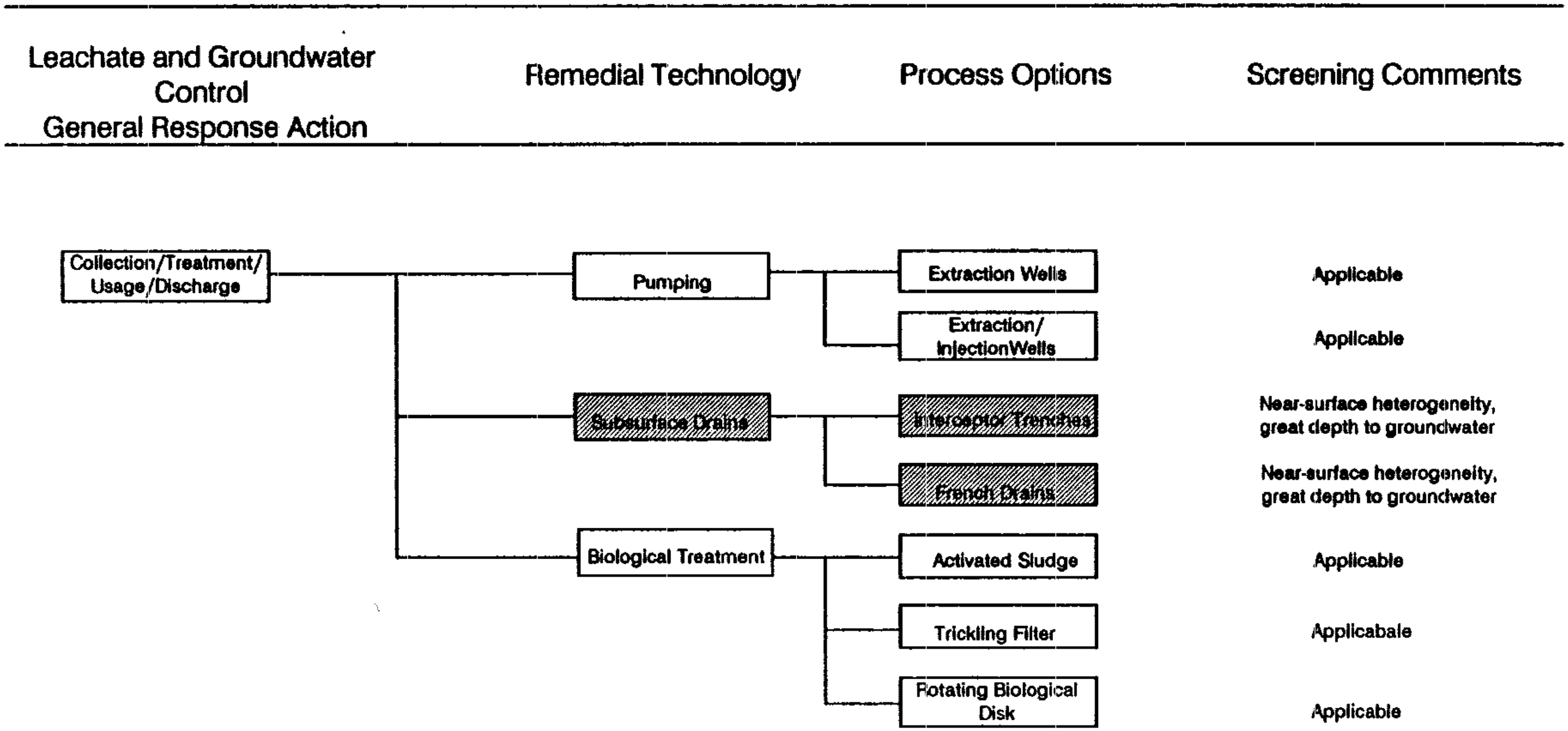


FIGURE 6-4. PRELIMINARY SCREENING OF TECHNOLOGIES MIGRATION CONTROL -- GROUNDWATER/LEACHATE CONTROLS (continued)

* Shading indicates technologies that are screened out



Leachate and Groundwater Control General Response Action	Remedial Technology	Process Options	Screening Comments
Collection/Treatment/ Usage/Discharge	Pumping	Extraction Wells	Applicable
		Extraction/ InjectionWells	Applicable
	▨ Subsurface Drains	▨ Interceptor Trenches	Near-surface heterogeneity, great depth to groundwater
		▨ French Drains	Near-surface heterogeneity, great depth to groundwater
	Biological Treatment	Activated Sludge	Applicable
		Trickling Filter	Applicabale
		Rotating Biological Disk	Applicable

FIGURE 6-4. PRELIMINARY SCREENING OF TECHNOLOGIES MIGRATION CONTROL -- GROUNDWATER/LEACHATE CONTROLS (continued)

* Shading indicates technologies that are screened out

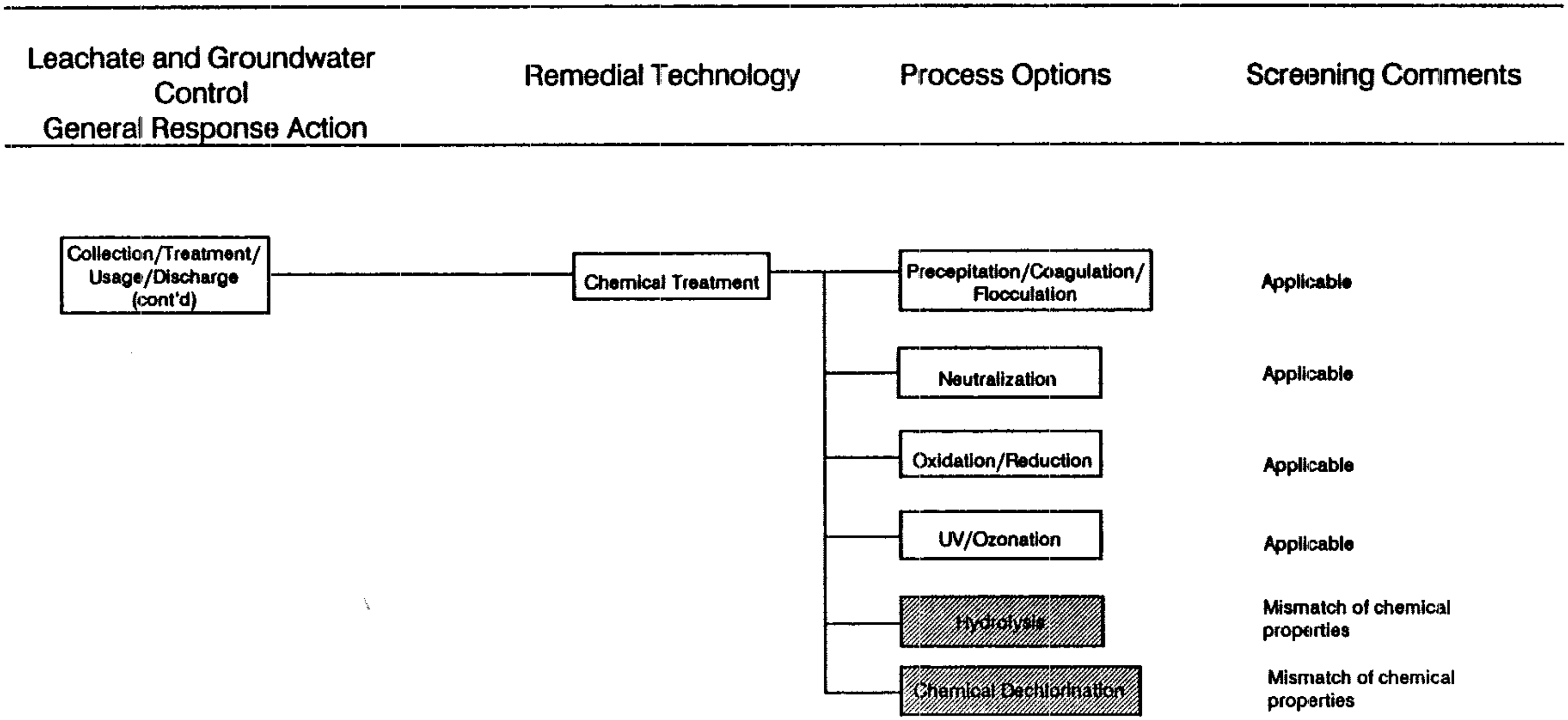


FIGURE 6-4. PRELIMINARY SCREENING OF TECHNOLOGIES MIGRATION CONTROL -- GROUNDWATER/LEACHATE CONTROLS (continued)

* Shading indicates technologies that are screened out

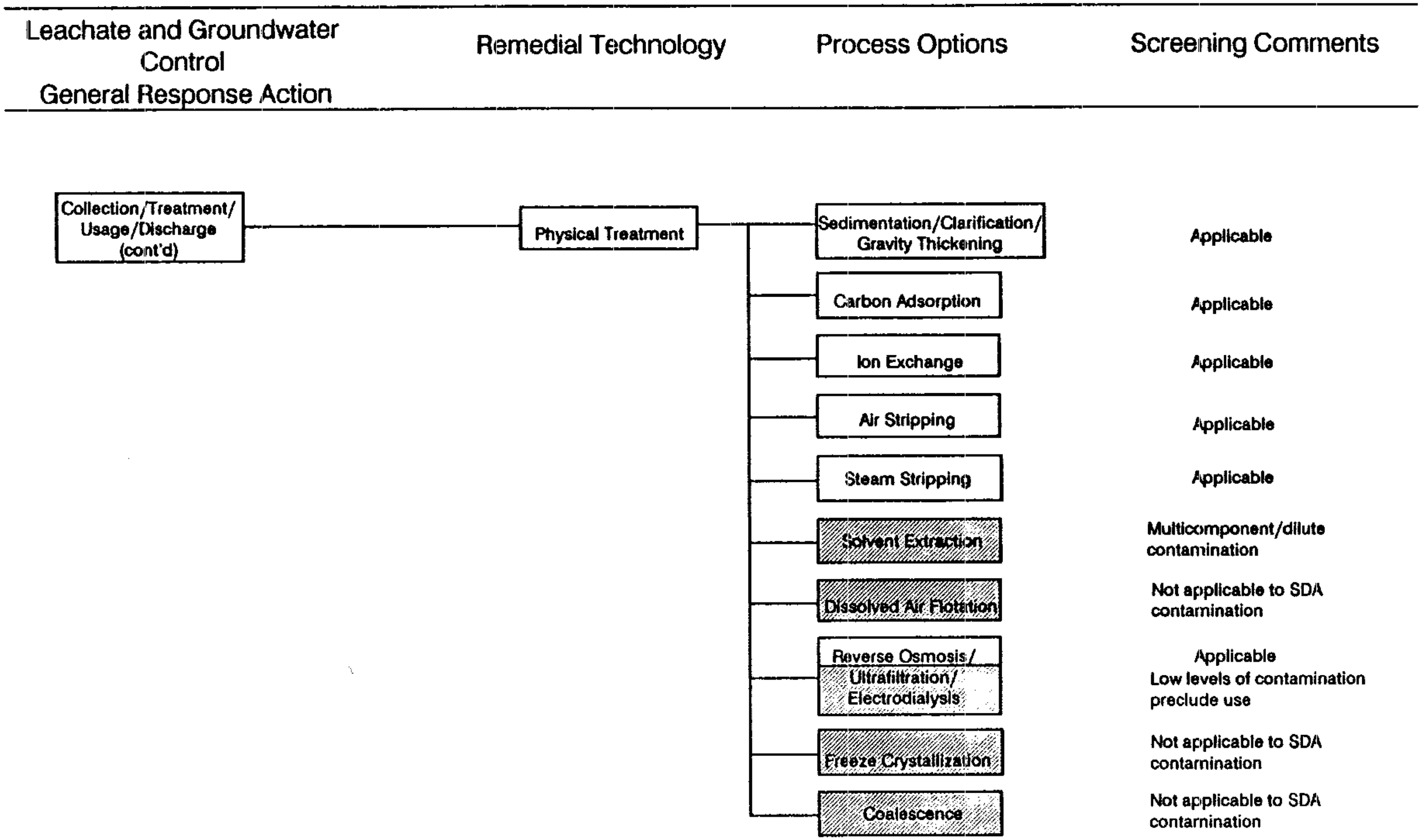


FIGURE 6-4. PRELIMINARY SCREENING OF TECHNOLOGIES MIGRATION CONTROL -- GROUNDWATER/LEACHATE CONTROLS (continued)

* Shading indicates technologies that are screened out

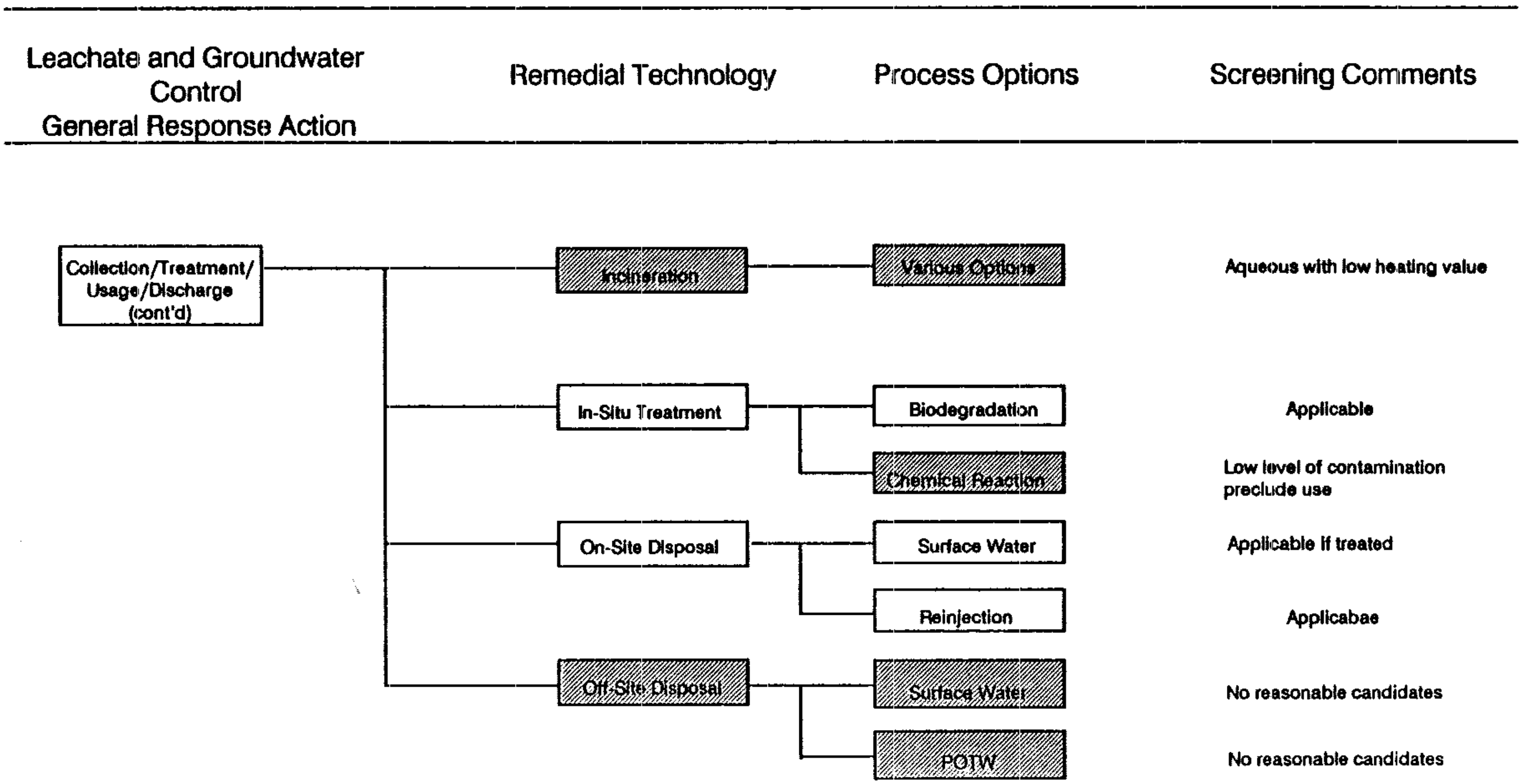


FIGURE 6-4. PRELIMINARY SCREENING OF TECHNOLOGIES MIGRATION CONTROL -- GROUNDWATER/LEACHATE CONTROLS (continued)

* Shading indicates technologies that are screened out

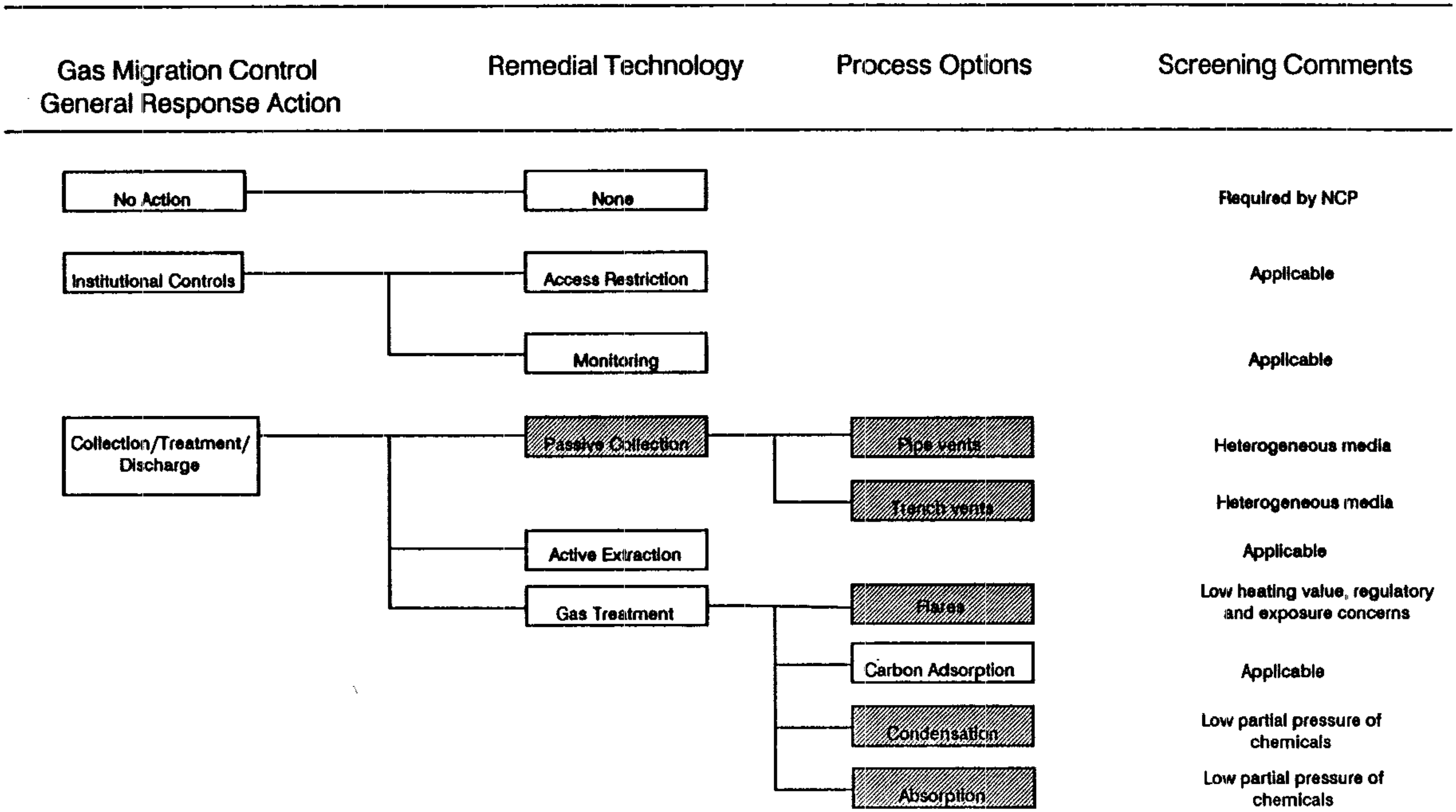


FIGURE 6-5. PRELIMINARY SCREENING OF TECHNOLOGIES MIGRATION CONTROL -- GAS CONTROLS

* Shading indicates technologies that are screened out

Migration control technologies were assessed for containment, in-place treatment, and recovery functions. Among containment controls, multi-media and single layer soil caps, grading, revegetation, surface water diversion and near-surface vertical barriers were considered potentially effective and passed the preliminary screening. Bioreclamation was considered an in-place treatment technology which was potentially effective for groundwater. Among recovery technologies for migration control, gas collection and groundwater pumping were considered potentially effective and passed the preliminary screening.

Among processes for treatment of recovered waste streams, a wide class of technologies pass the preliminary screening since inlet streams are not well characterized at the present time and each technology is considered effective in a particular application.

On- and off-site landfill disposal were considered effective and passed the preliminary screening although the large volumes of soil involved may preclude off-site disposal when evaluated in detail.

Potentially effective institutional controls at the SDA include monitoring of potlentially contaminated media, training programs to limit daily or casual exposure, site access controls, water treatment, and water substitution using bottled, trucked, or pipeline water. Installation of a new on-site well was presumed to be ineffective.

7. RECOMMENDATIONS FOR RESOLVING DATA NEEDS

The results in this report are preliminary. A number of analyses need to be conducted to refine the methodologies presented in this report and to substantiate the assumptions made. The following discussions briefly outline some of the data needs identified in the course of preparing this report and some additional analyses needed.

The nature and extent of contamination has not yet been sufficiently defined to enable selection of indicator chemicals or to fully assess the applicability of specific treatment technologies. Existing information on specific contaminants in each media (soils, surface water runoff, vadose zone (basalt and interbeds) and groundwater) needs to be compiled and evaluated to determine the extent of each constituent in each media; to determine the magnitude and variation in concentration of each constituent in each media; and to assess the adequacy of the number of data points to support various conclusions with regard to the extent of contamination by specific constituents. Some specific questions to be addressed are: (1) the average concentration of each contaminant over time as well as the range (high to low) in concentrations detected; and (2) calculations of the amount of each constituent in the originating waste and in each medium at this time (taking into account past transport that may not be currently detected). This information may be further utilized to narrow the number of chemicals to be evaluated in terms of need to clean up, chemicals of focus in performing risk assessments and health-risk-based cleanup objectives calculations, and further elimination of specific technologies that may have passed screening but may not be able to treat the particular constituents of concern.

A health-risk-based approach to establishing cleanup objectives was developed in this report as a means to estimate concentrations to be achieved in various environmental media as a result of remedial actions taken. This process evaluated long-term risk to residual concentrations of contaminants based on a specified target risk (10^{-6}). In the absence of analyses on the nature and extent of contamination currently found at the SDA, this methodology has used arbitrary allocations of risk:

- Between radioactive and nonradioactive chemicals - equal apportionment between chemical categories

- Between chemicals within a given category (e.g., each radionuclide) - equal apportionment across each chemical within a category

- Between exposure routes considered (ingestion of groundwater, showering with groundwater, ingestion of soil, inhalation of soil) - equal apportionment between each exposure routes.

As additional data and analyses become available, these allocations need to be re-examined. In particular, indicator chemicals need to be identified to reduce the number of chemicals requiring analysis. Other areas to be examined include:

- Determination as to whether radioactive or nonradioactive components, on a media-specific basis, may contribute more to the exposure calculations.

- Development of a weighting scheme for the four exposure routes considered. This may be based on the number of chemicals in each route, their relative contributions, their relative risk, and other factors. Average concentrations of each compound over time would be one way to approach this analysis.

- Evaluation of the adequacy of a target risk of 10^{-6} versus the adequacy of selecting a different value within the range of 10^{-4} to 10^{-7} (including a detailed justification to meet EPA satisfaction).

Data needs were also identified during the technology screening process. These data needs are presented throughout Section 6.3 in association with the pertinent screening analysis and are not repeated here.

8. BIBLIOGRAPHY AND REFERENCES

1. Rasmussen, T.L., EG&G, Letter to B.J. Mikkola (DOE-Idaho) Regarding FY-1988 Year End Status of Waste Innovative Ideas, TLR-121-88, 11/03/88.
2. Landon, J.L., EG&G, BWP Innovative Ideas Status of Projects, 6/88.
3. Baca, R.G. and J.C. Walton, EG&G, Preliminary Conceptual Models of Contaminant Migration at the RWMC- Informal Report, EGG-WM-8023, March 1988.
4. Walton, J.C., et. al., Model for Estimation of Chlorinated Solvent Release from Waste Disposal Sites, 05/03/88.
5. Markham, O.D., Summaries of the Idaho National Engineering Laboratory Radioecology and Ecology Program Research Projects, DOE/ID-12111, June 1987.
6. Reynolds, T.D. and O.D. Markham, Publications of the Idaho National Engineering Laboratory Radioecology and Ecology Program: 1974-1986, DOE/ID-12109.
7. Tkachyk, J.W., et. al., Annual Report- 1987 Environmental Surveillance for the EG&F Idaho Radioactive Waste Management Areas at the Idaho National Engineering Laboratory, EGG-2550, August 1988.
8. Laney, P.T., et. al., Annual Progress Report: FY-1987, Subsurface Investigations Program at the Radioactive Waste Management Complex of the Idaho National Engineering Laboratory, DOE/ID-10183, April 1988.
9. EG&G Idaho Environmental Chemistry, Report of Analysis- Corrected Issue, ROA No. 2, 07/13/88.
10. EG&G Idaho Environmental Chemistry, Report of Analysis, 07/19/88.
11. Well 88-1-D Sampling and Analysis (Mtg Morreale, Rasmussen, Solecki), 08/05/88.
12. Weston Analytics, Case Narrative and Inorganic Analysis Data Sheets, RFW No. 8807S099, 10/07/88.
13. Weston Analytics, Case Narrative and Inorganic Analysis Data Sheet, RFW No. 8807S079, 10/07/88.
14. Weston Analytics, Sample Data Package for EG&G INEL (selected pages), Lab. ID: 88-06-S079, 1/87 Rev.
15. SAIC, Preliminary Review of ARARs and Development of Remedial Objectives for the Buried Waste Program, Prepared for EG&G Idaho, 05/05/88.
16. Chew, E.W. and R.G. Mitchell, 1987 Environmental Monitoring Program Report for the Idaho National Engineering Laboratory Site, DOE/ID-12082(87), May 1988.

17. Loomis, G.G. and J.O. Low, Annual Technology Assessment and Progress Report for the Buried Transuranic Waste Studies Program at the Idaho National Engineering Laboratory (1987), EGG-2525, January 1988.

18. Low, J.O., Assessment of the In Situ Grouting Experiment at the INEL's Radioactive Waste Management Complex, EGG-WM-7927, November 1987.

19. USDOE, Environmental and Other Evaluations of Alternatives for Management of Defense Transuranic Waste at the Idaho National Engineering Laboratory, Volumes 1 & 2, April 1982.

20. USDOE, Environmental and Other Evaluations of Alternatives for Long-Term Management of Buried INEL Transuranic Waste, IDO-10085, December 1979.

21. Low, J.O., Annual Technology Assessment and Progress Report for the Buried Waste Program at the Idaho National Engineering Laboratory, EGG-2429, December 1985 (PAGES 25 & 26).

22. Low, J.O., et. al., Annual Technology Assessment and Progress Report for the Buried Waste Program at the Idaho National Engineering Laboratory, EGG-2483, January 1987 (PAGE 21).

23. Berreth, P.D., Annual Technology Assessment and Progress Report for the Buried Waste Program at the Idaho National Engineering Laboratory, EGG-2321, November 1984 (SELECTED PAGES).

24. EG&G Idaho, Title I Design Package (Technical Specification and Title I Drawings) for Buried Waste Program Retrieval Demonstration Containment Facility, Section III- Specifications for Buried Waste Program Retrieval Demonstration Facilities, 1988.

25. Low, J.O., Long-Range Plan for Buried Transuranic Waste Studies at the Idaho National Engineering Laboratory, EGG-2427, December 1985 (SELECTED PAGES).

26. Berreth, P.D., et. al., Long-Range Plan for Buried Transuranic Waste Studies at the Idaho National Engineering Laboratory, EGG-2350, November 1984 (SELECTED PAGES).

27. Bishoff, J.R., et. al., Alternatives for Retrieving Transuranic Waste Buried at the Idaho National Engineering Laboratory, Informal Report, EGG-WM-6481, November 1984.

28. Hinckley, J.P., et. al., Alternatives for Long-Term Management of Contaminated Soil Associated with Transuranic Waste Buried at the INEL, Informal Report, EGG-WM-6486, November 1984.

29. Murphy, T.L. and S.P. Fogdall, Conceptual Design Package, Volume 1 of 1, for Buried Waste Program Functional Waste Retrieval Demonstration Retrieval Equipment Design- Buried Waste Project Retrieval Demonstration Requirements, EGG-WT-7990, February 1988.

30. EG&G Idaho, RCRA Facility Investigation Workplan (Volumes I, II, & III), Informal Report, EGG-WM-8219, 09/01/88.

31. Card, D.H., History of Buried Transuranic Waste at INEL, EG&G WMP 77-3, March 1977. (See Ref. #30, Volume II)

32. EG&G Idaho, A History of the Radioactive Waste Management Complex at the Idaho National Engineering Laboratory, Internal Technical Report, WM-F1-81-003 (Rev. 3), July 1985. (See Ref. #30f, Volume II)

33. Rightmire, C.T. and B.D Lewis, Hydrology and Geochemistry of the Unsaturated Zone, Radioactive Waste Management Complex, Idaho National Engineering Laboratory, Idaho, U.S. Geological Survey Water Resources Investigations Report 87-4198, November 1987. (See Ref. #30, Volume II)

34. Humphrey, T.G., Subsurface Migration of Radionuclides at the Radioactive Waste Management Complex- 1978, EGG-2026, July 1980. (See Ref. #30, Volume II)

35. Barraclough, J.T., et. al., Hydrology of the Solid Waste Burial Ground, as Related to the Potential Migration of Radionuclides, Idaho National Engineering Laboratory, U.S. Geological Survey Open File Report 76-471, IDO-22056, August 1976. (See Ref. #30, Volume II)

36. Hubbell, J.M., et. al., Annual Progress Report: FY-1985, Subsurface Investigations Program at the Radioactive Waste Management Complex at the Idaho National Engineering Laboratory, DOE/ID 10136, December 1985. (See Ref. #30, Volume II)

37. Hubbell, J.M., et. al., Annual Progress Report: FY-1986, Subsurface Investigations Program at the Radioactive Waste Management Complex at the Idaho National Engineering Laboratory, DOE/ID 10153, January 1987. (See Ref. #30, Volume II)

38. Laney, P.T., et. al., Annual Progress Report: FY-1987, Subsurface Investigations Program at the Radioactive Waste Management Complex of the Idaho National Engineering Laboratory, DOE/ID 10183, April 1988. (See Ref. #30, Volume II)

39. Humphrey, T.G. and F.H. Tingey, The Subsurface Migration of Radionuclides at the Radioactive Waste Management Complex 1976-1977, TREE-1171, October 1978. (See Ref. #30, Volume II)

40. Low, J.O., et. al., Annual Technology Assessment and Progress Report for the Buried Transuranic Waste Studies Program at the Idaho National Engineering Laboratory, EGG-2483, January 1987.

41. Shuman, R.D., et. al., Documentation of a Simple Environmental Pathways Model of the Radioactive Waste Management Complex at the Idaho National Engineering Laboratory, EGG-WM-6916, September 1985.

42. USGS, Unpublished information- Concentrations of selected trace metals and purgeable organic compounds in ground water, 1988.

43. International Atomic Energy Agency, Management of Abnormal Radioactive Wastes at Nuclear Power Plants- Draft Report, Vienna, Austria, 1987-06-18.

44. Rawson, S.A., Geochemistry of Soil Waters from the Radioactive Waste Management Complex (RWMC)- An Informal Letter Report, EG&G Idaho, December 12, 1988.

45. Mann, L.J. and L.L. Knobel, Purgeable Organic Compounds in Ground Water at the Idaho National Engineering Laboratory, Idaho, U.S.G.S. Open File Report 87-766, Idaho Falls, Idaho, December 1987.

46. McKone, Thomas E., 1987, Human Exposure to Volatile Organic Compounds in Household Tap Water: The Indoor Inhalation Pathway, Environmental Science and Technology, Vol. 21, pp. 1194-1201.

47. U.S. Environmental Protection Agency, 1986, Superfund Public Health Evaluation Manual, Office of Emergency and Remedial Response, Washington, DC; EPA 540/1-86/060, October.

48. U.S. Environmental Protection Agency, 1988, Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA, Draft, Office of Emergency and Remedial Response, Washington, DC, March 1988.

49. U.S. Environmental Protection Agency, 1989, Integrated Risk Information System, On-Line Data Base of Toxicity Measures, Office of Research and Development, Environmental Criteria and Assessment Office, Cincinnati, OH, Electronic Mail Account Information via Dialcom, Inc. 600 Maryland Ave, SW, Washington, DC.

50. NRC, 1983, Risk Assessment in the Federal Government: Managing the Process, National Research Council, National Academy Press, Washington, DC.

51. Smith, S.M. and C.D. Zamuda, 1988, The Role of Risk Assessment and ARARs in Setting Protective Standards at CERCLA Sites, in Superfund '88, Proceedings of the National HMCRI Conference, Washington, DC, November 1988.

52. U.S. Environmental Protection Agency, 1984, Risk Analysis of TCDD Contaminated Soil, USEPA Exposure Assessment Group (John Schaum), Office of Health and Environmental Assessment, Office of Research and Development, Washington, DC.

53. U.S. Environmental Protection Agency, 1986, Guidelines for Carcinogenic Risk Assessment, Federal Register 51(185):33991-34003.

54. U.S. Environmental Protection Agency, 1986, Guidelines for Carcinogenic Risk Assessment, USEPA and the Health Risk Assessment of Chemical Mixtures, Federal Register 51(185):34014-34025.

55. U.S. Environmental Protection Agency, 1987, Superfund Program: Interim Guidance on Compliance with Other Applicable or Relevant and Appropriate Requirements, Federal Register 52(166):32496-32499.

56. U.S. Environmental Protection Agency, CERCLA Compliance with Other Laws Manual - Draft, Office of Emergency and Remedial Response, OSWER Directive 9234.1-01.

57. U.S. Environmental Protection Agency, 1988, National Oil and Hazardous Substances Pollution Contingency Plan (NCP), Federal Register 53(245):51394-51520.

58. Bowman, A.L., et. al., INEL Environmental Characterization Report, Volume I, II, and III, EGG-NPR-6688, September 1984.

59. JRB Associates, Methodology for Screening and Evaluation of Remedial Responses Draft, McLean, VA, March 1984.

60. U.S. Environmental Protection Agency, 1984 Remedial Response at Hazardous Waste Sites - Case Studies 1-23, Washington, DC, EPA-540/2-84-002G.

61. Landon, J.L., Memorandum to C.A. Allen et al, Innovative Ideas Project Status Report, July 30, 1988.

62. Anderson, D.B., Surveillance and Maintenance of the West Valley State Licensed Low-Level Radioactive Waste Disposal Area 1983-1987, in Waste Management Eighty Eight, R.G. Post and M.E. Wacks (ed), Proceedings of the Symposia on Waste Management, Tuscon, Arizona, February 28 - March 3, 1988.

63. U.S. Environmental Protection Agency, Remedial Action at Waste Disposal Sites Handbook, Office of Emergency and Remedial Response, Washington, DC, EPA/625/6-85/006, October 1985.

64. Lopez, E.A., et. al., Effects of Vegetation and Soil Surface Cover Treatments On The Hydrologic Behavior of Low-Level Waste Trench Caps, in Waste Management Eighty Eight, Proceedings of the Symposia on Waste Management, Tuscon, Arizona, February 28 - March 3, 1988.

65. O'Donnell, E., et. al., Control of Water Infiltration Into Near Surface LLW Disposal Units, in Waste Management Eighty Eight, Proceedings of the Symposia on Waste Management, Tuscon, Arizona, February 28 - March 3, 1988.

66. Applegate, J., et. al., Vacuum Extraction of Hydro-carbons from Subsurface Soils at a Gasoline Site, in Superfund '87, Proceedings of the Eighth National Conference, Washington, DC, November 16-18, 1987.

67. Fitzpatrick, V.F., et. al., In-Situ Vitrification, A Potential Remedial Action Technique For Hazardous Waste, in the Fifth National Conference On Management of Uncontrolled Hazardous Waste Sites, Washington, DC, November 7-9, 1984.

68. Buelt, J.L., and J.L. Westik, In-Situ Vitrification-Preliminary Results From The First Large Scale Radioactive Test, in Waste Management Eighty Eight, Proceedings of the Symposia on Waste Management, Tuscon, Arizona, February 28 - March 3, 1988.

69. Mrochek, J.E., et. al., Grout Formulation For The Immobilization Of Mixed Organic-Containing Wastes, in Spectrum '86, Proceeding of the American Nuclear Society International Topical Meeting, Niagara Falls, NY, September 14-18, 1986.

70. Haase, C.S., et. al., Studies To Determine The Fate Of Radioactive Wastes Disposed Of By Underground Injection At Oak Ridge National Laboratory, in Waste Management Eighty Eight, Proceedings of the Symposium on Waste Management, Tuscon, Arizona, February 28 - March 3, 1988.

71. U.S. Environmental Protection Agency, 1988, Technological Approaches to the Cleanup of Radiologically Contaminated Superfund Sites, Office of Research and Development, Washington, DC, EPA/540/2-88/002, August.

72. Lord, A.E., et. al., In-Situ, Vacuum Assisted, Steam Stripping of Contaminated Soil, in Superfund '87, Proceedings of the Eighth National Conference, Washington, DC, November 16-18, 1987.

73. Van Tassel, R. and P.N. LaMori, Innovative In-Situ Soil Decontamination System, in Superfund '87, Proceedings of the Eighth National Conference, Washington, DC, November 16-18, 1987.

74. White, E.L., Waste Salt Disposal At The Savannah River Plant, in Spectrum '86, Proceedings of the American Nuclear Society International Topical Meeting, Niagara Falls, NY, September 14-18, 1986.

75. Mayo, K.S., W.D. Black and F.D. Rowsell, Alternative Method of Solidification For Low-Level Class A Radioactive Waste, in Waste Management Eighty Eight, Proceedings of the Symposium on Waste Management, Tuscon, Arizona, February 28 - March 3, 1988.

76. Pugliones, P.S., et. al., Heavy Metals - Contaminated Soils, in Superfund '87, Proceedings of the Eighth National Conference, Washington, DC, November 16-18, 1987.

77. Peterson, R.D., et. al., Application of Microwave Energy for Solidification of TRV Waste, in Waste Management Eighty Eight, Proceedings of the Symposium on Waste Management, Tuscon, Arizona, February 28 - March 3, 1988.

78. Genthner, H., et. al., Solidification of Low-Level Salt Solutions With Microwaves, in Waste Management Eighty Eighty, Proceedings of the Symposium on Waste Management, Tuscon, Arizona, February 28 - March 3, 1988.

79. J.J. Barich, et. al., Soil Stabilization Treatability Study At The Western Processing Superfund Site, in Superfund '87, Proceedings of the Eighth National Conference, Washington, DC, November 16-18, 1987.

80. Science Applications International Corporation, "Energy Recovery From Hazardous Waste Incineration", Oak Ridge, TN, November 30,1987.

81. Dufrane, K.H. and M. Arnold, A Licensed Centralized Low-Level Waste Incinerator Facility, in Spectrum '86, Proceedings of the American Nuclear Society International Topical Meeting, Niagara Falls, NY, September 14-18, 1986.

82. Rulkens, W.H. and J.W. Assnk, Extraction As A Method For Cleaning Contaminated Soil; Possibilities, Problems and Research, in Management of Uncontrolled Hazardous Waste Sites, Fifth National Conference, Washington, DC, November 7-9, 1984.

83. Kohl, A. and F. Riesenfeld, Gas Purification, Gulf Publishing Co., Houston, TX, 1979.

84. Wallace, K.A., et. al., Evaluation of Groundwater Remediation Techniques for Fractured Bedrock Using Aquifer Response Tests, in Superfund '87, Proceedings of the Eighth National Conference, Washington, DC, November 16-18, 1987.

85. U.S. Environmental Protection Agency, 1973 Air Pollution Engineering Manual, J.A. Danelson (ed), Office of Air and Water Programs, Research Triangle Park, NC, May.

86. American Conference of Governmental Industrial Hygienists, Industrial Ventilation, 19th Edition, Cincinnati, Ohio, 1986.

87. Burchsted, C.A., et. al., Nuclear Air Cleaning Handbook, Oak Ridge National Laboratory, Oak Ridge, TN, ERDA 76-21, 1976.

88. Nalco Chemical Company, The NALCO Water Handbook, F.N. Kemmer (ed), McGraw Hill Book Company, New York, NY, 1979.

89. Bray, L.A., et. al., Experimental Data Developed to Support the Selection of a Treatment Process for West Valley Supernatant, Pacific Northwest Laboratory, Richland, Washington, PNL-4969, January 1984.

90. Collins, E.D., et. al., An Improved Ion Exchange Method For Treatment Of Slightly Contaminated Wastewaters, in Spectrum '86, Proceedings of the American Nuclear Society International Topical Meeting, Niagara Falls, NY, September 14-18, 1986.

91. Treybal, R.E., Mass Transfer Operations, McGraw Hill Book Company, New York, NY, 1968.

92. International Commission on Radiological Protection, 1980, Radiation Protection - Limits for Intakes of Radionuclides by Workers, ICRP Publication 30 (and Supplements), F. D. Sowby editor, Pergamon Press, Oxford, England.

93. International Commission of Radiological Protection, Publication 51.

APPENDICES

APPENDIX A

DERIVATION OF EQUATIONS FOR CALCULATING RISK-BASED REMEDIATION GOALS

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This appendix presents the derivation for the equations used in calculating risk-based remediation goals at the SDA. Section 4 of the report provides a more detailed discussion of the use of these equations and further clarification of a number of key variables. In this developmental phase, the cleanup levels calculated using the following equations must be considered preliminary/example remediation goals. A number of simplifying assumptions have presently been incorporated into the process in order to demonstrate the utility of the methods developed (see Section 4.). It is anticipated that these will be subsequently refined.

A.1 RISK-BASED REMEDIATION GOALS FOR EXPOSURE TO NONRADIOACTIVE CARCINOGENIC CHEMICALS

The general equation for estimating combined excess lifetime risk of cancer for exposure to nonradioactive carcinogens is defined as follows:

$$R = \Sigma \ (D \times CPF) \qquad (1)$$

where

R = combined excess lifetime risk of cancer for exposure to more than one carcinogenic chemical and exposure pathway. This method assumes additivity of cancer risk in the absence of data on synergism and antagonism.

D = chronic daily dose for the subject chemical via a given exposure route (mg/kg body weight/day)

CPF = Cancer potency factor for oral or inhalation exposure pathways. CPF is the 95% upper-bound estimate of the slope of the dose-response curve [(mg/kg body weight/day)$^{-1}$]

Remediation goals for any given chemical in soil or groundwater at the SDA are derived based on potential exposure of SDA personnel via one or two pathways. For a chemical in groundwater, the exposure pathways are direct ingestion and inhalation (of valatiles released) during showering. For compounds in soil, the exposure pathways include direct ingestion and inhalation of suspended soil particulates. As an example, the combined excess lifetime risk (R) of ingestion and inhalation (via showering) exposure to a chemical in groundwater could be calculated as follows:

$$R = (D_{ao} \times CPF_{ao}) + (D_{ai} \times CPF_{ai}) \qquad (2)$$

where

D_{ao} = Dose for chemical "a" from ingestion exposure to groundwater (i.e., oral route)

D_{ai} = Dose for chemical "a" from inhalation exposure to volatile chemicals released during showering (i.e., inhalation route)

CPF_{ao} = Cancer potency factor for chemical "a" for the oral exposure route

CPF_{ai} = Cancer potency factor for chemical "a" for the inhalation exposure route

The average daily lifetime dose (for a given chemical "a") may be generally defined by the following equation:

$$D_{aj} = C_a \times IF_j \qquad (3)$$

where

C_a = Concentration of chemical "a" in a given environmental medium under evaluation

IF_j = Intake factor for exposure route "j"

The subscript j denotes a specific exposure pathway. Let $j = o$ for the oral exposure route and $j = i$ for the inhalation exposure route.

The intake factor IF is generally defined by EPA as the quantity of environmental medium to which a receptor at risk of exposure may come in contact (for example, 2 liters of water per day for ingestion exposure to drinking water supplies). In this assessment of the SDA facility, the intake factor IF also incorporates a number of other variables. As described in Section 4, these include: (1) a measure of exposure duration/frequency; (2) an absorption factor reflecting the fraction of chemical bioavailable for uptake and absorption from a given environmental medium; and (3) the average body weight of the receptors at risk (this factor is incorporated only for nonradioactive materials in order that dose estimates may be expressed in the correct units).

Substituting equation (3) into equation (2) and rearranging yields the following expression:

$$R = C_a \times (CPF_{ao} \times IF_o + CPF_{ai} \times IF_i) \tag{4}$$

Solving equation (4) for C_a gives the following result:

$$C_a = R/(CPF_{ao} \times IF_o + CPF_{ai} \times IF_i) \tag{5}$$

Equation (5) is the general form of the equation for calculating risk-based remediation goals for nonradioactive carcinogenic chemicals in a given environmental medium. C_a is the remediation goal or target cleanup level for a given chemical ("a") and a specific environmental medium.

Equation (5) cannot be solved until a value is assigned to the variable R, the excess lifetime cancer risk. That is, the remediation goal C_a must be derived for a specified target risk level. As noted in Section 4 of this report, EPA has established the excess lifetime risk range of 10^{-4} to 10^{-7} as protective of human health and to be used as a basis for selecting remedial action alternatives. The excess lifetime risk level of 10^{-6} is suggested by EPA as a benchmark or "point of departure" in establishing acceptable levels of exposure.

In this initial work conducted for EG&G, 10^{-6} has been established as the overall target (excess) lifetime risk level for demonstrating the utility of the methods developed. The overall lifetime risk of combined exposure to all subject chemicals at the SDA, by all exposure routes must therefore equal 10^{-6}. One half of this risk level (5.0×10^{-7}) has thus been allocated to nonradioactive chemicals and to radionuclides as classes of compounds of concern at the SDA. (Note that this is a simplistic and arbitrary allocation of risk solely for the purposes of initially demonstrating the methodology that has been developed). Finally, half of this latter risk level (e.g., 2.5×10^{-7}) is allocated to groundwater and soil environmental media (each) for nonradioactive chemicals and radionuclides.

Given the allocated risk for a given environmental medium (e.g., 2.5×10^{-7} for groundwater or soil), an apportioned risk level must be determined for each "chemical-route" under evaluation. Equation (6) below is used to apportion target risk across the chemicals and exposure pathways under investigation. The equation derives the apportioned target risk per "chemical-route" (TRPCR).

$$\text{TRPCR} = \frac{2.5 \times 10^{-7}}{\text{Total no. of "chemical-routes}} \qquad (6)$$

The total number of "chemical-routes" is determined as the sum of the products of number of chemicals (with common exposure routes) times the number of exposure routes. Specifically, for carcinogens in each environmental medium:

- <u>Groundwater consumption and showering</u>

  Organics: 4 chemicals x 2 exposure routes = 8 "chemical-routes"
  Metals: 1 chemical x 1 exposure route = 1 "chemical-route"
  Total: 8 + 1 = 9 "chemical-routes"

  Radionuclides:
    1 chemical x 2 exposure route (Sr-90) = 1 "chemical-route"
    1 chemical x 2 exposure routes (Tritium) = 2 "chemical-routes"
  Total: 3 "chemical-routes"

- Soil ingestion and inhalation

  Organics: 3 chemicals x 2 exposure routes = 6 "chemical-routes"
  Total: 6 "chemical-routes"

  Radionuclides: 8 nuclides x 2 exposure routes = 16 "chemical-routes"
  Total: 16 "chemical-routes"

Equation (6) is used to calculate the apportioned target risk per "chemical-route" separately for: (1) the groundwater consumption and showering pathways; and (2) for the soil ingestion and soil inhalation pathways. Using the apportioned target risk level, preliminary risk-based remediation goals are then developed for each subject chemical.

The actual risk apportioned for chemical a would be the product of TRPCR and the number of "chemical-routes" (NCR) for this particular chemical. Substituting this apportioned risk measure (i.e., NCR x TRPCR) for the risk factor "R" in equation (5), the preliminary risk-based cleanup levels or remediation goals, are calculated for nonradioactive chemicals. As follows:

$$C_a = \frac{(NCR \times TRPCR)}{(CPF_{ao} \times IF_o + CPF_{ai} \times IF_i)} \qquad (7)$$

where

C_a = Preliminary remediation goal for chemical "a" in a given environmental medium. Units: ug/L for water or mg/kg for soil.

NCR = Number of "chemical-routes" of concern for chemical "a" under evaluation. (Note that NCR would take on a value of 1 or 2 for the chemicals under investigation at the SDA).

TRPCR = Target risk per "chemical-route" as defined above.

CPF_{ao} = Cancer potency factor for chemical "a", oral exposure route. Units: $(mg/kg\ body\ weight/day)^{-1}$

CPF_{ai} = Cancer potency factor for chemical "a", inhalation exposure route Units: $(mg/kg\ body\ weight/day)^{-1}$

IF_o = Intake factor for oral exposure route

IF_i = Intake factor for inhalation exposure route

A.2 RISK-BASED REMEDIATION GOALS FOR EXPOSURE TO RADIONUCLIDES

The incremental lifetime risk to humans associated with exposure to the radionuclides at the calculated dose (D) is estimated as follows:

$$R = (D)(CRF) \qquad (8)$$

where

R = Excess or incremental lifetime risk incidence of all cancers

D = Effective whole body dose (rem) as determined below

RCRF = Cancer incidence risk factor (per rem)

For more than one radionuclide, R would be calculated as follows:

$$R = (RCRF) \times \Sigma D_i \qquad (9)$$

where

ΣD_i = the sum of doses for all radionuclides from all exposure pathways, in rems.

The cancer incidence risk factor is derived from the use of high to low dose extrapolation models. EPA is currently using a RCRF of 6.2×10^{-4} per rem for low LET radiation (Personal communication January 1989: Paul Vollique, SAIC, Radiation Advisory Committee of the Science Advisory Board, the US Environmental Protection Agency). The range of cancer incidence is given as 1.9×10^{-4} to 1.9×10^{-3} per rem.

The effective whole body dose (for a given radionuclide in one environmental medium) via the exposure pathways of concern is calculated as follows:

$$D_i = (C_i) \times \Sigma(IF_j)(DCF_{ij}) \qquad (10)$$

where

D_i = Effective whole body dose in rem for radionuclide i

C_i = Concentration of radionuclide i (for a given environmental medium) in μCi/g or μC_i/L

IF_j = Intake factor for exposure route j for the exposure period of concern. IF is the product of the consumption rate (in L/day or g/day) and the period of exposure (in days).

DCF_{ij} = the dose conversion factor (rem/μCi) for radionuclide i and exposure route j

Following the procedures outlined above for nonradioactive chemicals, remediation goals for a given radionuclide "a" is derived by: (1) substituting the expression for dose in equation (10) into equation (9); (2) substituting the factor NCR x apportioned target risk level (TRPCR) from equation (6) for the variable R in equation (9); and (3) solving equation (9) for C_a, the remediation goal for radionuclide "a" in groundwater or soil. The expression derived is as follows:

$$C_a = \frac{(NCR \times TRPCR)}{RCRF \times [(IF_o \times DCF_{ao}) + (IF_i \times DCF_{ai})]} \qquad (11)$$

where

C_a = Preliminary remediation goal for radionuclide "a". Units: μCi/L or μCi/g

NCR = Number of "chemical-routes" of concern for radionuclide "a" under evaluation. (Note that NCR would take on a value of 1 or 2 for the radionuclides under investigation at the SDA).

TRPCR = Target risk per "chemical route" as defined above

RCRF = Cancer risk factor for radionuclides (conversion from rem to excess lifetime cancer risk). Units: cancer risk per rem

$DCFa_0$ = Dose conversion factor for radionuclide "a", oral exposure route. Units: rem/μCi

DF_{ai} = Dose conversion factor for radionuclide "a", inhalation exposure route. Units: rem/μCi

IF_0 = Intake factor for radionuclides for the oral exposure route. Units: liters or grams

IF_i = Intake factor for inhalation exposure pathway for radionuclides. Units: grams

APPENDIX B

SUMMARY DESCRIPTION OF REMEDIATION TECHNOLOGIES

The pages in Appendix B are incorrectly numbered; page numbers B-24 and B-25 were not used.

APPENDIX B

SUMMARY DESCRIPTION OF REMEDIATION TECHNOLOGIES

This Appendix provides a brief description of each technology that is potentially applicable to the INEL site. These technologies range from those that are proven with wide-spread implementation to emerging technologies that are considered innovative. In order enhance the organization of this report, the technologies have been classified in this section by (1) source control, (2) migration control, (3) waste stream treatment, (4) disposal technologies, and (5) institutional controls. It should be noted that many of these technologies can be placed in several of these classifications. If a technology is appropriate in more than one classification it is discussed in detail where it is likely to be the more significant technology and mentioned in the other appropriate sections.

This appendix summarizes technologies. It does not provide an exhaustive discussion of advantages, disadvantages, and limitations. Most of the information in this section was extracted from the Handkbook of Remedial Action at Waste Disposal Sites, EPA/625/6-85/006. The information can be used for a preliminary remedial action screening but not the detailed evaluation or final selection of alternatives.

B.1 SOURCE CONTROL

Source control technologies may be applied to the waste source to prevent further migration of hazardous constituents into the surrounding environmental media and they may also be applied to secondary sources, such as environmental contamination remaining once the waste source is removed that may be a continuing or future source of contaminant migration. Source control technologies include in-situ treatment methods for in-place waste and contaminated soil and contaminated soil excavation. The distinction between source control technologies and the migration control technologies discussed in Section B.2 can be arbitrary for many of the techniques presented in these sections. For example, slurry walls which are presented as a migration control would be a source control method if applied immediately around a source.

B.1.1 In-Situ Waste or Soil Containment

In-situ containment includes technologies such as chemical immobilization, grouting, and in-situ vitrification which may be used to prevent further migration of contaminants from a waste source or from residual contaminated environmental media.

B.1.1 In-Situ Waste and Soil Treatment

In-situ waste and soil treatment includes technologies such as bioreclamation or biological degradation, solidification/stabilization (grout-in-place), chemical treatment in place or to remove contaminants (soil washing), and physical treatment. These techniques either fix the contaminants in place, change their form, or selectively remove the contaminants.

B.1.1.1 Bioreclamation

Microorganisms, like all living organisms, require specific inorganic nutrients (i.e., nitrogen, phosphate-phosphorus, trace metals), and a carbon and energy source to survive. Bioreclamation relies upon microbial metabolic activity to convert toxic substances to a more desirable form. Indigenous microorganisms can generally be relied upon to degrade a wide range of compounds given adequate living conditions. Specially adapted or genetically manipulated microorganisms are also available. The technology of in-situ bioreclamation involves implementing methods to optimize environmental conditions in the subsurface to enhance microbial activity. This can include an injection system, an infiltration system, or other techniques to provide oxygen, provide nutrients, control temperature, or modulate any other parameter that can enhance microbial activity.

Bioreclamation can be expected to reduce the concentration of only those organic compounds which are amenable to biological degradation. These are compounds that are either substrates for microbial growth and metabolism, or are cometabolically broken down as the microorganism uses another primary substrate as its carbon and energy source. This technology would not be applicable to radionuclides or inorganics. Microbial metabolic activity can be classified into three main categories: aerobic respiration, in which oxygen is required as a terminal electron acceptor; anaerobic respiration, in which sulfate or nitrate serves as a terminal electron acceptor; and fermentation, in which the microorganism rids itself of excess electrons by exuding reduced organic compounds.

The bioreclamation method that has been most developed for in-situ treatment is one which relies on aerobic (oxygen requiring) microbial processes. For most compounds, the most rapid and complete degradation occurs aerobically. It can be generalized that for the degradation of petroleum hydrocarbons, aromatics, halogenated aromatics, polyaromatic hydrocarbons, phenols, halophenols, biphenyls, organophosphates, and most pesticides and herbicides, aerobic bioreclamation techniques are most suitable. Extensive data on the biodegradabilities of substances can be found in the literature. Relative aerobic biodegradability of compounds can also be estimated using laboratory data associated with biological, chemical, and ultimate oxygen demand (i.e., BOD, COD, UOD). In most instances, treatability studies are required to determine degradability of specific contaminants.

Aerobic bioreclamation has been demonstrated to be effective in degrading organics at more than 30 spill sites. Although it has not yet been fully demonstrated at hazardous waste sites, it can be expected to be effective and reliable provided the organics present are amenable to aerobic degradation. For applications to groundwater systems, the hydraulic conductivity of the aquifer must be sufficiently high for this process to be effective. There are substantial research data to suggest that microorganisms found at uncontrolled hazardous waste sites are well-acclimated to the wastes.

Anaerobic treatment is generally not as promising for site remediation as aerobic treatment. Anaerobic processes are slower, fewer compounds can be degraded, and the logistics of rendering a site anaerobic have not been developed to date. Anaerobic degradation under very reducing conditions appears to be the most suitable process for halogenated lower molecular weight hydrocarbons, such as unsaturated alkyl halides like PCE and TCE, and saturated alkyl halides like 1,1,1-trichloroethane and trihalomethane. Some lower molecular weight halogenated hydrocarbons will only degrade anaerobically.

Bioreclamation is capable of degrading organics sorbed to soils as well as organics in solution. The technology can be applied to soils or groundwater as long as the proper environment for the microbe is provided.

B.1.1.2 In-Situ Vitrification

In-situ vitrification is a technology being developed for the stabilization of transuranic contaminated wastes, and is conceivably applicable to other hazardous wastes. The technique could theoretically be applied to the waste itself or surrounding soil. It might be used to immobilize contaminated material or to solidify noncontaminated material so it would act as a barrier.

Several laboratory-scale and pilot-scale tests have been conducted, and a large-scale testing system is currently being fabricated. The technology is based upon electric melter technology. The principle of operation is joule heating, which occurs when an electrical current is passed through a molten mass. Contaminated soil is converted into durable glass, and wastes are pyrolyzed or crystallized. Off-gases released during the melting process are trapped in an off-gas hood. The off-gases depend upon the waste materials. The great temperatures involved could cause the volatilization to some extent of most materials. The energy requirements and physical need for hooding would complicate the application of this technique in a large scale application. The depth of the waste is a significant limiting factor in the application of this technology.

B.1.1.3 Solidification/Stabilization

Grouts can be used to (1) improve waste handling or other physical characteristics of the waste, (2) decrease the surface area across which transfer of contaminants can occur, and/or (3) limit the solubility or toxicity of contaminants. This technique can be applied to organics, inorganics and radionuclides. It could be applied to any waste type. Grouts are used primarily, but not exclusively, as a monolithic block of waste with high structural integrity. The contaminants do not necessarily interact chemically with the grout, but are mechanically locked within the solidified matrix. Contaminant loss is minimized by reducing the surface area.

In-situ grouting is a potentially applicable in-situ process whereby one of a variety of fluids is injected into the waste or soil mass where it is set in place to reduce water flow and to bind the contaminants or wastes. Grouting may best be suited for sealing voids in rock. Even in cases where rock voids are transmitting large water volumes, a grout can be formulated to set before it is washed out of the formation.

Cement has probably been used longer than any other type of material for grouting applications. Cement grouts utilize hydraulic cement which sets, hardens, and does not disintegrate in water. Because of their large particle size, cement grouts are more suitable for rock than for soil applications. The addition of clay or chemical polymers can improve the range of usage. Cement grouts have been used for both soil consolidation and water cut-off applications, but their use is primarily restricted to more open soils. Typically cement grouts cannot be used in fine-grained soils with cracks less than 0.1 millimeter wide.

Clays have been widely used as grouts, either alone or in formulations because they are inexpensive. Only certain types of clay minerals possess the physical and chemical characteristics favorable for use in grouting. These characteristics include the ability to swell in the presence of water to form a gel structure at low solution concentrations. Clays are subject to dissolution by acids and may not prevent migration of organics.

Bentonite grouts can be used alone as void sealers in coarse sands. Bentonite-chemical grouts can be used in medium to fine sands. Both of these grout types can also be utilized to seal small rock fissures.

Alkali silicates are the largest and most widely used type of chemical grouts. Sodium, potassium, and lithium silicates are available, with sodium silicates being used more frequently. Silicate grouts are used for both soil consolidation and void sealing applications. They are not suitable for open fissures or highly permeable materials because of syneresis (water expulsion) unless they are preceded by cement grouting. Silicate grouts may also have set up problems in the presence of organics.

Organic polymer grouts represent only a small fraction of the grouts in use. These grouts consist of organic materials that polymerize and crosslink to form an insoluble gel.

One of the greatest potential uses for grouting in hazardous waste site remediation is for sealing fractures, fissures, solution cavities, or other voids in rock. Nonetheless, rock grouting at waste sites is uncommon and no actual applications were found in the literature.

The ultimate success of a grouting project depends on thorough site characterization. The ability to seal water bearing voids or zones is dependent on being to locate them. In many remedial grouting operations, only a small portion of the soil mass will transport water and must be sealed. Consequently, the exploratory investigation must be very thorough.

Soil grouting is very much a specialty operation. It is performed by a limited number of contractors, and each such program is highly site-specific. Because this technique has rarely, if ever, been applied to controlling contaminated soil or waste, an assessment of performance and reliability is not possible.

B.1.1.4 Chemical Treatment

Chemical treatment methods are designed to render contaminants insoluble, to prevent leaching of the contaminants from the soil matrix, and to prevent their movement from the area of contamination. Little is currently known about the effectiveness and reliability of such treatment techniques. Treatment methods which are currently being investigated are precipitation, chelation, and polymerization.

Chemicals can also be used to immobilize, mobilize (for extraction), or detoxify subsurface organic and inorganic contaminants. Technologies placed in the category "immobilization" include precipitation, chelation, and polymerization. The category encompassing methods for mobilizing contaminants for extraction is termed "soil flushing." Flushing agents include surfactants, dilute acids and bases, and water. Detoxification techniques include oxidation, reduction, neutralization, and hydrolysis. These categories do not define the limits of each technology, as a technique implemented primarily for one objective may simultaneously perform one or more others.

In-situ chemical treatment covers a wide range of methods. Generalizations regarding the feasibility and effectiveness of these methods are not possible. However, all of these methods are developmental or conceptual and none have been fully demonstrated for hazardous waste site remediation. Of all the methods that will be described, soil flushing methods involving the use of water surfactants appear to be the most feasible for organics. They can use relatively cheap, innocuous treatment reagents, can be used to treat a broad range of waste constituents, and do not result in toxic degradation products. The most feasible methods for treating inorganics in-situ include soil flushing with dilute acids, chelating agents, or other treatment agents which will mobilize the metals.

The feasibility of an in-situ chemical treatment approach is dictated by site geology and hydrology, soil characteristics, and waste characteristics. Since the application of many chemical in-situ treatment techniques to hazardous waste disposal site reclamation is conceptual or in the developmental stage, there is little hard data available on the specific site characteristics that may limit the applicability of each method. Some of the site and soil characteristics considered important in evaluating the treatment applicability are as follows:

- Site location/topography
- Slope of site-degree and aspect
- Soil type and extent
- Hydraulic properties and conditions
- Climatological factors

The chemical treatment approach generally involve the delivery of a fluid to the subsurface. Minimal permeability requirements must be met if the treatment solution is to be delivered successfully to the contaminated zone. Sandy soils are far more amenable to in-situ treatment than clayey soils. Further, the solution used must be contained within the treatment zone. Measures must be taken to ensure that treatment reagents do not migrate and, of themselves, become contaminants. Care must be taken during the extraction process not to increase the burden of contaminated water by drawing uncontaminated water into the treatment zone from the aquifer or from hydraulically-connected surface waters.

Potential chemical reaction of the treatment reagents with the soils and wastes must be considered. A treatment approach that may neutralize one contaminant may render another more toxic or mobile; for example, chemical oxidation will destroy or reduce the toxicity of many toxic organics, but chromium III, if present, will oxidize to the more toxic and mobile chromium VI state. The permeability of soils may be reduced by the treatment approach. In soils high in iron or manganese, for example, oxidizing the subsurface could result in the precipitation of iron and manganese oxides and hydroxides, which could clog the delivery system and the aquifer or soil, thereby reducing the effectiveness for the targeted contaminants.

These methods may be applied to soils or groundwater.

Precipitation

Precipitation is the most promising method for immobilizing dissolved metals such as lead, cadmium, zinc, and iron. Some forms of arsenic, chromium, mercury, and some organic fatty acids can also be treated by precipitation. All the divalent metal cations can be precipitated using sulfide, phosphate, hydroxide, or carbonate. However, the solubility of the product and the stability of the metal complexes vary. Because of the low solubility product of sulfides and the stability of metal sulfides over a broad pH range, sulfide precipitation looks most promising.

Sodium sulfate used in conjunction with sodium hydroxide has shown wide-spread applicability for precipitation of metals. Precipitation takes place at a neutral or slightly alkaline pH. Resolubilization of sulfides is low. Addition of sodium hydroxide minimizes the formation of hydrogen sulfide gas by assuring an alkaline pH. Experiments with sulfide precipitation of zinc indicate that a high residual of unreacted sulfide may remain in solution.

Precipitation is most applicable to sites with sand or course silt strata. Disadvantages include the injection of a potential pollutant; the potential for formation of toxic gases (in the case of sulfide treatment); the potential for clogging soil pore space; and the possibility of precipitate resolubilization.

Chelation

A chelate is a type of compound in which a metal ion such as cobalt, nickel, copper, or zinc is attached by coordinate links to two or more nonmetal atoms in the same molecule. Heterocyclic rings are formed with the metal atom as part of each ring. Chelating agents promote the formation of chelates.

Chelating agents may be a very effective means of immobilizing metals although considerable research is needed in this area. Depending upon the specific chelating agent, stable metal chelates may be highly mobile or may be strongly sorbed into the soil. A common chelating agent is ethylenediaminetetraacetic acid (EDTA). Tetran is an example of a chelating agent which is strongly sorbed to clay in soils.

Polymerization

Polymerization involves injection of a catalyst into a plume to cause polymerization of an organic monomer (i.e., styrene, vinyl chloride, isoprene, methyl methacrylate, and acrylonitrile). The polymerization reaction transforms the once fluid substance into a gel-like, non-mobile mass. In-situ polymerization is a technique most suited for groundwater cleanup following land spills or underground leaks of pure monomer. Application for uncontrolled hazardous waste sites are very limited. Major disadvantages include very limited application and difficulty of initiating sufficient contact of the catalyst with the dispersed monomer.

Soil Flushing

Soil flushing (i.e., solvent flushing, ground leaching, or solution mining) is an extraction process that washes organic and inorganic contaminants from the soil. Water or an aqueous solution is injected into the area of contamination, and the contaminated elutriate is pumped to the surface for removal, recirculation, or on-site treatment and reinjection. During elutriation, sorbed contaminants are mobilized into solution by reason of solubility, formation of an emulsion, or by chemical reaction with the flushing solution. Solutions with the greatest potential for use in soil flushing are (1) water, (2) acids-bases, (3) complexing and chelating agents, (4) surfactants, and (5) reducing agents. Soil flushing may involve the recycling of elutriate through the contaminated material, with make-up solution being added to the system while a fraction of the elutriate stream is routed to a wastewater treatment system.

Water can be used to flush water-soluble or water-mobile organics and inorganics. Hydrophilic organics are readily solubilized in water. Organics amenable to water flushing can be identified according to their soil/water partition coefficient, or estimated using the octanol/water coefficient. High solubility organics, such as lower molecular weight alcohols, phenols, and carboxylic acids very amenable to this technique. Medium solubility organics which could be effectively removed from soils by water flushing include low to medium molecular weight ketones, aldehydes, and aromatics, and lower molecular weight halogenated hydrocarbons. Inorganics which can be flushed from soil with water are soluble salts such as the carbonates of nickel, zinc, and copper. Adjusting the pH with dilute solutions of acids or bases will enhance inorganic solubilization and removal.

Dilute solutions of acids have been widely used in industrial processes to extract metal ions. Solutions of sulfuric, hydrochloric, nitric, phosphoric, and carbonic acid are used in industrial applications to dissolve basic metal salts. However, because of the toxicity of many acids, it is desirable to use weak acids for in-situ treatment. Acidic solutions may serve to flush some basic organics such as amines, ethers, and anilines.

Complexing and chelating agents may also find use in a solution mining removal system for heavy metals. Chelating agents used for in-situ treatment must result in a stable metal-chelate complex which is resistant to decomposition and degradation. Another possibility for mobilizing metals which are strongly absorbed to manganese and iron oxides in soils is to reduce the metal oxides which results in release of the heavy metal into .pa solution. Chelating agents or acids can then be used to keep the metals in solution.

Surfactants can be used to improve the solvent property of the recharge water, emulsify nonsoluble organics, and enhance the removal of hydrophobic organics sorbed into soil particles. Surfactants improve the effectiveness of contaminant removal by improving both the detergency of aqueous solutions and the efficiency by which organics may be transported by aqueous solutions. Surfactant washing is among the most promising of the in-situ chemical treatment methods.

Numerous environmentally safe and relatively inexpensive surfactants are commercially available. Use of surfactants to date has been restricted to laboratory research. Most of the research has been performed by the petroleum industry for tertiary oil recovery. Aqueous surfactants have also been proposed for gasoline cleanup. In a study performed by the Texas Research Institute for the American Petroleum Institute, a mixture of anionic and nonionic surfactants resulted in contaminant recovery of up to 40 percent. In a laboratory study conducted by Ellis and Payne, crude oil recovery was increased from less than 1 percent to 86 percent, and PCB recovery was increased from less than 1 percent to 68 percent when soil columns were flushed with an aqueous surfactant solution.

Detoxification

Detoxification techniques are treatments that destroy, degrade, or otherwise reduce the toxicity of contaminants. The techniques include neutralization, hydrolysis, oxidation/reduction, enzymatic degradation, and permeable treatment beds. The techniques are applicable to specific chemical contaminants, therefore, uses of these in-situ techniques at waste sites will be limited.

Neutralization involves injecting dilute acids or bases to adjust the pH. This pH and adjustment can serve as pretreatment prior to in-situ biodegradation, oxidation, or reduction to optimize the pH range. It can be used to neutralize acidic or basic plumes that need no other treatment, or to neutralize groundwater following another treatment. It can also be used during oxidation, reduction, or precipitation to prevent the formation of toxic gases including hydrogen sulfide and hydrogen cyanide.

The pH adjustment can also be used to increase the hydrolysis rate of certain organics. The rate of hydrolysis can be increased up to one order of magnitude for a change of one standard unit in pH. Classes of compounds with potential for in-situ degradation by hydrolysis include: esters, amides, carbamates, phosphoric and phosphonic acid esters, and pesticides. Because a hydrolysis product may be more toxic than the present compound, the pathways for reactions must be determined to ensure toxic products are not produced. A collection system should be incorporated as a fail safe measure with this technique to prevent migration of the treatment reagents and any contaminants which are not successfully treated.

Oxidation and reduction reactions serve to alter the oxidation state of a compound through loss or gain of electrons, respectively. Such reactions can detoxify, precipitate, or solubilize metals, and decompose, detoxify, or solubilize organics. Oxidation may render organics more amenable to biological degradation. Oxidation/reduction techniques are standard wastewater treatment approaches, but their application as in-situ treatment technologies is conceptual.

Oxidation of inorganics in soils, is for all practical purposes limited to oxidation of arsenic and possibly some lead compounds. The in-situ oxidation of arsenic compounds with potassium permanganate has been used to successfully reduce the arsenic concentrations in groundwater in Germany. Three oxidizing agents, of the large number that are available, have been considered potentially useful in the in-situ detoxification of organics in groundwater and soil: hydrogen peroxide, ozone, and hypochlorites. Each can react with a broad range of organics and could potentially oxidize a number of different organic contaminants in a hazardous waste site. Selection of the appropriate oxidizing agent is dependent in part upon the substance or substances to be detoxified, but also upon the feasibility of delivery and environmental safety. Although there are some compounds that will not react with hydrogen peroxide but will react with ozone or hypochlorite, hydrogen peroxide appears to be the most feasible for in-situ treatment.

Ozone gas is a very strong oxidizing agent that is very unstable and extremely reactive. It cannot be shipped or stored; therefore, it must be generated on-site. Ozone rapidly decomposes and its half-life in groundwater is only 18 minutes. Ozone is used in the treatment of drinking water, municipal wastewater, and industrial waste, but has never been used in the treatment of contaminated soils or groundwater.

Hypochlorite, generally available as potassium, calcium, or sodium hypochlorite (bleach) is also used in the treatment of drinking water, municipal wastewater, and industrial waste. Hypochlorites have never been used in the treatment of contaminated groundwater or soils. The reaction of many organics with hypochlorite results in the formation of chlorinated organics which can be as or more toxic than the original contaminant. The formation of lower molecular weight chlorinated organics in drinking water hypochlorite treatment for disinfection purposes has become a major concern of the drinking water industry.

Hydrogen peroxide, a moderate strength chemical oxidant, is used routinely in municipal wastewater treatment to control various factors of biological treatment, and is also used in industrial waste treatment to detoxify cyanide and various organic pollutants. Hydrogen peroxide is commercially available in aqueous solutions of several concentrations and is miscible in water at all concentrations. It has been delivered successfully in dilute solutions to the subsurface as an oxygen source in a bioreclamation project.

Chemical reduction is the process by which the oxidation state of a compound is reduced. Reducing agents are electron donors. Chemical reduction does not appear to be as promising as oxidation for the treatment of organics. Although research has demonstrated reductive dehalogenation of a variety of chlorinated organics and reduction of unsaturated aromatics and aliphatics in the laboratory using catalyzed metal powders the effectiveness in soils has not been demonstrated. Chemical reduction does, however, appear promising for treatment of chromium and selenium in soils. The in-situ reduction of hexavalent to divalent chromium has been accomplished in Arizona well water using minute quantities of reducing agent.

There are a number of disadvantages with the use of oxidizing and reducing agents which limit their use at hazardous waste sites. The treatment compounds are non-specific and this may result in degradation of non-targeted compounds. There is the potential, particularly with oxidation, for the formation of more toxic or more mobile degradation products. Also, the introduction of these chemicals into the groundwater system may create a pollution problem in itself.

Enzymatic degradation of organics with cell-free enzymes holds potential as a possible in-situ treatment technique. Purified enzyme extracts, harvested from microbial cells, are commonly used in industry to catalyze a variety of reactions, including the degradation of carbohydrates and proteins. A bacterial enzyme preparation has been used to detoxify organophosphate waste from containers. Parathion hydrolase has been tested under field conditions in the degradation of the pesticide diazinon and has been found to effectively reduce concentrations in soil.

Permeable treatment beds are essentially excavated trenches placed perpendicular to groundwater flow and filled with an appropriate material to treat the plume as it flows through the material. Some of the materials that may be used in the treatment bed are limestone, crushed shell, activated carbon, glauconitic green sands, and synthetic ion exchange resins. Permeable treatment beds have the potential to reduce the quantities of contaminants present in leachate plumes. The system is applicable to relatively shallow groundwater tables containing a plume. To date, the application of permeable treatment beds at hazardous waste sites has not been performed.

In-situ treatment of a leachate plume using precipitation or polymerization techniques probably has limited application. There are several problems associated with these techniques. There is a need for numerous, closely-spaced injection wells even in coarse-grained deposits because the action of precipitation or polymerization will lower hydraulic conductivities near injection wells reducing treatment effectiveness. Contaminants are not removed from the aquifer and some chemical reactions can be reversed allowing contaminants to again migrate with groundwater flow. The treatment may involve the injection of a potential groundwater pollutant as well as the formation of toxic by-products.

B.1.1.5 Physical In-Situ Methods

A number of methods are currently being developed which involve physical manipulation of the subsurface in order to immobilize or detoxify waste constituents. These technologies, which include in-situ heating, and ground-freezing, are in the early stages of development and detailed information is not available.

Heating

In-situ heating has been proposed as a method to destroy or remove organic contaminants in the subsurface through thermal decomposition, vaporization, and distillation. Methods recommended for in-situ heating are steam injection and radio frequency heating.

The radio frequency heating process has been under development since the 1970s. Field experiments have been conducted for the recovery of hydrocarbons. The method involves laying a row of horizontal conductors on the surface of a landfill and exciting them with an RF generator through a matching network. The decontamination is accomplished in a temperature range of 300 to 400 degrees centigrade, assisted with steam, and requires a residence time of about two weeks. A gas or vapor recovery system is required on the surface. Excavation, mining, drilling, or boring is not required. This method appears very promising for certain situations involving contamination with organics, although more research is necessary.

Freezing

Freezing technology has the potential to contain any contaminant type in any media. Artificial ground freezing involves the installation of freezing loops in the ground and a self-contained refrigeration system that pumps coolant around the freezing loop. Although never used in an actual waste containment operation, the technology is being used increasingly as a construction method in civil engineering projects. Artificial ground freezing is done not on the waste itself, which may have a freezing point much lower than that of the soil systems, but on the soil surrounding the hazardous waste. It renders the soil practically impermeable, but is useful only as a temporary treatment approach because of the thermal maintenance expense.

B.1.2 Contaminated Soil Excavation

Excavation and removal followed by land disposal or treatment are performed extensively in hazardous waste site remediation. There are no absolute limitations on the types of waste which can be excavated and removed. However, worker health and safety weighs heavily in the decision to excavate explosive, reactive, or highly toxic waste material. Other factors which are considered include the mobility of the wastes, the feasibility of on-site containment or in-situ treatment, and the cost of disposing the waste or rendering it non-hazardous once it has been excavated. A frequent practice at hazardous waste sites is to excavate and remove contaminant "hot spots" and to use other remedial measures for less contaminated soils. Excavation and removal is applicable to almost all site conditions, although it may become cost-prohibitive at great depths, in complex hydrogeologic environments, or with highly dangerous explosive situations.

The nature and extent of preventative and mitigative measures required for controlling environmental releases during excavation and removal are site specific, although there are a number of general procedures that apply to all sites. Operating areas for staging and treating drummed wastes and contaminated soils should at a minimum be graded to prevent puddling; lined with polyethylene or clay; and bermed or diked. Where temporary impoundments must be used to store liquids, it may be acceptable to provide a thick clay liner and to excavate the contaminated soils after use of the impoundment is completed.

As soils are being excavated on-site, air monitoring should be conducted to detect unsafe levels of various constituents in the ambient air. Numerous portable direct reading instruments are available. As contaminated soils are excavated from the disposal area, they should be transferred to a box truck or a temporary storage area, preferably a diked or bermed area lined with plastic or low permeability clay. A layer of absorbent material should be placed on the bottom of the temporary storage area.

Excavation and removal can almost totally eliminate the contamination at a site and the need for long-term monitoring. Once excavation is begun, the time to achieve beneficial results can be short relative to alternative technologies. Excavation and removal can be used in combination with almost any other remedial technologies.

The greatest problems with excavation, removal, and off-site disposal are associated with worker safety, short term impacts, cost, and institutional aspects. Where highly hazardous materials are present, excavation can pose a substantial risk to worker safety. Short term impacts such as fugitive dust emissions, toxic gases, and contaminated run-off are frequently a major concern, although mitigation measures can be taken. The location of the nearest RCRA approved landfill or incinerator is a very important consideration in handling the treatment or disposal of excavation material.

The excavation technologies include loading and casting excavation, hauling excavation, pumping and industrial vacuum loaders. The excavation technologies use equipment that is well known and demonstrated. Detailed descriptions are not necessary.

Loading and casting can be accomplished by a wide variety of conventional equipment. The basic equipment types are backhoes, cranes, dozers, and loaders.

Hauling excavation is used for on-site and off-site transport of wastes. The hauling equipment includes scapers, haulers, dozers and loaders.

Pumping may be required in order to remove liquids and sludges from waste sites. The liquid wastes may be pumped to a treatment system or a tank truck for transport off-site. The selection of a pump is complicated by the presence of chemicals that could corrode or dissolve pump parts. Corrosive liquids having a low pH or a high chloride ion content can rapidly destroy most metal pumps. Wetted parts should be plastic, rubber, or ceramic, or if made of iron, should be alloyed with silicon and/or chromium. It is extremely important to check the chemical compatibility of seals with the fluid being pumped.

The presence of abrasive liquids also influences pump selection. Internal passages must have adequate dimensions or abrasive particles will damage parts that they rub against. Close internal clearances between stationary and moving parts is undesirable. Rubber and ceramic parts resist abrasive wear better than metal parts. Many manufacturers make abrasion-resistant models, and the pump should be selected after a detailed assessment of the waste to be pumped.

Industrial vacuum loaders such as the "Supersucker" can be used in large scale cleanup operations to remove soil or liquid waste. Using industrial loaders for soil removal is safer and more efficient than using hand tools. The typical equipment consists of a vehicle mounted high-strength vacuum that can carry solids, liquids, metal and plastic scraps, and almost any other material that can fit through the hose (i.e., 7 inch). Because of the large capacity of the vacuum cylinder, vacuum trucks are generally not well suited where the volume to be removed is less than equivalent of 30 drums.

An important consideration with vacuum loaders is the compatibility of wastes with materials of construction. Vacuum cylinders can be purchased in carbon steel, stainless steel, aluminum, and nickel. They can be treated with a variety of coatings including epoxy, fiberglass, and neoprene rubber.

B.2 MIGRATION CONTROL

Migration control technologies are those that will eliminate, reduce or modify the migration of a liquid plume or vapors in the subsurface or fugitive dust at the surface.

B.2.1 Runon/Runoff Controls

B.2.1.1 Capping

Capping is a process used to cover buried waste materials to prevent contact with water, to prevent gas releases to the air, to prevent infiltration and generation of leachate, and to control runon/runoff. The designs of modern caps usually conform to the performance standards in 40 CFR 264.310, which addresses RCRA landfill closure requirements. These standards include minimum liquid migration through the cover, low cover maintenance requirements, efficient site drainage, high resistance to damage by settling or subsidence, and a permeability lower than or equal to the underlying liner system or natural soils. These performance standards may not always be appropriate, particularly in instances where the cap is intended to be temporary, where there is very low precipitation, and when the capped waste is not leached by infiltrating rainwater.

There are a variety of cap designs and capping materials available. Most cap designs are multi-layered to conform with design standards, however, single-layered designs are also used for special purposes. The selection of capping materials and a cap design is influenced by specific factors such as local availability and costs of cover materials, desired functions of cover materials, the nature of the wastes being covered, local climate and hydrogeology, and projected future use of the site in question.

Capping is appropriate whenever contaminated materials (wastes or soils) are to be or left in place at a site. In general, capping is performed when extensive subsurface contamination at a site precludes excavation and removal of wastes or residual contaminated material once waste or "hot spots" are excavated. Capping may also be performed together with the groundwater extraction or containment technologies to prevent or significantly reduce further plume development. Groundwater monitoring wells are often used in conjunction with caps to detect unexpected migration of the capped wastes. A gas collection system should always be incorporated into a cap design when wastes may generate gases. Capping is also associated with surface water control technologies such as ditches, dikes and berms because these structures are often designed to accept rainwater drainage from the cap. Grading and revegetation are also incorporated into multi-layered caps.

Caps need long-term maintenance and have uncertain design lives. Caps need to be periodically inspected for settlement, ponding of liquids, erosion, and naturally occurring invasion by deep-rooted vegetation and burrowing mammals. Groundwater monitoring wells associated with caps need to be periodically sampled and maintained.

Caps generally have a minimum design life of 20 years when a synthetic liner is the only liquid barrier. This period may extend to over one hundred years when a synthetic liner is supported by a low-permeability base; the underlying wastes or soils are unsaturated; there is great distance between the contaminated material and the groundwater table; and proper maintenance procedures are observed.

Multi-layered caps generally must conform to EPA's guidance under RCRA which recommends a three-layered system consisting of an upper vegetative layer underlain by a drainage layer over a low permeability layer. The vegetative layer is served by the topsoil layer; the drainage layer can be composed of sand; and the low permeability layer can be formed by a combined synthetic and soil liner system. The cap functions by diverting infiltrating liquids from the vegetative layer through the drainage layer and away from the underlying waste or residual contaminated materials.

The low permeability layer of the multi-layered cap can be composed of natural soils, admixed soils, a synthetic liner, or any combination of these materials. However, a synthetic liner overlying at least 2 feet of low permeability natural soil or soil admix is recommended because the synthetic liner allows virtually no liquid penetration for a minimum of 20 years, while the soil layer provides assurance of continued protection even if the synthetic liner fails.

Standard design practices specify permeabilities of less than 10^{-7} cm/sec for the soil liner. This specification could be met with a natural soil or blending of different on-site soils. Chemical stabilizers, cements, clay, lime, ash, furnace slag, or other materials may be added to soil to modify its properties.

Flexible synthetic membranes made of polyvinyl chloride, chlorinated polyethylene, ethylene propylene rubber, butyl rubber, Hypalon, neoprene, and elasticized polyolefin can be used as liners. Synthetic liners are generally more expensive and involve labor-intensive sealing materials that require special field installation methods.

Single-layered caps can be constructed of any of the low permeability materials mentioned previously. Natural soil and admixes are not recommended because they are disrupted by freeze/thaw cycles and exposure to drying causes them to shrink and crack thereby reducing effectiveness. The most effective single layer caps are composed of concrete and/or bituminous asphalt.

Capping is a reliable technology for reducing infiltration, sealing off contamination from the aboveground environment, and significantly reducing underground migration of contaminants. Caps can be constructed over virtually any site, and can be completed relatively quickly if the ground is not frozen or saturated. Most of the soil materials for capping are readily available in most areas of the country, and the synthetic materials are widely manufactured and distributed. The equipment used for implementing this technology is mostly standard road construction equipment, however some specialized testing equipment must be supplied by the liner installer or a soil testing company.

The performance of a properly installed, multi-layered cap is generally excellent for the first 20 years of service. However, after this time period the integrity of the synthetic liner becomes uncertain and should be investigated regularly.

B.2.1.2 Covers

Single layer caps are often used as covers. These are described in Section B.2.1.1. Floating covers are included here to insure that all potential technologies are considered. This technology is not discussed in detail because the sources for which it is appropriate are not present at the SDA. Floating cover consist of a synthetic lining placed in one piece over an impoundment, with proper anchoring at the edges, and with floats to prevent the lining from submerging. This technology is used mainly to cover drinking water supply reservoirs, but it can be used temporarily to prevent overtopping at a waste lagoon.

B.2.1.3 Diversion/Collection Systems

Surface water and precipitation diversion and collection technologies include dikes, berms, channels, waterways, terraces, benches, chutes, downpipes, seepage basins, ditches, sedimentation basins and ponds, levees, and floodwalls. All these technologies are well-established. Many of these are intended for short-term use and are neither effective nor reliable for use as a long-term remedial measure.

All the diversion and containment methods described below require frequent inspection, maintenance, and performance checks to ensure continuous reliability. Operation and maintenance requirements for these measures are relatively simple. However, failure of some surface control measures can be costly.

Dikes and Berms

Dikes and berms are well-compacted earthen ridges or ledges constructed immediately upslope from or along the perimeter of disturbed areas. These structures are generally designed to provide short-term protection of critical areas by intercepting storm run-off and diverting the flow to natural or manmade drainage ways, to stabilized outlets, or to sediment traps.

Dikes and berms ideally are constructed of erosion-resistant, low permeability, clayey soils. The general design life of these structures is on the order of one year (maximum); seeding and mulching or chemical stabilization of dikes and berms may extent their life expectancy.

Channels and Waterways

Channels are excavated ditches. Diversion channels are used primarily to intercept run-off or reduce slope length. They may be stabilized with vegetation or stone rip-rap.

Failure of channels and waterways may result from insufficient capacity, excessive runoff velocity, or inadequate vegetative cover. Grassed waterways must be periodically mowed to prevent excessive retardation of flow and subsequent ponding of water. Vegetated channels may also require periodic resodding, remulching, and fertilizing. Sediment accumulation often results in failure of channels and waterways. Control of vegetation to prevent matted growth and high allowable design velocities will reduce sediment accumulation. Stone-lined channels have the advantage of requiring minimum maintenance.

Terraces and Benches

Terraces and benches are embankments constructed along the contour of very long or very steep slopes to intercept and divert flow and to control erosion by reducing slope length. These structures are classified as bench terraces or drainage benches. Bench terraces are used primarily to reduce land slope while drainage benches on broadbased terraces act to remove or retain water on sloping land.

Chutes and Downpipes

Chutes and downpipes are structures used to carry concentrated flows of surface run-off from one level to a lower level without erosive damage. They generally extend downslope from earthen embankments and convey water to stabilized outlets located at the base of terraced slopes. Chutes are open channels, normally lined with bituminous concrete, portland cement concrete, grouted rip-rap, or similar non-erodible material. Downpipes are temporary structures constructed of rigid piping or flexible tubing made of heavy-duty fabric.

Chutes and downpipes often represent key elements in combined surface control systems. They are especially effective in preventing erosion on long, steep slopes, and can be used to channel storm run-off to sediment traps, drainage basins, or stabilized waterways for off-site transport. However, they provide only temporary erosion control while slopes are stabilized with vegetative growth.

Seepage Basins and Ditches

Seepage basins and ditches are used to collect water and discharge it into the ground through seepage at selected areas. They may also be used in in-situ treatment to force reagents into the subsurface. Seepage basins and ditches are most effective in highly permeable soils so that recharge of the groundwater can occur. They are not applicable at sites where collected run-off or groundwater is contaminated. However, ditches may be used to convey liquids to other collection devices (basins, tanks, ponds, etc.).

Basins and ditches are generally used in areas with shallow groundwater tables. Very deep basins or trenches can be hazardous. Seepage ditches distribute water over a larger area than achievable with basins. They can be used for infiltration in all soil where permeability exceeds about 0.9 inches per day. It is unlikely that this technology would be appropriate for the INEL site because of the deep groundwater table, uncertainties associated with the vertical flow of liquids, and the need to reduce infiltration in the area surrounding the SDA.

Sedimentation Basins and Ponds

Sedimentation basins are used to control suspended solids entrained in surface flows. A sedimentation basin is constructed by placing an earthen dam across a water or natural depression, or by excavation, or by a combination of both. The purpose of installing a sedimentation basin is to impede surface run-off carrying solids, thus allowing sufficient time for the particulate matter to settle. Sedimentation basins are usually the final step in control of diverted, uncontaminated, surface run-off, prior to discharge. They are especially useful in areas where there exists a high silt or sand content in the surface run-off.

Levees and Floodwalls

Levees are earthen embankments that function as flood protection structures in areas subject to inundation from tidal flow or riverine flooding. Levees create a barrier to confine floodwaters to a floodway and to protect structures behind the barrier. Floodwalls perform much the same function as levees, but are constructed of concrete. For hazardous waste sites, levees and floodwalls help to control major losses of waste and cover material and prevent massive leachate production and subsequent contamination from riverine or tidal flooding.

Flood containment levees are most suitable for installation in flood fringe areas or areas subject to storm tide flooding, but not for areas directly within open floodways. Levees would not be applicable at the SDA.

B.2.1.4 Grading

Grading is the general term for techniques used to reshape the surface of covered landfills in order to manage surface water infiltration and run-off while controlling erosion. The spreading and compaction steps used in grading are techniques practiced routinely at landfills. The equipment and methods used in grading are essentially the same for all landfill surfaces, but applications of grading technology will vary by site. Grading is often performed in conjunction with surface sealing practices and revegetation as part of an integrated closure effort.

The techniques and equipment used in grading operations are well established and are widely used in all forms of land development. It is usually possible to find contractors and equipment locally, thus expediting the work and avoiding extra expenses.

Surface grading serves to (1) reduce ponding which minimizes infiltration and reduces subsequent differential settling, (2) reduces runoff velocities to reduce soil erosion, (3) roughens and loosens soils in preparation for revegetation, and (4) can be a factor in reducing or eliminating leaching of wastes or residual contaminants by reducing infiltration of precipitation.

There are potential difficulties associated with grading. Large quantities of a difficult to obtain cover soil may be required to modify existing slopes. Periodic regrading and future site maintenance may be necessary to eliminate depressions formed through differential settlement and compaction, or to repair slopes that have slumped or become badly eroded.

B.2.1.5 Revegetation

Revegetation is the establishment of a vegetative cover to stabilize the surface of a disposal site. This technique is often preceded by capping and grading. Revegetation decreases erosion by wind and water, and contributes to the development of a naturally fertile and stable surface environment. Revegetation includes (1) selection of plant species, (2) seedbed preparation, (3) seeding/planting, (4) mulching and/or chemical stabilization, and (5) fertilization and maintenance.

There are several potential problems implementing a revegetation program. Clays or synthetic barriers that support topsoil in poorly drained areas may cause swamping of cover soil and subsequent anaerobic conditions. Improperly vented gases and soluble phytotoxic contaminants may kill or damage vegetation. Periodic maintenance of revegetated areas may include liming, fertilizing, mowing, replanting, and periodic removal of deep-rooted plants.

A well-designed and properly implemented revegetation plan can effectively reduce erosion and stabilize the surface of a covered site, thereby improving the effectiveness and reliability of the cap. A multi-layered capping system and properly graded slopes, in combination with suitable vegetative cover, will eventually isolate buried wastes from surface hydrologic input.

Although vegetative cover requires frequent maintenance, it actually prevents more costly maintenance which would result from erosion by surface soils. Revegetation is also essential to the integrity and performance of dikes, waterways, and sedimentation basins.

B.2.2 Leachate and Groundwater Controls and Liquid Removal

Control of contamination in the groundwater involves one of four options: (1) containment of a plume; (2) removal of a plume after measures have been taken to halt the source of contamination; (3) diversion of groundwater to prevent clean groundwater from flowing through a source of contamination or to prevent contaminated groundwater from contacting a drinking water supply; or (4) prevention of leachate formation by lowering the water table beneath a source of contamination. Only options one through three are considered here as the groundwater is more than 600 feet beneath the SDA.

Remedial technologies for controlling groundwater contamination problems are generally placed in one of four categories: (1) groundwater pumping, involving extraction of water from or injection of water into wells to capture a plume or to alter the direction of groundwater movement; (2) subsurface drains, consisting of gravity collection systems designed to intercept leachate or groundwater; (3) low permeability barriers, consisting of a vertical wall of low permeability materials constructed underground to divert groundwater flow or minimize leachate generation and plume movement; (4) horizontal barriers to prevent infiltration to deeper zones; or (5) in-situ treatment methods to biologically or chemically remove or attenuate contaminants in the subsurface. These technologies can be used singularly or in combination to control leachate migration and groundwater contamination. This section describes these technologies. The 600 foot depth to the groundwater table and the overlying basalt layers at the SDA would make the implementation of some groundwater controls such as drains, wellpoints, and barriers inappropriate, difficult, cost prohibitive, or technically infeasible. However, they are presented in this section in limited detail to ensure that all technologies are considered.

B.2.2.1 Groundwater Pumping

Groundwater pumping techniques involve the active manipulation and management of groundwater in order to contain or remove a plume or to adjust groundwater levels in order to prevent formation of a plume. Types of wells used in management of contaminated groundwater include wellpoints, suction wells, ejector wells, and deep wells. The selection of the appropriate well type depends upon the depth of contamination and the hydrologic and geologic characteristics of the aquifer.

Pumping is most effective at sites where underlying aquifers have high intergranular hydraulic conductivity. It has been used with some effectiveness at sites with moderate hydraulic conductivities and where pollutant movement is occurring along fractured or jointed bedrock. In fractured bedrock, the fracture patterns must be traced in detail to ensure proper well placement.

Where plume containment or removal is the objective, either extraction wells alone or a combination of extraction and injection wells can be used. Use of extraction wells alone is best suited to situations where contaminants are miscible and move readily with water; where the hydraulic gradient is steep and hydraulic conductivity high; and where quick removal is not necessary.

A combination of extraction and injection wells is frequently used in containment or removal where the hydraulic gradient is relatively flat and hydraulic conductivities are only moderate. One function of the injection well is to alter the flow to direct contaminants to the extraction wells. This method has been used with some success for plumes which are not miscible with water. One problem with such an arrangement of wells is that, dead spots can occur when these configurations are between adjacent radii of influence. Another disadvantage is that injection wells can suffer from many operational problems, including air locks and the need for frequent maintenance. Injection wells may also be used to reinject groundwater that has been extracted and subsequently treated.

Groundwater barriers can be created using injection wells to change both the direction of a plume and the speed of plume migration. By creating an area with a higher hydraulic head, the plume can be forced to change direction. This technique may be desirable when short-term diversions are needed or when diversion will provide the plume with sufficient time for the contaminants to naturally degrade so that removal is not required.

Wellpoint systems are best suited for shallow aquifers where extraction is not needed below more than about 22 feet. Beyond this depth, suction lifting is ineffective. Suction wells operate in a similar fashion to wellpoints and are also depth limited. The only advantage of suction wells over wellpoints is that they have higher capacities.

For extraction depths greater than 20 feet, deep wells and ejector wells are used. Deep well systems are better suited to homogeneous aquifers with high hydraulic conductivities and where large volumes of water may be pumped. Ejector wells perform better than deep wells in heterogeneous aquifers with low hydraulic conductivities. A problem with ejector systems is that they are inefficient and are sensitive to constituents in the groundwater which may cause chemical precipitates and well clogging.

Groundwater pumping systems are the most versatile and flexible of the groundwater control technologies. When used together with a barrier wall and cap, complete hydrologic isolation of a site can be achieved in some circumstances. Groundwater pumping systems, however, perform poorly in aquifers with low transmissivity.

Operational flexibility is high since pumping rates can be modified to adjust to changes in flow rate. System performance is generally good provided the wells are properly designed and maintained. Deadspots and areas where cones of depression overlap should be continuously monitored to ensure effectiveness. The reliability of pumping systems can be adversely affected by mechanical and electrical failure of pumps which can result in loss of contaminants. However, repairs and replacement of parts can be done quickly and easily.

Well systems are generally safer to install than drains and barrier walls since there is no need for trench excavation. Installation is relatively easy and quick. Contractors qualified to drill and install wells are readily available. However, the effort may be costly in areas with large depths to groundwater.

B.2.2.2 Subsurface Drains

Subsurface drains include any type of buried conduit used to convey and collect aqueous discharges by gravity flow. Subsurface drains essentially function like an infinite line of extraction wells. They create a continuous zone of influence in which groundwater within this zone flows towards the drain.

Drains essentially function like an infinite line of extraction wells, they can perform many of the same functions as wells. They can be used to contain or remove a plume, or to lower the groundwater table to prevent contact of water with the waste material. The decision to use drains or pumping is generally based on cost-effectiveness.

For shallow contamination problems, drains can be more cost-effective than pumping, particularly in strata with low or variable hydraulic conductivity. Under these conditions, it would be difficult to design and it would be cost prohibitive to operate a pumping system to maintain a continuous hydraulic boundary. Subsurface drains may also be preferred over pumping where groundwater removal is required over a period of several years, because the operation and maintenance costs associated with pumping are substantially higher.

Subsurface drains are generally limited to shallow depths. Although it is technically feasible to excavate a trench to almost any depth, the costs of shoring, dewatering, and hard rock excavation can make drains cost prohibitive at depths of less than 40 feet. However, in stable low permeability soils where little or no rock excavation is required, drains may be cost-effective to depths of 100 feet. Other limitations to the use of this technology include the presence of viscous or reactive chemicals which could clog drains and envelope material. Conditions which favor the formation of iron manganese or calcium carbonate deposits may also limit the use of drains.

Relative to pumping, subsurface drains can be difficult and costly to install particularly where extensive hard rock excavation and dewatering is required. They are also time consuming to install and may not be an appropriate alternative where immediate remediation is required. Safety of field workers is also more of a concern with subsurface drains because of the need for extensive trench excavation.

Drains are generally more cost-effective than pumping in areas with low hydraulic conductivity particularly where pumping would be required for an extended period of time. They are easier to operate since water is collected by gravity flow. They are also more reliable from the standpoint that there are no electrical components which can fail. However, when drains fail due to clogging, breaks in the pipes, or sinkhole formation, they can be costly and time consuming to rehabilitate.

B.2.2.3 Subsurface Barriers (Vertical)

Subsurface barriers are a variety of methods whereby low permeability cut-off walls or diversions are installed below ground to contain, capture, or redirect groundwater flow in the vicinity or a site. The most commonly used subsurface barriers are slurry walls, particularly soil-bentonite slurry walls. Less common are cement-bentonite or concrete (diaphram) slurry walls, grouted barriers, and sheet piling cut-offs.

Slurry Walls

Slurry walls are the most common subsurface barriers because they are a relatively inexpensive means of vastly reducing groundwater flow in unconsolidated earth materials. The term slurry wall can be applied to a variety of barriers all having one thing in common: they are all constructed in a vertical trench that is excavated under a slurry. This slurry, usually a mixture of bentonite and water, acts essentially like a drilling fluid. It hydraulically shores the trench to prevent collapse, and, at the same time, forms a filter cake on the trench walls to prevent high fluid losses into the surrounding grounds. Slurry wall types are differentiated by the materials used to backfill the slurry trench. Most commonly, an engineered soil mixture is used to backfill the slurry trench. Typically, the mixture is blended with the bentonite slurry and placed in the trench to form a soil- bentonite slurry wall. In some cases, the trench is excavated under a slurry of portland cement, bentonite, and water, and this mixture is left in the trench to harden into a cement-bentonite slurry wall. In the rare case where great strength is required, pre-cast or cast-in-place concrete panels are constructed in the trench to form a diaphram wall.

Soil-bentonite slurry walls are backfilled with soil materials mixed with bentonite and water slurry. Of the three major types of slurry walls, soil-bentonite walls offer the lowest installation costs, the widest range of chemical compatibilities, and the lowest permeabilities. At the same time, soil-bentonite walls have the least strength and require a large work area, and, because the slurry and backfill can flow, are applicable only to sites that can be graded to nearly level.

A major concern in the application of soil-bentonite walls to site remediation is the compatibility of the backfill mixture with site contaminants. Evidence indicates that soil-bentonite backfills are not able to withstand attack by strong acids and bases, strong salt solutions, and some organic chemicals. For contaminant migration control there is a lack of long-term performance data. Soil bentonite walls have been used for decades for groundwater control in conjunction with large dam projects and there is ample evidence of their success in this application. The ability to withstand long-term permeation by many contaminants is in question.

Cement-bentonite slurry walls share many characteristics with soil-bentonite slurry walls. The principal difference between the two is the backfill. They are generally excavated using a slurry of Portland cement, bentonite, and water. This slurry is left in the trench and allowed to set up to form the completed barrier.

Cement-bentonite walls are more versatile than soil-bentonite in two ways. First, because the slurry sets up into a semi-rigid solid, this type of wall can accommodate variations in topography by allowing one section to set while continuing the next section at a different elevation. Second, because the excavation slurry is commonly the backfill too, this type of wall is better suited to restrict areas where there is no room to mix soil-bentonite backfill. Cement-bentonite is stronger than soil-bentonite and is used where the wall must have less elasticity, such as adjacent to a building or roads.

Cement-bentonite slurry walls are limited in their use by their higher costs, somewhat higher permeability, and their narrower range of chemical compatibilities. Cement-bentonite is susceptible to attack by sulfates, strong acids and bases, and other highly ionic substances.

Diaphragm walls are barriers composed of reinforced concrete panels, which are implaced by slurry trenching techniques. They may be cast-in-place or pre-cast, and are capable of supporting great loads. This degree of strength is seldom if ever called for at a waste site. This technology has the same limitations as cement-bentonite slurry walls.

Grout Curtains

Grout curtains are subsurface barriers created in unconsolidated materials by pressure injection. Grout barriers can be many times more costly than slurry walls, are generally incapable of attaining truly low permeabilities in unconsolidated materials, and there are numerous questions regarding the ability to construct the curtains without holes. A recent field test study at INEL of two chemical grouts revealed significant problems in forming a continuous grout barrier due to non-coalescence of grout pods in adjacent holes and grout shrinkage. This study concludes that conventional injection grouting is incapable of forming a reliable barrier in medium sands. Grout curtains, while requiring no operation and little or no maintenance may require more monitoring than other barriers. This is because if even a very small gap is left in the barrier, it can enlarge quite rapidly by piping or tunneling if there is a sufficient hydraulic gradient across the wall. Additional information on specific grouts may be found in Section B.1.1.3.

Sheet Piling

Sheet piling can be used to form a groundwater barrier. Sheet piles can be made of wood, pre-cast concrete, or steel. Wood is an ineffective water barrier, however, and concrete is used primarily where great strength is required. Steel is the most effective in terms of groundwater cut-off and cost. Steel is ineffective in rocky soils because damage or deflection of the piles is likely to render the wall ineffective.

The performance life of sheet piling wall can be between 7 and 40 years, depending on the condition of the soil in which the wall is installed. Sheet piling walls have been installed in various type of soils ranging from well-drained sand to impervious clay.

B.2.2.4 Barrier Walls (Horizontal)

Grouting techniques may also be applied to form a grout barrier beneath a waste site. Such a barrier can be used to isolate buried wastes from the environment and to prevent migration of contaminants. Jet grouting or directional drilling techniques may be used to emplace the barrier. The advantages and disadvantages of horizontal barriers are similar to those for grout curtains, as described above.

B.2.2.5 In-Situ Treatment

Groundwater plumes may be treated in-situ by many of the treatment techniques described in Section B.1.1, specifically bioreclamation (B.1.1.1) and chemical treatment (B.1.1.4).

B.2.3 Fugitive Dust Controls

Fugitive dust generated during remedial actions or due to winds at the site may be controlled using dust suppressants, wind fences/screens, water sprays, or other measures.

B.2.3.1 Dust Suppressants

Dust suppressants include a wide range of natural and synthetic waste materials which strengthen bonds between soil particles and hold this strengthened condition for an appreciable period of time. A wide variety of resins, bituminous materials and polymers are marketed as dust suppressants. Chemical dust suppressants are most commonly applied with water wagons equipped with muzzles that shoot a flat spray behind the vehicle. The effectiveness of a dust suppressant is dependent upon maintaining the soil-chemical crust. Emerging weeds and any type of disturbance from traffic will break this crust. This technology is an effective temporary control measure. It must be reapplied to provide long-term fugitive dust control. Application is straightforward and can be accomplished quickly. There is the potential for secondary impacts from the use of certain chemical dust suppressants which contain toxic substances.

B.2.3.2 Wind Fences/Screens

A wind fence is a porous screen which takes up or deflects a sufficient amount of wind so that the wind velocity is lowered below the threshold required for initiation of soil movement. Wind screens are typically 4 to 10 feet high and are composed of polyester or other high strength material. This technology is only 60 percent efficient in controlling inhalable particulates at wind speeds of 10 to 13 mph. Studies have shown no consistent benefits from windscreens for particles in the respirable size range. Maximum reduction of wind velocity can be expected for a distance of 1 to 5 fence heights downstream.

B.2.3.3 Water Sprays

Water spray is the most common means of dust control. It simply involves spraying water on the exposed surface areas. This method is mainly used to reduce fugitive dusts along active travel paths, excavation areas, and from truck boxes loaded with soils. Active travel areas dry quickly and water must be reapplied frequently (about every 2 hours) to maintain effectiveness. This method would not be suitable where infiltration is of concern.

B.2.3.4 Other Measures

Other measures for paved roads include sweeping, vacuuming, or flushing. These methods are not effective with fine particles. Dust from excavation activities can be reduced by maintaining a favorable slope and orientation on the waste or overburden piles. Piles can also be covered and an auger feed system can be installed to implace and remove material.

B.2.4 Gaseous Emissions Controls

Gases may be emitted by the vaporization of liquids, venting of entrained gases, or by chemical and biological reactions of solid and liquid waste material. Volatile organics may be released slowly but continuously from landfills. Methods for controlling the release of gaseous emissions to the atmosphere include capping for control of volatile emissions from impoundments and active gas collection systems for collection and control of gases generated in landfills.

B.2.4.1 Capping

See Section B.2.1.1 for discussion.

B.2.4.2 Covers

See Section B.2.1.2 for discussion.

B.2.4.3 Passive Perimeter Gas Control Systems

Passive perimeter gas control systems control gas movement by altering the paths of flow without the use of mechanical components. Passive systems may be further categorized as high permeability or low permeability.

High permeability systems entail the installation of highly permeable trenches or wells between the landfill and the area to be protected. Since the permeable material offers conditions more conducive to gas flow than the surrounding soil, paths of flow to points of controlled release are established. High-permeability systems generally take the form of trenches or wells excavated outside of the landfill limit and backfilled with a highly permeable medium such as a coarse crushed stone.

Low permeability systems effectively block gas flow into areas of concern by the use of barriers (i.e., synthetic membranes or clays) between the landfill and the area to be protected. With low-permeability systems, gases are not collected and therefore cannot be conveyed to a point of controlled release or treatment. The purpose of the system is to prevent or reduce gas migration into areas that are to be protected. These two concepts of passive gas control are often combined in the same system to provide controlled venting of gases and blockage of available paths for gas migration.

Passive gas control systems can be used at virtually any site where there is capability to trench or drill and excavation to at least the same depth at the landfill. Limiting factors could include the presence of a perched water table or rock strata. Passive vents should generally be expected to be less effective in areas of high rainfall or prolonged freezing temperatures. The depth of the trench is dictated by local site conditions. In general, the trench should extend from the ground surface to a relatively impermeable stratum of unfractured bedrock or clay or to the lowest groundwater table level. In some applications, the trench need not be as deep, so long as it extends to a sufficient depth to intercept all possible avenues of gas migration. This depth is a function of the landfill depth and the geology in the vicinity of the landfill. The logistics of excavating open trenches can constrain the use of passive venting trenches to relatively shallow depths of 30 feet and less.

Passive gas control systems are essentially self-operating. Vent pipes, drainage patterns and general conditions in the vicinity of the systems should be occasionally inspected to identify the need for repairs or other maintenance. Monitoring the effectiveness of passive gas control systems normally consists of periodic sampling of subsurface gases from probes installed in the area being protected.

High permeability gas control systems have functioned adequately in many applications; however, there appears to be no clear patterns which dictate success or failure of either system. While passive vents may perform effectively at some sites, the method cannot be considered to be reliable for gas migration control because of the inability of vents to control diffuse flow. Numerous passive well venting systems have been converted to active systems because of poor or unreliable performance. Low permeability systems block diffuse flow and are highly reliable when properly designed and installed. Passive gas control systems can be implemented with relatively conventional construction equipment, labor, and materials. Handling and placement of synthetic liners requires specialized equipment and labor.

B.2.4.5 Active Perimeter Gas Control Systems

Active perimeter gas control systems alter pressure gradients and paths of gas movement by mechanical means. These systems normally consist of (1) gas extraction wells, (2) gas collection headers, and (3) vacuum blowers or compressors. In a typical system, centrifugal blowers create vacuum through the collection headers and wells to the wastes and ground surrounding the wells. A pressure gradient is thereby established inducing flow from the landfill to the blower. Subsurface gases flow in the direction of decreasing pressure gradient and are released directly to the atmosphere, treated and released, or is some case recovered.

Active perimeter gas control systems can be used at virtually any site where there is capability to drill or excavate through landfilled material to the required depth. Limiting factors could include the presence of free-standing leachate or impenetrable materials within the landfill. Active systems are not sensitive to the freezing or saturation of surface or cover soils.

Gas extraction wells may be installed either within the landfill or in soil outside of the limit of fill. Wells normally consist of a drilled hole 12 to 36 inches in diameter which is backfilled with one-inch or larger crushed stone and 2- to 6-inch piping, which is perforated in the area where gas is to be collected and solid in the upper portions. Solid-wall pipe is used and a concrete or clay seal is provided in the upper portion of the well to minimize infiltration of atmospheric air into the system. A valve is provided on the lateral connection of each well to allow regulation of flow and balancing of systems consisting of multiple wells. A monitoring port is provided for measuring velocity, pressure, and gas composition. Well spacing is a critical factor in the design of the system. Spacings on the order of 100 feet are commonly used, however, the appropriate spacing for a given site will depend upon the depth of the landfill, the magnitude of the vacuum applied to the well, and the rate of gas withdrawal.

Active gas control systems require testing and adjustment throughout their lives of operation. Initial start-up testing is required to ensure that all components are functioning as intended. Throttling of individual well valves and blower control valves is required to balance the system. Mechanical components require regular service such as lubrication and part replacement. In addition, subsurface gas probes in the area being afforded protection should be monitored at least annually after system start-up to ensure that gas migration is being controlled.

Differential settlement of the landfill material beneath header pipes can cause pipe movements resulting in adverse slopes, accumulation of condensate in low spots, and partial or complete blockage of gas flow. Proper pipe slopes and condensate drains can minimize this problem. A regular program of periodic inspection and maintenance should be established to identify pipe breakage, condensate blockage, or other header system failure.

Active Interior Gas Collection/Recovery System

Active interior gas collection systems are similar to active perimeter systems except gas extraction wells are placed over the entire landfill surface. The design limitations and considerations are the same as perimeter systems except that spacing of wells is generally greater. Spacings of 200 feet are common. This technology has be applied or is underdevelopment for methane at over 50 sites worldwide.

B.3 WASTE STREAM TREATMENT

B.3.1 Aqueous Waste Treatment

Aqueous treatment methods may be applied to liquid wastestreams generated from remedial actions (e.g., pumped groundwater, collected leachate). Because of the potential diversity of liquid wastestreams, there are many treatment technologies that can be applied to aqueous waste streams. Rarely will any one treatment method be sufficient so these techniques are usually used in combination. The most common treatment processes are (1) activated carbon treatment, (2) biological treatment, (3) precipitation/flocculation, (4) ion exchange and sorptive resins, (5) reverse osmosis, (6) neutralization, (7) gravity separation, (8) air stripping, (9) oxidation, (10) reduction, (11) evaporation, and (12) solidification/stabilization.

B.3.1.1 Activated Carbon

Activated carbon treatment is the process of adsorption of contaminants onto activated carbon. It involves contacting a stream with the carbon, usually by flow through a series of packed bed reactors. The activated carbon selectively adsorbs constituents by a surface attraction phenomenon in which organic molecules are attracted to the internal pores of the carbon granules. Once the micropore surfaces are saturated with organics, the carbon is "spent" and must be either replaced or thermally regenerated. The time to reach "breakthrough" or exhaustion is the single most critical operating parameter.

Activated carbon is a well developed technology. It is especially well suited for removal of mixed organics from aqueous wastes. It is an effective and reliable means of removing low solubility organics. It is suitable for treating a wide range of organics over a broad concentration range.

Activated carbon is easily implemented into more complex treatment systems. The process is well suited to mobile treatment systems as well as to on-site construction. Space requirements are small, start-up and shut-down are rapid, and there are numerous contractors who are experienced in operating mobile units.

The most obvious maintenance consideration associated with activated carbon treatment is the regeneration of spent carbon for reuse. Regeneration must be performed for each column at the conclusion of its bed-life so the spent carbon may be restored as close as possible to its original condition for reuse; otherwise, the contaminanted carbon must be disposed as hazardous waste.

B.3.1.2 Biological Treatment

Biological treatment removes organic matter from an aqueous wastestream through microbial degradation. The most prevalent form of biological treatment is aerobic (i.e., requires oxygen). Specific processes that may be applicable include conventional activated sludge, pure oxygen activated sludge, extended aeration, contact stabilization, fixed film systems which include rotating biological discs and trickling filters.

There is considerable flexibility in biological treatment because of the variety of available processes and adaptability of the microorganisms themselves. Many organic chemicals are considered biodegradable, although the relative ease of biodegradation varies widely.

Biological treatment has not been widely used in hazardous waste site remediation. Although the process can effectively treat a wide range of organics, it has several drawbacks for waste site application. The reliability of the process can be adversely affected by "shock" loads of toxics. Start-up time can be slow if the organisms need to be acclimated to the wastes and the retention time can be long for complex wastes. However, the existence of cultures which have been previously adapted to hazardous wastes can dramatically decrease start-up and retention time.

Loss of volatile organics from biological treatment processes can pose some localized air pollution and a health hazard to field personnel. Sludge produced in biological waste treatment may be a hazardous waste itself due to the sorbtion and concentration of toxic and hazardous compounds contained in the wastewater.

B.3.1.3 Precipitation/Flocculation

Precipitation is a physiochemical process whereby some or all of a substance in solution is transformed into a solid phase. It is based on alteration of the chemical equilibrium relationships affecting the solubility of inorganic species. Removal of metals as hydoxides or sulfides is the most common precipitation application in wastewater treatment. Generally, lime or sodium sulfide is added to the wastewater in a rapid mixing tank along with flocculating agents. The wastewater flows to a flocculation chamber in which adequate mixing and retention time is provided for agglomeration of precipitate particles. Agglomerated particles are separated from the liquid phase by settling in a sedimentation chamber, and/or by other physical processes such as filtration.

Flocculation is the process by which small, unsettleable particles suspended in a liquid medium are made to agglomerate into larger, more settleable particles. Chemicals used to cause flocculation include alum, lime, various iron salts, and organic flocculating agents called polyelectrolytes. Once suspended particles have flocculated into larger particles, they usually can be removed from the liquid by sedimentation, provided that a sufficient density difference exists between the suspended matter and the liquid.

Precipitation is applicable to the removal of most metals from aqueous streams including zinc, cadmium, chromium, copper, fluoride, lead, manganese, and mercury. Also certain anionic species can be removed by precipitation, such as phosphate, sulfate, and fluoride.

Certain physical or chemical characteristics may limit the applicability of precipitation. Organic compounds may form organometallic complexes with metals, which could inhibit precipitation. Cyanide and other ions in the wastestream may also complex with metals, making treatment by precipitation less efficient. Highly viscous waste streams will inhibit settling of solids.

Precipitation and flocculation are well established technologies and the operating parameters are well defined. The processes require only chemical pumps, metering devices, and mixing and settling tanks. The equipment is readily available and easy to operate. Precipitation is nonselective in that compounds other than those targeted may be removed. Both precipitation and flocculation are nondestructive and generates a large volume of sludge which must be disposed.

B.3.1.4 Ion Exchange and Sorptive Resins

Ion exchange is a process whereby toxic ions are removed from the aqueous phase by being exchanged with relatively harmless ions held in the ion exchange material. Modern ion exchange resins are primarily synthetic organic materials containing ionic functional groups to which exchangeable ions are attached. These synthetic resins are structurally stable, exhibit a high exchange capacity, and can be tailored to show selectivity towards specific ions. The exchange reaction is reversible and concentration dependent. It is possible to regenerate the exchange resins for reuse. Sorptive resins are also available for removal of organics and the removal mechanism is one of sorption rather than ion exchange.

Ion exchange can be use to remove a broad range of ionic species from water including: all metallic elements when present as a soluble species, inorganic anions, organic acids, and organic amines. Sorptive resins can remove a wide range of polar and non-polar organics.

Ion exchange is a well established technology for removal of heavy metals and hazardous anions from dilute solutions. Ion exchange can be expected to perform well for these applications when fed wastes of variable composition, provided the system's effluent is continually monitored to determine when resin bed exhaustion has occurred. Consideration must be given to disposal of contaminated ion exchange regeneration solution.

B.3.1.5 Reverse Osmosis

Reverse osmosis is the application of sufficient pressure to the concentrated solution to overcome osmotic pressure and force the net flow of water through the membrane toward the dilute phase. This allows the concentration of solute to build up in a circulating system on one side of the membrane while relatively pure water is transported through the membrane. Ions and small molecules in true solution can be separated from water by this technique.

Reverse osmosis is used to reduce the concentrations of dissolved solids, both organic and inorganic. In treatment of wastestreams, the use of this process would be primarily limited to polishing low flow streams containing highly toxic contaminants. Good removal can be expected for high molecular weight organics and charged anions and cations. Multivalent ions are treated more effectively than are univalent ions. Recent advances in membrane technology have made it possible to remove such low molecular weight organics as alcohols, ketones, amines, and aldehydes.

Reverse osmosis is an effective treatment technology for removal of dissolved solids presuming appropriate pretreatment has been performed for suspended solids removal, pH adjustments, and removal of oxidizers, oil, and grease. Because the process is so susceptible to fouling and plugging, on-line monitors may be required to monitor pH, suspended solids, etc. on a continuous basis. Reverse osmosis has not been widely used for treatment of hazardous waste streams.

Reverse osmosis will not reliably treat wastes with a high organic content, as the membrane may dissolve in the waste. Lower levels of organic compounds may also be detrimental to the unit's reliability, as biological growth may form on a membrane fed an influent containing biodegradable organics.

B.3.1.6 Neutralization

Neutralization consists of adding acid or base to a waste in order to adjust the pH. The most common system for neutralizing acidic or basic waste streams utilizes a multiple compartmental basin usually constructed of concrete. This basin is lined with acid brick or coated with a material resistant to the expected environment.

Neutralization can be applied to any wastestream requiring ph control. It is a relatively simple unit treatment process which can be performed using readily available equipment. Only storage and reaction tanks with accessory agitators and delivery systems are required. Because of the corrosity of the wastes and treatment reagents, appropriate materials of construction are needed to provide a reasonable service-life for equipment. The process is reliable provided pH monitoring is conducted.

Neutralization of wastestreams has the potential of producing air emissions. Acidification of streams containing certain salts, such as sulfide or cyanide, will produce toxic gases. Feed tanks should be totally enclosed to prevent escape of acid fumes. Adequate mixing should be provided to disperse the heat of reaction if wastes being treated are concentrated. The process should be controlled from a remote location.

B.3.1.7 Gravity Separation

Gravity separation is a purely physical phenomenon in which the oil is permitted to separate from water in a conical tank. It offers a straightforward, effective means of phase separation provided the oil and water phases separate adequately within the residence time of the tank. Simple, readily available equipment can be used and operational requirements are minimal. Consideration must be given to the disposal of the extracted waste constituents collected.

B.3.1.8 Air Stripping

Air stripping is a mass transfer process in which volatile contaminants in water or soil are transferred to gas. Air stripping is frequently accomplished in a packed tower equipped with an air blower. The packed tower works on the principle of countercurrent flow. The wastestream flows down through the packing, while the air flows upward and is exhausted through the top. Volatile, soluble components have an affinity for the gas phase and tend to leave the aqueous stream for the gas phase.

In a cross-flow tower, water flows down through the packing as in the countercurrent packed column, however, the air is pulled across the water flow path by a fan.

The coke tray aerator is a simple, low maintenance process requiring no blower. The water being treated is allowed to trickle through several layers of trays. This produces a large surface area for gas transfer.

Diffused aeration stripping and induced draft stripping use aeration basins similar to standard wastewater treatment aeration basins. Water flows through the basin from top to bottom or from one side to another with the air dispersed through diffusers at the bottom of the basin. The air-to-water ratio is significantly lower than in either the packed column or the cross-flow tower.

In recent years, air stripping has gained increasing use for the effective removal of volatile organics from aqueous wastestreams. It has been used most cost-effectively for treatment of low concentrations of volatiles or as a pretreatment step prior to activated carbon. The equipment for air stripping is relatively simple, start-up and shut-down can be accomplished quickly, and the modular design of packed towers makes air stripping well suited for waste site applications.

B.3.1.9 Oxidation

Oxidation or reduction-oxidation reactions are those in which the oxidation-state of at least one reactant is raised while that of another is lowered. In chemical oxidation, the oxidation state of the treated compound is raised. Common commercially available oxidants include potassium permanganate, hydrogen peroxide, calcium or sodium hypochlorite, and chlorine gas. Chemical oxidation is used primarily for detoxification of cyanide and for treatment of dilute waste streams containing oxidizable organics. Among the organics for which this treatment has been reported are aldehyde, mercaptans, phenols, benzidine, unsaturated acids, and certain pesticides.

B.3.1.10 Reduction

Chemical reduction involves the addition of a reducing agent that lowers the oxidation state of a substance in order to reduce toxicity or solubility or to transform it to a form which can be more easily handled. See the earlier discussion of in-situ chemical treatment processes for more technical details.

Commonly used reducing agents for aqueous liquids include sulfite salts, sulfur dioxide, and the base metals (iron, aluminum, and zinc). Chemical reduction is used primarily for reduction of hexavalent chromium, mercury, and lead. Very simple equipment is required for chemical reduction. This includes storage vessels for the reducing agents and perhaps for the wastes, metering equipment for both streams, and contact vessels with agitators. Some instrumentation is required to determine the concentration and pH of the waste and the degree of completion of the reduction reaction.

B.3.1.11 Evaporation

Evaporation is a process whereby an aqueous wastestream is heated to drive off water vapor in order to reduce the volume of the wastestream. This is generally performed in a tank-like system. Organic chemicals may be driven off in the evaporation process as may tritium or volatile metals such as mercury.

B.3.1.12 Solidification/Stabilization

Solidification and stabilization techniques described in Section B.1.1.3 may be used on a batch unit basis to treat aqueous wastestreams. Such treatment may result in a greater volume of waste to be disposed after treatment than before. Aqueous wastestreams may be better suited for use as make-up water in the batch solidification of contaminated soils. See Sections B.1.1.3 and B.3.3.3 for additional details.

B.3.2 Solids/Water Separation

Wastestreams may be generated in the course of remedial actions that require removal of solids from a liquid stream in order to facilitate further aqueous treatment or to selectively separate more highly contaminated solids. Methods for solid/water separation include filtration, sedimentation, separation, and dewatering.

B.3.2.1 Filtration

Filtration is a physical process whereby suspended solids are removed from solution by forcing the fluid through a porous medium. Granular media filtration is typically used for treating aqueous waste streams. The filter media consists of a bed of granular particles. The bed is contained within a basin and is supported by an underdrain system which allows the filtered liquid to be drawn off while retaining the filter media in place. As water laden with suspended solids passes through the bed of filter medium, the particles become trapped on top of and within the bed. In order to prevent plugging, the filter is backflushed at high velocity to dislodge the particles. The backwash water contains high concentrations of solids and requires further treatment.

Filtration is a reliable and effective means of removing low levels of solids from wastestreams provided the content does not vary greatly and the filter is backwashed at appropriate intervals. Filtration equipment is relatively simple, readily available in a wide range of sizes and easy to operate and control. The significant maintenance consideration is handling the backwash. Backwash will generally contain high concentrations of contaminants and require subsequent treatment.

Three types of filtration are commonly used for dewatering: belt press filtration, vacuum filtration, and pressure filtration.

Belt filter presses employ single or double moving belts to continuously dewater sludges. The sludge usually after some conditioning contacts the moving belt(s). The space containing the sludge is gradually decreased as the sludge moves through the process. Progressively more and more water is expelled throughout the process until the end where the cake is discharged.

A vacuum filter consists of a horizontal cylindrical drum which rotates partially submerged in a vat of sludge. The drum is covered with a continuous belt of fabric or wire mesh. A vacuum is applied to the inside of the drum. The wet solids adhere to the outer surface. As the drum continues to rotate, it passes from the cake forming zone to a drying zone, and finally to a cake discharge zone where the sludge cake is removed from the media.

Pressure filtration is a category of filters in which rigid individual filtration chambers are operated in parallel under relatively high pressure. The filter press, the most common type, consists of vertical plates that are held rigidly in a frame and are pressed together by a large screw jack or hydraulic cylinder.

B.3.2.2 Sedimentation

Sedimentation

Sedimentation is a process that relies upon gravity to remove suspended solids in an aqueous waste stream. The process consists of a basin that will maintain the liquid in a quiescent state, a means of directing the liquid to the basin in a manner conducive to settling, and a means of physically removing the settled particles. This technology is applicable to the removal of particles heavier than water. Sedimentation provides a reliable means to remove suspended matter and is capable of 90 to 99 percent efficiency.

Commonly used types of settling basins are impoundment basins, conventional clarifiers, and high rate clarifiers. An impoundment basin is an earthen impoundment or diked area that is lined in a manner that is appropriate for protecting underlying groundwater. They are used to remove particles in the size range of gravel down to fine silt of 10 to 20 microns with flocculants. Conventional clarifiers are rectangular or circular settling basins which are typically equipped with built-in solids collection and removal mechanisms. A high rate clarifier uses multiple "stacked" plates, tubes, or trays to increase the effective settling surface area of the clarifier and decrease the actual surface area needed to effect settling.

Sedimentation employing impoundment basins and conventional clarifiers is a well established technology for removing particles ranging in size from gravel down to fine silt. Proper flocculation is essential to ensure removal of silt-sized particles. Sedimentation methods have not been widely employed for classifying solids according to particle-size. They can be expected to be less effective in classifying solids than classifiers, cyclones, and screens.

Dewatering Lagoons

Dewatering lagoons use a gravity or vacuum assisted underdrainage system to remove water. The base of the lagoon is lined with clay plus a synthetic liner or other appropriate liner material to prevent migration of contaminants into the underlying soils and groundwater. At a minimum, the liner consist of a low permeability clay layer which is several feet thick. When the lagoon is no longer in use, the clay liner is excavated and properly disposed.

Dewatering lagoons are best suited to large-scale dewatering operations where the volume of sludge or sediment would require an inordinately large number of mechanical dewatering units. Lagoons are one of the more effective dewatering methods. A gravity dewatering system is capable of achieving 99 percent solids removal and dewatered cake of 35 to 40 percent solids after 10 to 15 days. The major limitations on the use of dewatering lagoons is that they require large land areas and long set-up times. Because of their large surface area they may not be well suited to areas with heavy rainfall or to areas where long periods of freezing would prevent dewatering.

B.3.2.3 Separation

Methods for solids separation include sieves and screens, hydraulic and spiral classifiers, and cyclones. These are all well demonstrated technologies that are widely adapted in industrial processes and wastewater treatment.

Sieves and Screens

Sieves or screens consist of bars, woven wire, or perforated plate surfaces which retain particles of a desired size range while allowing smaller particles and the carrying liquid to pass through the openings in the screening surface. Types of sieves or screens include grizzlies, moving screens, and fixed screens.

Hydraulic Classifiers

Hydraulic classifiers are commonly used to separate sand and gravel from slurries and classify them according to grain size. These units consist of elevated rectangular tanks with v-shaped bottoms to collect the material. Discharge valves which are located along the bottom of the tank are activated by motor-driven vanes that sense the level of solids as they accumulate. The principal of operation is simple. The slurry is introduced into the feed end of the tank. As the slurry flows to the opposite end, solids settle out according to particle size as a result of differences in settling velocity.

Spiral Classifiers

The spiral classifier consists of one or two long, rotating screws mounted on an incline within a rectangularly shaped tub. It is used primarily to wash adhering clay and silt from sand and gravel fractions. The screw conveys settled solids up an incline to be discharged through an opening at the top of the tub. Fines and materials of low specific gravity are separated from sand and gravel through agitation and the abrading and washing action of the screw, and are removed along with the wastewater overflow at the bottom of the tub.

Cyclones

Cyclones and hydroclones are separators in which solids that are heavier than water are separated by centrifugal force. A hydroclone consists of a cylindrical/conical shell with a tangential inlet for feed, an outlet for the overflow of slurry, and an outlet for the underflow of concentrated solids. Cyclones and hydrocyclones contain no moving parts. The slurry is fed to the unit with sufficient velocity to create a "vortex" action that forces the slurry into a spiral and, as the rapidly rotating liquid spins about the axis of the cone, it is forced to spiral inward and then out through a centrally located overflow outlet. Smaller-sized particles remain suspended in the liquid and are discharged through the overflow. Larger and heavier particles of solids are forced outward against the wall of the cone by centrifugal force within the vortex. The solids spiral around the wall of the cyclone and exit through the apex at the bottom of the cone.

B.3.2.4 Dewatering

Dewatering is a physical unit operation used to reduce the moisture content of slurries or sludges in order to facilitate handling and prepare the materials for final treatment or disposal. Device which can be used to dewater materials include gravity thickeners, centrifuges, filters, and dewatering lagoons.

Gravity Thickeners

Gravity thickening is generally accomplished in a circular tank, similar in design to a conventional clarifier. The slurry enters the thickener through a center feedwell designed to dissipate the velocity and stabilize the density currents of the incoming stream. The feed sludge is allowed to thicken and compact by gravity settling. A sludge blanket is maintained on the bottom to help concentrate the sludge. The clarified liquid overflows the tank and the underflow solids are raked to the center of the tank and withdrawn by gravity discharge or pumping. Flocculants are often added to the feed stream to enhance agglomeration of the solids and promote quicker or more effective settling.

Gravity thickeners are used to concentrate slurries and are capable of achieving a solids concentration of approximately 2 to 15 percent. They generally produce the thinnest and least concentrated sludge of all the dewatering methods. The intent in using a gravity thickener is usually to reduce the hydraulic load of a slurry that is to be fed to a more efficient dewatering method. Gravity thickening provides a simple, low maintenance method for concentrating slurries, thereby reducing the hydraulic load to subsequent dewatering processes. This is suitable for operations where a high degree of operator supervision cannot be provided.

Centrifuges

Centrifugal dewatering is a process which uses the force developed by fast rotation of a cylindrical drum or bowl to separate solids and liquids by density differences under the influence of centrifugal force. Dewatering is usually accomplished using solid bowl or basket centrifuges. Disc centrifuges are also available and are mainly used for clarification and thickening.

Centrifuges can be used to concentrate or dewater soils ranging in size from fine gravel down to silt. Effectiveness of centrifugation depends upon the particle sizes and shapes, and the solids concentration among other factors. Data from the dewatering of municipal sludges indicate that solids concentrations ranging from about 15 to 40 percent are achievable with the solid bowl centrifuge. Solids capture typically ranges from about 85 to 97 percent with chemical conditioning.

B.3.3 Solids Treatment

This section presents methods of treating solids that have been excavated. These methods always produce a solid waste that requires a supplemental treatment or disposal technology.

B.3.3.1 Incineration

Thermal destruction is a treatment method which uses high temperature oxidation under controlled conditions to degrade a substance into products that generally include carbon dioxide, water vapor, sulfur dioxide, nitrogen oxides, hydrogen chloride gas, and ash. The hazardous products of the thermal destruction/incineration include all the previously mentioned products except carbon dioxide and water vapor, plus incomplete products of combustion. Air pollution equipment is required to control the release of the hazardous products. Thermal destruction methods can be used to destroy organic contaminants in liquid, gaseous, and solid waste streams. The most common incineration technologies applicable to hazardous waste sites are rotary kiln, multiple hearth, fluidized bed, and liquid incineration. Advanced incineration technologies include molten salt, wet air oxidation, plasma arc torch, circulating bed, high temperature fluid wall, pyrolysis, supercritical water, electric tube reactor, and vertical tube reactor. Many of these advanced technologies show promise and have been demonstrated to varying degrees, with a wide range of applicabilities, limitations, and reliabilities. They are not presented here for conciseness and to allow focus on the most significant incineration technologies. However, they are well documented in the literature and should be evaluated if thermal treatment is included in the remedial action.

Rotary Kiln

Rotary kilns are capable of handling a wide variety of solid and liquid wastes. They are cylindrical, refractory-lined shells that are fueled by natural gas, oil, or pulverized coal. Most of the heating of the waste is due to heat transfer with the combustion product gases and the walls of the kiln. The basic type of rotary kiln incinerator consists of a kiln and an afterburner.

Wastes are injected into the kiln at the higher end and are passed through the combustion zone as the kiln rotates. The rotation creates turbulence and improves combustion. Rotary kilns often employ afterburners to ensure complete combustion. Most rotary kilns are equipped with a wet scrubber for acid gas and possibly particulate emission control.

Rotary kilns are capable of burning wastes in any physical form. They can incinerate solids and liquids independently or in combination and can accept waste feed without any preparation. Wastes that have been treated in rotary kilns include PCBs, tars, obsolete munitions, polyvinyl chloride, and bottoms from solvent reclamation operations. Because of their ability to handle waste in any physical form, and their high incineration efficiency, rotary kilns are the preferred method for treating mixed hazardous solid residues.

Rotary kilns are susceptible to thermal shock which necessitates very careful maintenance. They need additional air due to leakage, have high particulate loadings, relatively low thermal efficiency, and a high capital cost.

Multiple Hearth

Multiple hearth incinerators consist of a refractory lined steel shell, a rotating central shaft, a series of solid flat hearths, a series of rabble arms with teeth for each hearth, an air blower, waste feeding and ash removal systems, and fuel burners mounted on the walls. They also have an afterburner and can have liquid waste burners, and side ports for tar injections.

The multiple hearth incinerator can be used for the disposal of all forms of combustible materials, including sludges, tars, solids, liquid, and gases. The incinerator is best suited for sludge destruction. Solid waste often requires pretreatment such as shredding and sorting. It can treat the same wastes as the rotary kiln provided that solids are pretreated. The principal advantages of multiple hearth incineration include high residence time for sludge and low volatile materials; the ability to handle a variety of sludges; the ability to evaporate large amounts of water; high fuel efficiency; and the utilization of a variety of fuels.

Multiple hearth units are susceptible to thermal shock. They are unable to handle wastes that produce an ash which fuses into large rock-like structures or wastes requiring very high temperatures. Control of the firing of supplemental fuels is difficult. This type of incinerator has high maintenance and operating costs.

Fluidized Bed

Fluidized bed incinerators consist of a cylindrical vertical refractory-lined vessel containing a bed of inert granular material, usually sand on a perforated metal plate. Combustion air is introduced through a plenum at the bottom of the incinerator and rises vertically fluidizing the bed and maintaining turbulent mixing of bed particles. Waste material is injected into the bed and combustion occurs within the bubbling bed. Heat is transferred from the bed into the injected wastes. Auxiliary fuel is usually injected into the bed. Since the mass of the heated, turbulent bed is much greater than the mass of the waste, heat is rapidly transferred to the waste materials; a residence time of a few seconds for gases and a few minutes for liquids is sufficient for combustion.

The most typical wastes being treated in fluidized beds include slurries and sludges. Some waste requires pretreatment such as drying, shredding, and sorting. The fluidized bed can handle the same wastes as the rotary kiln. They have been used for the disposal of municipal wastewater treatment sludges, oil refinery waste, and pulp and paper mill waste. There are limited data on the use of this technology for hazardous waste incineration. It has been used for phenolic wastes and methyl methacrylate. It is particularly well suited for high-moisture wastes, sludges, and wastes containing large quantities of ash.

The advantages of fluidized bed incineration include simple design, minimal NOx formation, long life of the incinerator, high efficiency, and simplicity of operation. It has the ability to trap some gases in the bed, reducing the need for an emission control system. The disadvantages include difficulty in removing residual materials from the bed, a relatively low throughput capacity, and the difficulty of handling residues and ash from the bed.

Liquid Injection

A liquid incineration system consists of a single or double refractory-lined combustion chamber and a series of atomizing nozzles. Two chamber systems are more common. The primary chamber is usually a burner where combustible liquid and gaseous wastes are introduced. Noncombustible liquid and gaseous wastes are introduced downstream of the burner in the secondary chamber.

Liquid injection can be used to destroy virtually any pumpable waste. If viscosity precludes atomization, mixing and heating can be used prior to atomization to improve viscosity. These units have been used in the destruction of PCBs, solvents, still and reactor bottoms, polymer wastes, and pesticides. Unlikely candidates for destruction include heavy metal wastes and wastes high in inorganics.

Liquid incinerators have no moving parts and require the least maintenance of all types of incinerators. The major limitations of these units are the ability to incinerate only wastes which can be atomized in the burner nozzle and the burner's susceptibility to clogging. It also needs supplemental fuel. Liquid injection incinerators are highly sensitive to waste composition and flow changes. Storage and mixing tanks are usually required to ensure a reasonably steady and homogenous waste flow.

B.3.3.2 Separation

The treatment of solids involves their classification by grain size. Classification of particles according to grain size may be undertaken for one of two reasons. First, more efficient use can be made of equipment and land area by taking advantage of the differences in settling velocity of different sized particles. Second, there is recent evidence to suggest that classification by grain size is important in managing contaminated soils because of the apparent tendency of contaminants to adsorb preferentially onto fine-grained materials. Sieves and screens, classifiers, and cyclones may be used for solids separation. These technologies are presented in Section B.3.2.3.

B.3.3.3 Solidification/Stabilization

Solidification and stabilization are terms which are used to describe treatment systems which (1) improve waste handling or other physical characteristics of the waste, (2) decrease the surface area across which transfer of contaminants can occur and/or (3) limit the solubility or toxicity of contaminants. Solidification is used to describe processes where these results are obtained primarily, but not exclusively, by production of a monolithic block of waste with high structural integrity. The contaminants do not necessarily interact chemically with the solidification reagents, but are mechanically locked within the solidified matrix. Contaminant loss is minimized by reducing the surface area. Stabilization methods usually involve the addition of materials which limit the solubility or mobility of waste constituents even though the physical handling characteristics of the waste may not be improved. Methods involving combinations of solidification and stabilization techniques are often used. The state-of-the-art of solidification/stabilization methods is advancing rapidly. Many manufacturers are marketing processes which involve the use of various combinations of alkaline earth materials often together with organic polymers and proprietary chemicals.

Cement-based Solidification

Cement-based solidification involves mixing the wastes directly with Portland cement. The waste is incorporated into the rigid matrix of the hardened concrete. The end product may be a standing monolithic solid or may have a crumbly, soil-like consistency, depending upon the amount of cement added.

Most hazardous wastes slurried in water can be mixed directly with cement and the suspended solids will be incorporated into the rigid matrix. Although cement can physically incorporate a broad range of waste types, most wastes will not be chemically bound and are subject to leaching. Cement solidification is most suitable for immobilizing metals because at the pH of the cement mixture, most multivalent cations are converted into insoluble hydroxides or carbonates.

There are many disadvantages to cement-based solidification. Metal hydroxides and carbonates are insoluble only over a narrow pH range and are subject to solubilization and leaching in the presence of even mildly acidic leaching solutions (i.e., rain). Portland cement alone is not effective in immobilizing organics. Cement-based solidification results in wastes that are twice the weight and volume of the original material thereby increasing transportation and disposal costs. Some wastes are incompatible with cement such as some sodium salts (i.e., arsenate, borate, phosphate, iodate, and sulfide), salts of magnesium, tin, zinc, copper, and lead, organic matter, some silts and clays, coal, and lignite. The major advantage of the method is its low cost and the use of readily available mixing equipment.

Silicate-based Solidification

Silicate-based processes refer to a very broad range of solidification and stabilization methods which use a siliceous material together with lime, cement, gypsum, and other suitable setting agents. Extensive research is currently underway on the use of siliceous compounds in solidification. Many of the available processes use proprietary additives and claim to stabilize a broad range of compounds. The basic reaction is between the silicate material and polyvalent metal ions. The silicate material which is added in the waste may be fly-ash, blast furnace slag or other readily available materials. Soluble silicates such as sodium silicate or potassium silicate are also used. The polyvalent metal ions which act as initiators of silicate precipitation and/or gelation come either from the waste solution, and added setting agent, or both. The setting agent should have low solubility, and a large reserve capacity of metallic ions so that it controls the reaction rate. Portland cement and lime are most commonly used because of their good availability. However, gypsum, calcium carbonate, and other compounds containing aluminum, iron, magnesium are also suitable. The solid which is formed in these processes varies from a moist, clay-like material to a hard-dry solid similar in appearance to concrete. There are a number of silicate-based processes which are currently available or in the research stages. Manufacturers' claim differ significantly in terms of the capabilities of these processes for stabilizing different waste constituents.

There is considerable research data to suggest that silicates used together with lime, cement, or other setting agents can stabilize a wide range of materials including metals, waste oil and solvents. The feasibility of using silicates for any application must be determined on a site-specific basis particularly in view of the large number of additives and different sources of silicates which may be used. Soluble silicates such as sodium and potassium silicate are generally more effective than fly ash, blast furnace slag, etc. There is some data to suggest that lime-fly ash materials are less durable and stable to leaching then cement fly ash materials.

Common problems with lime-fly ash and cement-fly ash materials relate to interference in cementitious reactions that prevent bonding of materials. Materials such as sodium borate, calcium sulfate, potassium dichromate and carbohydrates can interfere with the formation of bonds between caladium silicate and aluminum hydrates. Oil and grease can also interfere with bonding by coating waste particles. However several types of oil sludges have been stabilized with silicate-based processes.

One of the major limitations with silicate-based processes is that a large amount of water which is not chemically bound will remain in the solid after solidification. In open air, the liquid will leach until it comes to some equilibrium moisture content with the surrounding soil. Because of this water loss, the solidified product is likely to require secondary containment.

Commercial cement mixing and handling equipment can generally be used for silicate-based processes. A number of mobile, trailer-mounted systems are available.

Sorbents

Sorbents include a variety of natural and synthetic solid materials which are used to eliminate free liquid and improve the handling characteristics of wastes. It can be applied to any waste type where free liquids (water or organics) need to be bound. Commonly used natural sorbent materials include flyash, kiln dust, vermiculite, and bentonite. Synthetic sorbent materials include activated carbon which sorbs dissolved organics, Hazorb (Dow Chemical) which sorbs water and organics, and Locksorb (Radecca Corporation) which is reportedly effective for all emulsions.

Sorbents are widely used to remove free liquid and improve waste handling. Some sorbents have been used to limit the escape of volatile organic compounds. They may also be useful in waste containment when they modify the chemical environment and maintain the pH and redox potential to limit the solubility of wastes. Although sorbents prevent drainage of free water, they do not necessarily prevent leaching of waste constituents and secondary containment is generally required. Equipment requirements for addition and mixing of sorbents are simple.

Thermoplastic Solidification

Thermoplastic solidification involves sealing wastes in a matrix such as asphalt bitumen, paraffin, or polyethylene. The waste is dried, heated, and dispensed through a heated plastic matrix. The mixture is then cooled to form a rigid but deformable solid. Bitumen solidification is the most widely used of the thermoplastic techniques.

Thermoplastic solidification involving the use of an asphalt binder is most suitable for heavy metal or electroplating wastes. Relative to cement solidification, the increase in volume is significantly less and the rate of leaching significantly lower. Thermoplastics are not affected significantly by either water or microbial attack.

There are a number of waste types which are incompatible with thermoplastic solidification. Oxidizers such as perchlorites or nitrates can react with many of the solidification materials to cause an explosion. Some solvents and greases can cause asphalt materials to soften and never become rigid. Xylene and toluene diffuse quite rapidly through asphalt. Salts that partially dehydrate at elevated temperatures can be a problem. Sodium sulfate hydrate, for example, will lose some water during asphalt incorporation and if the waste asphalt mix containing the partially dehydrated salt is soaked in water, the mass will swell and crack due to rehydration. This can be avoided by eliminating easily dehydrated salts or coating the outside of the waste/asphalt mass with pure asphalt. Chelating and complexing agents can cause problems with containment of heavy metals. Certain wastes, such as tetraborates, and iron and aluminum salts can cause premature solidification and plug up the mixing machinery.

High equipment and energy costs are principal disadvantages of thermoplastic solidification. Another problem is that the plasticity of the matrix-waste mixture generally require that containers be provided for transportation and disposal of materials which greatly increases the cost. Thermoplastic solidification requires specialty equipment and highly trained operators to heat and mix the wastes and solidifier. The common range of operating temperatures is 130 to 230 degrees Centigrade. The energy intensity of the operation is increased by the requirement that the wastes be thoroughly dried before solidification.

Surface Microencapsulation

Surface encapsulation includes those methods which physically microencapsulate wastes by sealing them in an organic binder or resin. Surface encapsulation can be accomplished using a variety or approaches.

A process developed by Environmental Protection Polymers involves the use of 1,2-polybutadiene and polyethylene to produce a microencapsulated waste block onto which a high density polyethylene (HDPE) jacket is fused. The 1,2-polybutadiene is mixed with particulated waste which yields, after solvent evaporation, free flowing dry resin-coated particulates. The resulting polymers are resistant to oxidative and hydrolytic degradation and to permeation by water. The next step involves formation of a block of the polybutadiene/waste mixture. In the final step, a 1/4 inch thick HDPE jacket is mechanically and chemically locked to the surface of the microencapsulated waste. An alternative process developed by the same company involves a much similar approach. Contaminated solids or sludges are loaded into a high density polyethylene overpack. A portable welding apparatus is then used to spin weld a lid onto the container forming a seam free encapsulate.

Another encapsulation method uses an organic binder to seal a cement-solidified mass. United States Gypsum Company manufactures a product called Envirostone Cement which is a special blend of high-grade polymer modified-gypsum cement. Emulsifiers and ion exchange resins may be added along with the gypsum cement which hydrates to form a freestanding mass. A proprietary organic binder is used to seal the solidified mass. The process can be used to stabilize both organic and inorganic wastes.

The major advantage of encapsulation processes is that the waste material is completely isolated from leaching solutions. These methods can be used for both organic and inorganic waste constituents. They allow for efficient space utilization during transport, storage, and disposal. The hazard of accidental spills during transport is minimized. Encapsulation materials are commercially available, very stable chemically, nonbiodegradable, mechanically tough, and flexible. They can withstand the mechanical and chemical stresses of a wide range of disposal schemes.

The disadvantages of encapsulation techniques include the high cost of the binding resins and that the processes are energy intensive. In addition, skilled labor is required to operate molding and fusing equipment.

B.3.3.4 Vitrification

Vitrification of wastes involves combining the wastes with molten glass at a temperature of 1,350 degrees Centigrade or greater. There are some processes that allow temperatures as low as 850 degrees.

Vitrification is quite costly and so far has been restricted to radioactive or very highly toxic wastes. To be considered for vitrification, the wastes should be either stable or totally destroyed at the process temperature.

Vitrification offers the greatest degree of containment of all the common solidification methods. Most resultant solids have an extremely low leach rate. Some glasses, such as borate-based glasses, have high leach rates and exhibit some water solubility. The high energy demand and requirements for specialized equipment and trained personnel greatly limit the use of this method.

B.3.3.5 Soils Treatment

Any of the techniques for in-situ treatment described in Section B.1.1.4 may be applied on a batch or continuous unit basis to excavated soils. Soil washing is another method that may be applied and is described below.

Soil Washing

Soil washing is a process whereby excavated contaminated soil is washed with water to remove the contamination from the soil grains into the washwater. Chemical agents such as surfactants or chelants can be added to the washwater to increase the efficiency of contaminant removal. There is little or no actual experience with washing of excavated soil at hazardous waste sites in the United States. A few projects in the planning stages are reported. The soil-washing process has been used in several installations in Holland and West Germany. The process has been the subject of a U.S. EPA research program since about 1982, and at least one private firm (ECOVA) in the U.S. is attempting to market the process. In Europe soil-washing facilities are reported in Germany and the Netherlands.

The soil washing process consists of the following steps. First, the soil feed is screened to remove debris. The soil is then mixed with washwater in measured proportions. It is washed or scrubbed to obtain intensive contact between the soil grains and the washwater. Energy may be introduced into the mixture by high-pressure water jets, vibration devices, and/or other means. Next the washed soil is separated out of the washwater. Coarse soil particles can be separated in a trammel or vibrating screen device; finer sand is separated in a sedimentation tank; and silt in a hydrocyclone or centrifuge device. The resulting fine soil and contaminated water mixture must then be treated for final disposal of solids and recycling of the water.

Soil-washing works successfully to clean coarse-grained soils of a wide range of organic and inorganic contaminants. It removes most water-soluble volatile organics and other highly mobile hydrophilic compounds from soil. The soil-washing process has great difficulty removing from fine-grained soils those organics and inorganic compounds which do not readily separate from the soil to water. There is a minimum soil grain size below which soil-washing cannot effectively remove metals and most nonvolatile and semivolatile organics. The addition of chelants and surfactants will somewhat reduce the minimum soil grain size which can be successfully cleaned. The addition of the chemicals to the washwater complicates the later treatment of the washwater for recycle or disposal.

Bench scale tests of soil washing with water alone on coarse soil particles greater than 2000 microns have reduced the levels of volatile organics, semivolatile organics and metals by 99.9, 93.9, and 96.7 percent, respectively. However, as the soil particles decreased in size, washing with water alone was much less affective. For grain sizes less than 250 microns, there was no reduction in the levels of semivolatile organics and metal inorganics.

Despite the lack of U.S. experience and limited European experience with soil-washing there is nothing to imply reliability problems. The equipment used for soil washing is similar to equipment routinely used in the sand, gravel, and ore-processing industry. Good reliability is likely if the soil-washing equipment is designed for the site soil and if it is properly maintained.

B.3.4 Gaseous Waste Treatment

This section presents methods for treating gases after they have be collected using methods presented earlier for migration control of gases. The only treatment methods are incineration, flaring, and adsorption.

B.3.4.1 Flaring

Flaring exposes gases to an open flame where no special features are employed to control temperatures or residence time. Supplementary fuels may be used to sustain continuous combustion. Flares are commonly used in the oil and gas industry to dispose of waste gases and fume at refineries; at sewage treatment plants to dispose of digestor gas; and at sanitary landfills to dispose of landfill gas. Although flares provide sufficient destruction of contaminants for conventional applications, destruction removal efficiencies required by current environmental regulations for thermal destruction of hazardous wastes are generally too stringent to be met by flaring. Exceptions may be gaseous waste streams consisting of relatively simple hydrocarbons.

B.3.4.2 Incineration

Incineration, which can also be applied to solids and liquids, is discussed in Section B.3.3.1.

B.3.4.3 Activated Carbon

See Section B.3.1.1 for discussion.

B.4 DISPOSAL TECHNOLOGIES

Disposal technologies include on-site landfills, off-site landfills, POTWs, and underground injection wells.

B.4.1 On-Site Landfills

The on-site disposal of wastes by landfilling will require the design and construction of new landfills which comply substantially with RCRA landfill facility standards under 40 CFR Part 264. It should be noted that EPA guidance for CERCLA responses requires most on-site disposal actions "to attain or exceed applicable and relevant standards of Federal public health and environmental laws, unless specific circumstances" dictate otherwise.

The RCRA requirements under 40 CFR Part 264 and all associated guidance are concerned with the proper location, design, construction, operation, and maintenance of hazardous waste management facilities. These requirements preclude landfilling in areas of seismic instability, in a 100-year floodplain, and where the integrity of the liner system would be adversely affected. These requirements also preclude landfilling of liquids and several types of highly mobile and/or highly toxic wastes. In addition to complying with these requirements, the evaluation of an on-site landfill program must address potential risks posed by the depth to groundwater at the site and the degree of naturally available groundwater protection if the liner system should fail. Other factors entering this evaluation include costs for monitoring the groundwater, collecting any accumulated leachate, and for implementing further corrective action if the groundwater has been contaminated by a leak from the new landfill.

The operating life of an on-site landfill should be minimized to avoid unnecessary generation of leachate caused by rainfall into an open cell. Sometimes it is more efficient to construct several landfill cells in sequence rather than to construct on large cell which will remain open for a long time period. All materials placed into a landfill should be compacted as much as possible using heavy equipment. This practice will minimize settling after closure. All equipment operators and workers must be thoroughly trained.

RCRA requires all land disposal facilities to establish a groundwater monitoring program. The program must be capable of determining the facility's impact on the quality of groundwater in the uppermost aquifer underlying the facility.

On-site landfilling is an expensive technology which should only be considered when: (1) there is so much waste to be disposed that the total cost of off- site waste management at an acceptable site is comparable; (2) simple capping of the site will not provide adequate protection of human health and the environment; and (3) on-site conditions will allow the construction of a landfill that will protect human health and the environment. Since it is rare that all three of the above conditions are met at a site, the on-site landfill option is not frequently used.

B.4.2 Off-Site Landfills

Determining the feasibility of off-site disposal by landfilling, requires knowledge of RCRA regulations (40 CFR Parts 261-265) and other regulations developed by states. RCRA generator and manifest requirements must be complied with for all wastes that are shipped off-site. The generator must ensure that the facility selected to receive the wastes is in compliance with all applicable Federal and State regulations. RCRA storage and disposal facilities are required to notify the generator, in writing, that they are capable of managing the wastes. The generator must keep a copy of this written notification on file as part of the operating record.

A detailed waste analysis is generally required before a waste is accepted by a treatment/disposal facility. On-site pretreatment of wastes may be required in order to make them acceptable for off-site transport or to meet the requirements of the disposal facility, and to meet the RCRA land disposal ban requirements (40 CFR 268).

The transportation of wastes is regulated by the Department of Transportation (DOT), the EPA, the States, and in some instances local regulations. The EPA regulations under RCRA adopt DOT regulations pertaining to labeling, placarding, packaging, and spill reporting. Vehicles for off-site transport must be DOT approved and must display the proper DOT placard. Before a vehicle is allowed to leave the site, it should be rinsed or scrubbed.

B.4.3 POTW

Often liquid wastestreams generated from treatment process can be discharged with other industrial wastes to a publicly owned treatment works (POTW). The wastestream must meet all applicable discharge limitations established by the local POTW. In some cases, pipelines can be constructed, with the approval of the POTW, to connect with the system. Facilities located at some distance from a POTW may find the pipeline construction costs prohibitive.

B.4.4 Underground Injection

Wastes may be injected into the subsurface for disposal using injection wells. The wastes and injection system must meet the underground injection control requirements under the Safe Drinking Water Act and some aquifers are precluded from usage or must be protected. Some wastes are banned from underground injection.

B.5 INSTITUTIONAL CONTROLS

Institutional controls are measures that can be taken by a private or public institution to reduce or eliminate environmental exposure to contaminants. These technologies do not affect the level or location of the contamination or its movement. Instead they alter receptor activities to preclude contact. Institutional controls considered include site access restrictions, alternative drinking supplies, and treatment of the existing water supply. All the techniques are proven and can be implemented with a high degree of reliability.

B.5.1 Access Restriction

Access restriction involves the implementation of legal and physical barriers to prevent either transient or permanent access to the site by animals or humans. The remedial technologies include land controls and fencing/signs. Land controls could include deed restrictions for installation of wells within the area of influence, groundwater monitoring, or other zoning and land use planning types of restrictions. Since DOE owns the SDA, and it can stay in Federal control in perpetuity. Such controls can be implemented with good reliability. Fences and signs can be used to exclude humans and animals. These physical barriers and warnings can be used in combination.

B.5.2 Alternative Drinking Water Supply

Water supplies that are contaminated at the source or in transmission through pipelines can be replaced permanently or temporarily with an independent supply at the point of usage. Such supplies could include (1) bottled and trucked water, (2) a new production well, and (3) a pipeline from an existing production well.

The use of bottled and trucked water is common for temporary or semi-temporary water supplies on an emergency basis until more permanent water supply arrangements can be made. Bottled water is widely available in large quantities from commercial distributors. Such water can be provided in portable tanks (trailers or tank trucks) by commercial, clean water contractors.

A new production well can be used to replace existing contaminated potable water supplies. Such a well would have to be sited at a nearby location and at a depth that would avoid contaminated groundwater and avoid drawing in other plumes that may exist in the area. Potable water could also be piped from nearby existing deep production wells.

There are many possible combinations of these alternative drinking supply technologies that need to be considered. An alternative water supply could be implemented for drinking water while other water uses could continue with contaminated water. Bottled or trucked water could be used as an interim measure while a pipeline or new production well is under construction. Water could be trucked from the existing production well.

The existing water supply can be treated to acceptable quality using a central treatment system. Central treatment could require the installation of new facilities. Available water treatment methods include physical, chemical, and biological technologies, and combinations of these methods may be used for removal of some contaminants. A summary of potential technologies is present in Section B.3.1 of this Appendix.