Table B-1. (continued).

Remedial Technology	Process Option	Description	Effectiveness	Implementability	Relative Cost	Screening Comments
	Foams, sprays, misters, fixatives, and washes	These processes can be applied quickly and remotely to perform a variety of functions—including controlling odors, VOCs, dust, and other emissions—by creating a barrier between the work surface and the atmosphere, fixing loose airborne and/or settling contamination to a surface, and decontaminating personnel, the atmosphere, or equipment. The processes are readily available in nontoxic, nonhazardous, nonflammable, and biodegradable forms and range from water to polymeric mixtures. Commonly used fixatives include aerosol fogs and strippable coatings, which can be used to either secure contamination or decontaminate the atmosphere or equipment. Aerosol fogs are used to capture and hold airborne contaminants and prevent contaminants on the surface from becoming airborne. Strippable coatings can be applied to clean or dirty surfaces. When applied to contaminated surfaces, the coating attracts, absorbs, and chemically binds the contaminants in its polymeric structure. When applied to clean surfaces, the coating protects the area from contamination. Other common methods of decontamination include sprays and washes, which are chemicals that can be sprayed on and then wiped off.	This is a proven process option. Foams, sprays, misters, fixatives, and washers are effective at controlling emissions, dust, and source material; they are also effective at decontaminating equipment to a certain degree, but not 100%.	This option is implementable. Systems are readily available and many technologies are well developed. Foams, sprays, misters, fixatives, and washers can be effectively applied remotely.	Costs are expected to be relatively low if standard equipment is used.	Retained.
	Electrostatically charged plastic	Electrostatically charged plastic and electrostatic curtains can be used as barrier walls to minimize the spread of contamination from one location to another, but do not collect dust once it becomes airborne. The curtains can be used upstream of emission-filtering systems to neutralize charged dust particles. Electrostatically charged plastic can be used in enclosures to minimize the airborne particles in dust.	Electrostatically charged plastic is effective at minimizing the spread of contamination from one location to another, but not in collecting dust once it becomes airborne.	The electrostatically charged plastic option is difficult to implement. Plastic sheets would be cumbersome in an excavation and would only collect dust generated near the sheet.	Costs would depend on application and site-specific design requirements.	Not retained—technology not applicable to large area retrieval actions.
	In situ stabilization	In situ soil stabilization controls contamination in the soil and waste matrix. Grout, resin, or polymer (e.g., EKOR) may be injected into the waste to solidify it before retrieval. Other stabilizing technologies that could be used include vitrification and ground freezing.	Effective ISG, ISV, and ground freezing would be successful at stabilizing waste and soils in place and minimizing contaminant-control requirements during retrieval actions.	In situ stabilization is implementable. The implementability of the ISV, ISG, and ground freezing technologies is discussed in this table. Retrieval action and equipment would have to be specifically designed to address stabilized matrix.	Costs vary widely depending on the stabilizing technology used.	Retained.
Excavation methods	**Standard construction equipment**	A variety of standard heavy-construction equipment is available to remove buried waste and overburden soil. Front-end loaders, backhoes, and trenchers are three common types of excavation equipment that have been used to remove buried hazardous waste. The front-end loaders are used for digging, lifting, dumping, and hauling. The backhoe is used for trench digging and small area excavations and is frequently used in a backhoe and front-end loader combination. Trenchers are similar to backhoes in their function, but have a smaller carrying capacity and thus would be used in smaller excavation and grading applications. Dozers are used to remove soil covers.	Standard construction equipment is effective at performing the material-handling tasks for which they were designed, but is not effective at protecting workers from exposure. In areas of contamination, standard equipment must be combined with other protective process options.	This option is implementable. A wide range of equipment is readily available for the wide range of tasks required.	Capital costs depend on the type of equipment needed, but are expected to be low in relation to remote excavation methods or modified equipment for a sealed environment. The O&M costs are expected to be low in relation to remote methods.	Retained.

Table B-1. (continued).

Remedial Technology	Process Option	Description	Effectiveness	Implementability	Relative Cost	Screening Comments
	Standard construction equipment with modification	Conventional equipment—such as front-end loaders, backhoes, and trenchers—can be modified in a variety of ways to provide better protection to the operator in highly contaminated environments. Modifications may include (but are not limited to) a shielded cabin, a sealed and pressurized cabin with filtered air, or a sealed and pressurized cabin with supplied air. Shielded excavators have been used successfully (e.g., Hanford). In addition, equipment with pressurized and sealed cabs has been successfully used (with supplied air at Niagara Falls and filtered air at Maralinga).	Standard construction equipment is effective at performing material-handling tasks and also at protecting workers when combined with contamination control.	This option is implementable and proven in contaminated environments.	Capital costs are expected to be moderate to high, depending on project requirements.	Retained.
	Remotely operated equipment	Remotely operated excavators have been used at sites to remove hazardous, pyrophoric, and radioactive wastes with remote controls and remote end-effectors that maintain distance between the source and the operator. The technology to modify standard heavy equipment is available, and remote excavators have been demonstrated. Remotely operated vacuum systems could remove soil and small loose debris from an isolated area. This option would not be used to remove the buried waste, but could be used to remove portions of the soil overburden or underburden if standard heavy equipment was not feasible. A nozzle offers remote control and long-distance extension to control operator exposure. Remotely operated cranes could be used to remove buried waste in a precise manner, offer ease of control, and can be stationary or portable. There are several types of cranes available, including a 24.4-m (80-ft) remotely operated gantry crane designed at the INEEL.	Remotely operated equipment is effective at removing buried waste, as demonstrated in cold tests. However, experience with this option as a digging device to remove buried waste is limited. Remotely operated vacuum systems are effective at removing dry soil and small loose debris from isolated areas. However, they have limited effectiveness on hard-packed clays and moist material. Remotely operated cranes are effective at removing buried waste from precise locations, at protecting operator(s) from exposure, and for hanging other equipment (e.g., monitors and misters) over an excavation area. However, any riggers required for specific removals would need to be protected by other process options.	This option is implementable and has become more recently available for purchase rather than for lease or by special design.	Capital costs are expected to be moderate to high in relation to other retrieval process options and depending on project-specific requirements.	Retained.
Ex Situ Treatment						
Physical Treatment	**Screening/ classification**	Different-sized sieves and screens separate material types into smaller volumes. Screening/classification equipment includes grizzly shakers and rotary trommels. The process can separate out oversized material as a pretreatment step for further processing. For separation of contaminants, excavated soil can be passed through progressively finer screen sizes to separate fine-grained from coarse-grained fractions. Most contaminants tend to bind to soil fines (silts and clays) rather than to coarse components (coarse types of sand, gravel, and cobble). This process option may be used alone or in combination with other treatment process options to reduce the volume of contaminated materials for disposal. Standard process equipment or remotely operable, specially designed equipment may be used in this option. Screening processes are well-established technologies used in many applications.	This option is effective at separating soils or other materials by size. Sieving/screening is a well-established technology for wastewater treatment, soil, sediments, and sludge and as a pretreatment step for waste processing. Its value as the sole method of contaminant separation is limited.	This option is implementable with standard equipment. It may be utilized remotely. Design considerations include techniques to prevent and clear clogging of the equipment.	Capital costs are expected to be low in relation to other ex situ treatments, depending on the dust control measures required.	Retained.
	Sizing	Sizing consists of reducing the size of larger pieces of soil, rock, or other materials with cutting, shredding, and/or crushing machinery. Various types of equipment standard to the waste processing, recovery, mining, and demolition industries may be used. This equipment includes jaw crushers, gyratory crushers, hammermills, shear shredders, and dual-auger shredders. Standard industrial equipment is robust and proven (UIMME 2001).	This option is effective at reducing the size of larger soil and rock particles, concrete, wood, some metals, construction debris, and many other waste materials. It is important as a pretreatment step for some process technologies.	Sizing is implementable for certain portions of the waste stream.	Costs are expected to be low to medium in relation to other ex situ treatments.	Retained.

Table B-1. (continued).

Remedial Technology	Process Option	Description	Effectiveness	Implementability	Relative Cost	Screening Comments
	Compaction	Compaction is the process of applying high pressure to the wastes to reduce void space and achieve volume reduction. The volume reduction achieved is a function of void space in the waste, the force applied by the press, the bulk density of the material, and the spring-back characteristics of the waste. Supercompactors can achieve a 2 to 4 volume reduction factor for noncompactible waste and 6 to 7 for compactible waste. Volume reduction can be improved by preshredding the waste (DOE 1996).	This option's effectiveness depends on the characteristics of the waste material. Compaction is a well-proven treatment technology in both nuclear and nonnuclear industries.	Compaction is implementable for certain portions of the waste stream.	Costs are expected to be low in relation to other ex situ treatments.	Retained.
	Gravity separation	Gravity separation is a solid/liquid separation process that exploits a density difference between the solid- and liquid-phase densities. Equipment size and effectiveness of gravity separation depend on the solids' settling velocity, which is a function of the particle's size, density difference, fluid viscosity, and concentration. Gravity separation also is used to remove immiscible oil phases and for classification where particles of different sizes are separated. This technique is often preceded by coagulation and flocculation to increase particle size, thereby allowing the removal of fine particles (FRTR 2001).	This option's effectiveness depends on the solids' settling velocities. Gravity separation is a well-established process for treatment of wastewater, soil, sediment, and sludge.	The gravity separation option is implementable. This option requires slurry formation with waste. It generates secondary wastes in the form of wastewater.	Capital cost is expected to be low in relation to other ex situ treatments.	Retained.
	Magnetic separation	Magnetic separation is used to extract slightly magnetic radioactive particles and metals from host materials such as water, soil, or air. Uranium and plutonium compounds are slightly magnetic, while most host materials are not magnetic. The process operates by passing contaminated fluid or slurry through magnetized media. The magnetized media contain a magnetized matrix, such as steel wool, that extracts the slightly magnetic contamination particles from the slurry. Magnetic separation is a new technique to remove radioactive contaminants from soil and has recently been bench-scale tested at DOE sites (FRTR 2001).	Magnetic separation is effective at removing slightly magnetic radioactive and metal particles from water, soil, or air, as shown in the bench-scale test. New technology has not been tested at full scale.	Magnetic separation is technically implementable. This option requires slurry formation with waste. It generates secondary waste in the form of wastewater.	Capital costs are expected to be low in relation to other ex situ treatments.	Not retained—process has not been proven at full scale.
	Electrostatic separation	Electrostatic separation of materials is based on differences in surface conductivity and preferential charging and attraction of materials to an electric field of opposite charge. A variety of electrostatic separation equipment is available, depending on the type of material to be separated. The process can be used for nonconductors, mineral processing, recycling, and laboratory- or pilot-scale devices (Carpco 2001). For mineral processing, minerals essentially are sprayed with electrons from the active electrode and develop a charge that pins them to the grounded rotor. Conductors, however, immediately lose the charge and drop straight down. Semiconductors and nonconductors stay pinned longer, thus separating (UIMME 2001).	Electrostatic separation is effective at separating different types of materials. It is a proven, commercially available process (Carpco 2001).	The electrostatic separation option is implementable. Materials would require screening and sizing (UIMME 2001).	Capital costs are expected to be moderate in relation to other ex situ treatments.	Retained.
	Gamma monitor, conveyor, and gate system	This process option combines a feed hopper, a conveyor belt, gamma spectroscopy, and a gate to separate soils into categories based on gamma activity. The gamma monitoring, conveyor, and gate system are most effective in reducing the volume of contaminated material requiring treatment and disposal, when combined with other technologies. Used for design of Pit 9, this option has been successfully demonstrated to reduce volumes of radiologically contaminated soil at several locations (SNL 1999).	This option is effective at sorting radioactive materials from nonemitting or low-emitting materials. Materials must be sized to <5 cm (2 in.) in diameter. The system has been successfully used at SNL, ER 16 in 1998 (SNL 1999).	This option is implementable. However, it must be combined with sizing process options.	Capital costs are expected to be moderate in relation to other ex situ treatments.	Retained.

Table B-1. (continued)

Remedial Technology	Process Option	Description	Effectiveness	Implementability	Relative Cost	Screening Comments
	Flotation	Flotation separates fine-grained from coarse-grained sediment and soil by increasing differences in their settling velocities in a clarifier. The process is only applicable to contaminants that are preferentially partitioned on the fine-particle fraction of the soil. Coarse-grained material settles to the bottom, while fine-grained particles rise to the surface where they can be recovered by skimmers. The process is technically implementable with standard process equipment (UIMME 2001).	Flotation is effective at separating fine-grained fractions from coarse-grained fractions. Effectiveness of contamination removal depends on the degree of contaminant association with a particular size fraction.	This flotation option is implementable. This option requires slurry formation, and it generates secondary waste in the form of wastewater.	Costs are expected to be low in relation to other ex situ treatments.	Retained.
Chemical treatment	**Fixation/ stabilization**	Chemical fixation and stabilization process options immobilize radioactive and hazardous constituents in waste by mixing in additives that bind or absorb the waste into a solid waste form. This option may be required prior to waste packaging for shipment or storage to immobilize liquids and/or contaminants. Processes use either organic or inorganic additives, which either serve as chemical bonding agents/ absorbents or provide containment. Additives include Portland cement, modified sulfur cement, and polymers (DOE 1996).	Fixation/stabilization is effective at absorbing liquids and immobilizing waste forms and binding them into a solid waste form.	The fixation/stabilization option is implementable. Treatability studies would be needed to define process variables such as additives, concentrations, and mixing times.	Capital costs are expected to be moderate in relation to other ex situ treatments.	Retained.
	Soil washing	Soil washing uses an aqueous solution and detergent to remove organic material from the surface of soil particles and separates fine particulates, which contain most of the organic contaminants in the porous fines, from the coarse soil. Soil washing does not destroy the organic material, but produces three products: (1) a wastewater stream, (2) a sludge of contaminated fine particulates, and (3) soil that may contain regulated levels of heavy metals and radionuclides. Soil washing is applicable to soils contaminated with a wide variety of heavy metals, radionuclides, and organic contaminants. Additional treatment steps may be required to address hazardous levels of washing solvent remaining in the treated residuals. The wash solution also would require treatment and proper disposal. Equipment and space requirements for soil washing systems are extensive, and soil-washing operations tend to be complex (DOE 2000).	Removal efficiency of contaminants and fine-grained material from coarse-grained material depends on contaminant solubility in the wash solution, residence time, and affinity for the matrix. The system may not be applicable to waste streams containing both metals and organics. Removing organics adsorbed onto clay-size particles may prove difficult (DOE 2000).	Soil washing is moderately implementable. Waste must be sized before processing; separated contaminants require treatment. Treatability study is required to formulate surfactant. This process generates secondary waste in the form of wastewater.	Capital costs are expected to be high in relation to other ex situ treatments. Additional costs are required for the treatment of separated contaminants and secondary waste streams.	Not retained—limited application for SDA wastes. Not cost effective in relation to other ex situ treatments.
	Acid extraction	Acid extraction uses hydrochloric acid to extract heavy metal contaminants from soils. In this process, soils are first screened to remove coarse solids. Hydrochloric acid is then introduced to the soil in the extraction unit. The residence time in the unit varies depending on the soil type, contaminants, and contaminant concentrations. The soil and extractant are separated with hydrocyclones. When extraction is complete, the solids are rinsed with water to remove entrained acid and metals. The extraction solution and rinse waters are regenerated, and the heavy metals are concentrated in a form potentially suitable for recovery. During the final step, the soils are dewatered and mixed with lime and fertilizer to neutralize any residual acid (FRTR 2001).	Acid extraction is effective at removing metals from soil and sludge (FRTR 2000).	The acid extraction option is implementable. It requires physical separation, which may include screening, density separation, flotation, and magnetic separation as a pretreatment. Acid extraction generates secondary waste in the form of spent chemicals and wastewater.	Costs are expected to be moderate to high in relation to other ex situ treatments. Efficiency of scale is expected (FRTR 2001).	Retained.

Table B-1. (continued).

Remedial Technology	Process Option	Description	Effectiveness	Implementability	Relative Cost	Screening Comments
	Solvent extraction	Organic solvents are used commonly to extract contaminants from soil. Solvent extraction uses a solvent to remove soluble contaminants from the waste (not unlike dry cleaning). Depending on site-specific conditions, the process may function as a stand-alone option or in combination with other options, such as solidification/stabilization, incineration, or soil washing. Removal efficiency is highly variable, depending on the individual contaminant solubility in the solvent, residence time, affinity to the matrix, and moisture content. Organically bound metals can be extracted along with the target organic contaminants, thereby creating residuals with special handling requirements. Traces of solvent may remain within the treated soil matrix, which makes the toxicity of the solvent an important consideration. Secondary waste includes spent solvents (DOE 2000).	Solvent extraction has proven effective in treating soil containing primarily organic contaminants such as PCBs, VOCs, halogenated solvents, and petroleum wastes. This option is difficult to use on waste containing multiple complex contaminants.	The solvent extraction option is moderately implementable. Waste must be sized before processing; separated contaminants require treatment. Treatability study is required to formulate solvent. Process generates less secondary waste than soil washing.	Capital costs are expected to be high in relation to other ex situ treatments. Additional costs are required for the treatment of separated contaminants and secondary waste streams.	Retained.
	Dehalogenation	Dehalogenation involves adding reagents to soils contaminated with halogenated organics and heating the mixture. The dehalogenation process is achieved through either the replacement of the halogen molecules or the decomposition and partial volatilization of the contaminants. This option is potentially applicable if combined with other processes to address inorganic and radionuclide COCs. This relatively mature and simple technology operates at a low temperature with low off-gas and good destruction efficiencies for chlorinated compounds.	Dehalogenation has been successfully field tested in treating PCBs. The process option can be used, but may be less effective against selected halogenated VOCs. Process meets regulatory requirements for treating PCB-contaminated soil, but remaining chlorinated organics may require further treatment. Processes are slow (FRTR 2001). Potential concerns include (1) further treatment of nonchlorinated organics, (2) the amount of pretreatment needed to maximize exposure of the chlorinated compounds, (3) the ability to treat the diversity of wastes (waste pH and moisture content appear to be important), and (4) safety associated with handling sodium and anhydrous ammonia and high system pressure in a radioactive environment (DOE 2000; FRTR 2001).	Dehalogenation is moderately implementable. Treatability tests may be required to determine the operating parameters of the unit. Off-gas treatment is required for VOC and dust. Dehalogenation may require a nitrogen blanket to avoid explosive conditions (DOE 2000; FRTR 2001).	This technology generally is not cost effective for large waste volumes (FRTR 2001).	Not retained—process not cost effective for SDA wastes in relation to other available processes. This is a very specific treatment for limited COCs.
	Hydrolysis	The D-Plus (Sinre/DRAT) process involves the use of chemical inputs to stimulate enzymes and provide a favorable chemical environment (alkaline, reducing, anaerobic) for hydrogenation, dehalogenation, and hydrolysis chemical reactions. The technology, which is a biochemical process, uses heat to break carbon-halogen bonds and volatilize light organic compounds. Other processes utilizing hydrolysis to break down organic chemicals are primarily related to biological treatment (EPA 1994).	Hydrolysis is potentially effective in bioremediation. This option employs water and catalyst to break down organic contaminants. This is not a commercialized process (EPA 1994).	Hydrolysis is moderately implementable for chlorinated organics. Treatability study is required to demonstrate applicability on SDA wastes. This option is not yet available on a commercial scale (EPA 1994).	The relative cost of hydrolysis is unknown	Not retained—process is not fully proven.

Table B-1. (continued).

Remedial Technology	Process Option	Description	Effectiveness	Implementability	Relative Cost	Screening Comments
	Reduction-oxidation manipulation	Re-dox reactions chemically convert hazardous contaminants to nonhazardous or less toxic compounds that are more stable, less mobile, and/or inert. Re-dox reactions involve the transfer of electrons from one compound to another. Specifically, one reactant is oxidized (loses electrons) and one is reduced (gains electrons). Re-dox reactions can be used to detoxify, precipitate, or solubilize metals or organics. Metals and radionuclides are retained in solution and need to be treated. Chemical re-dox is a full-scale, well-established process option. Enhanced systems are now being used more frequently to treat contaminants in soil. This option can be operated with standard process equipment in batch or continuous modes. However, process control is difficult if waste composition varies significantly (DOE 1996).	Chemical oxidation destruction efficiency depends on the organic material treated, the oxidizing agent used, and residence time. The effectiveness of re-dox processes in treating wastes also depends on system design and operating parameters. Solids and immiscible liquids are difficult to treat with some processes.	Re-dox is moderately implementable. Waste stream would require demonstration to determine efficiency. Waste requires pretreatment for size reduction and slurry formation. Wastewater and precipitated sludge would require treatment. Treatability studies would be required for a particular waste stream (DOE 1998).	Costs are not well understood, but may be competitive with incineration.	Not retained—limited application for SDA waste.
	Neutralization	Neutralization is used to adjust basic or acidic waste to an acceptable pH range by adding alkaline waste or chemical reagents to acidic waste or vice versa. This may be needed to reduce reactivity or corrosivity. The process is reliable, readily available, and employs standard process equipment (DOE 1996).	This process option is effective at neutralizing materials at any pH. Corrosivity of waste and reagents may be hazardous.	Neutralization is implementable. Construction materials must be resistant to corrosivity.	Capital costs are expected to be moderate in relation to other ex situ treatments.	Neutralization has been retained for its value as a pretreatment process.
Thermal treatment	**Incineration**	Incineration is widely used to thermally destroy the organic constituents of a waste, both to reduce the volume and to produce more easily handled ash products. High temperatures (760 to 1,200°C) volatilize and combust (in the presence of oxygen) halogenated and other refractory organics in hazardous wastes. Waste constituents that can be efficiently destroyed include organic and combustible substances. Typical process configurations include rotary kilns, multiple hearth incinerators, fluidized bed combusters, and liquid injection incineration.	Incineration is effective for treating organic waste including PCBs, reducting waste volume, and producing ash waste form. Incineration is a well understood process with a long history of application in industry and DOE and DOD operations.	Incineration is technically implementable and accepts all waste forms. Frequent maintenance is required. Secondary waste is generated in the form of ash. Incineration relies on off-gas treatment, and it has low public acceptance.	Costs are expected to be high in relation to other nonthermal ex situ treatments.	Incineration has been retained, but would be difficult to implement at the INEEL due to difficulties with past approvals for incineration at this site.
	Off-gas treatment —catalytic oxidation	Catalytic oxidation equipment is used for destroying contaminants in exhaust gases from many remedial activities. It can also be used for destroying contaminants in exhaust gases from thermal treatment systems. The catalyst accelerates the rate of oxidation at much lower temperatures than those required by conventional thermal oxidation. The VOCs are thermally destroyed at temperatures typically ranging from 320 to 540°C. Catalytic oxidation is a mature technology and an alternative to conventional thermal oxidation for many contaminated gas streams. However, some catalysts are subject to damage by chlorinated hydrocarbons and some heavy metals (e.g., lead) in the gas stream. Most catalytic oxidation systems are subject to degradation from particulate in the gas stream. Destruction of halogenated compounds requires special catalysts, special materials or construction, and the addition of a flue gas scrubber to reduce acid gas emissions.	Despite its relatively newer application in remedial activities, catalytic oxidation is a mature technology, and its status as an implementable technology is well established for selected gas streams.	This option is moderately implementable as a nonincineration technology for the oxidation of off-gas from primary thermal oxidation processes. Technical difficulties include possible short catalyst life due to off-gas contaminants. Applications to treatment of off-gas from solid waste thermal treatment systems are unknown.	Capital costs are expected to be moderate in relation to other ex situ treatments.	Retained.

Table B-1. (continued).

Remedial Technology	Process Option	Description	Effectiveness	Implementability	Relative Cost	Screening Comments
	Pyrolysis	Pyrolysis breaks down organic compounds under high temperature in an oxygen-deficient environment. This system forms inorganics, including heavy metals, into an insoluble solid char residue. A thermal oxidizer is required to combust the produced volatile organics and carbon monoxide. Equipment configurations are similar to those used for incineration (e.g., rotary kiln, rotary hearth furnace, and fluidized bed furnace). In Europe, pyrolysis has been used historically on tires and polymer waste where the pyrolysis gas is used for energy recovery (Uhamburg 2001). Advantages over incineration are primarily lower off-gas volume and less particulate carryover.	Pyrolysis has high destruction efficiency and is a proven technology for some applications. Volume reduction is less than incineration or steam reforming due to char residue. The process is applicable for the separation of organics from most waste forms.	Pyrolysis is implementable, but may not be applicable to waste at the SDA. Secondary waste is generated in the form of char. This option relies on off-gas treatment. Pyrolysis may have a low public acceptance due to its similarity to incineration.	Costs are slightly lower than those of incineration due to lower off-gas volumes.	Not retained—proven applications remain narrowly focused.
	Steam reforming	Steam reforming operates in a reducing environment and uses a super-heated steam to convert organics to a hydrogen-rich synthesis gas and chlorinate compounds to HCl. These gases can be oxidized in a thermal oxidizer or discharged directly to the atmosphere after appropriate cleanup. This option can remove and destroy organic components in a waste stream or reduce organic material to a small volume of ash. Most radionuclides and heavy metals are retained in the ash. Typical steam reforming can take place in many different chamber configurations, including fluidized bed and rotary kiln. Steam reforming also can be used to volatilize organics directly from waste drums to remove and destroy organic components in the waste stream. Steam reforming is a mature process option applicable to a wide variety of waste streams. The requirements for sorting and sizing waste depend on the equipment configuration.	Steam reforming has high destruction efficiency for organic material. Process option is applicable to a wide variety of waste forms. Applicability to radioactively contaminated inert solids requires demonstration (DOE 2000).	Steam reforming is implementable for organic COCs. This option generates secondary waste in the form of ash and bed material, off-gas, and wastewater (DOE 2000). Steam reforming relies on an off-gas treatment system.	Costs are comparable with those of incinerators (DOE 2000).	Retained.
	Supercritical water oxidation	Supercritical water oxidation destroys organic waste with the use of an oxidant in water at temperatures and pressures above the critical point of water (705°F) and 218 atm. Under these conditions, organic materials and gases become highly soluble in water—making rapid, complete oxidation possible using water as a carrier medium. This process is a compact, totally closed system. Waste streams applicable to this process option must be in a liquid or slurry form and include organic low-level radioactive waste or mixed waste. The process runs at low temperatures relative to other thermal treatments with very low off-gas by-products and effluents that are easy to manage. This is a relatively mature process option with a long history of development for specific applications. However, the high pressure and corrosiveness of the system present safety concerns, and the process option may require substantial pretreatment of waste to ensure that the waste is in liquid or slurry form (DOE 2000, 1996).	This option has high destruction efficiency for organic material and is not applicable to inorganics and radionuclides. Issues regarding long-term reliability and safety need to be resolved (DOE 2000).	Supercritical water oxidation is moderately implementable. This option requires waste sorting and slurry formation. Metals precipitate as salts and oxides, which can plug the reactor. Demonstrations are still needed (DOE 2000).	Costs are not well understood, but may be competitive with incineration.	Not retained—limited applicability for SDA waste forms.

Table B-1. (continued).

Remedial Technology	Process Option	Description	Effectiveness	Implementability	Relative Cost	Screening Comments
	Thermal desorption	Thermal desorption is a process that heats waste to volatilize water and organic contaminants. Thermal desorption is used for soil, sludge, and other solid media contaminated with organics. In most thermal desorption processes, contaminated material is fed into dryers. A carrier gas or vacuum system transports volatilized water and organics to a gas treatment system. The dryer temperatures and residence times designed into these systems volatilize selected contaminants, but will typically not oxidize them. Two common thermal desorption systems are the rotary dryer and thermal screw. Rotary dryers are horizontal cylinders that can be indirect- or direct-fired. For the thermal screw units, screw conveyors or hollow augers are used to transport the medium through an enclosed trough. Hot oil or steam circulates through the auger to indirectly heat the medium.	Thermal desorption effectively transfers organic contaminants into the vapor phase where they can be captured and treated. Thermal desorption may pyrolyze nonvolatile organics, depending on the operating temperature. Efficiency depends on temperature, residence time, moisture content, and matrix affinity. This is a well-known, mature technology (DOE 2000).	Thermal desorption is implementable. Most of the hardware components for thermal desorption systems are readily available off the shelf. Significant sorting and sizing of waste are required. Off-gases, condensed liquids, and activated carbon require treatment (DOE 2000).	Thermal desorption may be more expensive than incineration, depending on the treatment requirements of secondary waste.	Retained.
	Vitrification	Vitrification processes employ heat to drive off organic materials and melt the inert materials into a glass or slag. The high temperatures destroy or volatilize the organic constituents with few by-products. These systems are primarily designed to immobilize hazardous or radioactive substances within a nonleachable, long-life, solid, and glass-like form that can meet shipping and storage criteria. Materials such as heavy metals and radionuclides are incorporated into the melt. In addition to solids, the process can be applied to waste liquids, wet or dry sludge, and combustible materials. This process can operate in a reducing or steam-reforming mode. Viable technologies include joule-heated melters, plasma torch systems, and DC arc melters (DOE 2000).	Vitrification high destruction efficiencies and volume reduction. Some systems can treat waste or media without pretreatment. This option produces a stable waste form. Some COCs may be volatilized requiring treatment in an off-gas system. Off-gas volumes are less than those of incineration (DOE 2000).	Vitrification is implementable and is a mature technology. This option generates off-gas and wastewater secondary waste types. Vitrification may require a pilot test of SDA-type waste to determine radionuclide partitioning. Safety and reliability concerns exist regarding water-cooled plasma torch systems (DOE 2000).	Vitrification is competitive with the incinerator option (DOE 2000).	Retained.
	Molten metal system	The system heats waste in a reducing mode to destroy organics and reduce inorganics to metal ingots and slag, which produces a stable waste form. Molten aluminum system can treat most waste forms and materials. Off-gas systems are required and may result in secondary wastewater, which will require treatment. Refractory lining stability must be matched to the waste stream, and refractory life is unknown when treating a heterogeneous mixture of waste.	The molten metal system's ability to destroy organics and retain metals and radionuclides needs demonstration (DOE 2000).	The molten metal system is not implementable. This option requires further study and demonstration on radioactive waste (DOE 2000).	Capital costs are expected to be relatively high. Costs are comparable to costs of incineration (DOE 2000).	Not retained—system is not a proven technology.
	Molten salt system	Organic waste and oxygen are injected into a hot molten salt bath that provides the thermal energy to break down organic material and the medium to enable intimate contact between oxygen and organic fragments. The process is used for combustible liquids, slurries, and solid particles. Spent salt is an example of secondary waste. A salt recovery system is normally employed. Waste must be sorted and sized to less than 0.32 cm in diameter. The technology is relatively mature, but its long-term reliability and ability to destroy organics and retain metals and radionuclides must be demonstrated (DOE 2000).	The molten salt system's ability to destroy organics and retain metals and radionuclides needs demonstration (DOE 2000).	This option is moderately implementable. Refractory corrosion and failure are issues. Salt viscosity may lead to freezing and requires monitoring. In addition, this option requires sizing of waste to <0.32 cm (DOE 2000).	Capital costs are expected to be relatively high. Costs are comparable to costs of incineration, but salt recovery to reduce secondary waste will increase cost (DOE 2000).	Not retained—effectiveness has not been proven.

Table B-1. (continued).

Remedial Technology	Process Option	Description	Effectiveness	Implementability	Relative Cost	Screening Comments
Electrokinetic treatment	**Mediated electrochemical oxidation**	Electrokinetic treatment is an aqueous, low-temperature (<80°C) process that treats mixed waste by electrochemically oxidizing the organic components of mixed waste into carbon dioxide and water. The inorganic components of the waste go on to the final forms system, where they are immobilized. This option appears suited for destroying aqueous organic liquids, organic liquids, and some organic solids that can be pulped or slurried. Metals may be dissolved in the analyte solution. This requires two secondary systems—acid recovery and silver recovery—both of which are important for economic operation. It is not clear whether recovery and reuse are possible or economically viable with radionuclide contaminants. Off-gas system is required (DOE 2000; FRTR 2001).	Mediated electrochemical oxidation's effectiveness has not been fully proven, and its ability to treat PCBs is uncertain.	Mediated electrochemical oxidation has not been fully demonstrated. This option requires significant pretreatment. Corrosion and erosion are concerns (DOE 2000).	It is unclear whether this process can be economically viable. The use of the system remains to be demonstrated in the presence of radionuclides (DOE 2000).	Not retained—not fully proven.
Biological treatment	**Aerobic degradation**	Bacteria indigenous to the soil or specifically cultured bacteria are used to biologically degrade organic contaminants. Aerobic degradation, performed by microorganisms that require oxygen for growth, is commonly used to degrade toxic organic petroleum contaminants to nontoxic by-products, thereby reducing the waste volume requiring disposal. Aerobic process residues are usually CO, CO_2, H_2O, salts, and biomass sludge (dead cell material). Because contaminants must be available to the microorganisms, contaminants that are not water-soluble are more difficult to treat. Though chlorinated organics are difficult to treat, some bacteria do degrade chlorinated organics in the course of metabolizing other more easily degraded compounds. Several processes for ex situ aerobic degradation exist, such as the use of a containment cell, land farming, and bioreactors/composting. Aerobic degradation is a well-developed, highly effective method to treat organic contaminants[c] (EPA 1994).	Efficiency is dependent on the contaminant as nutrient for microbial population, oxygen concentration, temperature, and pH (EPA 1994).	Aerobic degradation is marginally implementable. Microbe populations are easily upset by contaminant/nutrient balance, oxygen concentration, temperature, and pH. Waste must be sized. Biomass, wastewater, and off-gases require treatment. Large system is needed due to slow process time (EPA 1994).	Aerobic degradation may be more expensive than incineration due to frequent shutdown and maintenance issues and additional treatment requirements (EPA 1994).	Not retained—limited applicability for SDA waste contaminants.
	Anaerobic degradation	Bacteria indigenous to the soil or specially cultured bacteria are used to biologically degrade organic contaminants. Anaerobic degradation is carried out in the absence of oxygen and yields methane, carbon dioxide, and biomass. Since the contaminants must be available to the microorganisms, contaminants that are not water-soluble (e.g., solids and immiscible organics) are more difficult to treat. Chlorinated organics are difficult to treat because their degradation is not a significant source of energy for the bacteria. Several options for ex situ anaerobic degradation exist, including the use of a containment cell, bioreactors, and others[c] (EPA 1994).	Efficiency is dependent on contaminant as nutrient for microbial population, oxygen concentration, temperature, and pH (EPA 1994).	Process times are slower than aerobic degradation due to generally lower microbial metabolism (EPA 1994).	Anaerobic degradation may be more expensive than incineration due to frequent shutdown and maintenance issues and additional treatment requirements (EPA 1994).	Not retained—limited applicability for SDA waste contaminants.

c. DOE-RL, 1996, "Corrective Measures Study for the 100-NR-1 and 100-NR-2 Operable Units, Richland, Washington (Draft)," DOE/RL-95-111, Rev. A, U.S. Department of Energy, Richland, Washington, November 1996

Table B-1. (continued).

Remedial Technology	Process Option	Description	Effectiveness	Implementability	Relative Cost	Screening Comments
Storage and Disposal						
Onsite storage and disposal	**Temporary onsite storage**	A containment structure must be created for onsite staging and storage of waste that has been retrieved from the SDA before the waste can be transported to either an off-Site or on-Site disposal or ex situ treatment facility. Design would be in accordance with state and federal requirements for temporary storage facilities and would be sized as required to meet processing requirements.	Structure would be designed to effectively contain waste and COCs during staging between retrieval and treatment or disposal. Secondary containment of the stored waste would be required.	Temporary onsite storage is implementable.	Costs are expected to be low in relation to other process options within this GRA (with consideration to the temporary nature of this option).	Retained.
	RWMC (SDA)	The RWMC is located in WAG 7 at the INEEL site and can accept some low-level contaminated soil. However, RCRA-regulated hazardous materials cannot be disposed of permanently at the RWMC, and waste acceptance criteria are strict (DOE-ID 2002).	This option is effective for a very narrowly focused portion of the waste in the SDA.	This option is implementable. Additional capacity is not available to receive retrieved SDA waste. Any disposal would require screening for very specific acceptance criteria (DOE-ID 2002).	Costs are expected to be low in relation to other disposal options.	Not retained – operational and capacity constraints.
	ICDF	The ICDF will be located in WAG 3 at the INEEL site, and the facility will open and begin accepting shipments of low-level radioactive waste in 2003. Roadways would be used for transportation.	The ICDF is effective for long-term disposal. Facility is designed with triple liner and other features for low-level radioactive waste and mixed low-level waste.	This option is potentially implementable for limited volume of low-level radioactive waste and mixed waste, depending on available capacity for non-WAG 3 waste. The MLLW must be treated to meet the waste acceptance criteria.	Costs for disposal are expected to be low in relation to offsite disposal options.	Retained
	CFA landfill	The CFA landfill, located in WAG 4 at the INEEL site, accepts nonhazardous industrial waste from INEEL sites. Roadways would be used for transportation.	The CFA landfill is effective for nonhazardous, nonradioactive industrial waste.	The CFA landfill is not implementable for LLW or MLLW streams from the SDA. However, the CFA landfill is potentially implementable for the nonhazardous portion of retrieved waste if it is segregated out.	Costs for this waste stream are expected to be low to moderate in relation to other disposal options.	Not retained
	Engineered onsite facility	An engineered facility would be constructed within the SDA for the disposal of LLW and treated MLLW. The facility would be designed in accordance with RCRA Subtitle C lined landfill requirements with leachate collection/treatment and landfill gas collection/treatment systems.	An engineered onsite facility is effective for the disposal of LLW and treated MLLW. The approved WAG 3 ICDF design has been identified for this process option. The facility would not be effective for the disposal of TRU waste.	This option is potentially implementable and would entail standard construction with available materials. Lead time would be required for development of waste acceptance criteria, design approval, and construction.	Costs are projected to be lower than disposal at offsite facilities.	Retained.
disposal	**Nevada test site**	This facility, located in southwestern Nevada, accepts low-level radioactive industrial waste and mixed low-level radioactive waste. Roadways would be used for transportation.	The Nevada test site is an effective option.	Implementability depends on the approval of INEEL waste characterization procedures.	Costs for this waste stream are expected to be high in relation to other disposal options.	Retained.

Table B-1. (continued).

Remedial Technology	Process Option	Description	Effectiveness	Implementability	Relative Cost	Screening Comments
	WIPP	This facility—located in Carlsbad, New Mexico—accepts defense-related, contact-handled TRU waste only. Remote-handled TRU waste is expected to be accepted in the near future following approval of a proposed RCRA permit modification. Mixed TRU waste is acceptable under specific waste codes.	The WIPP is an effective option.	This option is implementable. The TSA waste is currently being transported to the WIPP. Acceptance of SDA waste depends on the approval of INEEL waste characterization procedures.	Costs for the TRU waste stream are expected to be high.	Retained.
	Barnwell Waste Management Facility	This facility—located in Barnwell, South Carolina—accepts low-level radioactive waste. Waste is contained in concrete vaults and then buried. Roadways would be used for transportation.	The Barnwell Waste Management Facility would be moderately effective due to concrete vault containment prior to direct burial.	Implementability depends on the approval of INEEL waste characterization procedures.	Costs are expected to be high in relation to other disposal options.	Retained.
	Environmental Restoration Disposal Facility	This facility—located in Richland, Washington—accepts low-level radioactive waste, but currently does not accept mixed waste. Roadways would be used for transportation.	The Environmental Restoration Disposal Facility would be effective for disposal of low-level radioactive waste.	This option is implementable for low-level radioactive waste if material is treated and/or segregated before shipment. The Environmental Restoration Disposal Facility is not currently approved for mixed waste. Implementability depends on the approval of INEEL waste characterization procedures.	Costs are expected to be high in relation to other disposal options.	Retained.
	Envirocare	This facility—located in Clive, Utah—accepts low-level radioactive waste, mixed low-level radioactive waste, and radioactive PCB waste. Treatment options available at the site include stabilization, reduction/oxidation, deactivation, neutralization, and macroencapsulation and microencapsulation.	Envirocare would be highly effective due to its ability to treat incoming waste at the disposal site.	Implementability depends on approval of INEEL waste characterization procedures.	Costs are expected to be high in relation to other disposal options.	Retained.
	WCS	This facility—located in Andrews County, Texas—is a treatment, storage, and disposal facility that will be permitted for low-level radioactive, RCRA, and TSCA mixed waste treatment and disposal. Radioactive concentrations in excess of Class C and TRU limits can be accepted for treatment. The low-level waste permit is pending. Disposal units are RCRA compliant with independent liner and leachate collection systems. Cells are enclosed in a natural clay barrier. The WCS is accessible by rail from the INEEL.	The WCS would be highly effective due to its ability to treat incoming waste at the disposal site and the wide range of waste accepted.	Implementability depends on the approval of INEEL waste characterization procedures.	Costs are expected to be high in relation to other disposal options.	Retained.
	U.S. Ecology	This facility—located in Richland, Washington—accepts low-level radioactive waste and uses direct burial disposal. Roadways would be used for transportation.	The U.S. Ecology option has a low effectiveness due to their direct-burial disposal practices.	Implementability depends on the approval of INEEL waste characterization procedures.	Costs are expected to be high in relation to other disposal options.	Retained.
	Yucca Mountain	This facility—located in Nye County, Nevada—is currently under construction as a permanent repository for high-level waste.	Yucca Mountain would be potentially effective.	Yucca Mountain is not currently available for disposal. It is still under construction.	Costs are expected to be high in relation to other disposal options.	Retained.

Table B-1. (continued).

Remedial Technology	Process Option	Description	Effectiveness	Implementability	Relative Cost	Screening Comments

CFA = Central Facilities Area
COC = contaminant of concern
DC = dual component
DNAPL = deuse nonaqueous phase liquid
DOD = U.S. Department of Defense
DOE = U.S. Department of Energy
DOE-ID = U.S. Department of Energy Idaho Operations Office
DUS = dynamic underground shipping
EM = Environmental Management
GRA = general response action
HEPA = high-efficiency particulate air
HLW = high-level waste
HRE – Homogeneous Reactor Experiments (Oak Ridge)
ICDF = INEEL CERCLA Disposal Facility
INEEL = Idaho National Engineering and Environmental Laboratory
ISG = in situ grouting
ISTD = in situ thermal desorption
ISV = in situ vitrification
LLW = low-level waste
MLLW = mixed low-level waste
O&M = operations and maintenance
ORNL = Oak Ridge National Laboratory
PCB = polychlorinated biphenyl
RAO = remedial action objective
RCRA = Resource Conservation and Recovery Act
Re-dox = reduction-oxidation manipulation
RFH = radio frequency heating
RWMC = Radioactive Waste Management Complex
SDA = Subsurface Disposal Area
SL-1 = Stationary Low-Power Reactor No. 1
SNL = Sandia National Laboratory
SVE = soil vapor extraction
SVOC = semivolatile organic compound
TRU = transuranic
TSA = Transuranic Storage Area
TSCA = Toxic Substances Control Act
VOC = volatile organic compound
WAG = waste area group
WCS = Waste Control Specialists
WIPP = Waste Isolation Pilot Plant

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