STUDENT SUMMER INTERNSHIP TECHNICAL REPORT

Low Level and Mixed Low Level Waste Treatment Technology and Orphan Waste Stream Identification

DOE-FIU SCIENCE & TECHNOLOGY WORKFORCE DEVELOPMENT PROGRAM

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ABSTRACT

During the summer of 2013, DOE Fellow Gabriela Vazquez was given the opportunity to intern with the Office of Environmental Management (EM) at Department of Energy (DOE) Headquarters in Germantown, Maryland. During this time, Mrs. Vazquez assisted Ms. Christine Gelles, Associate Deputy Assistant Secretary of the Office of Waste Management EM-30 and Mr. Douglas Tonkay, Director of the Office of Disposal Operations EM-31. EM-30 supports EM's mission by planning and optimizing tank waste processing and nuclear materials, developing policy and guidance and providing technical advice on the tank waste system and nuclear materials, and by providing leadership to planning and executing EM programs for the storage, retrieval, pretreatment, treatment, and final preparation of these materials for disposal and tank closure planning.

The DOE Environmental Management Office of Waste Management is dedicated to safely disposing of waste and seeks cost effective and environmentally responsible project execution methods.

This report is an update of a research task that summarizes the current treatment technologies available from private sector vendors to treat low level waste (LLW) and mixed low level waste (MLLW). The report was written for the Department of Energy Office of Environmental Management (DOE-EM) with the objective of identifying and expanding on treatment technologies used in the past or currently available within the U.S. that might be useful to other nations to treat their orphan wastes. Additionally, this research identifies which U.S. orphan waste streams either do not have a technology available for treatment or whose treatment pathway is not cost effective; this identification can lead to international collaboration to develop a treatment process pathway for disposal for these orphan waste streams as well as international orphan waste streams. Comprehensive research was undertaken to identify companies with treatment capabilities. The Office of Disposal Operations EM-31 will use the obtained information to collaborate with the U.K and other international partners to explore new treatment technology options for orphan waste streams.

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1. INTRODUCTION

Private sector capacity for treatment of various categories of radioactive waste has been researched and reviewed for the Department of Energy (DOE) Environmental Management Office of Waste Management. The purpose of this project is to develop concise information describing current and historical United States (U.S.) commercial and federal mixed low-level waste (MLLW) treatment capabilities and potential treatment technology needs for DOE waste streams. As the primary objective, this information will be shared with other countries to support exchanges on M/LLW treatment capabilities, with a particular focus on technologies to address orphan (challenging) waste streams that lack a disposition path. The information will also serve other DOE initiatives, such as increasing DOE generator awareness of available technologies and informing DOE participation in federal working groups on disposition of contaminated materials from potential radiological dispersal device events.

The survey of private sector vendors was limited to vendors currently capable of performing low-level waste (LLW) volume reduction and/or mixed LLW treatment.

2. EXECUTIVE SUMMARY

This research work has been supported by the DOE-FIU Science & Technology Workforce Initiative, an innovative program developed by the U.S. Department of Energy's Environmental Management (DOE-EM) and Florida International University's Applied Research Center (FIU-ARC). During the summer of 2013, a DOE Fellow intern, Ms. Gabriela Vazquez, spent 10 weeks doing a summer internship at Department of Energy (DOE) Headquarters in Germantown, Maryland under the supervision and guidance of Ms. Christine Gelles, Associate Deputy Assistant Secretary of the Office of Waste Management EM-30 and Mr. Douglas Tonkay, Director of the Office of Disposal Operations EM-31. The intern's project was initiated in June 3, 2013, and continued through August 10, 2013 with the objective of identifying and expanding on treatment technologies used in the past or currently available within the U.S. that might be useful to other nations to treat their orphan wastes as well as those of the U.S.

3. RESEARCH DESCRIPTION

The deliverable for this research was to develop a U.S. M/LLW technology treatment matrix correlating U.S. waste streams to available technologies, and supporting summary descriptions of each treatment technology. Information sources included: Waste Management Information Management System (WIMS) (http://www.emwims.org/), site treatment plans, commercial treatment facility waste acceptance criteria, licensing documentation, other related on-line information, DOE treatment contracts, and interviews of commercial and DOE site points of contact.

The current treatment and disposal facilities that accept DOE waste were listed on the Waste Management Information Management System (WIMS). From a list of 32 sites, 9 facilities had treatment capabilities on site: Permafix with 4 facilities, EnergySolutions with 2 facilities, Studsvik, Philotechnics, and Waste Control Specialists. Treatment capability information was gathered from each company's respective website. A report was then sent to each vendor point of contact and they were asked to review the capability description and to identify which waste streams they are able to treat, they could make any necessary revisions, and return the information as soon as possible.

The information was then compiled into a variety of matrices included in this report. The level of accuracy in identifying the treatment capabilities for the different waste streams may vary due to the broad waste categories and the level of interpretation of the definitions provided. Further detail was not collected from the vendors; therefore, the details on each technology was collected from online searches.

The report entitled "Review of Private Sector and Department of Energy Treatment, Storage, and Disposal Capabilities for Low-Level and Mixed Low-Level Waste" and distributed in 1996 listed and summarized the 1996 private sector vendor capabilities for the treatment, storage, and disposal of low-level and mixed low-level waste. To gather information on past technologies available, each company was researched to determine if they continue to be in service today and what treatments might have been available previously or available currently that might be of use to other nation's waste streams.

4. RESULTS AND ANALYSIS

SECTION I: Past Private Sector Vendors and Where They are Today

The report entitled “Review of Private Sector and Department of Energy Treatment, Storage, and Disposal Capabilities for Low-Level and Mixed Low-Level Waste” and distributed in 1996 listed and summarized the 1996 private sector vendor capabilities for the treatment, storage, and disposal of low-level and mixed low-level waste. The table below shows the information currently available regarding each of those private sector vendors. If they are marked with a “-“, no information regarding the company is currently available or the company no longer exists. Those highlighted in yellow accept waste from DOE sites according to the Waste Information Management System (WIMS) and have LLW or MLLW treatment capabilities. Further investigation was done to gather detail on those capabilities that are further described in the report. Those highlighted in green may have some sort of treatment capability available but LLW or MLLW is not sent there from DOE sites. The notes in red identify the companies that have been restructured under a parent company.

Table 1. Summary of Past Private Sector Vendors and Where They are Today

Vendor	Current Website	Notes about Services and Past Technologies
ADCO Services, Inc	www.adcoservices.com	Radioactive waste disposal and hazardous waste disposal has been ADCO Services' line of business since 1965. One of the United States' oldest waste brokerage companies for radioactive and hazardous wastes such as: self luminous exit signs, radioactive and /or hazardous sludge, radioactive animal carcasses / biological, scintillation vial / fluids, radioactive sources, smoke detectors, dry active waste, mixed waste, and hazardous waste disposal for industrial settings, places of research, and medical fields. Additionally, ADCO Services developed specialized services in NRC manifesting / paperwork preparation, preparation of hazardous waste manifests (hazmats), decontamination and decommissioning, emergency response assignments, health physics services, training programs, and sealed source (gauge and device) disassemblies, removals, and disposals, as well as proper handling and treatment of naturally occurring radioactive items such as Thorium, Uranium (Uranyl compounds), and Radium. ADCO will accept low-level radioactive waste in any type of U.S.D.O.T. approved package from cardboard boxes, ("excepted packages"), up to and including Sea Land containers. This includes fiber drums of any size, pails, metal drums ranging from 10-110 gallon, Super Sacks, even polybags, (with advance notification).
ADTECHS Corporation	-	-
Advanced Recovery Systems, Inc	-	-
Afftrex, Ltd	-	-
ALARON Corporation	http://www.veoliaes.com/en/services/enterprise/management/nuclear-services.html	Veolia's portfolio of services provided to the nuclear industry includes: • Asset Recovery : Decontamination services to allow for the reuse of assets • Coatings & Painting : Nuclear Service Level 1 surface preparation and coating services • Low-Level Radioactive Waste: Dry active waste processing • Licensed Facility Access : Work under Veolia's Radioactive Materials License • Machine Shop : Nuclear licensed machining equipment • Metals & Large Components : Process and decontaminate over-sized contaminated components • Motor & Pump Refurbishment : Repair and refurbishment services for small and large motors • Source Recovery : Sealed source recovery and recycling for radioactive applications • Contaminated Asset Storage : Interior and exterior monitored and inspected storage • Transportation : Transportation services for radioactive materials, including truck and rail access • Lead Blankets : A case study on the decontamination and recycling of lead blankets

Vendor	Current Website	Notes about Services and Past Technologies
Allied Technology Group	http://www.ettpreuse.com/allied.html	Operates a radioactive materials processing facility at ETTP's Heritage Center. Trained technicians segregate and process radioactive waste at the facility before it is transferred to other processing facilities or sent for final disposal. ATG operates radioactive and mixed waste management and nuclear service operations for commercial and government clients nationwide. ATG has operating facilities in three other states. https://www.dndkm.org/DOEKMDocuments/ITSR/TRUMixedWaste/Demonstration%20of%20ATG%20Process%20for%20Stabilizing%20Mercury%20%28260%20ppm%29%20Contaminated%20Mixed%20Waste.pdf Demonstration of ATG Process for Stabilizing Mercury (<260 ppm) Contaminated Mixed Waste, September 1999 http://www.wmsym.org/archives/1997/sess29/29-22.htm Pilot of Testing of a Vitrification System for Low Level Radioactive Wastes, 1997
American Ecology Corporation	http://www.americanecology.com/	**Now U.S. Ecology, Inc** Treatment and disposal of hazardous and radioactive waste is U.S. Ecology’s specialty. We also provide onsite packaging and waste transport. U.S. Ecology's six disposal facilities are fully permitted to treat and dispose a wide range of hazardous and radioactive wastes. *Service offered:* • Hazardous Waste Treatment & Disposal • Low-Activity Radioactive Waste Disposal • Low-Level Radioactive Waste Disposal • Hydrocarbon Recycling Services • PCB Waste Services • Transportation • On-Site Services • Total Waste Solutions Program • Lab Support • Beneficial Re-use • Waste Water Treatment
Applied Health Physics, Inc.	http://appliedhealthphysics.com	Applied Health Physics, Inc. has been providing quality radiological safety and consulting services to industry, learning institutions and government agencies for over forty years.

Vendor	Current Website	Notes about Services and Past Technologies
Babcock and Wilcox Nuclear Environmental Services, Inc.	http://babcock.com/	Provides design, engineering, manufacturing, construction and facilities management services to nuclear, renewable, fossil power, industrial and government.
Bartlett Nuclear, Inc.	http://www.bartlettnuclear.com/	Established in 1979, Bartlett Nuclear, Inc. (BNI) has become the largest supplier of radiation safety and protection personnel to the U.S. commercial nuclear power industry. Our experience providing technical and professional services includes all 104 U.S. operating nuclear power stations and all 15 U.S. nuclear power stations that have been permanently shut down or are currently in the decommissioning process.
British Nuclear Fuels Limited, Inc.	-	-
Brown & Root Environmental	-	-
Chem-Nuclear Systems, Inc.	http://www.chemnuclear.com/	Chem-Nuclear Systems, L.L.C., a wholly-owned subsidiary of GTS Duratek, Inc., operates a commercial low-level radioactive waste disposal facility located on 235 acres in Barnwell County, South Carolina. **NOTE: GTS Duratek is now Energy Solutions - TN**
Clean Harbors	http://www.cleanharbors.com/	Clean Harbors Hazardous Waste Disposal & Recycling Services provide the widest range of recycling, treatment and disposal options for all your hazardous waste streams. Unmatched in North America, our infrastructure of hazardous waste management facilities services all of the U.S., and Canada, northern Mexico and Puerto Rico. We handle both drum and bulk hazardous waste in liquid, solid, semi-solid, sludge and gas forms. Clean Harbors employs the most advanced technologies to recycle, treat or dispose of hazardous waste materials including: • recycling • fuel blending • wastewater treatment • incineration • landfill disposal • explosives management
COGNIS, Inc.	-	http://aec.army.mil/usaec/cleanup/lcaap40.pdf In 1996, COGNIS, Inc. (COGNIS) conducted a treatability study to evaluate soil washing with acid leaching as a potential remediation technology for the firing range sand, which was being considered as an alternative to land disposal. The feed material for this study consisted of a 5-gallon bucket of sand fromthe 600-Yard Bullet Catcher, which was similar in origin and contained the same types of contaminants as the Area 10 sand piles. The results of this study are presented in the Treatability Study Report: Soil Washing/ Terramet® Leaching for Depleted Uranium/Lead Soil Mixed Waste Remediation (COGNIS, 1996).

Vendor	Current Website	Notes about Services and Past Technologies
Diversified Technologies Services, Inc.	http://www.dts9000.com/	DTS provides innovative, cost-effective and volume-saving solutions to help you manage liquid radioactive and hazardous wastes. Some of our processing include technologies, such as, ion exchange, filtration, ultrafiltration, reverse osmosis, dewatering, drying and polymer solidification. DTS capabilities include product development; system engineering, fabrication and operation; and project management. • Liquid Processing • Solidification and Encapsulation • Solids Handling • Consumables
Duke Engineering and Service, Inc.	-	-
Eastern Technologies, Inc.	-	-
Ecology and Environment, Inc.	http://www.ecologyservices.com/esi/	Ecology Services Inc. is an industry leader in radioactive and mixed waste management and disposal. Key resources included: • Certified Health Physicists and highly trained waste technicians and drivers • Licensed facility in Columbia, MD and soon to be licensed consolidation facility in Baltimore, MD • Company owned trucks and licenses/permits to handle any waste disposal project • Contracts and relationships with the top waste processors and disposal sites in the country Services included: • Waste characterization/identification and waste management programs • Packaging, labeling and manifesting • Loading and transportation including scheduled “milkrun” pickups, or if requested, dedicated truck pickups • Decay in storage • Sampling and analysis of radioactive and mixed wastes Ecology Services can take care of any radiological waste streams, including: • Dry solid waste (DAW) • Scintillation vials and liquids • Mixed waste solids and liquids • Aqueous liquids • Contaminated equipment/metals • NORM/NARM wastes • Animal carcasses and other biological wastes • Sealed sources • Nuclear gauges, exit signs, and smoke detectors

Vendor	Current Website	Notes about Services and Past Technologies
		• Thorium and uranium compounds • Ion exchange media
ElChroM Industries, Inc.	-	-
Energy Solutions	http://www.energysolutions.com/	EnergySolutions, headquartered in Salt Lake City, Utah, is one of the world's largest processors of low level waste, and is the largest nuclear waste company in the United States.
Envirocare of Utah, Inc.	-	**Now Energy Solutions**
Environmental Alternatives, Inc.	http://eairolloff.com/	Environmental Alternatives, Inc. specializes in roll-off services for the collection, processing, and disposal of construction and demolition (C&D) debris in the Maryland, Washington D.C., and Northern Virginia Area. Our goal is to redefine solutions to meet our customers waste management, lead recycling, and roll-off service needs.
Fluid Tech, Inc.	http://www.marinesystems-usa.com/	The Fluid Tech (FT) products are solidification/stabilization agents, developed for the efficient and economical disposal of radioactive, hazardous chemical, and mixed wastes. They are slightly alkaline, non-flammable, non-reactive and non-corrosive, and are not biodegradable. These reagents immobilize wastes (liquid, sludge, or solid) through the action of complex bonding mechanisms and ion exchange reactions. The end result is an homogenous waste solid with excellent leach resistance. They are Aquaset, Aquaset II, Aquaset II-H, Aquaset II-G, Aquaset II-GH, Petroset, Petroset-H, Petroset II, Petroset II-G.
Framatome Technologies, Inc.	-	-
Frank W. Hake Associates	-	-
Gencorp Aerojet	http://www.envirogen.com/welcome/home/	Envirogen Technologies is an environmental technology and process solutions provider that combines experience in water and vapor phase treatment with process development expertise, delivering long-term, guaranteed solutions in a broad range of treatment and process-related applications.Provide system design, process engineering, equipment and operating solutions for the treatment of groundwater, wastewater, VOC treatment & odor abatement as well as materials recovery for a range of industrial and non-industrial customers throughout North America. A fundamental part of Envirogen's offering to the marketplace is its broad, but targeted technology portfolio. This includes a strong position in high efficiency ion exchange and the use of a variety of adsorptive media that are adaptable to different types of organic and inorganic contaminants and process requirements. We also have a strong biological treatment platform with both modular and built-in-place systems for highly cost-effective treatment in a range of applications, including odor control, nutrient removal, water re-use, wastewater and groundwater. Other contaminant removal and destruction technologies include coagulation filtration, chemical purification and advanced oxidation. Envirogen's offerings are often modular in design for ease of installation and rapid start-up.

Vendor	Current Website	Notes about Services and Past Technologies
		Technology categories: • Ion Exchange • Bioreactors • Air Treatment • Biofilters • Regenration • Mobile Treatment Chemical Purification
GTS Duratek	-	**Now EnergySolutions**
Hazen Research, Inc.	http://www.hazenusa.com/	Hazen Research, Inc. is an employee-owned firm performing industrial research and development for clients in the mineral, chemical, energy, and environmental fields. Recent waste treatment and recycling activities include: • waste vitrification in a rotary kiln • thermal desorption of volatile metals and volatile and semivolatile organic compounds • pyrolysis of automobile shredder residue • smelting of spent automobile catalyst • recovery of tin from bronze scrap • thermal oxidation of spent catalyst • pyrolysis of nylon-6 to recover its monomer • injection smelting of electronic scrap
IDM Environmental Corporation	-	-
INET Corporation	-	-
International Technology Corporation	http://www.internationaltechcorp.net/	International Tech Corp. (ITC) is changing the way the world generates energy by using biomass, a renewable energy source. Our unique technology converts biomass or waste into energy from a wide range of fuels producing steam, syngas and valuable carbon products. The steam and syngas are clean energy products that can be released as heat or used as electricity with a carbon neutral footprint. The carbon products or biochar can be used as a soil amendment that rebuilds soil fertility, conserves water and sequesters CO2 long term. Our technology not only produces clean reliable energy, reduces carbon emissions, and saves companies money; it can also be a final step in eliminating waste.
Interstate Nuclear Services Corporation	-	-
Manufacturing Sciences Corporation	http://www.mfgsci.com/	**Now a part of Energy Solutions**
Maxim Technologies, Inc.	-	-

Vendor	Current Website	Notes about Services and Past Technologies
M.J.W. Corporation, Inc.	http://www.mjwcorp.com/	MJW Corporation, Inc. has established itself as one of the nation's leading specialists in radiation, health physics, and emergency management services. Since 1984, the firm has helped their clients to comply with government regulations, protecte both people and the environment from the threat of radiation exposure, provide expert management services for radiation protection programs across several disciplines. MJW can provide experienced Health Physicists to evaluate, quantify and properly protect workers and the general public from all forms of ionizing radiation, and exposure thereto. Nationally and internationally recognized experts in internal dosimetry. Radiological Services include: Dose Assessment, Radiological Engineering, Environmental Health & Safety, Licensing & Regulatory Support, Data Validation & Laboratory Assessment
Non-Destructive Cleaning, Inc.	-	-
Nuclear Fuel Services, Inc.	http://www.nuclearfuelservices.com/	Nuclear Fuel Services, Inc (NFS) is both a strategic asset for America and an economic engine for Northeast Tennessee. With more than 1,000 full-time employees and contract workers, the Erwin, Tennessee operation is committed to manufacturing specialty nuclear materials for the U.S. Navy's nuclear fleet and other customers while protecting its workers, the public and the environment.
Nuclear Metals, Inc.	http://www.nmisite.org/	The Nuclear Metals, Inc. (NMI) Site, also known as the Starmet Corporation Site, is located on a 46.4-acre parcel located at 2229 Main Street in Concord, Middlesex County, Massachusetts. From 1958 to the present, the Site has been used by various operators at various times as a specialized research and metal manufacturing facility, which was licensed to possess and process low-level radioactive substances. At various times, site operators used depleted uranium, beryllium, titanium, zirconium, copper, acids, solvents, and other substances at the Site. From 1958 to 1985, site operators disposed of manufacturing by-products, including waste solutions containing depleted uranium mixed with copper, spent acid, and lime, into an unlined holding basin located on-site. Other areas of the Site, including but not limited to a bog, a cooling water recharge pond, septic leaching fields, a sweepings pile, and a small landfill, are also believed to have been used for the disposal of manufacturing wastes. From approximately the late 1980s to 2000, the current site owner/operator, Starmet Corporation (Starmet), performed certain site investigations and a partial cleanup of the Site under the oversight of the Massachusetts Department of Environmental Protection (MADEP). In 1997, Starmet, with the financial support of the United States Army, excavated approximately 8,000 cubic yards of contaminated soils from the on-site holding basin and disposed of these soils at an off-site disposal facility licensed to accept low-level radioactive wastes.

Vendor	Current Website	Notes about Services and Past Technologies
		During previous investigations starting in the 1980s through the present, by others, soils and groundwater beneath the Site were found to contain elevated levels of depleted uranium and elevated levels of beryllium. Past sampling of sediments at the Site has revealed elevated levels of depleted uranium, copper, and volatile organic compounds.
Nuclear Sources & Services, Inc.	http://www.nssihouston.com/	**RADIOACTIVE WASTE TREATMENT** NSSI has collected, compacted, treated, and shipped radioactive waste to offsite facilities for disposal since 1971. NSSI is permitted for a full spectrum of radionuclide including special nuclear material (SNM). Radioactive waste is received, treated, repackaged and shipped for land disposal or incineration at offsite facilities. As needed, NSSI can provide personnel and equipment to aid in the packaging and transport of radioactive waste materials at customer sites. For sealed radioactive sources, NSSI can provide the design and fabrication of specialized containers for land disposal and accepts sealed sources for consolidation and packaging for land disposal. **HAZARDOUS WASTE TREATMENT** NSSI accepts a full spectrum of hazardous and radioactive waste materials for on-site treatment and off-site final disposal. NSSI treats solids, liquids, and gases bearing EPA hazardous waste codes as well as non hazardous. NSSI accepts many specialized chemical wastes such as Mercury and freons for recycling and reuse. NSSI can provide full hazardous waste services including on-site lab packing and labeling, transport, treatment, and final disposal. **MIXED WASTE TREATMENT** Wastes containing both radioactive and hazardous constituents are referred to as mixed wastes. NSSI is permitted for the acceptance of mixed wastes. Mixed wastes are treated at the NSSI facility to separate the radionuclide from the hazardous component or to treat the hazardous component so that the waste no longer is hazardous. Such separation or destruction, in most cases, will allow the individual components to be disposed as radioactive waste or hazardous wastes at offsite facilities permitted for final disposal. **COMPRESSED GAS TREATMENT** NSSI has specialized in the treatment of hazardous compressed gases. NSSI uses a variety of chemical processes to react the gases to form non-hazardous treatment residues. NSSI accepts a full spectrum of compressed gases including those with radioactive constituents. **WASTE TREATABILITY STUDIES** NSSI's permits to accept and treat radioactive, mixed, and hazardous waste materials allow NSSI to provide waste treatability studies to determine the chemical and mechanical treatments necessary to convert a waste to a form suitable for final disposal. On-site permitted units allow treatability studies for any waste volume. **TREATMENT OF URANIUM AND THORIUM COMPOUNDS**, **SEALED SOURCE DISPOSAL**, **BLENDABLE ORGANIC WASTE**, **PERMITTED TREATMENTS**

Vendor	Current Website	Notes about Services and Past Technologies
		• Operation of Mercury Retort Unit. • Recovery of waste chemicals and other material for reuse or resale. • Blending of wastes to form a fuel for use off site • Recycling of solvents.Breaking down of lab packs for reconsolidation for off-site disposal or on-site processing. • Consolidation of waste containers into lab packs. • Neutralization, oxidation, reduction, and other chemical reactions or physical processing (e.g. distillation) to render wastes less hazardous or more suitable for off-site disposal or on-site processing in an authorized tank or container storage area • Cleaning of cullet or particulate solids, empty drums, and equipment. • Centrifugation, filtration, and ion exchange in portable equipment in an authorized storage area. • Solidification or stabilization (including amalgamation) in portable equipment in an authorized container storage area. • Shredding of containers for recovery of contents. • Consolidation of miscellaneous compatible hazardous waste. • Chemical and or mechanical treatment to accomplish separation, settling removal of hazardous constituents by adsorption on solid media in portable equipment with an authorized containers storage area. • Drying of solids to meet off-site disposal criteria for release of water only. • Desorption of solvents from absorbents.

Vendor	Current Website	Notes about Services and Past Technologies
Octagon/Power Systems Energy Services, Inc.	http://www.pandeservices.com/	Power And Energy Services under one roof provides sales, service, and all solutions on an extensive array of equipment. Equipment includes: Generators, UPS, Fuel Cells, Engines, Turbines, HVAC, Switchgear, Transfer Switches, and more.
Perma Fix	http://www.perma-fix.com/	Perma-Fix provides total waste management for commercial and government agencies through the entire waste lifecycle. We have been managing and treating waste for disposal since 1990, and with our network of five fully licensed and permitted radioactive and hazardous waste processing facilities we are well versed in all phases of waste management. Perma-Fix plans treatment campaigns based on the designated disposal cell waste acceptance criteria and land disposal requirements, based on our vast experience of managing wastes destined for all major federal and commercial radioactive disposal cells in the United States. Perma-Fix offers the most comprehensive mixed waste management services in the nation and assists clients with their most challenging waste streams. Our Research and Development Laboratory performs treatability studies on clients' waste streams and develops treatment recipes and protocols to process wastes previously deemed "orphan" (no path forward). Perma-Fix has been instrumental in addressing many of the Department of Energy's (DOE's) orphan wastes, allowing for storage facility closures and decommissioning, and meeting treatment plan milestones at DOE sites across the country. Perma-Fix also provides project management, waste management, and waste treatment to support CHPRC in its mission to perform remediation, clean-up, and waste management activities for DOE. **Services Offered:** • Waste Handling Procedure Development • Waste Minimization Plans • Characterization • Sampling and Analysis • Treatability Studies • On-Site Waste Packaging • On- and Off-Site Waste Repackaging • Brokerage Services • Profiling and Manifesting for Treatment or Direct Disposal • Transportation Logistics Management • Radioactive Waste Treatment • Mixed Waste Treatment • All RCRA Waste Codes for Organic and Inorganic Wastes • TRU and TRUM Waste Management • PCB Treatment • TSCA Regulated Waste Treatment • Metals Recycling • Large Components • Classified Wastes • Mobile Treatment Processes • Thermal Destruction of Class A, B and C Resins

Vendor	Current Website	Notes about Services and Past Technologies
Philotechnics	http://www.philotechnics.com/	Philotechnics, Ltd., is a full-scope radiological services company headquartered in Oak Ridge, Tennessee. At the very core of our philosophy is our commitment to being the most responsive, broad-spectrum radiological services provider in the nation – dedicated to advising you on the most appropriate method to accomplish your objectives. Services are provided through three primary stand-alone product lines: Mixed and Radioactive Waste Brokerage Services - to provide RCRA, TSCA, Asbestos, Radioactive Waste Disposal Services. Decontamination & Decommissioning – to support license termination or modification. Health Physics Services - to support your needs in areas such as Decommissioning Funding Estimates and Updates, Radioactive Material License and Amendments, Emergency Response and Facility Recovery Operations, or many other Health Physics support needs.

SECTION II: U.S. Waste Groups & Their Descriptions

Using the 1995 DOE Waste Treatability Group Guidance report, six broad waste categories were established. The descriptions go into further detail of what specific waste would be included in each category. For the purpose of collaboration with the U.K., (based on the interpretation of the descriptions provided by the U.K. of their waste categories) the table also lists the U.K. category titles that would fall into the broad U.S. categories.

Table 2. U.S. Waste Groups and their Descriptions

	Waste Category	Description	U.K. Waste Stream within U.S. Category
1	Liquids / Aqueous Liquids / Slurries / Organic Liquids	Wastes that are liquids, including slurries. Slurries are defined as liquids with a total suspended/settled solids VSS) content of 21% and <30%. Only liquids and slurries packaged in bulk, free form (e.g., drum, tank) are included in this category. Liquids and slurries packaged as lab packs are assigned to other MPCs. Includes liquids and slurries containing less than 1 % total organic carbon (TOC). This waste is further evaluated per the criteria of Wastewaters (Acidic, Basic, Neutral, Cyanide) and Aqueous Slurries (Acidic, Basic, Neutral, Cyanide). This summary category includes liquids and slurries containing 21% TOC. This waste is further evaluated per the criteria of Aqueous/Organic Liquids (Aqueous/Halogenated, Aqueous/Nonhalogenated) and Pure Organic Liquids (Halogenated/Nonhalogenated).	• Aqueous liquids including bottles • Contaminated bulk oil • Material contaminated with oil • Triturated Oil
2	Solids / Homogeneous Solids	The initial Solids summary category addresses waste with physically solid matrices, including sludges. Sludges are defined as having a TSS > 30%. Certain waste with physically solid matrices are excluded from this category. These include solids that meet the criteria for assignment to the Specific (X) and Final (Z) Waste Forms summary categories. Homogeneous solids are defined as solid waste materials, excluding soil/gravel, that do not meet the EPA LDR criteria for classification as debris. Homogeneous solids may include water or other residual or absorbed liquids. Examples of homogeneous solids are sludges and particulate-type materials. This summary category includes waste that is at least 50% by volume homogeneous solids. The balance of the matrix may be other solid physical chemical forms. For example, a drum of waste from a spill cleanup may contain particulate absorbents and debris (e.g., rags, paper). The drum would be assigned to the appropriate homogeneous solids category provided the particulate absorbents, including any absorbed liquids, account for at least 50% of the waste volume. [If the waste volume were 50% or more debris, then the drum would be assigned to the appropriate debris category]. This waste is further evaluated per the criteria of the Inorganic Homogeneous Solids (Inorganic Particulates: Ash, Sandblasting Media, Inorganic Particulate Absorbents, Absorbed Organic Liquids, Ion Exchange Media, Metal Chips/Turnings, Glass/Ceramic Materials, Activated Carbon; Inorganic Sludges: Wastewater Treatment, Pond, Off-gas Treatment, Plating Waste, and Reprocessing Sludges; Paint Wate: Paint Chips/Solids, Paint Sludges; Salt Waste: Chloride, Sulfate, Nitrate, and Metal Oxides/Hydroxides Salts) and Organic Homogeneous Solids (Organic Particulates: Organic Resins, Organic Absorlbents; Organic Sludges: Biological, HOC Organic, NonHOC Organic Sludges; Organic Chemicals).	• Absorbent Materials • Bulk fines and particulates • Inorganic ion exchange materials • Material contaminated with oil • Organic ion exchange materials • Physically awkward waste

	Waste Category	Description	U.K. Waste Stream within U.S. Category
3	Soil / Gravel	This summary category includes waste estimated to be 50% by volume soil, including sand and silt, or rock and gravel that does not meet the EPA LDR criteria for classification as debris.	
4	Debris Waste	This summary category includes waste that is at least 50% by volume materials that meet the EPA LDR criteria for classification as debris. These criteria are as follows: “Debris means solid material exceeding a 60 mm particle size that is intended for disposal and that is: 1) a manufactured object, or 2) plant or animal matter, or 3) natural geologic material. However, the following materials are not debris: 1) any material for which a specific treatment standard is provided in Subpart D, Part 268,2) process residuals such as smelter slag and residues from the treatment of waste, wastewater, sludges, or air emission residues; and 3) intact containers of hazardous waste that are not ruptured and that retain at least 75% of their original volume. A mixture of debris that has not been treated to the standards provided by 5268.45 and other material is subject to regulation as debris if the mixture is comprised primarily of debris, by volume, based on visual inspection. This summary category includes waste that is at least 50% by volume materials that meet the above criteria. The balance of the matrix may be other physical or chemical waste forms. For example, the drum of spill cleanup waste discussed in the definition for Homogeneous Solids would be assigned to the appropriate debris category, provided the debris materials account for at least 50% of the bulk matrix volume. This waste is further evaluated per the criteria of the Inorganic Debris (Metal Debris: Metal Debris W/out Pb or Cd, Metal Debris With Pb, Metal Debris With Cd; Inorganic Nonmetal Debris: Concrete, Ceramic/Brick, Asbestos, Glass, Rock, and Graphite Debris), Organic Debris (Plastic/Rubber Debris: Leaded Gloves/Aprons, HOC Plastic Debris, NonHOC Plastic Debris; Wood Debris; Paper/Cloth Debris; Biological Debris), and Heterogeneous Debris (Composite Filters; Predominantly Inorganic Debris, Predominantly Organic Debris, Aslphalt Debris, Electronic Equipment) categories	• Absorbent Materials • Aqueous liquids including bottles • Asbestos • Concrete-lined drums • Graphite • Lead • Physically awkward waste

	Waste Category	Description	U.K. Waste Stream within U.S. Category
5	Lab Packs	Per this guidance, a lab pack configuration is defined as two or more waste containers packaged within a larger outer container. Typically, the inner containers are surrounded by absorbent materials; however, this is not an absolute criterion. If present, the absorbents can be homogeneous solids or debris materials. Examples may include rags, vermiculite, diatomaceous earth, and paper wipes. This summary category includes waste that either (a) is packaged as a lab pack upon generation, or (b) will be packaged as a lab pac before transfer to long-term storage or treatment. The reason for inclusion of the second item is that many sites maintain inventories of small waste volumes (e.g., excessed or expired chemicals) in temporary storage. Often, this waste is lab packed before transfer for long-term storage or treatment. This category does not include lab packs of elemental liquid mercury or paint waste. In addition, waste packaged in a lab pack configuration that is considered overpacked is excluded. A typical example of an overpack is a single 55-gallon drum of waste that is placed in a 85-gallon drum because of deterioration of the 55-gallon container. This waste should be assigned the appropriate category based on the waste within the inner, overpacked container(s). (includes: Organic, Aqueous, and Solid Lab Packs, and Scintillation Cocktails)	• Absorbent Materials
6	Special Waste Forms	In general, this summary category includes waste that (a) is inherently hazardous (Le., the bulk material itself is RCRA hazardous), often with specific LDR treatment technology requirements, or (b) presents unique treatment concerns. This waste is further evaluated per the criteria of the Elemental Hazardous Metals (Elemental Lead, Elemental Cadmium, Other Elemental Hazardous Metals), Batteries (Lead Acid Batteries, Cadmium Batteries, Mercury Batteries, Other), and Reactive Metals (Bulk Reactive Metals, Reactive Metal Contaminated Components, Pyrophoric Fines, Other) summary categories, and the Elemental Mercury , Beryllium Dust, Explosives/Propellants, and Compressed Gases/Aerosols specific detailed categories. Special waste that does not meet the criteria specified for any of these categories is assigned to the Unknown/ Other Special Waste detailed category.	• Batteries • Bulk fines and particulates • Lead • Mercury wastes • Pressurized wastes • Pyrophoric material • Reactive Metals

SECTION III: Technology Treatment Matrices

The matrix in Table 3 correlates U.S. treatment technologies to U.S. waste streams. If a box is colored in, it means that the technology listed in the row is capable of treating the waste listed in the corresponding column.

The matrix in Table 4 is for the purpose of collaboration with the U.K. The U.K. provided their own set of waste categories and descriptions. This was provided to the vendors and based on their interpretation of the waste included in that specific category, they identified which of their available treatment technologies would be capable of treating the waste.

Table 3 U.S. Technology Treatment Matrix

		Low Level Waste				Mixed Low Level Waste				
		Debris Waste	Liquids / Aqueous Liquids / Slurries / Organic Liquids	Soil / Gravel	Solids / Homogenous Solids / Sludge	Debris Waste	Lab Packs	Liquids / Aqueous Liquids / Slurries / Organic Liquids	Soil / Gravel	Solids / Homogenous Solids / Sludge
Chemical Techniques	Amalgamation							■		■
	Chemical Oxidation	■	■	■	■	■	■	■	■	■
	Chemical Reduction	■	■	■	■	■	■	■	■	■
	Controlled Reaction		■		■			■	■	■
	Deactivation	■	■	■	■	■	■	■	■	■
	Decontamination	■								
	Neutralization		■	■	■	■	■	■	■	■
	Solidification		■	■	■			■	■	■
	Stabilization		■	■	■	■	■	■	■	■
High Temperature Techniques	Incineration	■	■	■	■			■		
	Metal Melt Furnace	■								
	Retort									
	Steam Reforming		■					■		
	Vacuum Assisted Thermal Desorption (Separation)					■		■	■	■
Immobilization Techniques	Dewatering	■	■	■	■	■		■	■	■
	Macroencapsulation	■			■	■	■			■
	Microencapsulation	■			■	■				■
Physical Techniques	Compaction / Supercompaction	■	■	■	■	■				
	Sort/Segregate	■	■	■	■	■	■	■	■	■

Table 4. U.S./U.K. Treatment Technology Treatment Matrix

		Absorbent Materials	Aqueous liquids including bottles	Asbestos	Batteries	Bulk fines & particulates	Concrete-lined drums	Containerized Wastes	Contaminated bulk oil	Graphite	Halide-based fire suppressant powers	High Fissile / moderator / heat waste	ILW fuel	Inorganic ion exchange materials	Isotope cartridges	Lead	Material contaminated with oil	Mercury wastes	Miscellaneous Activated Components (MAC)	Organic ion exchange materials	Physically awkward waste	Pressurized wastes	Putrescible & cellulose waste	Pyrochemical waste	Pyrophoric material	Radium/ Thorium/ Americium contaminated waste	Reactive Metals	Sealed Sources	Sludge	Solvents	Tritiated Oil	Tritium contaminated waste	Undefined Waste	Ventilation Filters	Zinc Bromide
Chemical Techniques	Amalgamation																	X								X						X			
	Chemical Oxidation	X	X			X	X	X			X	X		X						X	X			X		X	X		X	X		X	X		X
	Chemical Reduction	X	X			X	X	X			X	X		X						X	X			X		X	X		X	X		X	X		X
	Controlled Reaction	X	X			X	X	X				X		X						X	X			X		X						X	X		X
	Deactivation	X	X			X	X	X			X	X		X						X	X	X		X		X	X		X			X	X		X
	Decontamination				X											X						X				X		X				X			
	Neutralization		X				X	X			X	X		X						X	X			X	X	X	X		X	X		X	X		X
	Solidification		X			X								X						X				X	X	X	X	X	X	X	X	X			
	Stabilization	X	X			X	X	X			X	X		X		X		X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
High Temperature Techniques	Incineration		X						X	X	X			X			X			X			X	X	X	X		X	X	X	X	X		X	X
	Metal Melting																		X		X					X									
	Retort																	X								X			X			X			
	Steam Reforming																																		
	Vacuum Assisted Thermal Desorption (Separation)	X	X						X		X			X			X	X		X			X	X	X	X			X	X	X	X			X
immobilization Techniques	Dewatering	X	X				X	X				X		X					X	X	X			X		X			X			X	X		X
	Macroencapsulation			X	X		X	X		X						X			X		X		X			X	X	X				X	X	X	
	Microencapsulation						X									X			X		X					X						X	X	X	
Physical Techniques	Compaction / Supercompaction			X															X			X				X	X					X		X	
	Sort/Segregate	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

SECTION IV: U.S. Supplier Information

The table identifies which treatment technologies are available from each vendor.

Table 5. U.S. Supplier Information

Technology		Energy *Solutions*	Perma Fix	Philotechnics	Studsvik	WCS
Chemical technologies	Amalgamation	✓	✓			
	Chemical Oxidation	✓	✓			✓
	Chemical Reduction		✓			✓
	Controlled Reaction					✓
	Deactivation	✓	✓			✓
	Decontamination	✓				
	Neutralization	✓	✓			✓
	Solidification	✓	✓			
	Stabilization	✓	✓			✓
High temperature technologies	Incineration	✓	✓		✓	
	Metal melting		✓		✓	
	Retort	✓				
	Steam Reforming				✓	
	Vacuum Assisted Thermal Desorption (Separation)	✓	✓			
Immobilization technologies	Dewatering					✓
	Microencapsulation					✓
	Macroencapsulation	✓	✓	✓		✓
Physical technologies	Compaction / Super compaction	✓	✓			
	Sort / Segregate	✓	✓			

SECTION V: Summary of Treatment Technologies

Table 6 contains the specific details of each available technology. The table provides a summary description, applicability, a specific example of applicability, advantages/disadvantages and its stage of development. Some treatment processes listed are broad, while specific types of those technologies are included. For more information on those specific treatments, further research would have to be completed.

Table 6. Summary of Treatment Technologies

KEY: (C = chemical techniques, H = high temperature techniques, I = immobilization techniques, and P = physical techniques)

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
C I	Amalgamation	Amalgamation requires a patented process that uses proprietary reagents that meets the EPA technology treatment standard (AMALGM). The process treats elemental mercury waste to meet the requirement of AMALGM using chemical reagents that bind the mercury and render it non-leachable.	· Mercury wastes · Radium / Thorium / Americium contaminated waste · Tritium contaminated waste	Fine copper/zinc powder is washed with nitric acid and then milled. Elemental mercury is added to the mixture and then milled. It is then allowed to harden and later crushed into a powder.	+ Produces a stable solid waste. + Simple process.	In use within the U.S. nuclear industry.

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
C	Chemical Oxidation (Ultraviolet Photolysis and Photo-Oxidation, Photo-Catalytic Oxidation, Electron Beam Oxidation, Chromox, Mixed Oxidants (MIOX), Wet Air Oxidation, Wet Oxidation (WETOX), Catalyzed Wet Oxidation-Detox, Nitric Phosphoric Acid Oxidation, Silver Mediated Electrochemical Oxidation (MEO), Cerium Mediated Electrochemical Oxidation (MEO), Cobalt Mediated Elctrochemical Oxidation (MEO))	Chemical oxidation offers the potential for selectively converting undesired organic compounds in a mixed waste stream to CO2 and water, while converting any radioactive compounds to reusable materials. Advanced Oxidation Processes including ultraviolet (UV) radiation, ozone, and/or hydrogen peroxide are used to destroy organic contaminants as water flows into a treatment tank. If ozone is used as the oxidizer, an ozone destruction unit is used to treat collected off gases from the treatment tank and downstream units where ozone gas may collect, or escape.	· Absorbent materials · Aqueous liquids including bottles · Bulk fines & particulates · Concrete – lined drums · Containerized wastes · Halide-based fire suppressant powers · High fissile / moderator / heat waste · Inorganic ion exchange materials · Organic ion exchange materials · Physically awkward waste · Pyrochemical waste	Direct chemical oxidation involves the use of sodium or ammonium peroxide sulphate, a strong oxidant for decomposing organic waste. The operating temperature is normally 80-95°C and the final bisulphate ion is recycled to produce new oxidant by conventional electrolysis. The organic compounds are converted to carbon dioxide and the inorganic residue products can be collected for immobilization in cement.	+ A low risk treatment option that offers the potential for selectively converting undesirable organic compounds in a mixed stream containing radioactive impurities into reusable materials provide a less harmful and environmentally friendly option for treating radioactive organic waste. + Provide the potential for the recovery and reuse of waste materials. + The ability to use processing temperatures of between about 250-700° F and low pressure as compared to processes such as incineration, which require the use of high temperatures (up to 2000° F), or wet-air oxidation, which requires the application of pressure up to 5,000 psi. + The use of inorganic acids may speed up the degradation and hydrolysis of organic waste into less toxic compounds.	In use within the U.S. nuclear industry.

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
C	Chemical Oxidation (Ultraviolet Photolysis and Photo-Oxidation, Photo-Catalytic Oxidation, Electron Beam Oxidation, Chromox, Mixed Oxidants (MIOX), Wet Air Oxidation, Wet Oxidation (WETOX), Catalyzed Wet Oxidation-Detox, Nitric Phosphoric Acid Oxidation, Silver Mediated Electrochemical Oxidation (MEO), Cerium Mediated Electrochemical Oxidation (MEO), Cobalt Mediated Elctrochemical Oxidation (MEO))		· Radium / Thorium / Americium contaminated waste · Reactive metals · Sludge · Solvents · Tritium contaminated waste · Undefined waste · Zinc Bromide			

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
C	Chemical Reduction	Chemical Reduction utilizes a proprietary liquid reactant metal alloy bath composed primarily of mixtures of natural highly chemically reactive aluminum, magnesium, and lithium, along with specific alloys of other alkaline metals. These chemically reactive reducing alkaline metal alloys molecularly decompose complex organic chemicals, and all halogenated hydrocarbons, including PCBs, while capturing in the liquid bath all metals. This includes all radioactive isotopes contained within the waste materials introduced into this chemical reduction medium.	· Absorbent materials · Aqueous liquids including bottles · Bulk fines & particulates · Concrete – lined drums · Containerized wastes · Halide-based fire suppressant powers · High fissile / moderator / heat waste · Inorganic ion exchange materials · Organic ion exchange materials · Physically awkward waste · Pyrochemical waste	The chemical reduction waste treatment process will be utilized for the decontamination/destruction technology demonstration for the removal of organics in transuranic waste. All organic materials, including all halogenated hydrocarbon compounds, will be chemically processed, removed, and separated from the transuranic metals. The alloyed transuranic metals will be placed into metal ingots, which are good for long-term storage. The chemically reduced pure metals can be reclaimed from the ingots if needed. The removal of organics from radioactive metals eliminates the production of hydrogen gas during shipment and storage. Radiolysis cannot occur without organic materials.	+ Does not produce any EPA or RCRA listed effluents or by-products in off-gas emissions. + Chemical Reduction has earned an exemption from Title Five of the Clean Air. This exemption is a lifetime exemption. + Chemical reduction waste treatment process operates in an anaerobic environment, at water-cooled lower temperatures, and with less than 5% oxygen. All chlorine atoms are chemically converted into aluminum chloride salts by chemical synthesis.	In use within the U.S. nuclear industry.

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
C	Chemical Reduction		· Radium / Thorium / Americium contaminated waste · Reactive metals · Sludge · Solvents · Tritium contaminated waste · Undefined waste · Zinc Bromide			

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
C	Controlled Reaction	Controlled water reaction is a particular application of hydrolysis. Hydrolysis is the use of water as a reagent to destroy, decompose, or alter a chemical species. In general, the reaction involves the displacement of a functional group on a molecule with a hydroxyl group from water. Hydrolysis of organic compounds can result from a neutral reaction with water or it can be catalyzed in the presence of an' acid or a base. The EPA considers controlled water reaction or hydrolysis to be the Best Demonstrated Available Technology (BDAT) for the treating waste alkali metals. The process will eliminate the reactive characteristic of these metals. Performance is affected by temperature, pH, the homogeneity oil the waste mixture, and the ability to mix the waste with water. For treating alkali metals, the metal waste will normally be received in some type of sealed containers such as metal cans or drums. These are fed manually onto a conveyor leading to size reduction equipment such as a hammer mill. The hammer mill is contained in a sealed enclosure where water is constantly introduced to initiate reaction as soon as the containers are breached. When the size of the debris is reduced sufficiently, it exits the hammer mill to a sealed reaction tank to complete reaction. Solids and liquids resulting from the process remain in the tank. Off-gas from the process goes to a treatment system for removal of particulate. The hydrogen can then be flared off. Solids are filtered from the aqueous waste and the pH adjusted by addition of acid prior to discharge. Typically, the process equipment will be	· Absorbent materials · Aqueous liquids including bottles · Bulk fines & particulates · Concrete-lined drums · Containerized wastes · High fissile /moderator /heat waste · Inorganic ion exchange materials · Organic ion exchange materials · Physically awkward waste · Pyrochemical waste · Radium / Thorium / Americium contaminated waste	The process has been used at the INEL for the destruction of reactive metals in wastes containing sodium and sodium-potassium (NAK).	+ The process is simple and highly effective. + Capital and operating costs are modest. + The reagent (water) is abundant and inexpensive. - The reaction is highly exothermic, making the process difficult to monitor and control. - Production of hydrogen as a byproduct increases the hazards associated with the process.	In use within the U.S. nuclear industry.

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
C	Controlled Reaction	housed in a dedicated facility designed to handle explosions. This includes reinforced walls and provision for safely venting excess pressure. During operation, the process facility is maintained at negative pressure to reduce risks of escape of hydrogen. Exhaust from the facility is vented through the off-gas treatment system.	· Tritium contaminated waste · Undefined waste · Zinc Bromide			

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
C	Deactivation	Removes the characteristics of ignitability, corrosivity, and reactivity.	· Absorbent materials · Aqueous liquids including bottles · Bulk fines & particulates · Concrete – lined drums · Containerized wastes · Halide-based fire suppressant powers · High fissile / moderator / heat waste · Inorganic ion exchange materials · Organic ion exchange materials · Physically awkward waste · Pressurized wastes	"Microbiological deactivation": The phenomena of isotope transmutation in growing microbiological cultures. Transmutation in microbiological associations is 20 times more effective than in pure cultures. Transmutation of radioactive nuclei to stable isotopes in such associations was investigated. The most accelerated rate of Cs^{137} to stable Ba^{138} isotope transmutation was 310 days. http://www.epa.gov/osw/hazard/tsd/ldr/ldr-sum.pdf Appendix D: **Recommended Technologies to Achieve Deactivation of Characteristics in 40 *CFR* 268.42**		In use within the U.S. nuclear industry.

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
C	Deactivation		· Pyrochemical waste · Radium / Thorium / Americium contaminated waste · Reactive metals · Sludge · Tritium contaminated waste · Undefined waste · Zinc Bromide			

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
C P	Decontamination	The removal of radioactive contamination which is deposited on surfaces or spread throughout a work area. Decontamination methods are mechanical or chemical. Commonly used mechanical methods are vacuum cleaning, sand blasting, blasting with solid carbon dioxide, flame cleaning, scraping, ultrasonic cleaning, vibratory finishing, and using lasers to vaporize contaminants. Chemical methods are used primarily to decontaminate components and tools that are immersed in a tank, either by means of a chemical solvent to dissolve the contaminant, or by using electropolishing techniques to remove the surface layer, including contaminants, from metals. Chemical decontamination methods are also used to remove radioactive deposits from the interior surfaces of piping, pumps, heat exchangers, and boilers. For these applications, the solvent is pumped or flushed through the system, dissolving the radioactive deposits. The solution itself is then radioactive, and the contaminants are typically removed using filters or ion-exchange resins. The use of this approach to clean the coolant systems of nuclear reactors has become common. Dilute chemical reagents, including organic acids, are used to decontaminate the primary coolant systems of operating nuclear power plants to minimize radiation exposure of the workers. **Chemical decontamination** uses concentrated or dilute chemical reagents in contact with the contaminated item, to dissolve the contamination layer covering	· Batteries · Lead · Pressurized waste · Radium / Thorium / Americium contaminated waste · Sealed sources · Tritium contaminated waste	http://www.oecd-nea.org/rwm/reports/1999/decontec.pdf Decontamination Techniques, 1999 Phosphoric acid is normally used as electrolyte in electropolishing because of its stability, safety and applicability to a variety of alloy systems. Moreover, the non-drying nature of phosphoric acid helps minimise airborne contamination, and the good complexing characteristics of phosphoric acid for metal ions is a significant factor in minimizing recontamination from the electrolyte. In the waste treatment facilities liquid wastes are treated by using evaporation systems or flocculation and co-precipitation systems. Two evaporation systems are installed for different category of waste mainly according to radioactive concentration in liquid. One of them is installed in a concrete cells in order to reduce radiation dose to the workers because of rather high concentration in liquid waste. Some specified liquid such as contaminated sea-water are treated by using flocculation and co-precipitation system with chemical treatment. The condensate from each evaporation system and supernatant from co-precipitation	**Chemical Decontamination** + Chemical decontamination is relatively simple and similar to classical cleaning in the conventional industry for which a lot of experience exists. It may also be relatively inexpensive where additional equipment is not required. + Chemical decontamination is a known practice in many nuclear plants and facilities. + With proper selection of chemicals, almost all radionuclides may be removed from contaminated surfaces. Problems of recontamination may be reduced by continuously rinsing the surface with water. + With strong mineral acids, a decontamination factor of more than 100:1 decrease in activity levels may be achieved, and in many cases, the item may be decontaminated up to releasable levels. + Chemical decontamination may also remove radioactivity from internal and hidden surfaces. However, in this case, its effectiveness may be	In use within the U.S. nuclear industry.

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
C P	Decontamination	the base metal and eventually a part of the base metal. In most cases, required decontamination levels may be obtained by continuing the process as long as necessary, taking care to ensure that tank walls or piping are not penetrated by corrosion. In mild chemical decontamination processes, dissolution of the contamination layer is envisaged, but the process should be non-destructive to the base metal and is generally used for operating facilities. Aggressive chemical decontamination techniques involving dissolution of the base metal should only be considered in decommissioning programs where reuse of the item will never occur. **Mechanical and manual decontamination** are physical techniques. More recently, mechanical decontamination has included washing, swabbing, foaming agents, and latex-peelable coatings. Mechanical techniques may also include wet or dry abrasive blasting, grinding of surfaces and removal of concrete by spalling or scarifying. These techniques are most applicable to the decontamination of structural surfaces. Some of them are also applicable to non-metallic surfaces, such as plastics. Abrasive blasting systems, both wet and dry, have been used with success. They provide mechanical methods, derived from the conventional industry, that give very high decontamination factors. The longer the operations are continued, the more destructive they are. However, wet abrasive systems produce a mixture of dust and water droplets that might be difficult to treat. Care must be taken not to introduce		system are released to the environment after confirming that their radioactivity levels are below the release limit. Concentrates from evaporation systems and sludge from precipitation system are mixed homogeneously with cement in 200 drums.	low, and measurement at release levels will be a problem. + Chemical decontamination involves relatively minor problems of airborne contamination, similar to those of the closed-system approach. - The main disadvantage of chemical decontamination is the generation of secondary liquid waste, resulting in relatively high volumes compared to other processes, such as electropolishing. The treatment and conditioning of this secondary waste requires appropriate processes to be considered when selecting the decontamination option. Moreover, in some cases (*e.g.*, internal and hidden surfaces), the effectiveness of the decontamination may be relatively low. - Usually the solution must be heated up to 70 to 90°C in order to improve the kinetics of the decontamination process. - A further disadvantage in obtaining high decontamination factors is that corrosive and toxic reagents may need to be handled.	

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
C P	Decontamination	the contamination into the material surface (hammering effect) in order for the ability to meet clearance levels not to be jeopardized. These techniques are not appropriate for complicated surfaces where uniform access may not be guaranteed.			- Chemical decontamination is mostly not effective on porous surfaces. **Mechanical Decontamination** + Generally, abrasive-blasting techniques have proved effective. In many cases, the equipment is well developed and commercially available. Industrial equipment is also available for remote operation. + Several methods remove tightly adherent material, including corrosion layers. Special tools for cleaning the inside of tanks and pipes are also available. + The abrasive-blasting technique gives result in a relatively short time. - Abrasive-blasting techniques generally produce a large amount of waste, if recirculation and/or recycling of abrasives and/or water is not available. In some cases, it is difficult to control the amount of base metal removed. In dry abrasive systems, dust-control measures are needed to control dust and/or airborne contamination. Wet abrasive systems also produce a mixture of dust and water	

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
C P	Decontamination				droplets that might be difficult to treat. - Care must be taken not to introduce the contamination into the material surface (hammering effect) in order for the ability to meet clearance levels not to be jeopardized.	

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
C	Neutralization	The addition of applicable reagents to acidic or basic mixed wastes can render the wastes non-corrosive. After neutralization, wastes are processed by thermal or non-thermal means, depending on regulatory requirements, waste matrix, and cost considerations. Neutralization is an effective, low-cost treatment method since the simple addition of neutralizing reagents can remove the characteristic hazard. Neutralization is a chemical reaction between an acid and a base. The reaction involves acidic or caustic wastes that are neutralized (pH is adjusted toward 7.0) using caustic or acid additives. Neutralization is used to adjust basic or acidic waste to an acceptable pH range (,usually between pH 6.0 and pH 9.0). The pH is adjusted by adding alkaline wastes or chemical reagents to acidic wastes and vice versa. Neutralization is used to treat wastes in order to reduce or eliminate ther reactivity or corrosiveness. The process can be operated either batch or in a continuous mode depending upon application. Equipment needs are modest consisting of pumps, tanks, mixers, and pH instrumentation for control. Besides modest capital requirements, operating costs can be inexpensive. The only major requirement is that adequate mixing should be provided to ensure complete reaction. *As* an option, a second reactor stage may also be provided. Equalization takes place during the second stage where further mixing occurs, allowing time for the neutralization reactions to reach equilibrium. Care must be taken to ensure compatibility of the waste with the treatment chemicals to prevent formation of	· Aqueous liquids including bottles · Concrete – lined drums · Containerized wastes · Halide-based fire suppressant powers · High fissile / moderator / heat waste · Inorganic ion exchange materials · Organic ion exchange materials · Physically awkward waste · Pyrochemical waste · Pyrophoric material · Radium / Thorium / Americium contaminated	A process for neutralizing radioactive wastes such as Plutonium and Americium is demonstrated using Hydroxy Gas in combination with a metal matrix. Hydroxy gas is an energized form of water vapor that exhibits some very strange properties including the ability to sublimate tungsten (10,000 F) with a flame that burns strangely cool (130 C). The pyrochemical process evidently causes low energy induced nuclear reactions resulting in stable end products through subcritical cold fission, nuclear spallation and accelerated decay reactions.	+ Neutralization is an effective, low-cost treatment method since the simple addition of neutralizing reagents can remove the characteristic hazard. + The process is simple, using readily available equipment. + It is reliable and can be automated. + The process can be applied in situ. + It can be applied either continuously or as a batch operation. + Overall treatment costs are normally quite modest. - Construction materials must be resistant to corrosively of the wastes and reagents. - The potential exists for hazardous violent, and or exothermic, reactions to occur in the neutralization process, and to produce air emissions in some cases. -The byproducts can be hazardous.	In use within the U.S. nuclear industry.

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
C	Neutralization		waste · Reactive metals · Sludge · Solvent · Tritium contaminated waste · Undefined waste · Zinc Bromide			

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
C	Neutralization	significant solids or hazardous byproducts. Liquids, slurries, and sludges are all amenable to treatment by neutralization. In situ neutralization involves injecting dilute acids or bases into the ground to either optimize pH for further treatment or to neutralize plumes so that further treatment is not necessary.				

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
C I	Solidification	Solidification media used includes polymers, cement, fly ash, or a similar material that is compatible with the waste. The end product may be a solid monolith or an unconsolidated soil-like form, depending on the disposal facility acceptance criteria. Solidification methods result in a solid, low-permeable block of contaminated soil. To accomplish this, we incorporate specialized, solidifying admixtures which mechanically lock contaminants within the solidified matrix. This may or may not involve chemical bonding between the toxic contaminant and the additive. By decreasing the exposed surface area and/or encapsulating the waste, contaminant migration can be significantly decreased. Chemical process to solidify liquid wastes for disposal.	· Aqueous liquids including bottles · Bulk fines and particulates · Inorganic ion exchange materials · Organic ion exchange materials · Pyrochemical waste · Pyrophoric material · Radium / Thorium / Americium contaminated waste · Reactive metals · Sealed sources · Sludge · Solvents · Tritiated oil · Tritium contaminated waste	Sodium polyacrylate granules have been used to solidify zinc bromide, followed by land burial of the waste in drums. The chemically bonded phosphate ceramic process has been used to solidify radium contaminated waste.	+ The resulting solid material does not set hard but formed a friable material capable of recovery for further processing as was required. + Resulting solid is chemically neutral. + Addition of water reduced the tritium concentration of the solution and resulting solid.	In use within the U.S. nuclear industry.

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
C I	Stabilization	A stabilization process is typically used for soluble mercury in wastes in this category. This process chemically reduces the mercury to an insoluble, low-leaching form. This method is operated at ambient temperature and atmospheric pressure. Stabilization techniques limit the solubility or mobility of contaminants, even though the physical characteristics of the waste may not be changed or improved. To accomplish this, reagents or other specialized materials are added and blend them with the sludge or soil. Stabilization ensures that the hazardous components are maintained in their least mobile or toxic form. Chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility	· Absorbent materials · Aqueous liquids including bottles · Bulk fines & particulates · Concrete-lined drums · Containerized waste · Halide-based fire suppressant powers · High fissile / moderator / heat waste · Inorganic ion exchange materials · Lead · Mercury waste · Organic ion exchange materials · Physically awkward waste	DOE has demonstrated the Polyethylene Encapsulation of Radionuclides and Heavy Metals (PERM) process at the bench scale. The process is a waste treatment and stabilization technology for mixed waste. Specific targeted contaminants include radionuclides (e.g., cesium, strontium, and cobalt), and toxic metals (e.g., chromium, lead, and cadmium). Scale-up from bench-scale tests has demonstrated the feasibility to process waste at approximately 2,000 lb/hr. The scale-up feasibility tests have successfully demonstrated the potential to encapsulate at least 60% by weight nitrate salt in polyethylene. Polyethylene waste forms have been demonstrated to exceed Nuclear Regulatory Commission, EPA, and Department of Transportation waste form criteria. Waste forms containing up to several thousand ppm of toxic-metal contaminants have passed the EPA's TCLP.	- Environmental conditions may affect the long-term immobilization of contaminants. - Some processes result in a significant increase in volume (up to double the original volume). - Certain wastes are incompatible with different processes. Treatability studies are generally required. - Organics are generally not immobilized.	In use within the U.S. nuclear industry.

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
C I	Stabilization		· Putrescible and cellulose waste · Pyrochemical waste · Pyrophoric material · Radium / Thorium / Americium contaminated waste · Reactive metals · Sealed sources · Sludge · Solvents · Tritiated oil · Tritium contaminated waste · Undefined waste · Ventilation filters · Zinc Bromide			

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
H	Incineration (Multiple Heart, Controlled Air, Slagging Furnace, Infrared Electric Furnace, Catalytic incineration, Cyclone Furnace, Blast Furnace, *Fixed Hearth Incineration, Circulating Bed Combustor (CBC), Fluidized Bed Infrared Combustion Rotary Kilns)*	High temperatures, 870-1,200 °C (1,600-2,200 °F), are used to combust (in the presence of oxygen) organic constituents in hazardous wastes. High temperatures, 870 to 1,200 °C (1,400 to 2,200 °F), are used to volatilize and combust (in the presence of oxygen) halogenated and other refractory organics in hazardous wastes. Often auxiliary fuels are employed to initiate and sustain combustion. The destruction and removal efficiency (DRE) for properly operated incinerators exceeds the 99.99% requirement for hazardous waste and can be operated to meet the 99.9999% requirement for PCBs and dioxins. Off gases and combustion residuals generally require treatment. Incinerator off-gas requires treatment by an air pollution-control system to remove particulates and neutralize and remove acid gases (HCl, NO_x, and SO_x). Baghouses, venturi scrubbers, and wet electrostatic precipitators remove particulates; packed-bed scrubbers and spray driers remove acid gases. Incineration, primarily off-site, has been selected or used as the remedial action at more than 150 Superfund sites. Incineration is subject to a series of technology-specific regulations, including the following federal requirements: CAA (air emissions), TSCA (PCB treatment and disposal), RCRA (hazardous waste generation, treatment, storage, and disposal), NPDES (discharge to surface waters), and NCA (noise).The duration of incineration technology ranges from short- to long-term.	· Aqueous liquids including bottles · Contaminated bulk oil · Graphite · Halide based fire suppressant fire powers · Inorganic ion exchange materials · Material contaminated with oil · Organic ion exchange materials · Putrescible and cellulose waste · Pyrochemical waste · Pyrophoric material · Radium / Thorium / Americium contaminated waste	Incineration is used to remediate soils contaminated with explosives and hazardous wastes, particularly chlorinated hydrocarbons, PCBs, and dioxins. Combustion is conducted in a direct-fired boiler industrial furnace (BIF) that meets the provisions of 40 CFR 266 and is applicable for destruction of many liquid mixed and radioactive waste streams. Wastes are sampled and analyzed prior to processing, and then blended to control concentrations of contaminants and optimize processing parameters. The boiler system is designed and operated to combust waste liquids and propane gas as fuel sources. It provides direct energy conversion and recovery by placing waste fuel combustion flue gases in contact with the "fire tubes" of a steam generator. The water outside these tubes is converted to steam that is subsequently converted to electrical power through a turbine-induction motor generator system. The residual ash generated from combustion processing is stabilized to meet Land Disposal Restricted (LDR) standards, and disposed. To expand the types of wastes acceptable for processing through the combustion system, a liquefaction unit is employed. Solid or semi-solid materials can be converted to a liquid state using	- There are specific feed size and materials handling requirements that can impact applicability or cost at specific sites. - Heavy metals can produce a bottom ash that requires stabilization. - Volatile heavy metals, including lead, cadmium, mercury, and arsenic, leave the combustion unit with the flue gases and require the installation of gas cleaning systems for removal. - Metals can react with other elements in the feed stream, such as chlorine or sulfur, forming more volatile and toxic compounds than the original species. Such compounds are likely to be short-lived reaction intermediates that can be destroyed in a caustic quench. - Sodium and potassium form low melting point ashes that can attack the brick lining and form a sticky particulate that fouls gas ducts.	In use within the U.S. nuclear industry.

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
H	Incineration (Multiple Heart, Controlled Air, Slagging Furnace, Infrared Electric Furnace, Catalytic incineration, Cyclone Furnace, Blast Furnace, *Fixed Hearth Incineration, Circulating Bed Combustor (CBC), Fluidized Bed Infrared Combustion Rotary Kilns)*		· Sealed sources · Sludge · Solvents · Tritiated oil · Tritium contaminated waste · Ventilation filters · Zinc Bromide	high shear mechanical mixers, homogenizers, and mills. The materials are reduced in size and create a colloidal suspension with the free liquid resulting in a pumpable liquid waste that can be combusted in accordance with EPA requirements.		

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
H	Metal Melting	Processes metal scrap, such as stainless steel, carbon steel, copper, aluminium or lead. The end product is metal ingots which normally can be free-released as conventional scrap metal. Residual products (slag, sorted material, cutting and blasting residues and dust from the ventilation filters) and ingots that cannot be free-released are returned to the customer.	· Miscellaneous Activated Components (MAC) · Physically awkward waste · Radium / Thorium / Americium contaminated waste	A laboratory reported melts of uranium-contaminated nickel, nickel and stainless steel, stainless steel, aluminum, and copper. The uranium content of all but the aluminum was reduced to around 1 ppm. The aluminum was not successfully cleaned by this oxidation treatment due to preferential combination of aluminum with oxygen. The uranium content of the aluminum ingots was reduced 30 to 50%.	+ Melting reduces the volume, resulting in reduced costs for interim on-site storage and final disposal. - Scrapped large components present a challenge since, due to their size, the disposal of whole components in a repository is usually very expensive and complicated.	In use within the U.S. nuclear industry.

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
H	Retort	Retorting (RMERC) is currently an approved technology for treatment of high mercury waste. Radioactive elemental mercury in virtually the liquid form must be treated via amalgamation (AMALG); however, solid wastes contaminated with elemental mercury are subject to RMERC treatment standards. Thermal retorting (RMERC) systems, the more available technology, thermally volatilizes mercury and captures it via condensation. The recovered radioactive mercury can then be stabilized by amalgamation.	· Mercury waste · Radium / Thorium / Americium contaminated waste · Sludge · Tritium contaminated waste	SepraDyne-Raduce developed, patented, and commercialized an indirectly heated rotary retort that operates at a high vacuum and high temperature. The unique combination of these features produces an environment capable of volatilizing water, all organics, and metals with low to moderate boiling points (e.g., Hg, As, Se, and Cd) with near-zero toxic air emissions. The process has been shown to volatilize and pyrolyze organic compounds (Adams, Kalb, and Malkmus 2000). It also reduces feed material volume by 25–40%. Since air and sweep gases are eliminated from the retort, combustion will not occur and total gas volume exhausted to the atmosphere is minimized. Only volatilized material will exit the retort, and therefore, the off-gas equipment is drastically minimized in size. The operating parameters and processing sequence of the rotary vacuum retort are as follows. Mercury mixed with waste such as soil, sludge, personal protective equipment, and building materials are reduced in size by a shredding and/or grinding process before being fed to the retort through a feed system. Any liquid and/or sludge inventory can be pumped into the retort.	+ Air pollution is expected to be less because of the elimination of sweep gas and the effectiveness of the rotary seal. + The equipment is expected to be easier to site and permit because air pollution is reduced. + Products of incomplete combustion such as dioxins and furans are not produced because of the reduced oxygen in the processing environment. + Less off-gas treatment is required, decreasing capital and maintenance cost requirements.	In use within the U.S. nuclear industry.

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
H	Steam Reforming (Thermal Organic Reduction Steam Reforming Process(THOR))	Steam reforming system to volume and mass reduce organic waste streams to a non-reactive waste form. Wet radioactive waste is heated up without any air supply, which starts a form of dry distillation, called pyrolysis. The process breaks down organics to form gaseous steam and CO_2 , while retaining the radionuclides and inorganic material in solid form to be disposed. The non-leachable, dry, and homogenous output is a safer and more stable for disposal or on-site storage.. Steam reforming is the reaction of steam with organic materials at elevated temperature (300oC to 1200oC) to yield synthesis gas comprised of CO, CO2, H2, H2O, CH4, and other light organic gases. The process is energy intensive. Most wastes do not contain sufficient organic material to provide the heat required to sustain the process.	***Ion Exchange Resins (IER)*** Primary Chemical Components: Long-chain Organics Secondary Chemical Components: Boron, Sulfur, Iron, Sodium, and Lithium Commercial Treatment of IERs for over 10 years ***Dry Active Waste (DAW)*** Primary Waste: Filters Secondary Waste: Clothing, Plastics, Rubber, etc. Commercial Treatment of DAW for over 10 years ***Nitrate Wastes*** Primary Chemical Component: Sodium Nitrate and other Nitrates and Nitrites	Steam reforming is usually accomplished in multiple stages. In the first stage waste is destroyed pyrolyticaly and/or has volatile constituents removed. Exposure to steam or a mixture of steam and recycled synthesis gas at temperatures between about 300oC and 800oC produces synthesis gas from any organic material present. Volatile organic species generated in the first stage are further reacted in the second stage with steam at temperatures up to 1200oC to produce additional synthesis gas. The final residues from pyrolysis of organic material include coke or char together with non-volatile inorganic ash materials. A drum reaction chamber is used for packaged or contained wastes. A full of drum of waste may be introduced into the processor with the drum serving as the reaction vessel. Aqueous and organic liquids and slurries are processed in fluidized beds or moving beds (re-circulated inorganic or inert spheres). Shredded debris or rubble waste and contaminated soils are treated in shredders and/or screw conveyors. For waste treatment application, acid gasses (mainly HCl) are scrubbed or adsorbed from the synthesis gas; the cleaned gas is then burned to produce CO2 and H2O for release to the environment.	+ Volume Reduction. + Lower Disposal Cost. + Safer, more stable, inorganic Class A Waste Form that is non-leachable, dry and homogeneous. + The result is a safer, more stable, inorganic waste form. + Complete destruction of fragments or products of incomplete combustion/pyrolysis and removal of chlorine prior to release of the treated gas. + A relatively omnivorous process, although each waste stream may require a unique primary evaporation system. + Minimization of dioxin and furan formation. - The process requires handling large volumes of hydrogen and other fuel gasses (internal re-circulating) at high temperature. - The second/third stage unit used for the thermal destruction of volatile organic and products of incomplete combustion/pyrolysis makes this treatment the essentially	In use within the U.S. nuclear industry.

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
H	Steam Reforming (Thermal Organic Reduction Steam Reforming Process(THOR))		Secondary Chemical Components: Organics, Sulfates, Chlorides, Calcium ***<u>Various Wastes Liquids and Sludges</u>*** Primary Wastes: Oils, Sludges, etc. Secondary Wastes: Heavy Metal (Uranium and Magnesium) bearing wastes	THOR Steam Reforming Process • Liquids are evaporated • Organics are destroyed • Carbon is gasified • Reactive chemicals convert to a stable mineralized waste products Hanford: THOR® has been shown to successfully treat the low level, nitrate liquid wastes as an alternative to vitrification Savannah River Site:	equivalent to two-stage incineration. - The process generally requires a different reactor for each waste matrix to be treated. - High-temperature electrically heated reforming reactors have exhibited severe corrosion during processing of halogenated hydrocarbons. **Thermal Organic Reduction Steam Reforming Process(THOR))** + THOR is Flexible • Ion Exchange Resins • Dry Active Waste • Nitrate Wastes • Various Sludges and Liquid Wastes + THOR is Customizable • Volume Reduction: Metal Oxides Product • Leach Resistance and Durability • Modularity to meet Client needs and requirements + THOR is Cost Effective • Volume Reductions from 5:1 to 70:1 have been achieved for over 12 years	

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
H	Steam Reforming (Thermal Organic Reduction Steam Reforming Process(THOR))				+ THOR is Proven • 12^{+} year history of commercial operations • Predictable Costs • Low Maintenance • Robust Design	

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
H	Vacuum Assisted Thermal Desorption (Separation)	A process that produces a physical separation of organic chemicals from contaminated soil waste materials. A thermal desorption process which is used to remove the free organic fraction from inorganic solids that contain volatile or semi-volatiles. This process uses a combination of temperature (up to 625°F), vacuum and carrier gases (e.g. steam & inert gases) to aid in the separation and desorption. This process is performed in an oxygen free environment. The desorbed constituents are then treated via direct chemical oxidation or combustion. In some cases, this desorption process can also be used as a destruction process. Once thermally desorbed the waste could require stabilization to render it amenable for disposal. The secondary liquids generated through this process are thermally destroyed via combustion.	· Absorbent materials · Aqueous liquids including bottles · Contaminated bulk oil · Halide-based fire suppressant powers · Inorganic ion exchange materials · Material contaminated with oil · Mercury wastes · Organic ion exchange materials · Putrescible and cellulose waste · Pyrochemical waste · Pyrophoric material · Radium / Thorium /	Thermal desorption is the treatment method of choice at many Superfund sites. For example, it was used at the TH Agriculture & Nutrition Company site in Albany, Georgia, to treat 4,300 tons of soil contaminated with pesticides. The system ran from July to October 1993 and met the cleanup goals, removing over 98% of the pesticides in the treated soil. http://pbadupws.nrc.gov/docs /ML0911/ML091180084.pdf **Energy Solutions Thermal Desorption Operations** **http://www.tdxassociates.com/P DF /VTD_PROJECT_PROFILE.pdf** Vacuum Thermal Desorption Deployment Project	+ Thermal desorption allows complete transfer of all target analyses to the analytical system, with no dilution or solvent interference. Detection limits offered by thermal desorption methods are typically 103 to 104 higher than equivalent solvent extraction methods facilitating ambient monitoring at ppt/ppb levels as well as higher ppm (and %-level) concentrations. + Thermal desorption efficiency is readily validated and is always above 95%, independent of ambient conditions and the nature of the target analyses – polar/apolar, volatile/semi-volatile, etc. The desorption efficiency of charcoal /CS2 extraction methods is typically in the order of 80% under best case conditions – i.e. with volatile a polar target compounds collected from dry atmospheres. + Thermal desorption offers enhanced automation and greatly reduced running costs. Tubes are re-usable at least 100 times (typically >200 times). TD also eliminates solvent purchase and disposal concerns.	In use within the U.S. nuclear industry.

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
	Vacuum Assisted Thermal Desorption (Separation)		Americium contaminated waste · Sludge · Solvents · Tritiated oil · Tritium contaminated waste · Zinc Bromide			

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
I	Dewatering	Dewatering is the removal of water from solid material or soil by wet classification, centrifugation, filtration, or similar solid-liquid separation processes, such as removal of residual liquid from a filter cake by a filter press as part of various industrial processes. Dewatering is distinguished from drying in that dewatering involves pumping and/or gravitationally draining water from wet solids w*i*th higher solids content, possibly after centrifuging. Several type of dewatering equipment are available, including: (1) strainers - metal or fiber screens set across a duct or pipe to catch larger solids, (2) belt filter presses - two porous conveyer belts that are pressed together to squeeze the water out of the sludge, (3) rotary vacuum filters - water drawn by 10 to 20 in. of mercury vacuum through the cloth- or metal-mesh-covered drum to !eavc a cake build up on the outside of the drum, (*4*) sludge clarifiers - used to filter the finer particles through a sludge bed to produce a fluid stream essentially free of ali tramp material, and (5) centrifuges and other types of filtration that are covered in other sections of this document.	· Absorbent materials · Aqueous liquids including bottles · Concrete-lined drums · Containerized wastes · High fissile /moderator /heat waste · Inorganic ion exchange materials · Miscellaneous Activated Components (MAC) · Organic ion exchange materials · Physically awkward waste · Pyrochemical waste · Radium / Thorium / Americium	Inputs are any pumpable streams composed of solids suspended in a fluid, e.g., slurries, sludges, and suspensions. Outputs are solids with retained liquid; fluid with reduced amount of suspended solids. Degree of separation dependent on solid and fluid properties and the type or' filtration system.	**Strainers** + Low equipment cost. + Low power requirements. + Does not require skilled personnel to operate. - Requires frequent cleaning. - Requires down time to clean strainers. **Belt Filter Presses** + High pressure machi*n*e is capable of producing dry cake. + Low power requirements. - Sensitive to incoming feed characteristics. - Machines hydraulically limited in throughput. - Short media life as compared with other devices using cloth media. **Rotary Vacuum Filters** + Does not require skilled personnel. + Has low maintenance requirements for continuous operating equipment. + Provides a filtrate with a low suspended solids	In use within the U.S. nuclear industry.

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
I	Dewatering		contaminated waste · Sludge · Tritium contaminated waste · Undefined waste · Zinc Bromide		concentration. - Consumes the largest amount of energy per unit of sludge dewatered in most applications. - Requires continuous attention. - Auxiliary equipment (vacuum pumps) is loud. **Sludge Clarifiers** + Capable of reducing the solids content of the filtrate by filtering through the sludge bed. + Does not require skilled personnel to operate. + Low equipment costs. + Low power requirements. - Subject to carryover if design flow rates are exceeded.	

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
I	Macro encapsulation	Macro-encapsulation involves pouring the encasing material over and around a larger mass of waste, thereby enclosing it in a solidified block. Immobilized /encapsulated waste product is produced.	· Asbestos · Batteries · Concrete-lined drums · Containerized wastes · Graphite · Lead · Miscellaneous Activated Components (MAC) · Physically awkward waste · Putrescible and cellulose waste · Radium / Thorium / Americium contaminated waste · Reactive metals · Sealed sources · Tritium contaminated waste	Macro-encapsulation is the proposed treatment for miscellaneous lead solids. A two stage macro-encapsulation process was employed in treating swarf. In the first stage each individual particle or chip was wetted by epoxy and allowed to harden into an initial monolith. The second stage encapsulated the initial monolith with a secondary layer of epoxy forming a larger final monolith.	- Encapsulating material must be resistant to degradation by the batteries and their contaminants and by leachate, other waste and microbes. - Items weighing in excess of several tons cannot be macro-encapsulated.	In use within the U.S. nuclear industry.

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
I	Macro encapsulation		· Undefined waste · Ventilation filters			

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
I	Microencapsulation	To reduce the leachability of hazardous constituents in mixed wastes that are generally dry, fine-grained materials such as ash, powders or salts. Microencapsulation (MICRO) is a technology used on Mixed Waste to reduce the leachability of the hazardous constituent. The types of Mixed Waste most suitable for MICRO include, but are not limited to, ash, powders, and salts. MICRO involves the combining of waste with molten polyethylene to form a material that does not leach hazardous constituents in excess of established TCLP treatment standards. Mixed Waste is placed into the mixer with polyethylene. These are mixed at a high frequency with shear and frictional forces until the polyethylene melts and mixes with the waste to create a microencapsulated waste form. The treatment system includes size separation, size reduction, and a waste dryer for waste preparation prior to treatment.	· Concrete-lined drums · Lead · Miscellaneous Activated Components (MAC) · Physically awkward waste · Radium/ Thorium/ Americium contaminated waste · Tritium contaminated waste · Undefined waste · Ventilation filters	Two microencapsulation treatment technologies were installed and permitted at the Envirocare facilities. Polyethylene microencapsulation is a technology used on wastes to achieve concentration-based treatment standards. Microencapsulation, achieved in either an extruder or kinetic mixer, involves the combining of waste with molten low-density polyethylene (LDPE) to form a material that does not leach hazardous constituents in excess of established treatment standards. For microencapsulation using an extruder, waste and LDPE are mixed at the feed and extruded together within the equipment. For the kinetic mixer, waste is placed into the mixer with the polyethylene. These are mixed together at a high frequency with shear and frictional forces until the polyethylene melts and mixes with the waste to create a microencapsulated form. Microencapsulation is most advantageous for dry powder or salt wastes because of the process ability to completely encapsulated fine powders with LDPE. Microencapsulation using an extruder has a maximum particle size limit of 3 mm and moisture limit of 2%. Microencapsulation using the kinetic mixer has a maximum particle size of 16 mm and a 40% moisture limit. It is		In use within the U.S. nuclear industry.

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
I	Microencapsulation			estimated that up to 3 tons of waste per day may be treated using the kinetic mixer and up to 5 tons per day using the extruder. Both technologies pour the molten waste and LDPE into 208 L (55-gallon) molds.		

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
P	Compaction / Supercompaction	Compaction is a mechanical volume reduction process by which waste material is compressed in disposal containers. The process achieves volume reduction by removing void space. Compaction is a well-proven treatment technology. Compactor systems consist of a press, using horizontal or vertical rams to apply pressure to the waste in a drum or box-type container. Volume reduction achieved during compaction is a function of void space in the waste, the force applied by the press, the bulk density of the material, and its springback characteristics. The volume reduction factors are generally between 3 and 10. Parameters determine the size and power requirements of a compactor include the throughput, type of waste, size of items to be compressed, disposal container size, and desired volume reduction. Compactors can be divided into two main categories: low-pressure and high-pressure units. Low pressure systems typically have ram pressures of of around 35 psig, and arc used to reduce general combustible and compactable trash. High-pressure compactors (supercompactors) have ram pressures ranging from 5,200 to 11,400 psig, and are capable of volume reduction with both noncombustible and traditionally noncompactible waste. Supercompactors can achieve a 2 to 4 volume reduction factor for noncompactible waste, and a 6 to 7 factor for compactable trash. The volume reduction achieved by a compactor can be improved by preshredding the waste, using antispringback devices, and increasing the power of the unit (supercompactor).	·Asbestos · Miscellaneous Activated Components (MAC) · Pressurized waste · Radium / Thorium / Americium contaminated waste · Reactive metals · Tritium contaminated waste · Ventilation filters	A common system used in the nuclear industry is the 55-gal drum compactor, which contains a power unit, a hydraulic or mechanical drive, a platen, a base plate, structural supports, a drum-positioning platform, and a control panel. Waste is loaded into the drum, and the power unit is activated to bring the platen down onto the material in the drum. The platen is then raised, the drum recharged, and the process repeated.	+ Free liquid is pressed out and voids are eliminated. + Effective technique for a wide range of solid organic waste. + High waste throughout. + Compaction is a proven process used throughout the world in the nuclear industry. + Compaction systems are simple, and tend to be reliable and trouble free. + Waste compaction is relatively inexpensive. + The process is simple to operate. - Volume reduction is dependent on the nature of the waste to be compacted and on the compaction force used. - Excludes explosive material, compressed gases and bulky materials. - If combined with remote computer controlled handling and encapsulation it becomes a sophisticated operation needing skilled personnel.	In use within the U.S. nuclear industry.

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
P	Compaction / Supercompaction				- Most commercial compactor systems are not available with adequate exhaust equipment and must be modified. - Compactors cannot reduce the hazard of the incoming waste, and are therefore not appropriate for treating waste streams with hazardous constituents. - Compaction is not recommended for wastes containing free liquids, or with wastes containing explosives. - Compaction should not be used on dense or bulky items where minimum volume reduction would be achieved.	

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
P	Sort/Segregate	Techniques used to separate different components of wastes, similar to mechanical separation techniques. Clean components can be recycled; contaminated components require immobilization.	· Absorbent materials · Aqueous liquids including bottles · Asbestos · Batteries · Bulk fines and particulates · Concrete-lined drums · Containerized wastes · Contaminated bulk oil · Graphite · Halide-based fire suppressant powers · Inorganic ion exchange materials · Isotope cartridges · Lead · Material	Swarf is transferred to a separation cave where its contents are tipped from a skip onto a coarse vibrating screen which separates the waste into an undersize and oversize fraction. Molecular sieving has been used to segregate tritium contaminated wastes. Shaking used to segregate mercury wastes.	+ Good application of the waste hierarchy. - Time consuming. - Causes double-handling of wastes. - Can increase worker dose burden. - If done too late in the process there is a real risk of cross contamination, which leads to difficulty segregating clean waste. Segregation is ideally done at source.	In use within the U.S. nuclear industry.

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
P	Sort/Segregate		contaminated with oil · Mercury wastes · Miscellaneous Activated Components (MAC) · Organic ion exchange materials · Physically awkward waste · Pressurized wastes · Putrescible & cellulose waste · Pyrochemical waste · Pyrophoric material · Radium / Thorium / Americium contaminated waste · Reactive metals · Sealed sources			

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
P	Sort/Segregate		· Sludge · Solvents · Tritiated Oil · Tritium contaminated waste · Undefined waste · Ventilation filters · Zinc Bromide			

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
C	Kurion Ion Specific Media (ISM) Separation Technology	Selectively remove hazardous ions from aqueous waste streams using ion exchange process. Currently there are four classes of ISM: • Herschelite-Based: An engineered material based off of the media used to treat waste at Three Mile Island • Zeolite-Based: Materials engineered for specific waste conditions • Glass Microsphere-Based: Perfectly round, specific media for different applications • Fully Synthetic: Specialty media for difficult projects	Environmentally relevant ions and ions which have relatively long half-lives, such as: · Cesium (Cs+): Specifically 134 Cs+ and 137Cs+ · Strontium (Sr2+): 89Sr2+ and 90Sr2+ · First-Row Transition Metals: 63Ni2+, 58/60Co2+, and 55Fe2+ · Technetium: 99Tc (as pertechnetate) · Anionic Isotopes: Antimonate (125Sb), Iodine (129 I-), Selenate, Arsenate and Bismuthate			In world-wide use within the nuclear power industry. Technology is being used to treat 134/137Cs+ from the wastewater at the Fukushima Daiichi Nuclear Power Plant site.

	Technology Name	Summary of Description	Applicability	Specific examples of applicability	Advantages (+) and disadvantages (-)	Stage of development
C	Kurion GeoMelt® In-Container Vitrification (ICV™) Stabilization Technology	The GeoMelt® process uses electric current to convert waste into a stable glass and crystalline product. The process uses soil or industrial mineral blends to provide the glass-formers necessary for vitrification. The ICV™ process uses commercially available containers, which are then refractory lined to serve as the melt container.	A wide range of mixed organic, inorganic, and radioactive contaminants.	Used commercially in Japan since 2003 for the treatment of hazardous waste, including asbestos, PCBs, dioxins, and other persistent organic pollutants. At the Hanford site, a full-scale GeoMelt® plant for the treatment of Low Activity Waste (LAW) has been designed as a supplemental approach to treating a portion of the 47 million gallons of LAW. This extensive testing has resulted in the production of more than 200 tons of glass and reflects the technology's considerable process maturity. Technology has also been demonstrated at other DOE sites (e.g., LANL).	+ Modular, robust and easily deployable in-container solution. + Ideal for liquid and tank waste where temperature, glass former and process flexibility is important to address waste streams with varying and/or challenging chemistries and densities. + Commercially proven at large scale. + High tolerance for debris, such as concrete, scrap metal, wood and plastic.	In world-wide use within the nuclear power industry.

SECTION VI: Emerging Technologies

Table 7 includes upcoming technologies that are in the process of being introduced into the industry.

Table 7. Summary of Emerging Treatment Technologies

Technology	Summary of Description	Applicability	State of Development
Arvia™ Organics Destruction technology	Oxidizes organics using an electrochemical process at room temperature and pressure and results in a low active waste water stream which can typically be disposed of via a site's active effluent treatment system. The process does not generate any significant quantities of secondary waste and it can treat a large range of organics.	Radioactive wastes streams containing high organic content including PBC-contaminated oils, dioxins or furans	Successfully demonstrated in U.K. to treat small quantities of a high alpha-contaminated. Ongoing plans to test technology on U.S. DOE waste streams.
Kurion Modular Vitrification System (MVS®)	A single-cycle, inductively heated, melt-in-the-final-container system that the company is maturing into a scalable and low-cost application of vitrification (a volume reduction and stabilization process that immobilizes waste in a leach-resistant glass matrix so that the resulting waste form provides the ultimate assurance of long-term environmental isolation).	A wide range of mixed organic, inorganic, and radioactive contaminants	Kurion has entered into a cooperation agreement with Pacific Northwest National Laboratory (PNNL) to test and demonstrate its Modular Vitrification System (MVS®) using radioactive waste simulants as the next step in its commercialization strategy. All testing and analysis will be performed by PNNL at its Radiochemical Processing Laboratory located at the DOE Hanford site.

SECTION VII: Summary of U.S. Orphan Wastes, Their Descriptions & Risk Issues

The WIMS database identified waste streams that don’t have a treatment path and why, these orphan wastes are presented in Table 8.

Table 8.Summary of U.S. Orphan Wastes, Their Descriptions and Risk Issues

Stream Name	Waste Type	Physical Form	Site	Treatment	Description	Risk Issue	Assumed UK Waste Category
Miscellaneous Reactive Metals	MLLW	Solids	Hanford – RL	Multiple / Various	Sodium metal contaminated debris (e.g., piping, piping components, etc). The solidified sodium metal is encased inside the components, or the components have been wetted by sodium metal.	Currently, there are no known commercial facilities able to accept this type of metal reactive waste for treatment. The facility used to treat the majority of the legacy waste volume during FY2011 filed for bankruptcy in CY2012 and is currently out of business (i.e., IMPACT Services). Additionally, funding has not been authorized to pursue the treatment of this waste. It is assumed the disposition of this waste will get funded in FY2017 at which time a procurement RFP will be issued to determine if capability is available and establish the pricing.	Reactive Metals
High Tritium Waste MLLW	MLLW	Liquids	Hanford - RL	Stabilization / Solidification	One 55- gallon drum containing scintillation cocktails with a total tritium (H3) inventory of approximately 77 Ci. The waste is designated as Washing State only dangerous waste with a “WT02” waste code.	Treatment of the waste by commercial means is fiscally irresponsible and unreasonable (current estimates are over $390,000.00 for the drum of waste). Alternative methods to meet Washington State disposal requirements are being investigated. Beginning in FY2012, funding is not available to pursue other disposition options for this waste. Funding is in the budget request to disposition this waste in FY2017.	Tritium Contaminated Waste

Stream Name	Waste Type	Physical Form	Site	Treatment	Description	Risk Issue	Assumed UK Waste Category
INL CH – MLLW Treatment Onsite at Sodium Components Maintenance Shop with subsequent disposal to NNSS	MLLW	Solids	Idaho	Multiple / Various	BEA Site Treatment Plan mixed waste backlog at MFC. Consists primarily of sodium and NaK contaminated components treated onsite at the Sodium Components Maintenance Shop. Mixed waste will be treated to a degree that the RCRA characteristic waste codes (D001,D003) are removed and the treatment product can be disposed as CH-LLW. This waste is included in INLCH002. Currently 2m3/year of CH MLLW is treated per year in SCMS (located at MFC). The resulting volume to be disposed at NNSS is included in INLCH002 projections.	Existing treatment capability at MFC (i.e., SCMS) inappropriately sized for much of backlog waste inventory. Alternate treatment for large components may need to be established.	Reactive Metals
3 glove boxes	LLW	Debris	Lawrence Livermore	TBD	High SCO contamination levels exceed Type A quantity (GTCC)	Disposition TBD – high SCO contamination levels exceed Type A quantity (GTCC)	Physically awkward waste
Reactives	MLLW	Solids	Lawrence Livermore	Neutralization		LLNL is unsure if a commercial alternative is available or what the cost for commercial treatment may be.	Reactive Metals
Radioactive Contaminated Dioxins	MLLW	Specific	Lawrence Livermore	TBD	Radioactively contaminated dioxins	No known commercial alternative available	
042-NPTD-LLW-15	LLW	Solids	Oak Ridge	TBD		Waste ULCC is greater than DOT requirement (300 PE-g) and greater than NTS WAC disposal limit (350 FGE); waste requires further processing and repackaging.	
13B-NPTD-MLLW-11_COMM	MLLW	Liquids	Oak Ridge	Incineration		Treatment capabilities currently do not exist for radioactive contaminated liquid phase dioxin and furan waste.	

Stream Name	Waste Type	Physical Form	Site	Treatment	Description	Risk Issue	Assumed UK Waste Category
Special LLW_L-110	LLW	Solids	Oak Ridge	TBD	Berylium Reflector and Activated Metal from High Flux Isotope Reactor	It is expected that certain isotopes C14, Ni59, Ni63 will require waivers from the Disposal WAC. The size of the components coupled with the Co60 and Eu nuclides present significant handling and transportation issues. The potential buildup of transuranium isotopes may exceed 100 nCi/g/	Miscellaneous Activated Components
Tritiated Oil / Debris with Mercury – DP	MLLW	Organic Liquids	Savannah	Incineration	This waste stream includes used oil from pumps and compressors in the Tritium Facilities contaminated with mercury and high levels of tritium. The levels of tritium contamination on this waste are very high there-by precluding treatment of all at this time.	The levels of tritium in this waste exceed the acceptance criteria for current commercial facilities. The current plan, as identified in the SRS Site Treatment Plan (STP), is to store this waste until such time that the tritium decays to levels that allow treatment.	Tritiated Oil
Activated or Contaminated Smoke Detectors	MLLW	Debris	SLAC	Multiple / Various	Waste stream for non-contaminated, non-leaking moves out regularly as return to manufacturer. Contaminated and leaking detectors are mainly a legacy waste stream. Technically exempt waste stream as a unit. BMP separate sources from body of detector. Generate source waste stream and a mixed waste stream of the carcasses.	Path forward for source component TBD	Sealed Sources

SECTION VII: Additional Notes

Throughout the process of completing this research, there were several discussions that occurred; points made in those discussions are noted in this section as well as information on points of contact and points for further research.

- **U.S. Waste Categories-** The U.S. waste categories are very broad. Originally, it was going to be more specific. For example, Homogenous Solids, Organic Liquids, etc… but when the first draft of the survey was sent out to the vendor (Renee Echols from Perma Fix), feedback was provided that this would be repetitive and require more work for the vendors because a Homogeneous Solid, Organic Homogenous Solid, or Solid would all fall under the same treatment technologies. Thus, she provided us with the 5 main broad categories that could be applied for the treatment technologies. These 5 categories were then maintained in the following surveys sent out to the other vendors. When trying to categorize the U.K. Waste Categories into the U.S. categories according to the 1995 DOE Treatment Group Guidance, U.K. categories such as batteries and reactive metals did not fall under any other category except Special Waste Forms. Looking back, it would have been beneficial to provide the vendors with that specific 6th category. Thus, 6 categories are listed in Section II.

- **Survey Response-** When the surveys were sent out to the different vendors, a list of the U.S. waste categories and U.K. waste categories were provided to them. Thus, the points of contact had to interpret what waste would fall under each of the broad categories and complete the matrix to the best of their ability considering what they knew their treatment technologies would be able to process. The points of contact that filled out the surveys are listed below:

Renee Echols
Services, Inc.
Senior Vice President
Sales & Marketing
2800 Solway Road
Knoxville, TN 37931
O: (865) 342-7635
C: (865) 599-4064
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Energy*Solutions*
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Perma-Fix Environmental
Andy Avila
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C: (214) 918-8797
mlabarge@valhi.net

- **Steam Reforming-** On the treatment matrix, there are waste categories that are designated to be treated by this technology. This is because a survey was not sent out to Studsvik for the information; rather Mr. Andy Avila, Sales Manager of Studsvik, Inc., provided us with a PowerPoint presentation that included information about their THOR treatment technology. Thus, in the treatment technology table, a list of what they can treat is included but the treatment matrix was left blank because we are not experts on what categories those specific wastes would fall under.

- **Philotechnics-** A survey was not sent out to Philotechnics. A call was made to the facility and via phone interview they informed us that the only onsite treatment capability available was macroencapsulation.

- **Rocky Flats-** Information was requested about Rocky Flats. Frazer Lockhart (Frazer.Lockhart@em.doe.gov) provided a link (http://rockyflats.apps.em.doe.gov/) to access the Rocky Flats Closure Legacy Report. Chapter 9 specifically addresses waste disposition and Appendices 2 and 3 both have some topics relevant to waste disposition. There was not much detail regarding treatment technologies, but rather a summary that is copied below:

Treatment and Disposal Sites

Rocky Flats principally used two waste disposal sites for its LLW – DOE's Nevada Test Site disposal facility (NTS) and the Envirocare of Utah (Envirocare, now called Energy Solutions) commercial disposal facility. Initial planning favored NTS for LLW disposal since it could accept wastes with activity levels greater than 10 nCi/gm (and less than

100 nCi/gm) which were above the levels acceptable under Envirocare's Waste Acceptance Criteria (WAC). Also, the disposal cost per volume was nominally less at NTS than at Envirocare. Over time, the commercial treatment and disposal site's greater flexibility and responsiveness overcame the initial cost differential between them and the DOE-owned and DOE-operated facilities. Rocky Flats continued to use NTS for disposal of its LLW that was packaged and greater than 10 nCi/gm. However, particularly for its lower-activity bulk waste, Envirocare's lower disposal fees for mixes of different waste materials (e.g., soil and debris), its willingness to negotiate lower fees in exchange for quantity guarantees, and its lower transportation cost (particularly by rail) resulted in a lower actual disposal cost. Additionally NTS required a rigorous set of programmatic controls to ensure waste was acceptable for disposal. Envirocare depended upon specific characterization of waste to provide evidence that WAC was met. Consequently, administrative errors caused delays in shipments to NTS, whereas this was seldom the case for. As the project progressed Rocky Flats also learned that NTS was less flexible in adapting their operations to accommodate Site efforts to improve disposal efficiency. For example, Rocky Flats wanted to dispose of several very large pieces of equipment without size reduction. NTS was unable to accommodate this request. NTS was also unable to accept large volume shipments of intermodal containers and rail cars. Envirocare was much more flexible and was able to accommodate both requests, saving the project substantial effort and cost. The WAC at the TSCA Incinerator in Tennessee was very restrictive and the process for gaining acceptance of waste at TSCAI was very cumbersome, often requiring senior management intervention. The lead time for gaining TSCAI acceptance for shipment of waste was six to twelve months, partially as a result of aggressive oversight by the State of Tennessee. In contrast most commercial sites required lead time of about one month.

Orphan Wastes

In the mid- to late-1990s the Site identified certain mixed waste forms that had no approved treatment and/or disposal pathway. The predominant population in this category was the >10nCi/g LLMW. Neither DOE's Hanford nor NTS were able to provide a disposal path (except for about 500 55-gallon drums disposed at Hanford in the few weeks it was available). Others, predominantly the organic and mercury contaminated radioactive wastes, were "treatment orphans." Facilities permitted to treat the organic component of these wastes were not licensed to handle radioactive waste. Early in the project, orphan wastes existed in the shadow of more pressing special nuclear material (SNM) packaging and disposition issues. But as these SNM issues were resolved, orphan waste treatment and disposal gained visibility as a critical issue. Orphan waste issues were some of the most complex from a closure project perspective, because they required the negotiation of technical, regulatory, political, and administrative processes. All orphan wastes were placed on a tracking system, regardless of the volume or number of containers. The status of treatment and disposal options was reported routinely at the DOE headquarters level to provide visibility. Because of the myriad factors affecting the disposition of orphan wastes, it was essential that actions and responsible parties be clearly identified. DOE shared responsibility with K-H for the availability of disposal sites as a Government Furnished Service/Item. Prior to the

Closure Project, nearly all LLMW waste was treated or planned to be treated with onsite facilities and processes. As the project progressed, the philosophy shifted to using offsite commercial treatment facilities to provide LLMW waste treatment. This resulted in significant cost savings as the commercial vendors enjoyed an economy of scale by treating waste from multiple DOE sites. Commercial sites also had greater flexibility to accept waste, as most have comprehensive permits and a greater ability to adapt and adjust. DOE and K-H developed several strategies to treat and dispose of the orphan waste stream consisting of >10 nCi/g radioactive mixed wastes. The Site developed an agreement with NRC-licensed Envirocare that spelled out essential and applicable requirements consistent with an anticipated revision to the NRC Branch Technical Position on Concentration Averaging101. DOE did not prohibit mixing greater than NRC Class A waste with NRC Class C waste. And the NRC issued a guidance interpretation that allowed mixing wastes from different classes (i.e., mixing Class A with Class C) for purposes of meeting a TSDF WAC for sites undergoing closure. As such, Envirocare could offer bulk consolidation, co-processing, and disposal of Class A and Class C LLMW. Such consolidations were arranged so that limitations of the Branch Technical Position and Envirocare's SNM exemption criteria were satisfied. This resulted in the disposal of over 1,500 m3 of LLMW that would otherwise have become orphaned due to activity at levels greater than permitted under the WACs of Envirocare or other LLMW disposal sites. One particular issue that caused ongoing problems was the identification, collection, and disposal of excess chemicals. There were numerous instances of legacy chemicals, many with hazardous, oxidizer, or even explosive characteristics that continued to be discovered as Site demolition proceeded, despite a comprehensive excess chemical disposal program that began in the mid-1990s. Chemicals that were radioactive or retrieved from radiologically controlled areas, while small in volume, were extremely expensive to dispose of, one of the most extreme examples being one truckload costing over one million dollars. Two final types of material, lab returns and sources became a problem in 2005, not because they were inherently difficult to dispose of but because the waste management infrastructure was being reduced and disposal of these materials had not been properly anticipated and planned.

<u>Low Level, Mixed, and Orphan Waste Key Learning Points</u>
Commercial treatment and disposal facilities were generally easier to work with, especially for innovative treatment or disposal approaches. When administrative delays and other factors were included in the cost comparison, commercial facilities could also be less expensive.

- **Past Technologies-** The 1996 Review of Private Sector and Department of Energy Treatment, Storage, and Disposal Capabilities for Low-Level and Mixed Low-Level Waste provides great insight to the vendors treatment capabilities.

  There also used to be a National Low-Level Waste Management Program (NLLWMP) at the Idaho National Engineering and Environmental Laboratory (INEEL) that assisted the U.S. Department of Energy (DOE), and specifically the DOE's Center of Excellence for Low-Level and Mixed Low-Level Waste, in fulfilling its responsibilities under the Low-Level Radioactive Waste Policy Amendments Act of 1985. The NLLWMP assisted DOE by providing technical assistance to states and compact regions as they developed new commercial LLW management systems. As part of the NLLWMP's function of developing and distributing technical information, a National Low-Level Waste Management Program Technologies Database was developed that was publicly accessible on the Internet from the INEEL homepage. The database brought together two targeted groups: vendors of LLW and MLLW technologies and services, and LLW and MLLW generators. The database contained information about waste types, regulations, treatment technologies, and vendors that provide services and/or technologies for LLW or MLLW. These vendors updated their own information such as point of contact, services provided, treatment processes, and the types of wastes for which their services or treatment processes are applicable. **This database is no longer kept current and their website is no longer available. Below was what was able to be recovered:**

In addition to the vendor search capability, the site contains two treatment dictionaries: one for LLW and another for MLLW. These dictionaries describe the sources and characteristics of these wastes, the associated regulatory issues, and the technologies and processes applicable to the treatment of these wastes.

The LLW dictionary describes the type of commercial low-level radioactive waste streams emanating from nuclear power plants and from institutional and industrial facilities. It then describes potential commercial waste-treatment processes for these commercially generated waste streams. The commercially available technologies described on this Web site are listed in Table 9. Each category contains several technologies with a brief description of each including the types of input streams for which the technology is applicable, the output streams and secondary wastes generated, the advantages and disadvantages of using the technology, the status of the technology with respect to commercialization and availability, and commercial vendors available that provide a service with that technology. There are many companies that provide treatment for commercially generated low-level radioactive waste and mixed waste. These vendor's capabilities range from simple volume reduction technologies such as sizing and cutting to more sophisticated techniques such as incineration and vitrification. Some vendors provide brokerage services, which may be attractive to smaller waste generators who may not have time to evaluate a wide spectrum of treatment options. The MLLW dictionary is similar to the LLW dictionary in that MLLW and its sources are defined, and the issues associated with dual regulation under the Nuclear Regulatory Commission (NRC) and the Environmental Protection Agency (EPA) are discussed. In addition to the Atomic Energy Act, which authorizes regulation of nuclear material by the NRC, the Resource Conservation and Recovery Act (RCRA) and the Toxic Substances Control Act (TSCA) authorize regulation of hazardous materials by the EPA. A major portion of this dictionary is devoted to the discussion of MLLW regulations and the regulatory requirements. Methods for treating the various categories of MLLW shown in Table 5 are suggested along with a discussion of various technologies and processes.

This technology description follows the structure of the LLW dictionary including a brief description of the technology, descriptions of input and output streams, advantages and disadvantages of using the particular technology, technology status, and commercial vendors available that provide a service with that technology or are developers of that technology. Many of the LLW technologies are also applicable to MLLW and are referenced in the MLLW dictionary. However, the MLLW dictionary includes additional technologies that could be used for treatment or disposal of LLW, as well as technologies that are currently under development and may not be proven and available for several years. Thus, it is incumbent on the generator to contact the vendor or developer to determine the status and applicability of the technology of interest. The MLLW technologies described on this Web site are listed in Table 10.

Table 9. LLW technologies described in the NLLWMP Database.

LLW Technologies Described in the NLLWMP Database	
Sizing • Arc Saw Cutting • Plasma Arc Cutting • Oxygen Burning • Hacksaws and Guillotine Saws • Shredding • Cryogenic Fracturing • Abrasive Cutter • Thermite Reaction Lance • Laser Cutting • Water Jet Cutting • Abrasive Jet Cutting • Cryogenic Cutting • Shears • Pipe/Wire Cutters	**Physical/Chemical Treatment** • Neutralization • Oxidation/Reduction • Soil Washing • Steam Reforming • Alkaline Hydrolysis for Biological Materials • Supercritical Water Oxidation • Quantum-Catalytic Extraction Process • Thermal Desorption **Metal Recovery**
Volume Reduction • Compaction • Baling	**Incineration** • Controlled Air • Industrial Boiler
Filtration • Cartridge Filters • Bag-Type Filters • Reusable Filters Without Precoat • Reusable Filters With Precoat • Electrodialysis • Ultrafiltration • Granular Bed Filtration	**Separation** • Reverse Osmosis • Ion-Exchange • Carbon Adsorption • Precipitation • Centrifugation • Drying (Thermal) • Dewatering (Filtration) • Distillation • Steam Stripping
Decontamination • Mechanical Decontamination • Chemical Decontamination	**Vitrification** • Glass Furnace • Microwave Melter
Evaporation • Pot and Kettle Evaporators • Natural Circulation Evaporators • Forced Circulation Evaporators	**Immobilization/Stabilization** • Portland Cement Systems • Encapsulation • Absorption

Table 10. MLLW technologies described in the NLLWMP Database.

MLLW Technologies Described in the NLLWMP Database	
Thermal Destruction • Plasma Torch • DC Electric Arc Furnace • Molten Salt Oxidation • Rotary Kiln Incinerator • Gas Phase Reduction • Catalytic Chemical Oxidation (CCO)	**Wastewater Treatment** • Magnetic Separation • Regenerable Mercury Sorbent • Microfiltration • Ultraviolet (UV) Photo-Oxidation • Wet Oxidation
Nonthermal Treatment • Acid Digestion • Direct Chemical Oxidation (DCO) • Mediated Electrochemical Oxidation • Delphi DETOX(SM) Process • Base Hydrolysis	**Separation Processes** • Thermal Desorption • Vacuum Thermal Desorption • Mercury Leaching • Supercritical Carbon Dioxide Extraction • Self-Assembled Mesoporous Mercaptan Support (SAMMS) • Sonic Agitation with Peroxide
Nonthermal Stabilization • Chemically Bonded Phosphate Ceramic (CBPC) • Polymer Microencapsulation by Extrusion (PME) • Polymer Microencapsulation by Kinetic Mixing (PMK) • Sulfur Polymer Cement • MAECTITE • Enhanced Cement for High Salt Content Mixed Wastes • Sol-gel to Stabilize High Salt Content Mixed Wastes • Polysiloxane Based Material Binder for High Salt Content Mixed Wastes • Sintering for Stabilizing Fly Ash • Mercury Stabilization (De-Merc Process) • Liquid Elemental Mercury Amalgamation Treatment System	

5. CONCLUSION

The DOE Environmental Management Office of Waste Management is dedicated to safely disposing of waste and seeks cost effective and environmentally responsible project execution methods. This research explores the different treatment capabilities available in the U.S. by private sector companies. It provides a snapshot of all the different waste streams that are able to be treated and safely disposed. This information will be useful for future collaborations with international partners to determine common challenging untreatable waste streams and work together to develop technologies to treat and continue to disposal. The U.S. treatment and disposal programs have been in effect for many years and so, over the years, the U.S. has been able to learn from past challenges and improve the development of new technologies. Many countries can benefit from our lessons learned as they now begin to encounter the problems the U.S. once faced. Finally, the five companies surveyed are the main treatment options for the U.S. DOE waste streams; these companies are dependent on waste to be supplied to them for treatment. It is vital that as disposal of low level and mixed low level waste continues, these companies take part in the collaboration of technology development and treatment standards so that they can continue to develop technology to meet U.S. DOE waste treatment and disposal demands.

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