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Hanford/Rocky Flats Collaboration on Development of Supercritical Carbon Dioxide Extraction to Treat Mixed Waste

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HANFORD/ROCKY FLATS COLLABORATION ON DEVELOPMENT OF SUPERCRITICAL CARBON DIOXIDE EXTRACTION TO TREAT MIXED WASTE

EXECUTIVE SUMMARY

Proposals for demonstration work under the Department of Energy's Mixed Waste Focus Area, during the 1996 through 1997 fiscal years included two applications of supercritical carbon dioxide to mixed waste pretreatment. These proposals included task RF15MW58 of Rocky Flats and task RL46MW59 of Hanford.

This report has been prepared, jointly, by these sites to describe collaborative mechanisms between Hanford and Rocky Flats which may streamline the development and application of supercritical carbon dioxide extraction for complex wide needs and encourage resource and information sharing between Hanford, Rocky Flats, other Department of Energy Sites, and private industry.

This report describes the treatment needs and applicability of supercritical carbon dioxide extraction to Hanford and Rocky Flats solid wastes as well as current facilities, equipment and experience of the sites.

An analysis of compatibilities in wastes and work scopes yielded an expectation of substantial collaboration between sites whereby Hanford waste streams may undergo demonstration testing at Rocky Flats thereby eliminating the need for test facilities at Hanford. This form of collaboration is premised upon the continued deployment at Rocky Flats and the capability for Hanford samples to be treated at Rocky Flats. The recent creation of a thermal treatment contract for a facility near Hanford may alleviate the need to conduct organic extraction upon Rocky Flats wastes by providing a cost effective thermal treatment alternative, however, some waste streams at Hanford will continue to require organic extraction. Final site waste stream treatment locations are not within the scope of this document.

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HANFORD/ROCKY FLATS COLLABORATION ON DEVELOPMENT OF SUPERCRITICAL CARBON DIOXIDE EXTRACTION TO TREAT MIXED WASTE

1.0 INTRODUCTION

Within the United States Department of Energy (DOE), the Office of Environmental Management, Office of Technology Development (EM-50), retains the responsibility to develop, demonstrate, and introduce into practice innovative technologies for environmental remediation. In all interests of efficient use of funds, EM-50 can and should inhibit redundant developments or demonstrations wherever possible.

Proposals for demonstration work under the Mixed Waste Focus Area, during the 1996 through 1997 fiscal years included two applications of supercritical carbon dioxide extraction to mixed waste pretreatment. These proposals included task RF15MW58 of Rocky Flats and task RL46MW59 of Hanford.

This proposal discusses the collaboration of the development and application of supercritical carbon dioxide extraction to low level mixed waste streams at Hanford, Rocky Flats, and other Department of Energy sites. This collaboration will streamline the development of supercritical carbon dioxide extraction for complex wide waste treatment applications by preventing redundant effort and by encouraging resource and information sharing between Hanford, Rocky Flats, other Department of Energy sites, and private industry.

1.1 Purpose

The goal of a joint Hanford/Rocky Flats supercritical carbon dioxide extraction project is to test and demonstrate the effectiveness of supercritical carbon dioxide in the extraction of hazardous organic compounds and metals from various solid low level mixed waste streams in the DOE complex. Specific objectives are: 1) to demonstrate that the technology and equipment will reliably extract hazardous organic compounds from wastes at Hanford, Rocky Flats and other DOE sites and 2) to support the development of a treatment technology that is described as part of the site treatment plan for Rocky Flats. An important goal based on these objectives is that SCDE will be developed to a state of maturity so that it can be implemented at any site that must deal with similar mixed waste issues.

The purpose of this document is to review the efficacy of the proposed demonstration work and to recommend a scope of work which will maximize the benefits accrued from EM-50 demonstrations with this technology.

This review and analysis must describe:

- The application of this treatment to waste matrices,
- The applicability and expectations of success with this treatment technology to site wastes,

- The current and available facilities, equipment, and experience of the Hanford and Rocky Flats sites for this application,
- The work scopes and cost estimates proposed by the two sites, and
- Compatibilities and incompatibilities between the site work scopes, waste streams, and other contributing factors.

In conclusion, this document must recommend a work scope maximally beneficial to the needs of EM-50 in provision of demonstrated waste treatment for DOE with this technology.

1.2 Background

Large quantities of solid wastes such as soils, rags, coveralls, paper, metal, glass, plastics, rubber, sludge, and solidified oil that are contaminated with radionuclides, oils, greases, and hazardous organic and inorganic compounds have been generated at sites across the Department of Energy (DOE) complex. As long as the hazardous organic compounds are present, these solid wastes are considered land disposal restricted (LDR); when present at prohibited levels, these wastes cannot be disposed at any facility in the United States (EPA 1995). Supercritical carbon dioxide extraction is an organic contaminant removal technology that can be used to render these wastes into acceptable low level waste forms. The majority of industrial applications have involved the extraction of a known single solvent or oil from a single homogeneous substrate. The mixed waste treatment application of supercritical carbon dioxide extraction is the extraction of one or more organic contaminants from a non-homogeneous waste stream with radionuclides present (Brown October 1995).

1.2.1 Technology

In general, the majority of energy expenditure in solvent extraction is applied in separating the solute (extracted material) from the solvent (e.g. distillation). In application, supercritical carbon dioxide extraction (SCDE) is simply a solvent extraction making use of the phase behavior of carbon dioxide (Figure 1) to limit the energy intensive aspects of many other forms for solvent extraction.

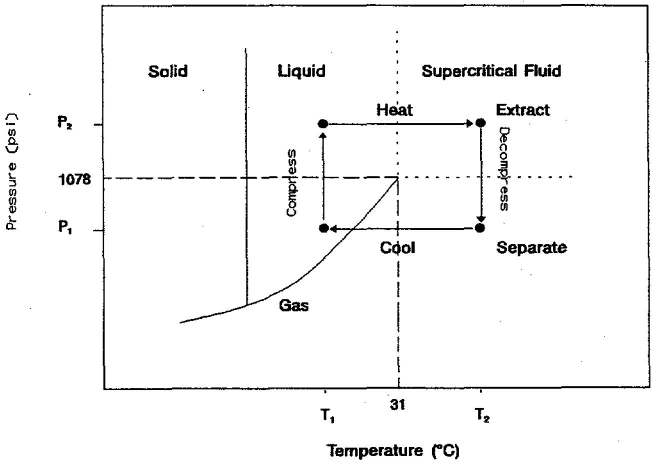

Figure 1: Supercritical Fluid Extraction Phase Behavior (CO_2 Extraction)

The special properties of fluids near critical points make them extremely desirable in mass transfer. High material densities yield high capacity for solutes, with solubility varying exponentially with the solvent density. The compressibility of carbon dioxide allows broad changes in properties with relatively small operational changes (pressure and temperature). With regard to transfer properties, supercritical fluids exhibit significantly larger molecular diffusivities than normal fluids while the viscosities are nearly as low as those of gases. These characteristics allow the supercritical fluids to permeate a matrix quickly and facilitate transfer out of a matrix while requiring little pump work. Solvent recovery is accomplished with relatively small temperature and pressure reductions. Recent economics studies (Barton 1994) by the DOE Industrial Waste Reduction Program Office have also vividly displayed the cost effectiveness in operation of SCDE systems over other, more conventional, solvent cleaning systems.

1.2.2 Site Applications

As described above, two applications have been proposed to the EM-50 Mixed Waste Focus Area (MWFA). Each application deals with treatment of radioactively contaminated mixed waste. Hazardous contaminants include polychlorinated biphenyls (PCBs), land disposal restricted and toxic organic solvents, and toxic metals. Radioactive contaminants of the streams under consideration include mixed fission products as well as actinides from fuel irradiation, separation, and special nuclear material handling. The waste stream matrices include step-off pad and decontamination wastes (cloth, plastic, paper), spill cleanup wastes, soils, and sludges.

The combination of waste contaminants described above for these streams inhibits direct incineration or stabilization technology normally considered for singly contaminated streams. To address their concern, proposals at Rocky Flats and Hanford were prepared to assess the efficacy of pretreatment of these waste streams using supercritical carbon dioxide extraction. Following such pretreatment, the separated waste streams may be treated and disposed through routine incineration or stabilization technologies.

1.2.2.1 Hanford

The DOE operates the Hanford Site in southeast Washington state. The Westinghouse Hanford Company is the Hanford Operations and Engineering Contractor for the DOE under contract DE-AC06-87RL10930. The Hanford Site has, historically, been involved with the production and separation of special nuclear material for defense purposes. DOE has determined that it no longer requires fuel irradiation and separation processes to proceed at this site. In legacy, 177 single- and double-shell tanks contain liquid, solid, and sludge wastes requiring treatment and disposal. In addition, production and various waste handling operations have generated, or received from offsite, solid waste streams which are not amenable to direct treatment or disposal. These latter waste streams contain mixtures of waste constituents including organic solvents, polychlorinated biphenyls (PCBs), and toxic metals including mercury and cadmium. Treatment considerations for these streams are further compounded by radioactive contamination with actinide and fission products.

These solid wastes are currently stored at the Hanford Central Waste Complex (CWC), Radioactive Mixed Waste Storage Facility, pending treatment and disposal. Hanford site waste treatment, storage and disposal are guided and controlled by milestone activities established within the Hanford Federal Facility Consent Decree (Ecology *et al.* 1994).

Upon the initial proposal to the EM-50 MWFA of application of SCDE to Hanford site solid wastes, the CWC had identified waste streams with volumetric projections of up to 1,500 m^3

without currently available or acceptable treatment due to the combination of waste contaminants present. Since that time, the CWC has requested and reviewed proposals for thermal treatment of a large segment of their wastes. CWC has selected a vendor for the thermal treatment and awarded a contract to Allied Technology Group (Freemont, CA) on November 3, 1995, for this offsite treatment of thermally treatable mixed waste. As a result, the volume of waste remaining which is not amenable to such treatment will be significantly reduced. In fact, such wastes are currently limited to approximately 5 m^3 of high-mercury content wastes which require that the organic solvent contaminants be removed prior to regulatorily mandated low-temperature mercury boil off (retort) and subsequent stabilization of the residuum (Place 1994). Further discussion of wastes in this high-mercury subcategory is provided in Section 2.2.

1.2.2.2 Rocky Flats Site

The DOE operates the Rocky Flats Environmental Technology Site (RFETS) in central Colorado, fifteen miles northwest of Denver. Kaiser-Hill, LLC, is the Rocky Flats Management and Integration Contractor for the DOE under contract DE-AC34-95RF00825. The Rocky Flats site has, historically, been involved with the handling and preparation of special nuclear materials for defense purposes. DOE has determined that it no longer requires weapons trigger operations at this site; however, as described above, production and various waste handling operations have generated waste streams contaminated with organic solvents, polychlorinated biphenyl, hazardous metals, cyanides, and actinide metals including plutonium and its radioactive daughters. Further discussion of wastes subject to SCDE treatment at this site is provided in Section 2.3.

The RFETS is operated in compliance with the Federal Facilities Compliance Act under a mutual consent agreement and the Site Treatment Plan signed in October 1995 by DOE and the Colorado Department of Health and the Environment which mandates the development, testing, and establishment of treatment for all waste streams under a rigid schedule. The development of SCDE proceeded at Rocky Flats with the milestone to start treatability studies on actual waste in 1996 and to complete a line item capital project to treat solvent and PCB contaminated wastes by 2002. This development and implementation could be stopped if other, more appropriate and cost effective, treatment becomes available before that date.

The Rocky Flats Site Treatment Plan identified 2,781 m^3 of low level mixed waste currently in storage requiring treatment other than that identified to be processed solely by cementation. In addition it is estimated that 3,600 m^3 of similar types of waste will be generated during the next five years of cleanup. 1,520 m^3 of the waste in storage (see Section 2.3) and most of the 3,600 m^3 which will be generated require extraction of hazardous organic compounds for treatment. Although most of the wastes under consideration for SCDE at Rocky Flats are amenable to incineration, public and environmental agency concerns have led to the conclusion that incineration will not be conducted at that site.

In the case of Rocky Flats, SCDE is part of a comprehensive treatment system directed at treating Rocky Flats' stored and newly generated low level mixed waste streams. The integrated treatment system is envisioned to handle both the waste constituents and the secondary waste streams associated with the whole process of treating the wastes. To this end, technologies are being developed which can be integrated to form LDR compliant final waste forms. An integrated approach using several technologies is needed because of the heterogeneity of the stored waste. The wastes to be treated include combustibles, organic liquids, and inorganic solids which are contaminated with small amounts of radioactive constituents and hazardous constituents including toxic metals, volatile and semi-volatile organic compounds, polychlorinated biphenyl, and cyanides. Because many of the waste streams carry multiple Environmental Protection Agency (EPA) waste codes, including codes for characteristic and listed waste, two and sometimes three treatment steps will be necessary to meet LDR.

2.0 WASTE STREAMS

As described in Section 1.1, an understanding of the treatment proposals must rely heavily upon an understanding of the breadth of treatment capabilities with supercritical carbon dioxide as well as an understanding of the waste composition. This section is intended to address the application of the proposed supercritical carbon dioxide extraction treatment to waste matrices and the applicability and expectations of success with current site wastes. A compendium of data sources for organic compound solubilities in supercritical and subcritical carbon dioxide is provided in Appendix A.

2.1 Waste Constituent Treatment

Supercritical fluid extraction has been successfully implemented for a wide variety of separation processes, including the decaffeination of coffee, recovery of hops, edible oils and other natural products, the regeneration of activated carbon, the separation of organic-water solutions, and the fractionation of polymers. These extractions are attractive because the solubility of solutes in supercritical fluids can be varied dramatically with small changes in temperature and pressure. Therefore, once a solute is dissolved in the fluid it can be easily separated from the supercritical solvent simply by reducing the pressure (most commonly) or adjusting the temperature.

Supercritical carbon dioxide is a particularly attractive solvent because of its mild critical point (T_c=31°C, P_c=72.8 atm.) and the fact that it is nonflammable and nontoxic. A typical extraction system is shown in Figure A-1. The mixture to be extracted is placed in the extraction vessel, as either a batch or semi-batch process. Then, the supercritical fluid is passed continuously through the bed, dissolving the components of interest. Typically, the solute is separated from the supercritical fluid simply by reducing the pressure (either completely depressurizing to atmospheric pressure or just partially depressurizing) across an expansion valve into a separation chamber. The solute is recovered and the supercritical solvent is recycled and repressurized.

It is quite common, especially when using carbon dioxide, to add a cosolvent to the solvent. A few percent of a cosolvent, like methanol or acetone, can frequently increase the solubility of a heavy organic solid solute by an order of magnitude or more, thus dramatically reducing the required volume of solvent. In this case, a cosolvent makeup pump is required since some or all of the cosolvent may exit the system with the solute, dependent upon the operating conditions in the separator. However, most of the compounds listed in F001-F005[1] are relatively volatile substances (many of which are common cosolvents), so it is unlikely that a cosolvent will be necessary to solubilize those compounds. In fact, dependent on operating conditions, many of the compounds may be completely miscible with carbon dioxide, as explained below.

In the typical operating range for carbon dioxide extraction of 40-100°C and 50-300 bar, most of the compounds identified in waste codes F001-F005 exist either as vapor/liquid equilibrium or are completely miscible with carbon dioxide. As an example, the phase behavior of a binary mixture of CO_2 + 1-butanol is shown in Figure A-2. The two-phase vapor/liquid equilibrium envelopes are shown for three temperatures. The two-phase region enlarges, i.e. extends to higher pressures, at higher temperatures. If one were to extract 1-butanol with CO_2 at 41.6°C (314.8 K), one would simply have to operate at pressures above about 80 bar (8 MPa) for the 1-butanol to be *totally miscible* with the CO_2. However, if the extraction took place at 64.0°C (337.2 K), one would have to operate above about 120 bar (12 MPa) for the 1-butanol to be totally miscible with the CO_2. This same trend is observed for the CO_2 + m-xylene system shown in Figure A-3 (Ng et al. 1982) and essentially all the compounds of interest. Therefore, if one wishes to operate an extraction where the solutes are totally miscible with the CO_2, one would choose lower temperatures and moderate pressures.

Conversely, if one chooses the temperature and pressure to operate the extraction in the two-phase region or if two phases inadvertently exist due to multicomponent or matrix interactions, it would be better to operate at as high a temperature as possible, as shown in Figure A-3 for the CO_2 + m-xylene system. The solubility of the m-xylene in the CO_2-rich vapor phase *increases* with increasing temperature. At 37.7°C (310.9 K) and pressures below about 80 bar the CO_2 extract would only contain about 0.003 mole fraction m-xylene. At 121.1°C (394.3 K) and the same pressure the CO_2 extract would contain $>$ 0.02 mole fraction m-xylene. Also, if any heavy organic solid solutes are present, such as polycyclic aromatics, higher temperatures and pressures will give higher solubilities. In choosing the appropriate operating conditions, it is basically a trade-off between temperature and pressure. If the equipment can handle moderate pressures (say, 200-300 bar) then the extraction can be done at low temperature (40-50°C). If the equipment is limited to low pressures (i.e. $<$ 100 bar or so) then the extraction will have to take place at high temperature (100-200°C).

Based solely on the solubility data, listed in Appendix A, it is likely that effective extraction of the compounds listed in F001-F005 from soil or other solid matrices could be done at relatively low temperatures (40-50°C) and moderate pressures (200-300 bar).

2.2 Hanford

Waste streams currently under consideration for pretreatment with SCDE at the Hanford site are currently those streams which are contaminated with various toxic metals, solvents, and

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[1] 40 CFR §261.31, Hazardous wastes from non-specific sources, U. S. Environmental Protection Agency, Washington, D.C., August 25, 1986.

radionuclides and fall into the U. S. Environmental Protection Agency's high-mercury subcategory D009 (mercury toxicity characteristic) wastes[2]. In addition, the waste streams carry listed waste designations[3] and toxicity characteristic (TC) designations[4] for their organic contaminants. Such wastes are required to be treated in conflicting manners. The organic components must be treated through incineration; however, standard incineration would not treat the mercury contamination. The mercury may be treated either by incineration or by mercury retort; following incineration, a mercury retort (a low temperature boil off and recovery) treatment must be applied to meet mercury treatment standards. As such, Hanford has proposed the application of organic extraction of the waste materials to limit the material that must be incinerated to only the organic materials while allowing the solid matrix to proceed to a mercury retort and stabilization.

Federal hazardous waste codes and the waste contaminants under consideration in this subcategory of waste are described in Table 1. As seen here, and as described in Section 2.1, the organic contaminants of interest are all treated with ease at low to moderate operating conditions during SCDE from many substrates. It is envisioned that mild operating conditions in the region of 10.3 MPa and 50°C (1,500 psi and 122°F) should provide an excellent pretreatment for these wastes.

A set of detailed summary tables describing the Hanford High-mercury subcategory wastes are contained within Appendix B (HANFORD HIGH-MERCURY SUBCATEGORY WASTE SUMMARY ANALYSIS). This information was assembled from waste package details provided in Place (1994) and associated onsite data retrieval systems.

2.3 Rocky Flats

Based on successful demonstration, SCDE could be the sole treatment technology for wastes that are only contaminated with volatile or semi-volatile organic constituents. However, much of the waste also contains hazardous metals or requires additional processing to make a compliant waste form. Polymer encapsulation of the solids remaining after SCDE is anticipated to be required for a majority of the wastes processed by SCDE. The SCDE demonstration system is scheduled to be installed in close proximity to the currently installed polymer systems, one for macroencapsulation and one for microencapsulation. The two polymer units will receive the solids from the SCDE system and stabilize them so that they meet LDR. This will allow the SCDE system to be tested on complex waste streams.

Table 2 lists the wastes that are targeted by the integrated system. Table 2 and a table with complete details provided in Appendix C give all the stored low level mixed waste at Rocky

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[2] 40 CFR §268.42, Table 2, Technology-Based Standards by RCRA Waste Code, U. S. Environmental Protection Agency, Washington, D.C., January 31, 1991.

[3] 40 CFR §261.31, Hazardous wastes from non-specific sources, U. S. Environmental Protection Agency, Washington, D.C., August 25, 1986.

[4] 40 CFR §261.24, Toxicity Characteristic, U. S. Environmental Protection Agency, Washington D.C., June 29, 1990.

Table 1: Hanford High-Hg Subcategory Hazardous Constituent Waste Codes

Hazardous Waste Constituents		
Chemical	Listed Codes	TC Codes
Arsenic		D004
Barium		D005
Cadmium		D006
Chromium		D007
Lead		D008
Mercury		D009
Selenium		D010
Silver		D011
Methylene Chloride	F001 F002	
Tetrachloroethylene	F001 F002	D039
Trichloroethylene	F001 F002	D040
Xylene	F003	
Acetone	F003	
Nitrobenzene	F004	D036
Methyl ethyl ketone	F005	D035
Toluene	F005	
Benzene	F005	D018

Flats showing the interrelationship of SCDE to other planned treatment at the site. 1,520 m^3 of the 2,781 m^3 need SCDE for treatment. There are 59 separate treatability study exemption tests required to test SCDE on Rocky Flats waste.

Beryllium Fines: Beryllium powder work consolidated commercial beryllium powder into metal parts by placing the powder into a mold within a beryllium-only glovebox and increasing the density of the powder using presses and a furnace. Paper wipes, gloves, and other materials may have become contaminated with beryllium powder during processing. After processing within the glovebox, beryllium particles were vacuumed into the house vacuum system. Depleted uranium and other metals were also collected with the beryllium because the house vacuum system serviced several areas in the building. Several subpopulations of this waste were also contaminated with solvents. These subpopulations require treatment by SCDE to remove the volatile and semi-volatile organic constituents before being solidified in polymer.

Cemented Composite Chips: Composite chips were generated during the machining of metal parts. The composite metal usually consisted of stainless steel and depleted uranium. The uranium was sometimes commingled with aluminum, beryllium, or copper. Occasionally, non-composite stainless steel, aluminum, beryllium, and copper parts were also machined in the process. There were four lathes regularly used for the machining of composite parts. Cutting oil flowed onto the part at the location of the cutting tool. After machining, the part was rinsed to remove the residual oil. The composite chips, cutting oil, and Freon-TF

Table 2: Rocky Flats Stored Low Level Mixed Waste Streams

MWIR #	Mixed Waste Description	Volume (M^3)
RF-W003	Cemented Composite Chips	95.4
RF-W005	Metal	163.13
RF-W006	Combustibles	1226.52
RF-W007	Roaster Oxide	66.36
RF-W009	Solidified Bypass Sludge	457.38
RF-W015	Fluidized Bed Incinerator Oil	38.27
RF-W017	PCB Liquids	39
RF-W020	Beryllium Fines	3.15
RF-W022	Incinerator Ash	10.92
RF-W023	Lead	34.69
RF-W024	Ground Glass	10.29
RF-W025	Used Absorbents	0.29
RF-W027	Paints	1.15
RF-W030	Leaded Gloves	3.57
RF-W031	Leaded Gloves-Acid	0.21
RF-W035	Glovebox Parts - Lead	0.42
RF-W042	Heavy Metal (Non-SS)	1.13
RF-W043	Glass	2.52
RF-W045	Insulation	2.94
RF-W046	Organics Discard Level	54.36
RF-W049	Miscellaneous Liquids	2.38
RF-W050	Soil & Cleanup Debris	406.05
RF-W054	Cyanides	0.42
RF-W055	Turnings	0.42
RF-W062	Solidified Organics	0.42
RF-W071	Particulate Sludge	87.6
RF-W074	Cemented Filters	4.14
RF-W075	Filters and Media	2.52
RF-W081	PCB Solids-Combustibles	10.81
RF-W082	PCB Solids-Metal	0.52
RF-W047	Analytical Lab Solutions	6.05
RF-W083	Excess Chemicals	6.69
RF-W084	Excess Chemicals	4.26
RF-W085	Excess Chemicals	2.94
RF-W086	Excess Chemicals	3.38
RF-WXXX	Excess Chemicals	30.13
	Total	2781.06

drained into the machine coolant reservoir and were later removed and placed in 55-gallon drums. The composite chips were completely submerged in reservoir liquid. The drums were transferred for composite chip cementation. The chips were removed from the liquid and allowed to drain for a short period of time before rinsing. A layer of Type I Portland cement mixed with water and sand was placed at the bottom of the drum. The drained chips were placed on top of the cement layer. Alternate layers of cement and chips were added to the drum while a vibrator mixed the contents. A top layer of cement was then added to cap the drum. Several holes were punched in the lower half of the drums to allow excess liquids to drain. Based on the mixture rule and the derived-from rule (EPA 1994), the cemented composite chips carry the listed codes associated with the reservoir waste from the lathes.

Cemented Filters: This material is either the filter media portion of High Efficiency Particulate Air (HEPA) filters or surface-water filters. Sock filters were used to prefilter operable unit 2 surface water prior to activated carbon treatment. Characterization of the surface-water filters is based on analytical data from the water being filtered. The filters are contaminated with carbon tetrachloride, trichloroethylene, and tetrachloroethylene. The surface water also contains chloroform, 1,1-dichoroethene, vinyl chloride, and carbon tetrachloride at below-RCRA regulatory levels. Used HEPA filters were processed to segregate those portions with high plutonium content from those with low content. This filter media can be free of acid contamination or can be heavily contaminated with acid residue. It can also be moist or dry. It could have originated from a production building and be contaminated with used solvents such as trichloroethane, carbon tetrachloride, and Freon.

Combustibles: Combustible wastes were produced by materials-handling and cleanup from production, research and development, laboratory, utility, custodial and maintenance activities. The combustible waste form includes wipes, gloves, personal protective equipment, cloth, paper, plastics, and mixed IDC's. Mixed Item Description Code (IDC) wastes are only generated outside the Protected Area and are not to contain more than 80 percent by volume of any single IDC. Combustibles are segregated by whether they were generated inside or outside the Protected Area, whether they are wet or dry (with wet defined as the material had to be wrung out before being placed into the container), and whether the waste is made of hard plastics. Combustibles were also segregated based on whether the waste is low level, transuranic, or a residue. Combustibles are contaminated with a large number of characteristic and listed hazardous constituents as combustibles were used in virtually every process at Rocky Flats. SCDE is targeted to treat those subpopulations that contain volatile or semi-volatile organic constituents and which will meet LDR after SCDE or after SCDE and polymer encapsulation. As shown in Table 2 and Appendix C, many of the combustibles are contaminated with cyanide or leachate. These wastes will require additional treatment.

Filters: Filters in this waste stream include HEPA filters (as described above), polyethylene filters, drybox filters, and plenum prefilters. Polyethylene filters are in-line cartridge filters used to remove particulate matter from specific fluid streams. The filters are one-piece, molded filters made from a red fibrous material which filtered particulate matter down to 5 micrometers (μm) in size. Polypropylene filters similar to the polyethylene filters were used to filter down to 5 or 1 μm-sized particles. Polyethylene filters are used in various liquid systems that include nitric acid and chloride acid systems, caustic systems, solvent systems, and water systems, and to filter particulate from the incinerator fume scrubber system. The drybox filters were used in atmospheres that could cause the filters to be contaminated with acids or bases used in chemical processing. The frame material will be either 3/4-inch fire-retarding, exterior grade plywood or wood particle board and 14-gauge cadmium-plated or chromized carbon steel. Neoprene, closed-cell, expanded rubber sockets, precoated with a rubber-based adhesive, are present an each filter. The filters as a whole are contaminated with a variety of characteristic and listed waste constituent codes, including solvents, metals, and cyanides. SCDE is targeted to treat a portion of this waste stream.

Glass: There are 12 drums of glass (not Raschig Rings) in the inventory. One drum contains leaded glove-box glass and 11 contain crushed fluorescent bulbs. The leaded glass is characteristic for lead and barium, and can be treated by solidification alone. The fluorescent bulbs contained mercury. The bulbs failed the Toxicity Characteristic Leaching Procedure (TCLP) [EPA 1995, Appendix I] in some cases so the bulbs are being managed as hazardous waste.

Ground Glass: This waste stream is almost identical to Glass. However, some of the drums of leaded glass are labeled with EPA codes for solvents and other metals. The reason for these codes is not known.

Heavy Metal: Heavy metals have been produced as by-products of Rocky Flats operations and include non-stainless-steel metals that are heavier than iron. Examples of this waste include crucibles, funnels, rods, and process fixtures. These items are made primarily from tantalum, tungsten, and platinum, but some parts could have been manufactured or contaminated with lead if the accumulation start date was prior to 1987. A new IDC was started in 1987 to separate lead parts from non-lead parts. This waste stream should be treated by polymer. However, the EPA code for mercury (D009) was assigned to this waste stream. The reason for this assignment is not clear. If mercury really is present, then SCDE can extract it from the metal prior to polymer macroencapsulation.

Insulation: Insulation consists primarily of aluminum oxide and silicon dioxide. This waste form also includes sweepings from insulation work cleanup, ceiling tiles, and plasterboard. Respirator cartridges, banding, and other combustibles, such as paper and gloves, contaminated with insulation could also be included in this waste. Maintenance, repair, and strip-out operations produced waste insulation. Insulation waste is generated by replacement of furnace heating elements, construction, maintenance, and demolition activities with the Protected Area. The insulation may have come in contact with listed constituents when leaks or spills occurred. Some of the insulation was visibly contaminated with sludge and salt produced in Building 374. This waste stream is like the combustibles and filters. SCDE will treat those subpopulations that apply.

Metal: The generation of metal materials at Rocky Flats was predominately through routine maintenance and strip-out activities. The maintenance operations generated material that ranged from screw-drivers and other tools to machine and process parts. The strip-out operations generated material upon process removal. This material included pipe work, machines, and any other metal material encountered through the process. Only three subpopulations are LDR restricted. One consists of painted metal conduit with lead. The paint is known to contain lead and is assumed to also contain chromium. The second subpopulation consists of metals contaminated with Saltcrete and Bypass Sludge generated in Building 374, and is assigned to codes for Saltcrete and Bypass sludge. This subpopulation will probably be treated by a cyanide washing technology followed by solidification, although SCDE may be required due to the listed solvent codes. The last subpopulation contains metal and parts from a cement mixer and bulldozer used to mix Pondcrete. This subpopulation will be handled in a manner similar to the painted metal conduit.

Particulate Sludge: Particulate Sludge consists of eight IDCs. Like the combustibles and filters, this waste stream is varied. During normal process operations, incinerator sludge was generated as a by-product of the Incineration Process in Building 771. The sludge was generated during the filtration of the potassium hydroxide scrubber liquid. The caustic solution from the scrubber was processed through a drum filter generating a damp sludge consisting primarily of the diatomite filter bed. Miscellaneous sludge was generated during the processing of residues where process pipe sludge, sludge dissolution heel, and filter plenum sludge were processed through nitric acid dissolution and sparging; in the analytical laboratory where soil and sludge samples from around the site were analyzed; and by the Rolling Process in Building 883 where quench sludge and uranium oxide sludge was produced. Oily Sludge includes a drum of oil sludge and four drums of solidified scintillation fluid waste. Firebrick was generated during maintenance operations in the incineration systems. Grit was generated during grit blasting operations primarily for cleaning steel and iron. Lead shielding was the most likely metal grit blasted, so the grit contains lead. The other three sludges are Miscellaneous Inorganic Sludge, Granulated Filter Media including pea gravel, charred bone, and granular activated carbon, and UO_2 Sludge from the filter press process. Multiple codes are assigned to this waste stream. Like the combustibles and filters, SCDE will be used when appropriate.

PCB Solids - Combustibles: This waste stream is like the combustibles, but with PCBs.

PCB Solids - Metals: These PCB solids are likely to be capacitors and small transformers, contaminated with solvents.

Soil and Cleanup Debris: The soil and cleanup debris waste form consists of blacktop, concrete, dirt, sand, and rock. It was generated by a variety of cleanup and construction activities. Soil and Cleanup Debris are listed with a variety of metals, organic compounds, cyanides, and leachate. SCDE will be required for a majority of the subpopulations. Cyanide removal, treatment for leachate, and polymer micro- and/or macroencapsulation will also be required.

Solidified Bypass Sludge: The solidified sludge consists of immobilized low level mixed materials from decontamination-precipitation and neutralization processes in the Building 374 Liquid Waste Treatment Facility. This waste stream contains multiple EPA codes as the sludge must be assigned the codes associated with the water that was sent to the processing system. Much of this waste stream will be handled by polymer microencapsulation.

Solidified Organic: Solidified organic wastes are cemented waste oils and solvents that were generated as a result of machining and tool degreasing. Most of the wastes fed to the solidified organic processes consisted of plutonium-contaminated oils and solvents. Waste oil and solvents were drained and pumped into storage tanks after machining and degreasing operations. The waste was then filtered to recover actinides. When the concentrations of plutonium and uranium were below transfer limits, the waste was transferred to the solidified organic process. Multiple EPA codes are assigned to this waste stream because the organics were commingled before solidification. Multiple treatment processes may be required to meet LDR requirements.

2.4 Other Sites

At present, insufficient coordination among DOE sites has accrued to detail all of the wastes that would benefit from execution of SCDE organic pretreatment. It is known that, at a minimum, four sites or their wastes, are considering application of SCDE to their wastes. These four include Hanford, Rocky Flats, Los Alamos National Laboratory, and Argonne National Laboratory.

The Los Alamos National Laboratory [LANL] has been involved with supercritical water oxidation as well as supercritical carbon dioxide precision cleaning and recently awarded an SCDE fabrication bid to Autoclave Engineers (Erie, PA). Among recent publications, LANL conducted operational cost studies of an SCDE system purchased from Autoclave Engineers (Barton 1994) and found that energy and material costs were extremely small relative to other, more conventional, solvent cleaning systems.

Many of the wastes described above for the Hanford site were received from the Argonne National Laboratory (Chicago, IL) [ANL]. These wastes were retrieved from a number of small tanks in a one-time effort to clean the tanks and eliminate the generation of wastes carrying unduly difficult treatment requirements. Specifically, the site standards laboratory had, historically, discarded wastes to these tanks. Following the cessation of waste accumulations in the tanks from the standards laboratory, the tanks were cleaned out. Thus, the existent waste stream will no longer be generated and no other SCDE applications are currently known for consideration of ANL wastes.

3.0 FACILITIES AND TREATMENT EQUIPMENT

The object of this section is to describe equipment, building and laboratory facilities available to support SCDE demonstration work for DOE. These facilities encompass both radiological and non-radiological laboratories, and both DOE and non-DOE facilities.

3.1 Hanford

Hanford laboratory space for evaluating SCDE to process mixed wastes will be available in Rooms 158 and 159 of the 306E Building (Figure 2), in the 300 Area at Hanford. The Process Engineering group's present laboratory facilities are in Building 377 for radiological work and Building 2703E for cold work. However, these facilities are slated to be closed by December 1995 and work done in these laboratories will be moved to the 306E Building.

Rooms 158 and 159 in the 306E Building (previously called the UO_2 Lab) were used as a low enriched uranium dioxide pellet fabrication facility from 1970 to 1987. The UO_2 Lab was shutdown to standby status in 1987 and contaminated equipment removed. Cleanout has been completed and only fixed contamination remains in these rooms. This lab, henceforth referred to as the PE lab, is being readied for use as a radiological facility for various bench and pilot scale tests to be performed by the Process Engineering (PE) group within the Engineering Testing and Technology Projects Department. Current plans are to have the PE hot lab ready for use by early January 1996.

Utilities available in the PE Lab are compressed air, piped argon, propane, and tap water. These interconnected rooms, covering approximately 420 sq. ft, currently contain four lab hoods, each 40" wide, and 15 ft of bench top space. All cabinets and hoods are anchored to walls to prevent spillage from a shock.

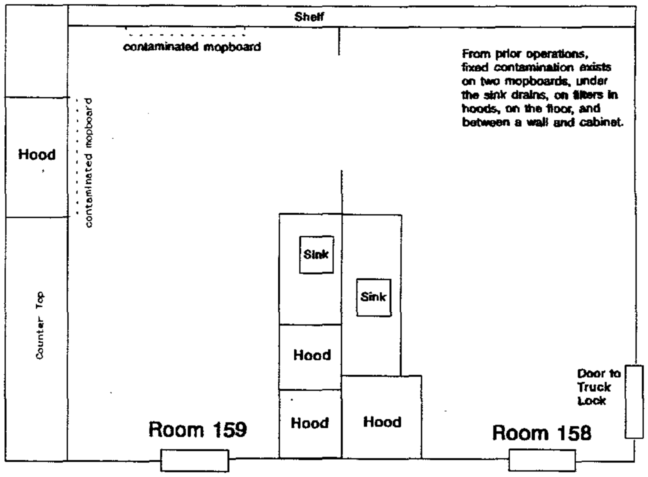

Figure 2: Building 306E, Rooms 158 and 159 Layout

Electric power at 110, 230, and 480 VAC is available in this lab. There are no drains out of the PE lab and all liquid effluents will be contained and disposed per established Westinghouse Hanford Company waste handling procedures. All test residues designated as mixed waste will be sent to the Central Waste Complex, for storage.

The fire loading of the room is very low (a very small amount of paper, electrical insulation, and a limited quantity of solvents). The PE lab is protected by a wet-pipe automatic sprinkler system. Actuation of the sprinkler system triggers an alarm in the 300 Area fire department, and firemen with their equipment can be on the scene within 3 minutes.

The PE lab is maintained slightly negative in air pressure with respect to the rest of the 306E Building, and its exhaust air is fed to a stainless steel filter plenum containing six high-efficiency particulate air (HEPA) filters located on the roof of the building.

The lab no longer has the fissionable material facility status. The entire exhaust and filter system for this lab was designed to meet the criteria for UO_2 facilities.

3.2 Rocky Flats

3.2.1 Hot Demonstration Facility at Rocky Flats

An automated sixty liter (sixteen gallon) mixed waste demonstration system, manufactured by Autoclave Engineers, has been procured by Rocky Flats. This system (Figure 3) will be located in a Rocky Flats building previously used for plutonium operations and has complete utilities to support the SCDE demonstration system and to allow work with actinide and fission product contaminated low level mixed waste. In addition, the system is being co-located with other technology demonstrations such as polymer microencapsulation, polymer macroencapsulation, and cyanide washing which are essential to a complete demonstration. This area is in Rocky Flats Building 777 rooms 455 and 457 (Figure 4).

The target date to complete system installation is September 30, 1996. This installation date includes completion of an initial systems operation test and a cold surrogate study. During the installation phase a parallel effort will be completed to notify the state of Colorado on each treatability study exemption (TSE) test that is planned and to obtain a research and development permit (RD&D) for longer term testing of the system. At the end of the installation phase, the system will be ready to treat low level mixed waste streams under these permits.

3.2.2 Cold Research Facility Based at the University of Colorado

The University of Colorado is currently working with Rocky Flats under a contract for development support. This contract provides a facility where a Rocky Flats owned one-gallon extraction system (Figure 5) is currently being used for SCDE laboratory demonstration. The University of Colorado also provides analytical support, graduate student support, and PhD level advisers. The cold one-gallon bench scale supercritical carbon dioxide system has been used for the last two years for several successful waste treatment studies and has completed demonstration at laboratory bench scale of the extraction of hazardous organic compounds from mixed waste. Future development is proposed at this facility to evaluate the extraction of hazardous metals and radionuclides from mixed waste with SCDE.

3.2.3 Industrial Partner Support

Final proposals by several possible industrial partners are being evaluated for in-kind cost sharing for the installation and demonstration of this technology at Rocky Flats and for eventual commercialization of this process. The industrial partner will also provide analytical services and support equipment modifications during the testing. The proposed work scope includes estimated participation by an industrial partner based on initial discussions with interested companies.

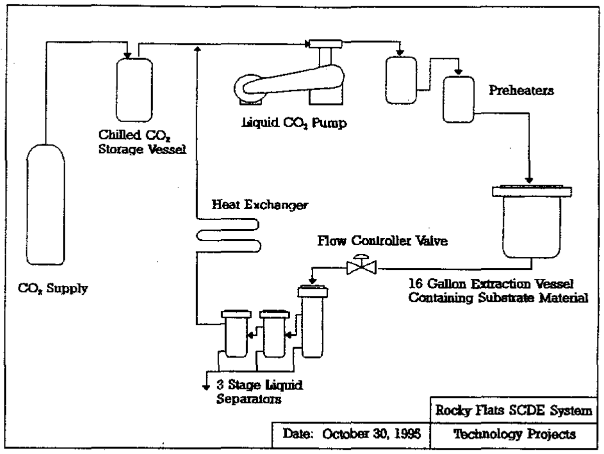

Figure 3: Rocky Flats Pilot Scale SCDE System

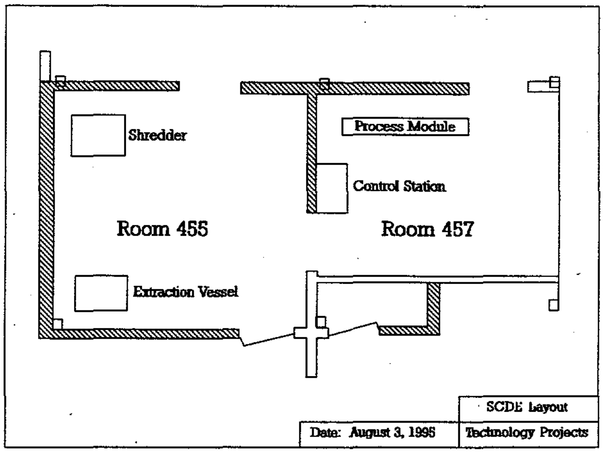

Figure 4: Rocky Flats Mixed Waste Treatment Facility

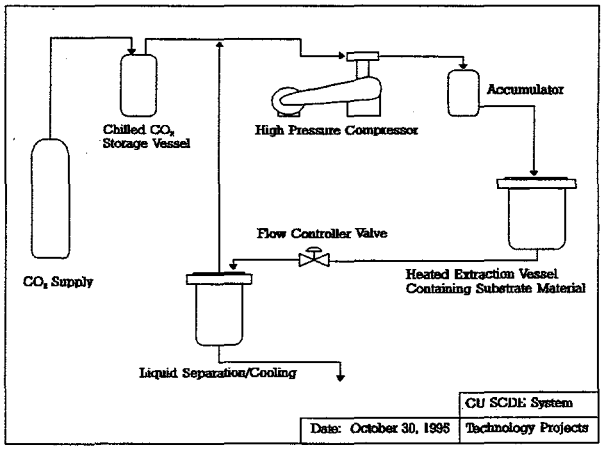

Figure 5: Rocky Flats Bench Scale SCDE System

3.3 Other Sites

Although work at Los Alamos is anticipated, the facilities and treatment equipment applicable to SCDE are unknown at this time other than those associated with precision cleaning and waste reduction studies [60L extraction system] (Barton 1994).

4.0 PRIOR WORK AND TECHNICAL EXPERIENCE

Each site proposing work for the EM-50 Mixed Waste Focus Area on SCDE has prior experience with waste handling, various forms of waste treatment, and with supercritical extraction.

4.1 Hanford

The staff and organization proposing to conduct the EM-50 work described in this document is that of the Westinghouse Hanford Company, Engineering Testing and Technology (ET&T), Process Engineering group.

4.1.1 Supercritical Extraction

Previous supercritical extraction for the Hanford Site has involved both products and waste treatments. Due to the differences in purposes, different organizations (indeed in different companies) have conducted that work.

Battelle's Pacific Northwest Laboratory (PNL) has been involved with the application of supercritical water oxidation for waste treatment as well as supercritical carbon dioxide extraction for precision cleaning (Phelps *et al.* 1994, Phelps *et al.* 1995, Snowden-Swan 1994). The target of PNL's precision cleaning work has been product surface decontamination for products such as optics, laser components, and medical devices which suffer performance degradation when surface contamination exists. This work demonstrated effective cleaning of components beyond typical precision cleaning standards of 10 $\mu g/cm^2$ as well as providing a review of the marketability and current market application of such cleaning processes.

The Westinghouse Hanford Company has previously directed research and demonstration of supercritical carbon dioxide extraction upon contaminated soils. Moody (1993) reported the performance of SCDE upon Hanford soils contaminated with PCBs, dioctyl phthalate, and diesel fuel. The application of SCDE upon Hanford soils was targeted at soil remediation from previous operations and waste handling while eliminating the destruction of fertility resulting from thermal treatment of these soils. His studies, with the Phasex Corporation (Lawrence, MA), scoped extraction performance under conditions varying from 41.4 MPa (6,000 psi) and 60°C down to approximately 9 MPa (1,300 psi) and 23°C. Extraction performance under these conditions yielded between 95% and 99% removal. Soils treated in this work, and intended to be treated if pilot-scale work had proceeded, were not radioactively contaminated.

4.1.2 Waste Treatability Studies

The equipment and staff proposed in address of Hanford demonstration of SCDE includes the capabilities of the site Chemical Engineering Laboratory (2703E building), the Geotechnical Engineering Laboratory (377 building) and the Development, Fabrication and Test laboratory (306E). The former two laboratories are currently slated for closure, in cost cutting efforts, with their capabilities and personnel reassigned to the 306E building. Recent work at the 377 building included treatability studies of the solidification (cementation) of N-Reactor fuel fabrication wastes which had been evaporated in the 183-H Solar Basins. Other treatability studies have recently included ozonation (Colby 1993a) and electrochemical oxidation (Colby 1993b) of organic constituents in Hanford tank waste simulants. Additionally, the staff of the Chemical Engineering Laboratory have been responsible for the preparation of nearly all tank waste simulants used in surrogate testing on the Hanford site.

4.1.3 Hazardous Material Handling

Current operations within the ET&T Process Engineering organization include the dismantling, packaging, and shipping of sodium-, lithium-, and NaK-wetted test and prototype loops which were constructed and used in the design of the Fast Flux Test Facility (FFTF), the sodium cooled reactor built at the Hanford site to test assemblies for the Clinch River Breeder Reactor program. Similarly, the ET&T operations are currently conducting a RCRA cleanup of the Hanford site Large Sodium Fire Facility, used for tests in designing safety systems for the FFTF.

4.1.4 Large-Scale Waste Treatment

Large scale treatments directed by the ET&T Process Engineering organization have recently included plasma calcination and plasma vitrification of Hanford tank waste simulants.

Plasma calcination involved the calcination of approximately 3,400 L of tank waste simulant in two tests of a continuous plasma-fired cupola yielding a sodium hydroxide/sodium carbonate/sodium aluminate solution (Delegard *et al.* 1994). This work was conducted at the Westinghouse Plasma Center at Waltz Mill (Madison, PA). Calcination of tank wastes was desired and tested for purposes of minimizing tank waste safety concerns with organic wastes at high nitrate concentrations while minimizing high level waste glass volumes by significantly enhancing the solubility of chromium and aluminum and allowing these materials to be separated from waste streams destined for deep geologic disposal.

Plasma vitrification involved the production of 13.7 Mg of vitrified Hanford tank waste at loadings of greater than 19% Na_2O in a borosilicate glass. This work was also conducted at the Westinghouse Plasma Center at Waltz Mill (Madison, PA). Three scoping tests of the vitrification process were conducted leading up to a twenty-six hour demonstration run (Hendrickson 1995a, Hendrickson 1995b). Plasma vitrification was conducted to support test needs for the Hanford Low-Level Waste Vitrification program.

4.2 Rocky Flats

4.2.1 Supercritical Extraction

Rocky Flats has procured a sixty liter SCDE system for the demonstration of the process with actual waste. This system has the capability to have a second extraction vessel added which would allow it to be run semi-continuously. It is also designed to recycle the carbon dioxide. With both extraction vessels, the system could meet processing requirements for mixed waste treatment of Rocky Flats once the demonstration is complete. Once funding has been identified to install the system, actual low level mixed waste can be treated within nine months under Treatability Study Exemptions and Research, Development and Demonstration permits.

Bench-scale development of supercritical carbon dioxide extraction of organic compounds has been completed. This development was carried out at the University of Colorado on a four liter system. Volatile organic compounds, semi-volatile organic compounds, and PCB surrogates have been successfully extracted from solid matrices. Solids tested include: cotton, paper, four types of plastic, neoprene, Oil Dri, soil, glass, and metal. This testing indicates that SCDE can treat all of Rocky Flats' low level mixed solid waste contaminated with hazardous organic substances.

For the bench scale development extraction runs were limited to one vessel volume of supercritical fluid exchanged (Teter 1994). After extraction, the sample was analyzed for residual organic contaminants by gravimetric analysis and with soxhlet extraction. All of the solvents used for these studies were extracted from all of the substrates using identical operating conditions. Flow and surface area contact, not higher pressures, were the important factors in the rapid extraction of the organic compounds (Brown *et al.* May 1995). The time that a sample was aged did not affect the extraction efficiency.

Table 3 summarizes typical extraction results for volatile organic compounds, semivolatile organic compounds, and water from various substrates. Extraction efficiencies for volatile organic compounds and water are determined by gravimetric analysis of residues remaining on substrate following a supercritical fluid extraction. Extraction efficiencies for semivolatile organic compounds were determined using the results from the soxhlet extraction.

All of the solvents used for the semi-volatile experiments were chosen as PCB surrogates with varying polarity and boiling points. To test the performance under extreme conditions, heavy solvent loading and sample aging techniques were used. These data demonstrated that all of the solvents tested are very easy to extract under identical operating conditions. Gravimetric analysis indicates that for polyethylene and polyvinylchloride, the CO_2 extraction is probably also removing some plasticizers from the matrix, since the extraction efficiency is over 100% for plastic substrates.

Table 4 shows typical extraction efficiencies for biphenyl, a solid at room temperature, dissolved in hexane and loaded onto the various substrates. This combination was aged to allow the biphenyl enough time to permeate into the pores of the substrate. After the aging process was complete the hexane solvent was evaporated off before the sample was

Table 3: Typical Results for Volatile/Semivolatile Extractions

	Sample Age	Solvent Loading	Solvent Removed
Carbon tetrachloride, Trichloroethane, Actone Mixed Matrix	1 week	Various	99.96 %
Di/trichlorobenzene, Cotton/Paper	259 hours	270 %	99.95 %
Di/trichlorobenzene, Polyethylene	114 hours	380 %	99.94 %
Di/trichlorobenzene, Neoprene	309 hours	160 %	99.81 %
Water, Cotton/Paper	--	390 %	63 %

Table 4: Typical Results for Biphenyl Extractions

	Sample Age	Solvent Loading	Solvent Removed
Cotton and Kim Wipes	502 hours	8.3 %	99.98 %
Spun Polyethylene	526 hours	18.7 %	99.93 %
Polyethylene	478 hours	4.1 %	99.77 %
Neoprene	598 hours	3.3 %	95.58 %
Latex	622 hours	4.8 %	97.68 %
PVC	646 hours	2.1 %	97.11 %

processed. The extraction efficiency was determined by soxhlet extraction followed by gas chromatography analysis.

Several additional bench-scale studies have also been completed. Preliminary tests using liquid carbon dioxide at room temperature gave similar results for most substrates. Experiments were completed testing the ability of SCDE to remove water from various substrate materials. These tests confirm that the supercritical carbon dioxide technology can be used as a drying technology as well as an effective organic compound extraction technology, although there are some system and cycle time limitations to water extraction.

Motor oil and machine coolants that contain paraffin and long chain polymers tended to be more difficult to extract in SCDE than other organic compounds; however, these oils can be extracted using longer extraction times. Ultrasonic agitation was tested to determine if it would improve the extraction efficiency of difficult to extract compounds. These tests indicate that any improvements are not significant.

4.2.2 Related Development at Rocky Flats

The Technology Integration organization within the Kaiser-Hill Company and its predecessor under EG&G-Rocky Flats have been involved in a fairly large effort to develop technologies to treat mixed waste and residue material, using both incineration and alternatives to incineration, for the last five years under a fairly rigid compliance agreement with the EPA and the State of Colorado. The following discusses some of that work which is needed in conjunction with a demonstration of SCDE to demonstrate a complete system to treat a wide variety of wastes such as those found at Rocky Flats and other DOE sites.

The Polymer Macroencapsulation of Debris project is a bench and pilot-scaled demonstration of waste immobilization using polyethylene or epoxy resin as the encapsulant. Demonstrations have been completed under Treatability Study Exemptions (TSEs) and are scheduled under Research, Development and Demonstration permits. Candidate waste streams are those that meet the definition of "debris" under RCRA and are low level mixed waste. Polymer Macroencapsulation has also been used to treat radioactively contaminated lead parts.

The goal of the Polymer Microencapsulation project is to develop and demonstrate the encapsulation of hazardous and radioactive waste streams using thermoplastic and thermosetting polymers. The specific objectives of the project are to demonstrate that this technology will provide a reliable system to microencapsulate numerous small volume salts and sludges, spray dried salt waste, bypass sludge, and secondary wastes from organic destruction technologies.

The Cementation Development project is developing RCRA and LDR compliant cement formulations for immobilizing hazardous radioactive mixed wastes including a variety of sludge and miscellaneous waste forms. The effort entails research to find suitable formulations, equipment selection, facility conceptualization, procedure development, and training.

The Low Temperature Thermal Desorption project was initiated in conjunction with SCDE to evaluate method of removing organic compounds from the surface of solid substrates. A pilot-scale demonstration was completed using surrogate waste, actual hazardous waste, and against one drum of actual radiologically contaminated combustibles. This technology competes with SCDE.

The Microwave Vitrification of Low Level and Transuranic Wastes project is demonstrating the operational reliability of solidifying LLM sludge in a full-scale system, and transuranic mixed waste using a bench-scale system. Microwave vitrification produces a glass encapsulated waste form.

The Alternatives to Incineration project team is experimentally evaluating alternative treatments by managing technical efforts at Rocky Flats, DOE sites, and industry facilities to gather experimentally derived data. This ongoing project's goal is to develop a complete suite of technologies that Rocky Flats can substitute for incineration systems to treat combustible, radioactively contaminated mixed wastes and nuclear residues. After extensive evaluation, two technologies have been selected for on-site demonstration with actual low level mixed waste: catalytic chemical oxidation and liquid chemical extraction. Catalytic chemical oxidation has completed laboratory scale demonstration against Rocky Flats waste types and has been proven to be effective in destroying solid combustible and liquid wastes. A 10-gallon demonstration system has been designed. Liquid chemical extraction will be used primarily to remove cyanides from solid waste substrates. Initial laboratory testing has been completed on this technology.

The Mercury Stripping project is a demonstration of a thermal desorption process as a means to strip mercury from hazardous radioactively-contaminated spent fluorescent lamps. The demonstration will take place as a RCRA treatability study. The crushed lamps will be heated in a vacuum furnace to volatilize the mercury, followed by condensation to separate and collect the mercury for subsequent disposal. This project is part of the Expedited Technology Demonstration program.

Ultraviolet/Peroxide Oxidation was successfully demonstrated in FY 1994 under RCRA treatability study exemption (TSE) provisions. The State of Colorado requested that Rocky Flats permit this technology for treating future waste volumes, but the activity has not been funded in FY96. The technology uses ultraviolet radiation and hydrogen peroxide to destroy the hazardous organic portion of hazardous radioactively contaminated mixed waste. This project is part of the Expedited Technology Demonstration program.

Cyanide destruction by electrochemical chlorination is part of the Expedited Technology Demonstration program developed to treat mixed waste spent plating bath wastes and excess chemical cyanides. The technology was successfully demonstrated under a TSE. A modification to the Rocky Flats Part B permit is pending approval before the process goes into operation.

4.3 Other Sites

It is believed that Lawrence Livermore National Laboratory has had some work with mercury retort operations for radioactive materials. This experience will support further treatments of Hanford and other site wastes.

5.0 WORK SCOPES PROPOSED

Work scopes described within the TTP packages of Hanford (RL46MW59) and Rocky Flats (RF15MW58) are tabulated in Table 5 and further described within this section. It is recognized that each work scope had been prepared independently and were subsequently amended to conform to collaborative efforts. Complete recommendations are provided in Section 7.1.

Table 5: Supercritical Carbon Dioxide Proposals

Hanford			Rocky Flats		
Work Scope Activity Description	Interval	Budget ($K)	Work Scope Activity Description	Interval	Budget ($K)
			FY96		
Assessment and Recommendation Report of Hanford/Rocky Flats Collaboration on Supercritical Carbon Dioxide Extraction	10/1/95 - 11/17/95	$50K	Assessment and Recommendation Report of Hanford/Rocky Flats Collaboration on Supercritical Carbon Dioxide Extraction	10/1/95 - 12/29/95	$50K
Applicability, Technology Assessment and Benefits Analysis of the Application of Supercritical Carbon Dioxide in the Extraction of Organic Contaminants from Mixed Wastes.	10/1/95 - 1/15/96	$76K	Bench Scale Studies (CU)	10/2/95 - 12/29/95	$50K
			Bench Scale Studies (CU)	1/2/96 - 10/29/96	$80K
Supercritical Carbon Dioxide Extraction Equipment Acquisition.	12/15/95 - 4/30/96	$244K	**Demonstration Scope**		
			Project Plans	1/2/96 - 9/30/96	$116.3K
			Safety System Analysis	1/2/96 - 5/31/96	$16.2K
			System Engineering	1/2/96 - 3/1/96	$100K
			Permitting	1/2/96 - 7/26/96	$62K
Test Plan for the Extraction of Organic Contaminants from Mixed Waste Matrices Using Supercritical Carbon Dioxide.	5/1/96 - 2/28/97	$300K	Demonstration System Installation	1/2/96 - 7/26/96	$229.4K
			Demonstration Systems Operations Testing	7/29/96 - 9/30/96	$42.3K
			Total FY96		$746.2K
Test Report of the Extraction of Organic Contaminants from Mixed Waste Matrices Using Supercritical Carbon Dioxide.	1/1/97 - 5/31/97	$193K	**FY97**		
			Demonstration Operations (Initial Run)	10/1/96 - 12/1/96	$128.6K
			Continuing Demonstration Operations	12/2/96 - 9/30/97	$597K
			Total FY97		$725.6K
Total		$863K	Total		$1,471.8K

5.1 Hanford

5.1.1 Work Scope

The proposal submitted to EM-50 early during 1996 included four milestones for the demonstration of SCDE upon Hanford mixed waste streams. Following review by EM-50, an additional, first task of collaborative analysis was added. A review of the description of those milestones is appropriate and provided herein.

The first milestone document (this document) provides an assessment of the needs and benefits of task work at the Hanford and Rocky Flats sites and recommendations on the combination of the task work between sites and future work at the Hanford site as a result of that recommendation.

The second milestone, originally proposed first, is a document that would provide the technical survey and analysis of applicability and benefits (e.g. cost of treatment and disposal) of the implementation of this extraction with these wastes.

The third milestone provided that equipment for the extraction test demonstrations would be acquired (purchase or lease dependent upon necessity of demonstration with radioactively contaminated wastes). Discussions with equipment manufacturers have substantially supported previous cost estimates for demonstration scale SCDE equipment. In queries to Fluitron, Inc (Ivyland, PA), an informal estimate (± 10%) of $70K was given for a manually operated 8L extraction system based upon a compressor (no chiller pump), a 15L reservoir, and 1L bolted separator with the system constructed of 316 SS and operated in the region of 11.7 MPa (1,700 psi) and 50°C. A similar inquiry to Supercritical Technology Consultants (Allentown, PA), yielded an anticipation of higher automation and system ratings with a consequent estimate of $125K to $150K. A cost factor of two, based upon pressure ratings and automation appears widely accepted in this industry. Additional data received from Autoclave Engineers (Erie, PA) yielded cost estimates for fully automated systems of their Superscrub[5] product line in Table 6.

Table 6: Superscrub™ Product Line Overview

Main Vessel Volume (L)	CO$_2$ Flow Rate (kg/hr)	Price Range ($1,000s)
13	114	100 - 150
30	227	180 - 240
56	340	250 - 330

The fourth milestone was to complete a task, waste component, and equipment specific test plan, written to conduct the experimentation and collect appropriate data for the demonstration of supercritical carbon dioxide organic compound extraction from the subject waste matrices. All appropriate permitting, equipment configuration, installation, startup, and full test plans are within the scope of this milestone.

The final milestone was to provide a final report on the demonstration of supercritical carbon

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[5] Superscrub is a trademark of Autoclave Engineers, Erie, PA.

dioxide extraction of organic contaminants from the mixed waste matrices tested. The initial needs and expectations would be compared to test results for recommendations of implementation at the Hanford Site.

5.1.2 Cost Estimate

Initially proposed as $340K in FY 1996 and $495K in FY 1997, the MWFA has preliminarily proposed authorization of $50K in the first quarter of FY 1996 to establish and evaluate collaboration with Rocky Flats followed by $545K in FY 1997. However, in accordance with the prior proposal, and supplemented by the first collaborative task, projected costs to completion remain at $863,170.

Cost detail for this estimate is provided in Table 7. Task numbers used in Table 7 are those described in the sequence of Table 5 for Hanford and in Section 5.1.1.

Table 7: Hanford SCDE FY 1996-1997 Budget Estimates

Task	Labor (mo)	Labor ($)	Support	Analysis	Services	Equipment	Lab Siting	G&A	Equip O/H	Total
1	2.25	$33,150	$4,248		$7,500			$4,862	$240	$50,000
2	4.375	$64,458	$3,000					$8,770	$0	$76,228
3	5.625	$82,875	$5,000		$5,000	$135,000		$11,424	$4,480	$243,779
4	12.5	$184,167		$45,000	$5,000	$15,000	$20,000	$29,792	$1,280	$300,238
5	7.5	$110,500	$10,000		$5,000		$50,000	$15,665	$1,760	$192,925
Total	32.25	$475,150	$22,248	$45,000	$22,500	$150,000	$70,000	$70,512	$7,760	$863,170

5.2 Rocky Flats

The following work scope breaks the proposed Hanford/Rocky Flats collaboration of SCDE development into two areas. The first area involves the bench scale studies in the extraction of newly defined waste streams found in this collaboration. The second involves the installation and demonstration of a mixed waste demonstration scale system and subsequent treatment of samples from both Rocky Flats and Hanford waste streams. The second list of tasks is costed based on cost sharing by an industrial partner.

5.2.1 FY96 Work Scope

5.2.1.1 Bench Scale Studies

The University of Colorado facility will be used primarily as a support lab for the mixed waste development effort. Work scope will consist of the testing of chelating agents for actinide and hazardous metals separation from waste and soil using surrogates based on Hanford and Rocky Flats waste streams.

Rocky Flats: $40K
University of Colorado contract: $80K

5.2.1.2 Hot Demonstration

The following list of tasks are required to install the new SCDE system and complete all related activities to begin a Hanford/Rocky Flats mixed waste treatment demonstration in the first quarter of FY97 assuming a January 1996 start date. It is proposed that these tasks be completed with $550K in FY96 and $656K in FY97 through the proposed Rocky Flats SCDE activities and in-kind technical support from the commercial partner. The commercial partner estimates for each activity are based on an equivalent reduction in hours and costs, applicable to the commercial partner, from the Rocky Flats SCDE activities.

5.2.1.3 Project Plans

Demonstration project planning consists of preparing the Demonstration Test Plan, the System Operation (SO) Test Plan, the Sampling and Analysis Plan, and the Midyear and Year End Status Reports. The commercial partner and Rocky Flats will co-author the Demonstration Test Plan, and SO Test Plan. The commercial partner will author the Sampling and Analysis Plan and Rocky Flats will author the Midyear and Year End Status Reports.

Rocky Flats Cost: $116.3K
Commercial Partner: 476 labor hours

5.2.1.4 System Safety Analysis

This Safety Analysis will be used to ensure that the SCDE system and operating area provide a minimal risk working environment for operating and support personnel. The commercial partner will prepare the supporting documentation for the Safety Analysis and complete all system safety reviews and analysis. Rocky Flats will provide support as required for this effort.

Rocky Flats Cost: $16.2K
Commercial Partner: 600 labor hours

5.2.1.5 Systems Engineering

Systems engineering includes refinement of waste handling and radiological control systems designs. The commercial partner and Rocky Flats, along with Site Radiological Engineering, will define the radiation control requirements, design the containment based on these requirements, evaluate the existing shredding equipment, design the shredder modifications, and evaluate and define the hoisting requirements for the extraction vessel liner. The commercial partner will design any required modifications to the existing shredding equipment and will provide radiation containment or in process analytical monitoring equipment. Rocky Flats will procure the radiological containment and provide the hoisting equipment and any remaining radiation control equipment.

Rocky Flats Cost: $100K
Commercial Partner: 718 labor hours + modifications + possible radiation control equipment.

5.2.1.6 Regulatory Permitting

Rocky Flats will prepare and maintain the documentation for the following: RCRA Treatability Study Exemption, NEPA, Clean Air, Readiness Review, and RD&D. The commercial partner will provide assistance and expertise to support preparation of these documents.

Rocky Flats Cost: $62K
Commercial Partner: 250 labor hours

5.2.1.7 Demonstration System Installation

Installation of the EviroPro[6] SCDE system will consist of operator training at Autoclave Engineers (Erie, PA), preparation of the demonstration site, shipment of the system from Autoclave, preparation of the required safety and radiological control documentation, and attendance at Plan of the Day and operations specific meetings. Rocky Flats and the commercial partner will complete operator training, assist in the preparation of the demonstration site, prepare the required safety and radiological control documentation, and attend the Plan of the Day and operations specific meetings. Rocky Flats will provide the funding to purchase the required hardware for the installation, engineering support, radiological operations support, and craft installation hours. The commercial partner will arrange and pay for the shipment of the EnviroPro system from Autoclave Engineers.

Rocky Flats Cost: $229.4K
Commercial Partner: 375 labor hours + Provide solvent capture apparatus

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[6] EnviroPro is a trademark of Autoclave Engineers, Erie, PA.

5.2.1.8 System Operations Testing

Before routine operation can begin, systems operation (SO) testing will be completed. A job safety analysis is required prior to SO testing to identify potential operational hazards and preventative measures. The SO test will include shakedown tests and a verification study using surrogate waste. A systems performance report will be prepared documenting the results of the SO test. Rocky Flats and the Commercial partner will attend plan of the day meetings, co-author the Job Safety Analysis and other safety related documentation, and will complete the SO testing defined in the test plan and the verification study. Both Rocky Flats and the commercial partner will co-author reports on the performance of the system. The commercial partner will provide all waste sampling and analytical services required for these tests.

Rocky Flats Cost: $42.3K
Commercial Partner: 348 labor hours + Sampling and Analytical Services

5.2.1.9 Summary of FY96 Cost Estimate

Rocky Flats Cost: $566.2K for demonstration, $130K for CU development, $50K for Report
Commercial Partner: 3107 labor hours + Waste Handling Equipment Modifications + Sampling and Analytical Services + Solvent Capture System

5.2.2 FY97 Work Scope

5.2.2.1 Demonstration Operations (Initial Run)

Demonstration operations will be completed to step through the operating procedure during the treatment of actual low level mixed waste. Demonstration operations will also be completed to allow time to dynamically evaluate radiological containment during operations. The first run will be evaluated so that changes in operating protocol can be made before continuous operations begin. Rocky Flats and the commercial partner will continue with demonstration operations once the findings from the initial run have been completed. The commercial partner will provide sampling and analytical services to determine extraction efficiencies.

Rocky Flats Cost: $128.6K
Commercial Partner: 336 labor hours + 336 hours of sampling and analytical services (including supplies)

5.2.2.2 Continuing Operations

Demonstration operations will continue through FY97 to demonstrate this technology on several low level mixed waste streams at Rocky Flats. These waste streams will be determined during the FY96 project planning phase. Rocky Flats and the commercial partner will continue with demonstration operations once the findings from the initial run has been completed. The commercial partner will provide analytical services to determine extraction efficiencies of the organic solvents from the various low level mixed waste stream samples treated during this demonstration.

Rocky Flats Cost: $597K
Commercial Partner: 1696 labor hours + 1696 hours of sampling and analytical services (including supplies)

5.2.2.3 Summary of FY97 Cost Estimate

Rocky Flats Cost: $725.6K
Commercial Partner: 4064 labor hours + Sampling and Analytical Services

Total Project Cost: $1,471.8K

6.0 COMPATIBILITIES/INCOMPATIBILITIES

The object of this section is to describe synergism, simple compatibility, and internal and or external conflict in collaboration between Hanford and Rocky Flats in application of SCDE to DOE wastes.

6.1 Waste Streams

Preliminary analysis of the waste streams described for Hanford and Rocky Flats finds that the materials are substantially compatible with regard to metal and organic contaminants as well as waste descriptions in the realm of supercritical carbon dioxide extraction. That is, although most of the wastes at Rocky Flats are soils and step-off pad wastes and those of Hanford are sludges, the material matrices do not make an irreconcilable difference between the stream treatments. The metal contaminants are primarily unaffected by the proposed treatment. The organic contaminants present in the wastes will vary, that variance may require slightly differing operating conditions; however, such operating conditions variance (pressure and temperature range) would be expected to be easily within the range of capability of any acquired SCDE system for this purpose.

However, it appears that significant incompatibilities between site waste streams based upon the radioactivity of the materials may exist. The Rocky Flats site, having worked only with triggers, is not currently contaminated with fission product waste. As such, none of their current facility procedures and safety analyses address fission products. Additionally, it is understood that the current Rocky Flats Site Treatment Plan is predicated upon the assumption that wastes from other sites will not be shipped to Rocky Flats for treatment. Some latitude in this matter may be available for the treatment of samples of material.

As described below, availability of incineration may significantly eliminate the waste streams considered herein; however, one small stream of high-mercury content waste remains at Hanford that requires organic extraction.

6.2 Facilities and Treatment Equipment

Rocky Flats has acquired and anticipates delivery of a sixty liter SCDE system. Anticipated extraction equipment for the Hanford site has not been procured. Both sites have targeted facilities for radioactive operations, the Hanford laboratory facilities are anticipated to be able to conduct radiological SCDE work in July 1996 while Rocky Flats anticipates hot operation in October 1996. With the rugged design (specified for wide operational ranges and ranging experimental work) of the Rocky Flats SCDE system, it is recommended that demonstration work on all wastes be conducted in this system if possible.

6.3 Work scopes

The work scopes described in Section 5 are not directly conflicting. In fact, the studies proposed therein are synergistic in that they demonstrate extraction of different materials in different substrate matrices. However, as described in Appendix A, essentially all of the target organic contaminants are *fully miscible* in supercritical and subcritical carbon dioxide. If the second set of tasks for Rocky Flats, those including treatment demonstration of Hanford wastes, may be completed, the work scope proposed for Hanford would become functionally redundant.

6.4 Other Applicable Treatment Availability

As briefly indicated in Section 1.2.2.1, the Hanford site has been in the process of acquiring offsite thermal treatment (incineration) capacity for low-level radioactive wastes. The first *Commerce Business Daily* notice for potential bidders for this project was January 30, 1992. Subsequent notices were published on December 27, 1993, and March 8, 1994. A large number of bids were received. From those bids, three finalist companies were requested to provide best and final offers in March 1995. On November 3, 1995, a contract was issued to Allied Technology Group (Freemont, CA) for this thermal treatment. This successful bidder proposed the use of plasma systems for low level mixed waste treatment.

In context, the contract requires the vendor to build and permit a low level mixed waste thermal treatment facility near, but not on, the Hanford site within five years of contract execution (i.e. 2001). Contractually, DOE does not guarantee a minimum waste volume, but expresses an estimate of 3,585 m^3 of contract waste during contract years six through ten. Contract years eleven through fifteen would be one year options with expected volumes to reach 5,120 m^3 in total.

The consequence of this procurement is that incineration treatment is to be available for all but 5 m^3 of over 1,500 m^3 of existent organically contaminated drummed mixed waste at the Hanford site. In addition, because of the small contractual volumes of waste described, the treatment unit will be desirous of additional feed and should easily welcome low level mixed waste from Rocky Flats. Thermal treatment of Rocky Flats wastes near Hanford would eliminate the need for SCDE application at that site.

7.0 RECOMMENDATIONS

The Rocky Flats development of supercritical carbon dioxide treatment of low level mixed waste has been in progress since 1991. During this time, several advances have been made in system design, operating protocol, and bulk waste treatment techniques. Taking these advances and current information and contingencies into account, this section provides recommendations of work scope and funding by site in the implementation of SCDE demonstration by EM-50.

7.1 Work Scope

It is the recommendation of this report that Rocky Flats be supported in completing the installation of the new SCDE system at Rocky Flats in FY96, with an intent of beginning solvent extractions on actual Rocky Flats mixed waste samples in October 1996. A contingent recommendation of this report is that, pending formal notice of acceptability of Hanford site wastes for treatability studies at Rocky Flats, that Hanford be supported in demonstrating SCDE treatment effectiveness upon waste streams described in proposal RL46MW59 and 5.1.1.

At Rocky Flats, extractions of a wide variety of waste types will be completed under TSE permits with an RD&D permit for operations against larger volumes of waste to follow. During the FY96 installation and support document preparation stage, samples of waste from Hanford will be selected and prepared for shipment to Rocky Flats.

This sample waste will be staged to Rocky Flats in September of 1996 for the FY97 demonstration. Hanford personnel will support the testing at Rocky Flats by assisting in the preparation of the Demonstration and Operating Test Plans and by preparing the waste samples for shipment to Rocky Flats. The goal of this part of the demonstration is to demonstrate this technology with Hanford low level mixed waste streams to allow implementation of the technology and not to treat entire waste streams. This recommendation is based on the fact that Rocky Flats has already provided a facility capable of this kind of waste treatment processing and purchased an automated sixty liter system for this application. This recommendation is further based on the fact that an industrial partner has offered support of the mixed waste demonstration at Rocky Flats by providing analytical support, equipment modifications, and support personnel. If Hanford waste sample shipment to, and treatment at, Rocky Flats is not possible, this report recommends continued demonstration support at Hanford.

This report also recommends the continued funding of the cold surrogate laboratory at the University of Colorado. This funding will provide an inexpensive cold support lab for the mixed waste demonstration effort and will also provide for the continued development of SCDE for the extraction of metals and radionuclides using chelating agents in supercritical carbon dioxide. The university has completed several solubility studies of metals such as mercury and chromium and is planning to complete solubility studies using cerium(IV) as a surrogate for actinide materials. The completion of this work will lead, not only the extraction of hazardous organic compounds from low level mixed waste, but also to the extraction of hazardous metals and actinides.

7.2 Site

Providing that Rocky Flats will be able to accept Hanford wastes for treatment study, the sites proposed for SCDE support are at Rocky Flats and the University of Colorado. These are anticipated to supply both radiological and non-radiological demonstration facilities.

7.3 Gains/Losses/Synergistic Effects

The successful development and implementation of SCDE could remove selected waste streams at both the Hanford and Rocky Flats sites from LDR prohibition status. A demonstration at Rocky Flats will help to define operating and treatment protocol for actual treatment systems at both sites and would demonstrate this technology in actual waste treatment operations. The sixty liter system, being used for the Rocky Flats demonstration, is robust enough to be used for continued mixed waste treatment operations once the demonstration has been completed. This use of this system for continued operations will eliminate most of the cost of purchase and installation of this technology as part of a line item capital project. The number of years to complete the treatment of the entire inventory of Rocky Flats waste streams applicable to SCDE would be reduced from eight to four years.

Because SCDE has been used in several applications in industry, skid-mounted SCDE systems of the approximate size procured by Rocky Flats are available as standard off-the-shelf items at prices ranging from $200K for a small unit to $400K for a large unit. Installation and implementation of a skid-mounted hot treatment unit can be completed within a six month time frame for a cost of about $500K. This makes this technology a useful resource for the mixed waste treatment at sites in the DOE weapons complex as well as commercial sites.

Due to the advent of thermal treatment capacity for low level mixed waste expected near Hanford from recent contractual assignment, SCDE must, however, be reconsidered in application at that site in organic contaminant removal. It is entirely possible that DOE may soon determine that is advantageous in cost and risk to use Allied Technology Group facilities constructed near Hanford for low level mixed waste thermal treatment to treat Rocky Flats wastes. Under such a scenario, SCDE activities at Rocky Flats would be minimized and SCDE demonstrations for Hanford waste streams requiring organic contaminant extraction could not be conducted. However, under the Rocky Flats compliance order, Rocky Flats must continue to pursue the demonstration and implementation of SCDE until such time that an alternative treatment solution has been proven.

7.4 Cost Estimate

The complete cost for the CU development is $130K in FY96. The complete cost of the mixed waste demonstration at Rocky Flats is $746.2K in FY96 and $725.6K in FY97 which will allow a large number of waste types to be tested. With Hanford wastes shipped to Rocky Flats for demonstration, the Hanford sampling, analysis, packaging, shipping, and administrative costs would be expected to be approximately $70K in FY96 and $35K in FY97. Contingent support of Hanford SCDE demonstration would be expected to be $368K in FY96 and $495K in FY97.

Overall cost estimates for these recommendations are $816.2K in FY96 and $760.6K in FY97 if Rocky Flats may demonstrate SCDE upon Hanford wastes and $1,114.2K in FY96 and $1,220.6K if Hanford waste treatment must be demonstrated at Hanford.

8.0 REFERENCES

Barton, Jerome C., 1994, *The Los Alamos Super Scrub™: Supercritical Carbon Dioxide System Utilities and Consumables Study*[7], LA-12786, Los Alamos National Laboratory, Los Alamos, New Mexico, June 1994.

Brown, C. M., W. L. Teter, and P. Buckley (University of Colorado), "FY95 Midyear Status Report on Supercritical Carbon Dioxide Extraction," Kaiser Hill Company, RFETS, Golden, Colorado, May 31, 1995.

Brown, C. M., W. L. Teter, "Bench and Pilot-Scale Treatment of Low Level Mixed Waste Using Supercritical Carbon Dioxide Extraction," Kaiser Hill Company, RFETS, Golden, Colorado, October, 1995.

Colby, Scott A., 1993a, *Ozone Destruction of Hanford Site Tank Waste Organics*, WHC-SP-1004, Westinghouse Hanford Company, Richland, Washington, April 1993.

Colby, Scott A., 1993b, *Status of Test Results of Electrochemical Organic Oxidation of a Tank 241-SY-101 Simulated Waste*, WHC-SP-1003, Westinghouse Hanford Company, Richland, Washington, April 1993.

Delegard, C. H., R. F. Creed, D. W. Hendrickson, and D. F. McLaughlin, *Calcination/Dissolution Process Development 1994*, WHC-SP-1093, Revision 0, Westinghouse Hanford Company, Richland, Washington, June 10, 1994.

Ecology, EPA, and DOE, 1994, *Hanford Federal Facility Agreement and Consent Order*, as amended, Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Olympia, Washington, 1994.

EPA, 1994, Title 40 *Code of Federal Regulations* Part 261, "Identification and Listing of Hazardous Waste," U.S. Environmental Protection Agency, Washington, D.C.

EPA, 1995, Title 40 *Code of Federal Regulations* Part 268, "Land Disposal Restrictions," U.S. Environmental Protection Agency, Washington, D.C.

Hendrickson, D. W., 1995a, *Engineering Report of Plasma Vitrification of Hanford Tank Wastes*, WHC-SD-WM-ER-434, Revision 0, Westinghouse Hanford Company, Richland, Washington, May 12, 1995.

Hendrickson, D. W., 1995b, *Evaluation of Plasma Melter Technology for Vitrification of High-Sodium Content Low-level Radioactive Liquid Wastes -- Demonstration Test #4 Final Test Report*, WHC-SD-WM-VI-016, Revision 0, Westinghouse Hanford Company, Richland, Washington, June 20, 1995.

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[7] Super Scrub is a trademark of Autoclave Engineers, Erie, PA.

Moody, Timothy E., *Feasibility of Contaminated Soils Remediation via Supercritical Fluid Extraction*, WHC-SA-1895-VA, Westinghouse Hanford Company, Richland, Washington, March 1993. Presented at American Chemical Society (205th National Meeting) Supercritical Fluid Extraction Symposium, Denver, Colorado, March 28, 1993.

Ng, Heng-Joo, Sam S.-S. Huang, and Donald B. Robinson, "Equilibrium Phase Properties of Selected m-Xylene binary Systems, m-Xylene-Methane and m-Xylene-Carbon Dioxide," J. Chem. Eng. Data, volume 27, 1982.

Phelps, M. R., M. O. Hogan, and L. J. Silva, *Fluid Dynamic Effects on Precision Cleaning with Supercritical Fluids*, PNL-SA-24365, Pacific Northwest Laboratory, Richland, Washington, 1994.

Phelps, M. R., M. O. Hogan, L. J. Snowden-Swan, J. C. Barton, K. E. Laintz, W. D. Spall, and S. B. Williams, *Waste Reduction Using Carbon Dioxide: A Solvent Substitute for Precision Cleaning Applications*, PNL-SA-25944, Pacific Northwest Laboratory, Richland, Washington, May 1995.

Place, Barry G., *Low Level Mixed Waste Thermal Treatment Technical Basis Report*, WHC-SD-W242-ES-003, Westinghouse Hanford Company, Richland, Washington, November 7, 1994.

Snowden-Swan, L. J., *Supercritical Carbon Dioxide Cleaning Market Assessment and Commercialization/Deployment Plan*, PNL-10044, Pacific Northwest Laboratories, Richland, Washington, August 1994.

Teter, W. L., "Supercritical Carbon Dioxide Test Plan, Revision 2," EG&G-Rocky Flats, RFETS, Golden, Colorado, September 1994.

Additional Resources

Bright, Frank V., and Mary Ellen P. McNally, ed., *Supercritical Fluid Technology, Theoretical and Applied Approaches to Analytical Chemistry*, ACS Symposium Series 488, American Chemical Society, Washington D. C., 1992.

Brown, C. M., et al., "Design Requirements for an Integrated Pilot Demonstration Using Non-Thermal Treatment of Rocky Flats Environmental Technology Site Low-Level Mixed Wastes," EG&G-Rocky Flats, RFETS, Golden, Colorado, January 23, 1995.

Brown, C. M., R.D. Santopietro, and W. L. Teter, "FY94 Mid-Year Status Report on Supercritical Carbon Dioxide Extraction," EG&G-Rocky Flats, RFETS, Golden, Colorado, March 10, 1994.

Bruno, Thomas, J., James F. Ely, *Supercritical Fluid Technology: Reviews in Modern Theory and Applications*, CRC Press Inc., Boca Raton, Florida, 1991.

Buckley, P., et al., "Evaluation of Supercritical Carbon Dioxide Extraction for Removal of Organic Contaminants from Low Level Mixed Wastes Stored at the Rocky Flats Environmental Technology Site," University of Colorado, Boulder, Colorado, September 1994.

Eckert, Charles A. John G. Van Alsten, and Thomas Stoicos, "Supercritical Fluid Processing," Environmental Science and Technology, Vol 20, No. 4, 1986, pp 319-325.

"Evaluation of the Effects of Salt Feed Characteristics on Polyethylene Waste Forms," Internal Report Number TD-34-034, EG&G Rocky Flats, Golden, Colorado, September 30, 1994.

Faucette, A.M., B.W. Logsdon, and J.H. Oldham, "Review of the Radioactive and Thermal Stability of Low Density Polyethylene Encapsulated Nitrate Salt Waste," EG&G-Rocky Flats, Golden, Colorado, August 7, 1992.

Faucette, A.M., "Polymer Encapsulation of Clarifier Bottoms," EG&G Rocky Flats, Golden, Colorado, February 24, 1995.

Faucette, A.M., R.H. Getty, "Stabilization of High Salt Wastes by Polymer Extrusion," Proceedings of the Emerging Technologies in Hazardous Waste Management VII, American Chemical Society, Atlanta, Georgia, September 17-20, 1995.

Getty, R.H., and M.J. Riendeau, "Polymer Macroencapsulation of LLM Beryllium Fines Contaminated Debris Waste," Kaiser-Hill, LLC, Golden, Colorado, September 30, 1995.

Getty, R.H., and M.J. Riendeau, "Polymer Macroencapsulation of LLM Debris Waste," Kaiser-Hill, LLC, Golden, Colorado, September 30, 1995.

Getty, R.H., "Polymer Macroencapsulation of LLM Lead Waste," Kaiser-Hill, LLC, Golden, Colorado, September 30, 1995.

Jain, Vinod, K., "Supercritical Fluids Tackle Hazardous Wastes," Environmental Science and Technology, Vol 27, No. 5, 1993, pp 806-808.

Johnston, Keith P. and Johannes M. L. Penniger, ed., *Supercritical Fluid Science and Technology*, ACS Symposium Series 406, American Chemical Society, Washington, D. C., 1989.

Kirian, Erdogan, and Joan F. Brennecke, ed., *Supercritical Fluid Engnineering Science, Fundamentals and Applications*, ACS Symposium Series 514, American Chemical Society, Washington, D. C., 1993.

Madras, Giridar, Can Erkey, and Aydin Akgerman, *Supercritical Extraction of Organic Contaminants from Soil Combined with Adsorption onto Activated Carbon*, Environmental Progress, Vol. 13, No. 1, February 1994.

Miller, Charles R. III, and Sue E. Wilder, *Tables and Charts of Equilibrium Thermodynamic Properties of Carbon Dioxide for Temperatures from 100 K to 25000 K*, NASA SP-3097, National Aeronautics and Space Administration, Washington D. C., 1976.

Paulitis, Michael E., Johan M. L. Penninger, Ralph D. Gray, Jr., and Phillip Davidson, *Chemical Engineering at Supercritical Fluid Conditions*, Ann Arbor Science, Ann Arbor, Michigan, 1983. (ISBN 0-250-40564-4; Library of Congress 82-71529; call TP156.E65 C46 1983).

Includes: Chapter 25, *Liquifaction of Biomass with Supercritical Fluids in a High Pressure/High Temperature Flow Reactor*, P. Köll, B. Brönstrup, J. O. Metzger, Universität Oldenburg Gachb.Chemie, Oldenburg, Germany.

"Rocky Flats Technology Evaluation Framework Comprehensive Report: Interim Draft," EG&G-Rocky Flats, RFETS, Golden, Colorado, May 1994.

U. S. Department of Energy, Rocky Flats Field Office, "1995 Annual Land Disposal Restriction Progress Report," RFETS, Golden, Colorado, March 31, 1995.

U. S. Department of Energy, Rocky Flats Field Office, "Rocky Flats Environmental Technology Site Proposed Site Treatment Plan: Revision 3," RFETS, Golden, Colorado, March 30, 1995.

APPENDIX A: SOLUBILITY OF ORGANIC COMPOUNDS IN SUPERCRITICAL AND SUBCRITICAL CARBON DIOXIDE

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Solubility of Organic Compounds in Supercritical and Subcritical Carbon Dioxide

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Summary

The purpose of this report is to provide a compendium of published data on the solubility of a variety of organic compounds in supercritical and liquid carbon dioxide that have bearing on the potential pretreatment of Hanford Site and Rocky Flats Site waste streams by extraction with carbon dioxide. The compounds focused upon in this report are those regulated in land disposal by federal and state agencies as waste codes F001-F005. Since the organic compounds in these lists are relatively volatile, based on the phase behavior data listed below, it appears that extraction with carbon dioxide at relatively mild conditions (i.e. 40-50 C and 200-300 bar) should be successful in removing significant amounts of contaminants. Most of the data is for equilibrium solubilities or phase behavior; however, some examples of the extraction of organic compounds from complex matrices were found, as well. Clearly, multicomponent interactions, desorption kinetics and mass transfer limitations may significant reduce the actual amounts extracted.

Introduction

Supercritical fluid extraction has been successfully implemented for a wide variety of separation processes, including the decaffeination of coffee, recovery of hops, edible oils and other natural products, the regeneration of activated carbon, the separation of organic-water solutions, and the fractionation of polymers (McHugh and Krukonis, 1994). These extractions are attractive because the solubility of solutes in supercritical fluids can be varied dramatically with small changes in temperature and pressure. Therefore, once a solute is dissolved in the fluid it can be easily separated from the supercritical solvent simply by reducing the pressure (most commonly) or adjusting the temperature. Supercritical carbon dioxide is a particularly attractive solvent because of its mild critical point (T_c=31°C, P_c=72.8 atm.) and the fact that it is nonflammable and nontoxic. A typical extraction system is shown in Figure A-1. The mixture to be extracted is placed in the extraction vessel, as either a batch or semi-batch process. Then, the supercritical fluid is passed continuously through the bed, dissolving the components of interest. Typically, the solute is separated from the supercritical fluid simply by reducing the pressure (either completely depressurizing to atmosphere pressure or just partially depressurizing) across an expansion valve into a separation chamber. The solute is recovered and the supercritical solvent is recycled and repressurized. It is quite common, especially when using carbon dioxide, to add a cosolvent to the solvent. A few percent of a cosolvent, like methanol or acetone, can frequently increase the solubility of a heavy organic solid solute by an order of magnitude or more, thus dramatically reducing the required volume of solvent. In this case, a cosolvent makeup pump is required since some or all of the cosolvent may exit the system with the solute, dependent upon the operating conditions in the separator. However, most of the compounds listed in F001-F005 are relatively volatile substances (many of which are common cosolvents) so it is unlikely that a cosolvent will be necessary to solubilize those compounds. In fact, dependent on operating conditions, many of the compounds may be completely miscible with carbon dioxide, as explained below.

In the typical operating range for carbon dioxide extraction of 40-100°C and 50-300 bar, most of the compounds identified in waste codes F001-F005 exist either as vapor/liquid equilibrium or are completely miscible with carbon dioxide. As an example, the phase behavior of a binary mixture of CO_2 + 1-butanol is shown in Figure A-2 (Jennings et al. 1993). The two-phase vapor/liquid equilibrium envelopes are shown for three temperatures. The two-phase region enlarges, i.e. extends to higher pressures, at higher temperatures. If one were to extract 1-butanol with CO_2 at 41.6°C (314.8 K), one would simply have to operate at pressures above about 80 bar (8 MPa) for the 1-butanol to be *totally miscible* with the CO_2. However, if the extraction took place at 64.0°C (337.2 K), one would have to operate above about 120 bar (12 MPa) for the 1-butanol to be totally miscible with the CO_2. This same trend is observed for the CO_2 + m-xylene system shown in Figure A-3 (Ng et al., 1982) and essentially all the compounds of interest. Therefore, if one wishes to operate an extraction where the solutes are totally miscible with the CO_2, one would choose lower temperatures and moderate pressures.

Conversely, if one chooses the temperature and pressure to operate the extraction in the two-phase region or if two phases inadvertently exist due to multicomponent or matrix interactions, it would be better to operate at as high a temperature as possible, as shown in Figure A-3 for the CO_2 + m-xylene system. The solubility of the m-xylene in the CO_2-rich vapor phase *increases* with increasing temperature. At 37.7°C (310.9 K) and pressures below about 80 bar the CO_2 extract would only contain about 0.003 mole fraction m-xylene. At 121.1°C (394.3 K) and the same pressure the CO_2 extract would contain > 0.02 mole fraction m-xylene. Also, if any heavy organic solid solutes are present, such as polycyclic aromatics, higher temperatures and pressures will give higher solubilities. In choosing the appropriate operating conditions, it is basically a trade-off between temperature and pressure. If the equipment can handle moderate pressures (say, 200-300 bar) then the extraction can be done at low temperature (40-50°C). If the equipment is limited to low pressures (i.e. < 100 bar or so) then the extraction will have to take place at high temperature (100-200°C).

Therefore, based solely on the solubility data listed below, it is likely that effective extraction of the compounds listed in F001-F005 from soil or other solid matrices could be done at relatively low temperatures (40-50°C) and moderate pressures (200-300 bar).

Literature Data

Each compound investigated is listed below in bold and underlined. It is listed with it's waste code (i.e. F001 - F005), as well as it's CAS (Chemical Abstract Service) Registry Number. If no solubility data was found for a particular compound then it is listed as such. The following information is provided for each of the citations listed below:

- authors and year
- technique used: [1] indicates a flow apparatus and [2] indicates a static cell
- temperature range investigated
- pressure range investigated
- the extraction matrix (i.e., soil, activated carbon) or an indication that the measurements were pure phase equilibrium (e.g., binary vapor liquid equilibrium).

Also included are a number of citations, particularly those involving extractions from complex matrices, that do not readily fall under any of the individual compounds but may be useful.

F001 TETRACHLOROETHYLENE (127-18-4) - no data found

F001 TRICHLOROETHYLENE (79-01-6) - no data found

F001 1,1,1-TRICHLOROETHANE (71-55-6)

Fink and Hershey, 1990 [2] 308-353 K 0.75-12.35 MPa binary VLE

High pressure VLE for CO_2/toluene and CO_2/1,1,1-trichloroethane.

CO_2/1,1,1-trichloroethane is one phase at 308 K above 7.6 MPa. The solubility of the trichloroethane in the CO_2-rich phase at pressures below 7.6 MPa ranges from 0.007-0.042 mole fraction.

CO_2/1,1,1-trichloroethane is one phase at 353 K above 11.2 MPa. The solubility of the trichloroethane in the CO_2-rich phase at pressures below 11.2 MPa ranges from 0.04-0.15 mole fraction.

Sengupta et al. 1994 [1] 313.2-323.2 K 6.2-16.54 MPa water

Extraction of 1,2-dichloroethane, 1,1,2-trichloroethane and 1,1,2,2,-tetrachloroethane from water with CO_2. These compounds are completely miscible in pure CO_2 at 313.2 and 323.2 K and over a pressure range from 6.2-8.27 MPa. Distribution coefficients are reported.

F001 METHYLENE CHLORIDE (75-09-2)

McGovern and Rice 1988 [1] T=not given P=not given aqueous waste stream

Extraction of methylene chloride, chloroform, 1,2-dichloroethane, etc. from an aqueouswaste stream resulted in 91-99 percent recoveries.

F001 CARBON TETRACHLORIDE (56-23-5)

Gupta and King 1972 [2] 0-75°C 1-60atm binary PVT

Carbon tetrachloride/carbon dioxide cross virial coefficients only.

F001 CHLORINATED FLUOROCARBONS

Roth et al. 1992 [2] 254-473 K to 25 MPa binary VLE

High pressure VLE of $CO_2/CHClF_2$ (R22) and CO_2/CHF_3 (R23) systems.

CO_2/R22 has some regions of immiscibility below about 7 MPa but the solubility of the R22 in the CO_2-rich phase is very large (>5 mol%) at most conditions. Similarly, CO_2/R23 has some very small regions of immiscibility below about 5.5 MPa but the solubility in the CO_2-rich phase is always quite substantial.

F002 CHLOROBENZENE (108-90-7)

Walther and Maurer 1992 [2] 313-393 K 6-18 MPa binary VLE

High pressure VLE for CO_2 binaries with benzaldehyde, bromobenzene, chlorobenzene, 1,2-dichlorobenzene and 2-chloro-1-methylbenzene.

CO_2/chlorobenzene is one phase above approximately: 313 K and 7 MPa, 353 K and 13 MPa, 393 K and about 18 MPa.

At pressures where the system is two phases the solubility of the chlorobenzene in the CO_2-rich phase ranges from about 0.004 mol fraction at lower temperatures to 0.06 mol fraction at higher temperatures.

Bicking et al. 1993 [1] 55-140°C 95-325 atm diatomaceous earth and soil

Extraction of chlorobenzene and hexadecane from spiked diatomaceous earth samples, as well as real soils.

Percent recoveries > 90%.

No solubility data.

Lee and Peart 1994 [1] 100°C 35 MPa sediments

Extraction of PCBs and chlorinated benzenes from sediments using CO_2.

The best recovery occurred using pure CO_2 at 100°C and 35 MPa and with a sample moisture content in the range of 11-50%.

Madras et al. 1993 [1] 308-318 K 100 atm activated carbon

Desorption of naphthalene, phenanthrene, *hexachlorobenzene* and pentachlorophenol from activated carbon with CO_2.

Regenerability of the activated carbon is dependent upon the adsorption-equilibrium limitations. The solubility of the organics in the fluid does not represent the limiting step of the regeneration process.

Akgerman et al. 1992 [1] 298-323 K 1200-4000 psia soil

Extraction of *Hexachlorobenzene* from soil.

Absorption constants and partition coefficients but no solubility data.

Alexandrou et al. 1992 [1] 40°C 3000 psi fly ash and adsorbents below

Extraction of 1,2,4,5-*tetrachlorobenzene*, *hexachlorobenzene*, 2,2',5-trichlorobiphenyl, 2,2',3,4,5'-pentachlorobiphenyl and 2,2',3,3',4,4'5,5'-octachlorobiphenyl from Tenax, Florisil, alumina, carbon, chemically modified silica and fly ash.

Percent recoveries given but no solubility data.

Some fractionation studies are included in the paper.

F002 **1,1,2-TRICHLORO, 1,2,2-TRIFLUOROETHANE (76-13-1)** - no data found

F002 **TRICHLOROFLUOROMETHANE (75-69-4)** - no data found

F002 **1,1,2-TRICHLORETHANE (79-00-5)**

Sweetman and Watts 1995 [1] 60-100°C 2000-6000 psi soil and sludge

A variety of chlorinated benzenes and PCBs were extracted from soils and sludges with pure CO_2 and with methanol added as a cosolvent to as high as 10%. Near quantitative recovery of the PCBs was achieved. The lower recovery of the chlorinated benzenes was believed to be due to their higher volatilities and, subsequent, lower trapping efficiencies after extraction.

F002 **o-DICHLOROBENZENE (95-50-1)**

Walther and Maurer 1992 [2] 313-393 K 6-18 MPa binary VLE

High pressure VLE for CO_2 binaries with benzaldehyde, bromobenzene, chlorobenzene, 1,2-dichlorobenzene and 2-chloro-1-methylbenzene.

CO_2/chlorobenzene is one phase above: 313 K and 8 MPa, 353 K and about 17 MPa, 393 K and > 20 MPa.

At pressures where the system is two phase the solubility of the dichlorobenzene in the CO_2-rich phase ranges from about 0.001 mol fraction at lower temperatures to 0.03 mol fraction at higher temperatures.

Bowadt et al. 1993 [1] 40°C 2000-3000 psi trapping efficiencies

Trapping of solutes from saturated (presumably) solutions of various chlorobenzenes and polychlorinated biphenyls in CO_2.

No solubilities, just collection efficiencies.

Wenclawiak et al. 1994 [1] 70°C 340 atm soil

Recoveries of 50-100% were obtained for a variety of chlorobenzenes that were extracted with CO_2 from soil. Efficiencies depended on the trapping method. No discussion of solubilities.

von Holst et al. 1992 [1] 40°C 160 atm. soil

Extraction of 1,2-dichlorobenzene, 1,2,4-trichlorobenzene, polychlorinated dibenzofurans and polychlorinated dibenzodioxins from soil with CO_2. Recoveries of >90% were typical.

F003 XYLENESmixed(1330-20-7),o-xylene(95-47-6),m-xylene(108-38-3),p-xylene(106-42-3)

Mohamed and Holder 1987 [1] 39.5-93°C 1-15.3 MPa binary VLE

High pressure VLE for CO_2 binaries with o-xylene, m-xylene, p-xylene, butyl ether and ethylbenzene.

Conditions to be one phase for o-xylene: 39.5°C and greater than 7.8 MPa, 65°C and 10.9 MPa, 93°C and 14.9 MPa. Below these pressures the solubility of the o-xylene in the CO_2-rich phase ranges from 0.003-0.02 mol fraction.

Conditions to be one phase for m-xylene: 39.5°C and greater than 7.2 MPa, 65°C and 10.4 MPa, 93°C and 15.4MPa. Below these pressures the solubility of the m-xylene in the CO_2-rich phase range from 0.003-0.02 mol fraction.

Conditions to be one phase for p-xylene: 39.5°C and greater than 7.3 MPa, 65°C and 10.8 MPa, 93°C and 14.2 MPa. Below these pressures the solubility of the p-xylene in the CO_2-rich phase range from 0.003-0.02 mol fraction.

Ng et al. 1982 [2] 310.9-477.6 K 0.3-17 MPa binary VLE

High pressure VLE for CO_2/m-xylene.

CO_2/m-xylene is one phase above: 310.9 K and 8 MPa, 338.7 K and 11.3 MPa, 394.3 K and 16.8 MPa, and 477.6 K and 17 MPa.

At pressures where it is two phase the solubility of the m-xylene in the CO_2-rich phase ranges from 0.002-0.2 mol fraction.

Vera and Orbey 1984 [2] 303.15-343.15 K 0.67-3.5 MPa binary VLE

High pressure VLE for CO_2 binaries with m-xylene, 1-heptene, 1-hexene, and 2-methyl-1-pentene.

Data for m-xylene is well below critical point of the mixture.

The solubility of the m-xylene in the CO_2-rich phase ranged from 0.003-0.014 mol fraction.

Kim et al. 1986 [2] 313-393 K 0-6.5 MPa binary VLE

High pressure VLE for CO_2/benzene, CO_2/toluene and CO_2/p-xylene. However, they do not get particularly close to the critical point of the mixtures. Thus, this paper is better for the solubility of the xylene in the CO_2-rich phase at pressures where the system exists as 2 phases. These range from about 0.01-0.18 mol fraction.

Sebastian et al. 1980 [1] 190-310 °C 9-50 atm binary VLE

High pressure VLE for CO_2/toluene and CO_2/m-xylene.

The data is not taken all the way to the critical point. However, the solubility of the m-xylene in the CO_2-rich phase in the pressure range listed above ranges from about 0.15 mol fraction at 190C to >0.7 mol fraction at 310C.

Gouw 1969 [2] -15C to -55°C P not given binary liquid CO_2

Gives the solubility of xylenes and benzene in liquid CO_2.

The solubility of the various xylenes range from 0.05-0.9 g hydrocarbon per ml of solution.

F003 ACETONE (67-64-1)

Kato et al. 1991 [2] 298 K 0-6 MPa binary VLE

Vapor/liquid equilibrium curve for CO_2/aetone.

At 298K CO_2/acetone is totally miscible above 6.1 MPa.

At lower pressures the solubility of acetone in the CO_2-rich phase is on the order of 2 mol%.

Katayama et al. 1975 [2] 25-40°C 2-80 atm binary VLE

Vapor/liquid equilibrium curves for CO_2/methanol and CO_2/aetone.

At 25°C CO_2/acetone is totally miscible somewhere above about 61 atm.

At 40°C CO_2/acetone is totally miscible somewhere above about 74 atm.

At lower pressures the solubility of acetone in the CO_2-rich phase is on the order of 0.3-6 mol%.

Traub and Stephan 1990 [2] 35-60°C 14.9-60.2 bar binary VLE

High pressure VLE for CO_2/acteone and CO_2/butane and CO_2/water/acetone.

At 40°C CO_2/acetone is one phase above about 80 bar.

At lower pressures the solubility of the acetone in the CO_2-rich phase is about 0.02-0.05 mol fraction.

Gurdial et al. 1993 [2] 304.0-323.5 K 74.0-90.4 bar T_c,P_c

Gives critical temperatures and pressures for low concentrations of acetone (mol percents to 6.48%) in CO_2; i.e. for a given operating temperature, if you are above the corresponding critical pressure it will be a one phase mixture.

CO_2 binary mixtures with acetone, methanol, ethanol, n-propanol, isopropanol, n-butanol, n-pentanol, n-hexanol, pentane, hexane, n-heptane, n-octane, n-nonane and n-decane included.

F003 ETHYL ACETATE (141-78-6)

Chrisochoou et al. 1995 [2] 313-333 K 4.4-86.6 bar binary VLE

High pressure VLE for CO_2/ethyl acetate, CO_2/isoamyl alcohol, CO_2/isoamyl acetate.
At 313 K CO_2/ethyl acetate is one phase above about 80 bar.
At 313 K the solubility of the ethyl acetate in the CO_2 below 80 bar is 0.9-2.6 mol%.
At 333 K CO_2/ethyl acetate is one phase above about 90 bar.
At 333 K the solubility of the ethyl acetate in the CO_2 below 90 bar is 3-4 mol%.

Wagner and Pavlicek 1994 [2] 303-323 2-9 MPa binary VLE

High pressure VLE for CO_2/ethyl acetate.
CO_2/ethyl acetate is one phase above: 303 K and 7.3 MPa, 313 K and 8.2 MPa, 323 K and 0.9 MPa.
At lower pressures the solubility of the ethyl acetate in the CO_2-rich phase ranged from 0.003-0.015 mol fraction.

Ikushima et al. 1989 NA 305-313 K 9.3-10.8 MPa 4 wt% entrainer

This article uses ethyl acetate as an entrainer with CO_2 for the extraction of oleic, linoleic and linoleic acid methyl esters. They *suggest* that a mixture of CO_2 and 4 wt% ethyl acetate is one phase at 305 K and 313 K and at pressures of 9.3 MPa and 10.8 MPa.

Ikushima et al. 1988 NA 313-333 K 7.8-27 MPa 4 wt% entrainer

This article uses ethyl acetate as an entrainer with CO_2 for the extraction of triglycerides. They *suggest* that a mixture of CO_2 and 4 wt% ethyl acetate is one phase at the above conditions.

Srinivasan et al. 1991 NA 315 K 108 atm activated carbon

This article describes the desorption of ethyl acetate from activated carbon with CO_2.
They are addressing desorption rates as a function of initial loading, as opposed to solubilities.

Srinivasan et al. 1990 NA 308-341 K 81-163 atm activated carbon

This article describes the desorption of ethyl acetate from activated carbon with CO_2.

They examine the effect of extraction temperature, particle size and flowrate. For this system the extraction actually decreases with increasing temperature.

Tan and Liou 1988 NA 300-338 K 87.1-129.3 atm activated carbon

This article describes the desorption of ethyl acetate from activated carbon with CO_2. As much as 60% of the ethyl acetate was recovered in one hour, with extraction efficiencies higher at higher extraction pressures.

F003 ETHYLBENZENE (100-41-4)

Mohamed and Holder 1987 [1] 39.5-93°C 1-15.3 MPa binary VLE

High pressure VLE for CO_2 binaries with o-xylene, m-xylene, p-xylene, butyl ether and ethylbenzene.

Conditions to be one phase for ethylbenzene: 39.5°C and 7.2 MPa, 65°C and 10.7 MPa, 93°C and 14.3 MPa. Below these pressures the solubility of the ethylbenzene in the CO_2-rich phase range from 0.003-0.03 mol fraction.

Bamberger et al. 1994 [1] 313-393K 6-18 MPa binary VLE

At 313 K the CO_2/ethylbenzene binary is one phase above about 7.5 MPa. Below 7.5 MPa the solubility of the ethylbenzene in the gaseous CO_2-rich phase is about 0.3-0.4 mol%.

At 393 K the CO_2/ethylbenzene binary is one phase above about 16 MPa. Below 16 MPa the solubility of the ethylbenzene in the gaseous CO_2-rich phase is about 3-8 mol%.

High pressure vapor/liquid equilibrium for CO_2/ethylbenzene, isopropylbenzene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, ethenylbenzene and isopropenylbenzene are included in the article.

Bamberger and Maurer 1994 [1] 313-393 K 0-18 MPa binary VLE

High pressure vapor/liquid equilibrium for CO_2/*propylbenzene*, CO_2/actophenone, CO_2/1-chloronaphthalene, and CO_2/methyl benzoate.

At 313 K the CO_2/propylbenzene binary system is one phase above about 8 MPa.

The solubility of propylbenzene in gaseous CO_2-rich phase below 8 MPa at 313 K is about 0.1-0.2 mol%. At 393 K it is in the range of 1-4 mol%.

F003 ETHYL ETHER (60-29-7)

Ohgaki and Katayama 1975 [2] 25-40°C 5-80 atm binary VLE

High pressure VLE of CO_2/ethyl ether and CO_2/methyl acetate.

CO_2/ethyl ether is one phase above: 25°C and 57 atm, 40°C and 72 atm.

At pressures where the system is two phase the solubility of the ethyl ether in the CO_2-rich phase ranges from 0.01-0.12 mol fraction.

F003 METHYL ISO-BUTYL KETONE (108-10-1) - no data found

F003 n-BUTYL ALCOHOL (71-36-3)

Jennings et al. 1993 [1] 314.8-337.2 K 5.5-12 MPa binary VLE

Vapor/liquid equilibrium curves for CO_2/ethanol, CO_2/n-butanol and CO_2/n-pentanol.

At 314.8 K CO_2/n-butanol is totally miscible above about 8 MPa.

At 337.2 K CO_2/n-butanol is totally miscible above about 12 MPa.

At lower pressures solubility of n-butanol in the CO_2-rich phase is on the order of 0.5 mol%.

Lists references for CO_2/1-alkanal HP VLE from methanol to octadecanol.

Jennings et al. 1991 [1] 314.8-337.2K 4.6-11.8 MPa binary VLE

High pressure VLE for CO_2/ethanol and CO_2/1-butanol.

Same data as reviewed in 1993 article above but with tables, as well.

At 314.8 K CO_2/n-butanol is totally miscible above 8 MPa.

At 337.2 K CO_2/n-butanol is totally miscible above 12 MPa.

At lower pressures solubility of n-butanol in the CO_2-rich phase is 0.2-5 mol%.

Gurdial et al. 1993 [2] 305.5-329.2K 75.8-108.1 bar T_c,P_c

Gives critical temperatures and pressures for low concentrations (mol percents to 3.34%) of n-butanol in CO_2; i.e. for a given operating temperature, if you are above the corresponding critical pressure it will be a one phase mixture.

CO_2 binary mixtures with acetone, methanol, ethanol, n-propanol, isopropanol, n-butanol, n-pentanol, n-hexanol, pentane, hexane, n-heptane, n-octane, n-nonane and n-decane included in this article.

Suzuki et al. 1991 [1] 313.4-333.4 K 1.42-10.02 MPa binary VLE

High pressure VLE for CO_2 binaries with ethanol, 1-propanol, 2-propanol and 1-butanol.

The solubility of 1-butanol in the CO_2-rich phase ranges from 0.0014-0.007 mol fraction at 313 K and from 0.0027-0.0136 at 333.4 K over the range of pressures investigated.

Borch-Jensen et al. 1994 [2] 313.4 K 1.6-8.31 MPa binary VLE

At 313.4 K the mixture is totally miscible above 8.31 MPa.

At lower pressures solubilities of n-butanol in the CO_2-rich phase range from 0.14-0.54 mol%.

Chang 1992 [1] 298 K 1-62.2 bar binary VLE

Liquid compositions only.

CO_2/toluene, CO_2/n-butanol and CO_2/cyclohexanone.

Solubilities of CO_2 in the liquid phase range from 0-80 mol%.

Jennings et al. 1992 [1] 314-337 K 5.2-12 MPa binary VLE

High pressure VLE for CO_2/*1-pentanol* system.

F003 CYCLOHEXANONE (108-94-1)

Chang 1992 [1] 298 K 1-62.2 bar binary VLE

Liquid compositions only.

CO_2/toluene, CO_2/n-butanol and CO_2/cyclohexanone.

Solubilities of CO_2 in the liquid phase range from 0-80 mol%.

F003 METHANOL (67-56-1)

Ohgaki and Katayama 1976 [2] 25-40°C 7.8-79.5 atm binary VLE

High pressure VLE for CO_2/methanol, CO_2/benzene and CO_2/n-hexane.

CO_2/methanol is one phase above: 25°C and 59 atm, 40°C and 80 atm.

At pressures where it is two phase the solubility of the methanol in the CO_2-rich phase ranges from 0.007-0.02 mol fraction.

Katayama et al. 1975 [2] 25°C 2-80 atm binary VLE

Vapor/liquid equilibrium curves for CO_2/methanol and CO_2/aetone.

At 25°C CO_2/methanol is totally miscible somewhere above about 61 atm.

At lower pressures the solubility of methanol in the CO_2-rich phase is on the order of 0.6-3 mol%.

Gurdial et al. 1993 [2] 305.0-320.5 K 76.2-93.5 bar T_c,P_c

Gives critical temperatures and pressures for low concentrations (mol percents to 6.93%) of methanol in CO_2; i.e. for a given operating temperature, if you are above the corresponding critical pressure it will be a one phase mixture.

CO_2 binary mixtures with acetone, methanol, ethanol, n-propanol, isopropanol, n-butanol, n-pentanol, n-hexanol, pentane, hexane, n-heptane, n-octane, n-nonane and n-decane included.

F004 mixed CRESOLS (cresylic acid)(1319-77-3), o-cresol (95-48-7), m-cresol (108-39-4)

Sebastian et al. 1980 [1] 189.5-391.5°C 19-50 atm binary VLE

High pressure VLE for CO_2/m-cresol and CO_2/quinoline.

The data is not taken all the way to the critical point. However, the solubility of the m-cresol in the CO_2-rich phase in the pressure range above ranges from about 0.03 mol fraction at 189.5°C to >0.7 mol fraction at 391.5°C.

Lee and Chao 1988 [1] 308-328 K 0-240 bar binary VLE

High pressure VLE for CO_2/m-cresol and CO_2/1-methylnaphthalene.

The data do not go all the way up to the critical point.

Solubilities of the m-cresol in the CO_2-rich phase range from 6 x 10^{-5} to 0.04 mol fraction.

Di Giacomo et al. 1994 [1] 308.2 K 22.9-406.2 bar binary VLE

Liquid phase compositions only of the m-cresol/CO_2 binary.

Solubility of the CO_2 in the liquid phase ranges from 12.4-56.2 mol% over pressure range given.

No solubilities given for the cresol in the CO_2-rich phase.

F004 NITROBENZENE (98-95-3) - no data found

F005 TOLUENE (108-88-3)

Ng and Robinson 1978 [2] 100-399 F 48-2218 psia binary VLE

High pressure VLE for CO_2/toluene system.

CO_2/toluene one phase above approximately: 100.6 F and 1123 psia, 175 F and 1785 psia, 249 F and 2218 psia, 399 F and 2208 psia.

At pressures where it is two phase the solubilities of the toluene in the CO_2-rich phase range from 0.003-0.2 mol fraction.

Fink and Hershey, 1990 [2] 308-353 K 0.75-12.35 MPa binary VLE

High pressure VLE for CO_2/toluene and CO_2/1,1,1-trichloroethane.

CO_2/toluene is one phase at 308 K above about 6.9 MPa. The solubility of the toluene in the CO_2-rich phase at pressures below 6.9 MPa ranges from 0.005-0.011 mol fraction.

CO_2/toluene is one phase at 353 K above about 12.35 MPa. The solubility of the toluene in the CO_2-rich phase at pressures below 12.35 MPa ranges from 0.02-0.12 mol fraction.

Morris and Donohue 1985 [2] 353-413 K 0.3-13.2 MPa binary VLE

High pressure VLE for CO_2/toluene and CO_2/1-methylnaphthalene.

Conditions for one phase CO_2/toluene system: 353 K and 12 MPa, 383 K and 13 MPa, 413 K and 13.4 MPa. The solubility of the toluene in the CO_2-rich phase at pressures where two phases exist range from about 0.02-0.10 mol fraction.

Sebastian et al. 1980 [1] 120-270°C 9-50 atm binary VLE

High pressure VLE for CO_2/toluene and CO_2/m-xylene.

The data is not taken all the way to the critical point. However, the solubility of the toluene in the CO_2-rich phase in the pressure range above ranges from about 0.1 mol fraction at 120°C to >0.7 mol fraction at 270°C.

Muhlbauer and Raal 1991 [2] 79°C 127-1595 psia binary VLE

High pressure VLE for CO_2/toluene.

Conditions for a one phase CO_2/toluene system: 79°C and ~120 bar.

Solubilities of the toluene in the CO_2-rich phase at $P < 120$ bar range from 0.02-0.07 mol fraction.

Kim et al. 1986 [2] 313-393 K 0-6.5 MPa binary VLE

High pressure VLE for CO_2/benzene, CO_2/toluene and CO_2/p-xylene. However, they do not get particularly close to the critical point of the mixtures. Thus, this paper is better for the solubility of the toluene in the CO_2-rich phase at pressures where the system exists as 2 phases. These range from about 0.02-0.25 mol fraction.

Chang 1992 [1] 298 K 1-62.2 bar binary VLE

Liquid compositions only.
CO_2/toluene, CO_2/n-butanol and CO_2/cyclohexanone.
Solubilities of CO_2 in the liquid phase range from 0-80 mol%.

Liou and Tan 1990 NA 308-338 K 61-170 atm activated carbon

Desorption of benzene and toluene with CO_2 from activated carbon.
Desorption rates are better at higher temperature for a given solvent density.

Tan and Liou 1989 NA 308-338 K 87-136 atm activated carbon

This article describes the desorption of toluene and benzene from activated carbon with CO_2. As much as 100% of the contaminants were recovered in one hour, with extraction efficiencies higher at higher extraction pressures.

Tan and Liou 1989 NA 308-338 K 87-136 atm activated carbon

This article describes the desorption of toluene from activated carbon with CO_2. As much as 100% of the contaminants were recovered in one hour, with extraction efficiencies higher at higher extraction pressures. Supercritical CO_2 regeneration was superior to steam regeneration.

F005 METHYL ETHYL KETONE (78-93-3) - no data found

F005 CARBON DISULFIDE (75-15-0)

Reiff et al. 1992 [1] 273-473 K 0.4-15.9 MPa binary VLE

High pressure VLE for CO_2/CS_2.

CO_2/CS_2 is one phase above approximately: 273 K and 3.2 MPa, 280 K and 3.9 MPa, 285 K and 4.3 MPa, 290 K and 4.9 MPa, 300 K and 5.9 MPa, 310 K and 7.4 MPa, 330 K and 9.4 MPa, 360 K and 12.6 MPa, 411 K and 15.9 MPa, 448 K and 15.7 MPa, 473 K and 14.5 MPa.

At pressures where the system is two phase the solubility of the CS_2 in the CO_2 ranges from about 0.01 mol fraction at low temperatures to as much as 0.50 mol fraction at high temperatures.

F005 ISOBUTANOL (78-83-1) - no data found

F005 PYRIDINE (110-86-1)

Warzinski and Holder 1992 [1] 40-45°C 13.9 MPa coal

CO_2 was used to extract the residual pyridine from the pyridine insoluble fraction of Illinois no. 6 coal. It is important to maintain porosity for later liquefaction steps and the CO_2 extracted sample did this marginally better than vacuum drying.

No solubility data.

Squires et al. 1982 NA 40°C 10.2MPa pyridine coal extract

CO_2 was used to remove the retained pyridine from pyridine coal extracts. The CO_2 is successful in removing essentially all of the retained but not irreversibly bound pyridine in the samples.

F005 BENZENE (71-43-2)

Ohgaki and Katayama 1976 [2] 25-40°C 7.8-79.5 atm binary VLE

High pressure VLE for CO_2/methanol, CO_2/benzene and CO_2/n-hexane.

CO_2/benzene is one phase above: 25°C and 57 atm, 40°C and 77 atm.

At pressures where the system is two phase the solubility of the benzene in the CO_2-rich phase ranges from 0.007-0.015 mol fraction.

Nagarajan and Robinson 1987 [2] 344 K 6.9-11 MPa binary VLE

High pressure VLE for CO_2/benzene and CO_2/cyclohexane.

Conditions for a one phase CO_2/benzene system: 344 K and > 10.96 MPa.

Solubilities in the CO_2-rich phase at $P < 10.96$ MPa range from 0.06-0.10 mol fraction.

Inomata et al. 1987 [1] 343-414 K 2.3-15.4 MPa binary VLE

The CO_2/benzene system is one phase at 343 K above 11-12 MPa.

At 343 K and pressures less than 11-12 MPa the solubility of the benzene in the CO_2-rich phase is about 0.03 mol fraction.

The CO_2/benzene system is one phase at 413 K above about 15 MPa.

At 413 K and pressures less than 15 MPa the solubility of the benzene in the CO_2-rich phase ranges from 0.1-0.25 mol fraction.

Kim et al. 1986 [2] 313-393 K 0-6.5 MPa binary VLE

High pressure VLE for CO_2/benzene, CO_2/toluene and CO_2/p-xylene. However, they do not get particularly close to the critical point of the mixtures. Thus, this paper is better for the solubility of the benzene in the CO_2-rich phase at pressures where the system exists as 2 phases. These range from about 0.01-0.3 mol fraction.

Gupta et al. 1982 [2] 313 K 0.7-13.3 MPa binary VLE

The CO_2/benzene system is one phase at 40°C above 7.72 MPa.

At 40°C and pressures less than 7.72 MPa the solubility of the benzene in the CO_2-rich phase ranges from 0.01-0.03 mol fraction.

Kay and Kreglewski 1983 [2] 304-562 K 49-147 bar T_c, P_c

Gives critical temperatures and pressures for benzene/CO_2 mixtures over the entire composition range; i.e. for a given operating temperature, if you are above the corresponding critical pressure it will be a one phase mixture. For example, if one operates at 313 K and pressures above 81 bar the system will be one phase.

Kaminishi et al. 1987 [2] 273-303 K 0-6.3 MPa binary VLE

Binary mixtures of CO_2/benzene but only compositions in the liquid phase.

Gouw 1969 [2] -15°C to -55°C P not given binary liquid CO_2

Gives the solubility of xylenes and benzene in liquid CO_2.

The solubility of benzene ranges from 0.1-0.7 g hydrocarbon per ml of solution.

Liou and Tan 1990 NA 308-338 K 61-170 atm activated carbon

Desorption of benzene and toluene with CO_2 from activated carbon.

Desorption rates are better at higher temperature for a given solvent density.

Tan and Liou 1989 NA 308-338 K 87-136 atm activated carbon

This article describes the desorption of toluene and benzene from activated carbon with CO_2. As much as 100% of the contaminants were recovered in one hour, with extraction efficiencies higher at higher extraction pressures.

F005 2-ETHOXYETHANOL (110-80-5)

Holscher et al. 1989 [2] 393 K 14-17.5 MPa binary VLE

High pressure VLE for binaries of CO_2 with hexadecane, 1-dodecanol, 1-hexadecanol and 2-ethoxyethanol.

The CO_2/2-ethoxyethanol system is one phase at 393 K above 17.4 MPa.

From a graph the solubility of the 2-ethoxyethanol in the CO_2-rich phase at pressures below 17.4MPa is about 1 mol%.

F005 2-NITROPROPANE (79-46-9) - no data found

POLYCHLORINATED BIPHENYLS

Dooley et al. 1990 [1 and 2] 313 K 101 bar wet and dry soil

Extraction of PCBs and DDT from contaminated topsoils of high organic content.

Pure CO_2 and CO_2/5 wt% cosolvent (toluene, acetone, methanol, acetic acid, diethylamine).

Solubility of DDT in pure CO_2 at 313 K and 101 bar is 9.2×10^{-5} mol fraction.

Solubility of Aroclor 1254 in pure CO_2 at 313 K and 101 bar is 5.9×10^{-3} mol fraction.

Extraction efficiencies are better when the soil is dry and contains moderate amounts of low-molecular weight organics.

Most cosolvents only marginally improve extraction rates over pure CO_2. However, methanol increases DDT removal from 50-80% to >95% and increases DDT and PCB extraction rates by as much as an order of magnitude.

Dooley et al. 1987 [1] 40-80°C 100 atm soil

Extraction of DDT from soils with CO_2 and CO_2/ 5 wt% methanol or toluene.

The predicted solubiltiy of DDT in pure CO_2 at 40°C is 0.7×10^{-3} mol fraction.

The solubility in the CO_2-rich phase is predicted to increase to 0.005-0.014 mol fraction when methanol or toluene is added.

CO_2/5 wt% methanol at a flowrate of 0.7 g/s can extract 95% of the DDT from a fixed bed of 10 g of soil at 40°C and 100 atm in 5 min.

Alexandrou et al. 1992 [1] 40°C 3000 psi fly ash and adsorbents below

Extraction of 1,2,4,5-tetrachlorobenzene, hexachlorobenzene, 2,2',5-trichlorobiphenyl, 2,2',3,4,5'-pentachlorobiphenyl and 2,2',3,3',4,4'5,5'-octachlorobiphenyl from Tenax, Florisil, alumina, carbon, chemically modified silica and fly ash.

Percent recoveries but no solubility data.

Some fractionation studies.

Lee and Peart 1994 [1] 100°C 35 MPa sediments

Extraction of PCBs and chlorinated benzenes from sediments using CO_2.

The best recovery occurred using pure CO_2 at 100°C and 35 MPa and moisture content in the range of 11-50%.

OTHER USEFUL ARTICLES

Eckert-Tilotta et al. 1993 [1] 65-150°C 40MPa soil

Petroleum hydrocarbons (JP4 jet fuel, no. 2 diesel fuel and no. 5 fuel oil) were extracted from contaminated soil samples.

Extractions efficiencies compared well with liquid extractions but no solubilities given.

Gupta et al. 1991 [1] 313-323 K 9.65-15.2 MPa water

In the extraction of phenol, m-cresol, p-chlorophenol and benzene from water with CO_2 there were found to be no cosolubility effects in this system; i.e. the presence of one contaminant did not increase or decrease the distribution coefficient between the water-rich phase and the CO_2-rich phase of another contaminant.

Roop and Akgerman 1989 [1] 298-323 K to 31 MPa water

In the extraction of phenol from water, the addition of 5 mol% of various entrainers increased the distribution coefficient of the phenol by as much as 50%. Entrainers included toluene, dichloromethane, chloroform, benzene and chlorobenzene.

Yeo and Akgerman 1990 [1] 318-330 K 80-110 bar water

CO_2 is used to extract benzene, toluene, naphthalene and parathion from water. Distribution factors are given. The presence of the other contaminants does not dramatically change the distribution coefficient of any particular contaminant.

Hess et al. 1991 [2] 297-349 K 9-30 MPa wet and dry soil

The extraction of phenol from soil.

Better extraction of the phenol from the soil with higher organic content in the soil, higher extraction temperatures, higher extraction densities.

The addition of water and methanol increased the extraction percentage over dry soil.

The addition of benzene to a methanol/CO_2 mixture caused a decrease in the amount of phenol removed.

Lopez-Avila et al. 1992 [1] 80°C 340 atm soils

Extraction of petroleum hydrocarbons (kerosene, various oils) from soils.

80-95% recoveries were typical.

Richards and Campbell 1991 [1] 80°C 39.5 MPa soil

A variety of chlorinated benzenes and phenols are extracted from soil with CO_2/2% methanol with recovery percents of about 70-90%.

Tena et al. 1994 [1] 40°C 281 bar soil

Extraction of polycyclic aromatic hydrocarbons (fluoranthene, pyrene, benzanthracene, etc.) from soil with CO_2. Cosolvents (hexane, acetone, methylene chloride, water and methanol) were added to the soil before extraction. Methanol, in particular, increased the extraction efficiency.

Yu et al. 1990 [1] 50-65°C 150-350 atm soil and sand

92% of the polycyclic aromatic hydrocarbons were removed from a coal tar contaminated soil with a mixture of 95%CO_2/ 5% methanol.

Dohrn and Brunner 1995

This article contains references to binary, ternary and multicomponent high pressure vapor liquid equilibrium data for a variety of supercritical fluid systems.

Francis 1954

This article contains qualitative information on the miscibility of 261 compounds with liquid carbon dioxide at 25°C, as well as triangular diagrams for 464 ternary systems.

Hyatt 1984

This article lists the solubility of a variety of organic compounds in liquid CO_2 at 22-24°C.

Kordas et al. 1994

In this article they are trying to fit binary interaction coefficients for high pressure VLE to various models. The benefit of the article is that they reference a wide variety of articles that contain high pressure VLE.

Spiliotis et al. 1994

This article lists references for data sources for the solubility of a variety of aromatic hydrocarbons in CO_2.

Scope of Literature Search

The literature cited was located by searching the Chemical Abstracts for articles that contained both the compound of interest and carbon dioxide, as well as extraction, equilibrium or supercritical. In identifying promising articles on these lists, many chromatography articles were omitted. These articles tended to be less quantitative; however, it is possible that they may contain some useful information. Only articles in English are included. There were a number of US and foreign patents that may contain some useful information. Although the US patents were ordered, they have not arrived in the limited time period allotted for this project. Finally, articles dealing with the extraction of various foods and natural products were not included.

Bibliography

Akgerman, Aydin, Can Erkey, and Seyyed M. Ghoreishi, "Supercritical Extraction of Hexachlorobenzene from Soil", Ind. Eng. Chem. Res., **1992**, 31, 333-339.

Alexandrou, Nick, Michael J. Lawrence, and Janusz Pawliszyn, "Cleanup of Complex Organic Mixtures Using Supercritical Fluids and Selective Adsorbents", Anal. Chem., **1992**, 64, 301-311.

Bamberger, Andreas, and Gerd Maurer, "High-Pressure Vapor--Liquid Equilibria in Binary Mixtures of Carbon Dioxide and Aromatic Hydrocarbons: Experimental Data and Correlation for CO_2 + Acetophenone, CO_2 + 1-Chloronaphthalene, CO_2 + Methyl Benzoate and CO_2 + n-Propylbenzene", The Journal of Supercritical Fluids, **1994**, 7, 115-127.

Bamberger, Andreas, Jurgen Schmelzer, Dieter Walther, Gerd Maurer, "High-Pressure Vapour-Liquid Equilibria in Binary Mixtures of Carbon Dioxide and Benzene Compounds: Experimental Data for Mixtures with Ethylbenzene, Isopropylbenzene, 1, 2, 4-Trimethylbenzene, 1, 3, 5-Trimethylbenzene, Ethenylbenzene and Isopropenylbenzene, and their Correlation with the Generalized Bender and Skjold-Jorgensen's Group Contribution Equation of State", Fluid Phase Equilibria, **1994**, 97, 167-189.

Bicking, M.K.L., T. G. Hayes, J. C. Kiley, S. N. Deming, "An Experimental Design Approach to the Optimization of Supercritical Fluid Extraction for the Determination of Oil and Grease in Soil", Journal of Chromatographic Science, **1993**, 31, 170-176.

Borch-Jensen, Christina, Arne Staby, and Jorgen Mollerup, "Mutual Solubility of 1-Butanol and Carbon Dioxide, Ethene, Ethane, or Propane at a Reduced Supercritical Solvent Temperature of 1.03", The Journal of Supercritical Fluids, **1994**, 7, 231-244.

Bowadt, S., F. Pelusio, L. Montanarella, B. Larsen, and S. Kapila, "Trapping Techniques in Supercritical Fluid Extraction", J. Trace and Microprobe Techniques, **1993**, 11(1-3), 117-131.

Chang, Chiehming J., "The Solubility of Carbon Dioxide in Organic Solvents at Elevated Pressures", Fluid Phase Equilibria, **1992**, 74, 235-242.

Chrisochoou, A., K. Schaber, and U. Bolz, "Phase Equilibria for Enzyme-catalyzed Reactions in Supercritical Carbon Dioxide", Fluid Phase Equilibria, **1995**, 108, 1-14.

Di Giacomo, G., S. Brandani, V. Brandani, and G. Del Re., "High Pressure Phase Equilibria of the System Phenol-m-Cresol-Carbon Dioxide", Fluid Phase Equilibria, **1994**, 94, 313-327.

Dooley, Kerry M., D. Ghonasgi, F. Carl Knopf, and Robert P. Gambrell, "Supercritical CO_2 - Cosolvent Extraction of Contaminated Soils and Sediments", Environmental Progress, **1990**, 9 (4), 197-203.

Dohrn, Ralf and Gerd Brunner, "High-Pressure Fluid-Phase Equilibria: Experimental Methods and Systems Investigated (1988-1993)", Fluid Phase Equilibria, **1995**, 106, 213-282.

Dooley, Kerry M., Chien-Ping Kao, Robert P. Gambrell, and F. Carl Knopf, "The Use of Entrainers in the Supercritical Extraction of Soils Contaminated with Hazardous Organics", Ind. Eng. Chem. Res., **1987**, 26, 2058-2062.

Eckert-Tilotta, Sally E., Steven B. Hawthorne and David J. Miller, "Supercritical Fluid Extraction with Carbon Dioxide for the Determination of Total Petroleum Hydrocarbons in Soil", Fuel, **1993**, 72 (7), 1015-1023.

Fink, Samuel D. and Harry C. Hershey, "Modeling the Vapor-Liquid Equilibria of 1,1,1-Trichloroethane + Carbon Dioxide and Toluene + Carbon Dioxide at 308, 323, and 353 K", Ind. Eng. Chem. Res., **1990**, 29, 295-306.

Francis, Alfred W., "Ternary Systems of Liquid Carbon Dioxide", J. Phys. Chem., **1954**, 58, 1099-1114.

Gouw, T. H., "Solubility of C_6-C_8 Aromatic Hydrocarbons in Liquid CO_2", Journal of Chemical and Engineering Data, **1969**, 14 (4), 473-475.

Gupta, Mukesh K., Ying-Hslao Li, Barry J. Hulsey, and Robert L. Robinson, Jr. "Phase Equilibrium for Carbon Dioxide-Benzene at 313.2, 353.2, and 393.2 K", J. Chem. Eng. Data, **1982**, 27, 55-57.

Gupta, S. K. and A. D. King, Jr., "Second Cross Virial Coefficients of Carbon Tetrachloride-Gas Mixtures Determine from Solubility Measurements at High Pressures", Can. J. Chem. **1972**, 50 (5), 660-668.

Gupta, S., D. Ghonasgi, K. M. Dooley, and F. C. Knopf, "Supercritical Carbon Dioxide Extraction of a Phenolic Mixture from an Aqueous Waste Stream", The Journal of Supercritical Fluids, **1991**, 4, 181-185.

Gurdial, G. S., Neil R. Foster, S. L. Jimmy Yun, and Kevin D. Tilly, "Phase Behavior of Supercritical Fluid-Entrainer Systems", in Supercritical Fluid Engineering Science, ACS Symp. Ser. 514, E. Kiran and J. F. Brennecke, eds., **1993**, 34-45.

Hess, Richard K., C. Erkey, and A. Akgerman, "Supercritical Extraction of Phenol from Soil", The Journal of Supercritical Fluids **1991**, 4, 47-52.

Holscher, I. F., M. Spee, and G. M. Schneider, "Fluid-Phase Equilibria and Ternary Mixtures of CO_2 with Hexadecane, 1-Dodecanol, 1-Hexadecanol and 2-Ethoxy-Ethanol at 333.2 and 393.2 K and at Pressures up to 33 MPA", Fluid Phase Equilibria, **1989**, 49, 103-113.

Hyatt, John A., "Liquid and Supercritical Carbon Dioxide as Organic Solvents", J. Org. Chem., **1984**, 49, 5097-5101.

Ikushima, Yutaka, Norio Saito, and Tomio Goto, "Selective Extraction of Oleic, Linoleic, and Linolenic Acid Methyl Esters from their Mixture with Supercritical Carbon Dioxide-Entrainer Systems and a Correlation of the Extraction Efficiency with a Solubility Parameter", Ind. Eng. Chem. Res., **1989**, 28, 1364-1369.

Ikushima, Yutaka, Kiyotaka Hatakeda, Shota Ito, Norio Saito, Takashi Asano, and Tomio Goto, "A Supercritical Carbon Dioxide Extraction from Mixtures of Triglycerides and Higher Fatty Acid Methyl Esters Using a Gas-Effusion Type System", Ind. Eng. Chem. Res., **1988**, 27, 818-823.

Inomata, H., K. Arai, and S. Saito, "Vapor-Liquid Equilibria for CO_2/Hydrocarbon Mixtures at Elevated Temperatures and Pressures", Fluid Phase Equilibria, **1987**, 36, 107-119.

Jennings, David W., Franchot Chang, Vivian Bazaan, and Amyn S. Teja, "Vapor-Liquid Equilibria for Carbon Dioxide + 1-Pentanol", J. Chem. Eng. Data, **1992**, 37, 337-338.

Jennings, David, W., Michael T. Gude, and Amyn S. Teja, "High-Pressure Vapor-Liquid Equilibria in Carbon Dioxide and 1-Alkanol Mixtures", in Supercritical Fluid Engineering Science, ACS Symp. Ser. 514, E. Kiran and J. F. Brennecke, eds., **1993**, 10-33.

Jennings, David W., Rong-Jwyn Lee, and Amyn S. Teja, "Vapor-Liquid Equilibria in the Carbon Dioxide + Ethanol and Carbon Dioxide + 1-Butanol Systems", J. Chem. Eng. Data, **1991**, 36, 303-307.

Kaminishi, Gen-Ichi, Chiaki Yokoyama, and Shinji Takahashi, "Vapor Pressures of Binary Mixtures of Carbon Dioxide with Benzene, n-Hexane and Cyclohexane up to 7 MPa", Fluid Phase Equilibria, **1987**, 34, 83-99.

Katayama, Takashi, Kazunari Ohgaki, Goro Maekawa, Motojiro Goto, and Tamon Nagano, "Isothermal Vapor-Liquid Equilibria of Acetone-Carbon Dioxide and Methanol-Carbon Dioxide Systems at High Pressures", Journal of Chemical Engineering of Japan, **1975**, 8 (2), 89-92.

Kato, Masahiro, Kazunori Aizawa, Takashi Kanahira, and Tomoki Ozawa, "A New Experimental Method of Vapor-Liquid Equilibria at High Pressures", Journal of Chemical Engineering of Japan, **1991**, 24 (6), 767-771.

Kay, Webster B. and Aleksander Kreglewski, "Critical-Locus Curves and Liquid-Vapor Equilibria in the Binary Systems of Benzene with Carbon Dioxide and Sulfur Dioxide", Fluid Phase Equilibria, **1983**, 11, 251-265.

Kim, Choon-Ho, P. Vimalchand, and Marc D. Donohue, "Vapor-Liquid Equilibria for Binary Mixtures of Carbon Dioxide with Benzene, Toluene and p-Xylene", Fluid Phase Equilibria, **1986**, 31, 299-311.

Kordas, Aris, Konstantinos Tsoutsouras, Sofia Stamataki, and Dimitrios Tassios, "A Generalized Correlation for the Interaction Coefficients of CO_2-Hydrocarbon Binary Mixtures", Fluid Phase Equilibria, **1994**, 93, 141-166.

Lee, Hing Biu, and Thomas E. Peart, "Optimization of Supercritical Carbon Dioxide Extraction for Polychlorinated Biphenyls and Chlorinated Benzenes from Sediments", Journal of Chromatography A, **1994**, 663, 87-95.

Lee, R. J. and K. C. Chao, "Extraction of 1-Methylnaphthalene and m-Cresol with Supercritical Carbon Dioxide and Ethane", Fluid Phase Equilibria, **1988**, 43, 329-340.

Liou, Din-Chung and Chung-Sung Tan, "Modeling of Desorption of Activated Carbon Loaded with Benzene and Toluene by Supercritical CO_2", Journal of the Chin. I. Ch. E., **1990**, 21 (6), 361-364.

Lopez-Avila, Viorica, Janet Benedicto, N. S. Dodhiwala, and Richard Young, "Development of an Off-Line SFE-IR Method for Petroleum Hydrocarbons in Soils", Journal of Chromatographic Science, **1992**, 30,335-343.

Madras, Giridhar, Can Erkey, and Aydin Akgerman, "Supercritical Fluid Regeneration of Activated Carbon Loaded with Heavy Molecular Weight Organics", Ind. Eng. Chem. Res., **1993**, 32, 1163-1168.

McGovern, William E., and Paul N. Rice, "Critical Fluid Extraction Treatment of Organic Wastewater", Pollution Engineering, **1988**, (Sept.), 122-126.

McHugh, Mark and Val Krukonis, Supercritical Fluid Extraction, 2nd ed., **1994**, Butterworth-Heinemann, Stoneham, MA.

Mohamed, Rahoma W., and Gerald D. Holder, "High Pressure Phase Behavior in Systems Containing CO_2 and Heavier Compounds with Similar Vapor Pressures", Fluid Phase Equilibria, **1987**, 32, 295-317.

Morris, William O., and Marc D. Donohue, "Vapor-Liquid Equilibria in Mixtures Containing Carbon Dioxide, Toluene, and 1-Methylnaphthalene", J. Chem. Eng. Data, **1985**, 30,259-263.

Muhlbauer, A. L., and J. D. Raal, "Measurement and Thermodynamic Interpretation of High-Pressure Vapour-Liquid Equilibria in the Toluene--CO_2 System", Fluid Phase Equilibria, **1991**, 64, 213-236.

Nagarajan, N., and R. L. Robinson, Jr., "Equilibrium Phase Compositions, Phase Densities, and Interfacial Tensions for CO_2 + Hydrocarbon Systems. 3. CO_2 + Cyclohexane. 4. CO_2 + Benzene", J. Chem. Eng. Data, **1987** 32,369-371.

Ng, Heng-Joo, and Donald B. Robinson, "Equilibrium Phase Properties of the Toluene-Carbon Dioxide System", Journal of Chemical Engineering Data, **1978**, 23 (4), 325-327.

Ng, Heng-Joo, Sam S.-S. Huang, and Donald B. Robinson, "Equilibrium Phase Properties of Selected m-Xylene Binary Systems, m-Xylene-Methane and m-Xylene-Carbon Dioxide", J. Chem. Eng. Data, **1982**, 27, 119-122.

Ohgaki, Kazunari, and Takashi Kayayama, "Isothermal Vapor-Liquid Equilibrium Data for Binary Systems Containing Carbon Dioxide at High Pressures: Methanol-Carbon Dioxide, n-Hexane-Carbon Dioxide, and Benzene-Carbon Dioxide Systems", Journal of Chemical and Engineering Data. **1976**, 21 (1), 53-55.

Ohgaki, Kazunari, and Takashi Katayama, "Isothermal Vapor Liquid Equilibria for Systems Ethyl Ether-Carbon Dioxide and Methyl Acetate-Carbon Dioxide at High Pressures", Journal of Chemical and Engineering Data, **1975**, 20 (3), 264-267.

Reiff, W. E., H. Roth, and K. Lucas, "Phase Equilibria in the Binary System Carbon Disulfide-Carbon Dioxide," Fluid Phase Equilibria, **1992**, 73, 323-338.

Richards, M. and R. M. Campbell, "Comparison of Supercritical Fluid Extraction, Soxhlet, and Sonication Methods for the Determination of Priority Pollutants in Soil", LC-GC, **1991**, 9 (5), 358-364.

Roop, Robert K., and Aydin Akgerman, "Entrainer Effect for Supercritical Extraction of Phenol from Water", Ind. Eng. Chem. Res., **1989**, 28, 1542-1546.

Roth, H., P. Peters-Gerth, and K. Lucat, "Experimental Vapor-Liquid Equilibria in the Systems R 22-R 23, R 22-CO_2, CS_2-R 22, R 23-CO_2, CS_2-R 23 and their Correlation by Equations of State", Fluid Phase Equilibria, **1992**, 73, 147-166.

Sebastian, Herbert M., Ho-Mu Lin, and Kwang-Chu Chao, "Gas-Liquid Equilibrium of Carbon Dioxide Plus m-Cresol and Carbon Dioxide Plus Quinoline at Elevated Temperatures", J. Chem. Eng. Data, **1980**, 25, 381-383.

Sebastion, Herbert M., James J. Simnick, Ho-Mu Lin, and Kwang-Chu Chao, "Gas-Liquid Equilibrium in Mixtures of Carbon Dioxide + Toluene and Carbon Dioxide + m-Xylene", J. Chem. Eng. Data, **1980**, 25, 246-248.

Sengupta, Satyajit, Sumnesh Gupta, Kerry M. Dooley, and F. Carl Knopf, "Measurement and Modeling of Extraction of Chlorinated Hydrocarbons from Water with Supercritical Carbon Dioxide", The Journal of Supercritical Fluids, **1994**, 7, 201-209.

Spiliotis, Nikolaos, Kostis Magoulas, Dimitrios Tassios, "Prediction of the Solubility of Aromatic Hydrocarbons in Supercritical CO_2 with EoS/G^E Models", Fluid Phase Equilibria, **1994**, 102, 121-141.

Squires, Thomas G., Clifford G. Venier, Jacqueline D. Hunt, Juliana C. Shei, and Barbara F. Smith, "Supercritical Solvents. Carbon Dioxide Extraction of Retained Pyridine from Pyridine Extracts of Coal", Fuel, **1982**, 61, 1170-1172.

Srinivasan, M. P., J. M. Smith, and B. J. McCoy, "Ethyl Acetate Desorption from Activated Carbon with Supercritical Carbon Dioxide: Effect of Initial Loading", Chemical Engineering Science, **1991**, 46 (1), 371-374.

Srinivasan, M. P., J. M. Smith, and B. J. McCoy, "Supercritical Fluid Desorption from Activated Carbon", Chemical Engineering Science, **1990**, 45 (7), 1885-1895.

Suzuki, Tatsuru, Naoki Tsuge, and Kunio Nagahama, "Solubilities of Ethanol, 1-Propanol, 2-Propanol and 1-Butanol in Supercritical Carbon Dioxide at 313 K and 333 K", Fluid Phase Equilibria, **1991**, 67, 213-226.

Sweetman, A. J., and C. D. Watts, "Development of a Supercritical Fluid Extraction Method for PCBS and Chlorobenzenes from Soils and Sludge-Amended Soils", Environmental Technology, **1995**, 16, 73-80.

Tan, Chung-Sun, and Din-Chung Liou, "Desorption of Ethyl Acetate from Activated Carbon by Supercritical Carbon Dioxide", Ind. Eng. Chem. Res., **1988**, 27, 988-991.

Tan, Chung-Sung, and Din-Chung Liou, "Supercritical Regeneration of Activated Carbon Loaded with Benzene and Toluene", Ind. Eng. Chem. Res., **1989**, 28, 1222-1226.

Tan, Chung-Sung, and Din Chung Liou, "Regeneration of Activated Carbon Loaded with Toluene by Supercritical Carbon Dioxide", Separation Science and Technology, **1989**, 24 (1&2). 111-127.

Tena, M.T., M. D. Luque de Castro, and M. Valcarcel, "Systematic Study of the Influence of Modifiers on the CO_2-Supercritical Extraction of PAHs in Soil", Chromatographia, **1994**, 38 (7/8). 431-435.

Traub, Peter, and Karl Stephan, "High-Pressure Phase Equilibria of the System CO_2-Water-Acetone Measured with a New Apparatus", Chemical Engineering Science, **1990**, 45 (3), 751-758.

Vera, Juan H., and Hasan Orbey, "Binary Vapor-Liquid Equilibria of Carbon Dioxide with 2-Methyl-1-Pentene, 1-Hexene, 1-Heptene, and m-Xylene at 303.15, 323.15, and 343.15 K", J. Chem. Eng. Data, **1984**, 29, 269-272.

von Holst, C., H. Schlesing, and C. Liese, "Supercritical Fluid Extraction of Polychlorinated Dibenzodioxins and Dibenzofurans from Soil Samples", Chemosphere, **1992**, 25 (7-10), 1367-1373.

Wagner, Zdenek, and Jan Pavlicek, "Vapour-liquid Equilibrium in the Carbon Dioxide-Ethyl Acetate System at High Pressure", Fluid Phase Equilibria, **1994**, 97, 119-126.

Walther, D., and G. Maurer, "High Pressure Vapour-Liquid Equilibria in Binary Mixtures of Carbon Dioxide and Benzaldehyde, Bromobenzene, Chlorobenzene, 1, 2-Dichlorobenzene and 2-Chloro-1-Methylbenzene at Temperatures between 313 and 393 K and Pressures Up to 22 MPa", Ber. Bunsenges Phys. Chem., **1992**, 96 (8), 981-988.

Warzinski, Robert P., and Gerald D. Holder, "Pyridine Treatment of Illinois No. 6 Coal. The effect of Pyridine Removal on Particle Morphology and the Liquefaction Characteristics of the Soluble and Insoluble Components", Fuel, **1992**, 71, 993-1002.

Wenclawlak, B. W., G. Maio, Ch. v. Holst, and R. Darskus, "Solvent Trapping of Some Chlorinated Hydrocarbons after Supercritical Fluid Extraction from Soil", Analytical Chemistry, **1994**, 66 (21), 3581-3586.

Yarborough, Lyman, "Vapor-Liquid Equilibrium Data for Multicomponent Mixtures Containing Hydrocarbon and Nonhydrocarbon Components", Journal of Chemical Engineering Data, **1972**, 17 (2), 129-133.

Yeo, Sand-Do, and Aydin Akgerman, "Supercritical Extraction of Organic Mixtures from Aqueous Solutions", AIChE Journal, **1990**, 36 (11), 1743-1747.

Yu, Xlaobing, Xlaoping Wang, Richard Bartha, and Joseph D. Rosem, "Supercritical Fluid Extraction of Coal Tar Contaminated Soil", Environ. Sci. Technol. **1990**, 24 (11), 1732-1738.

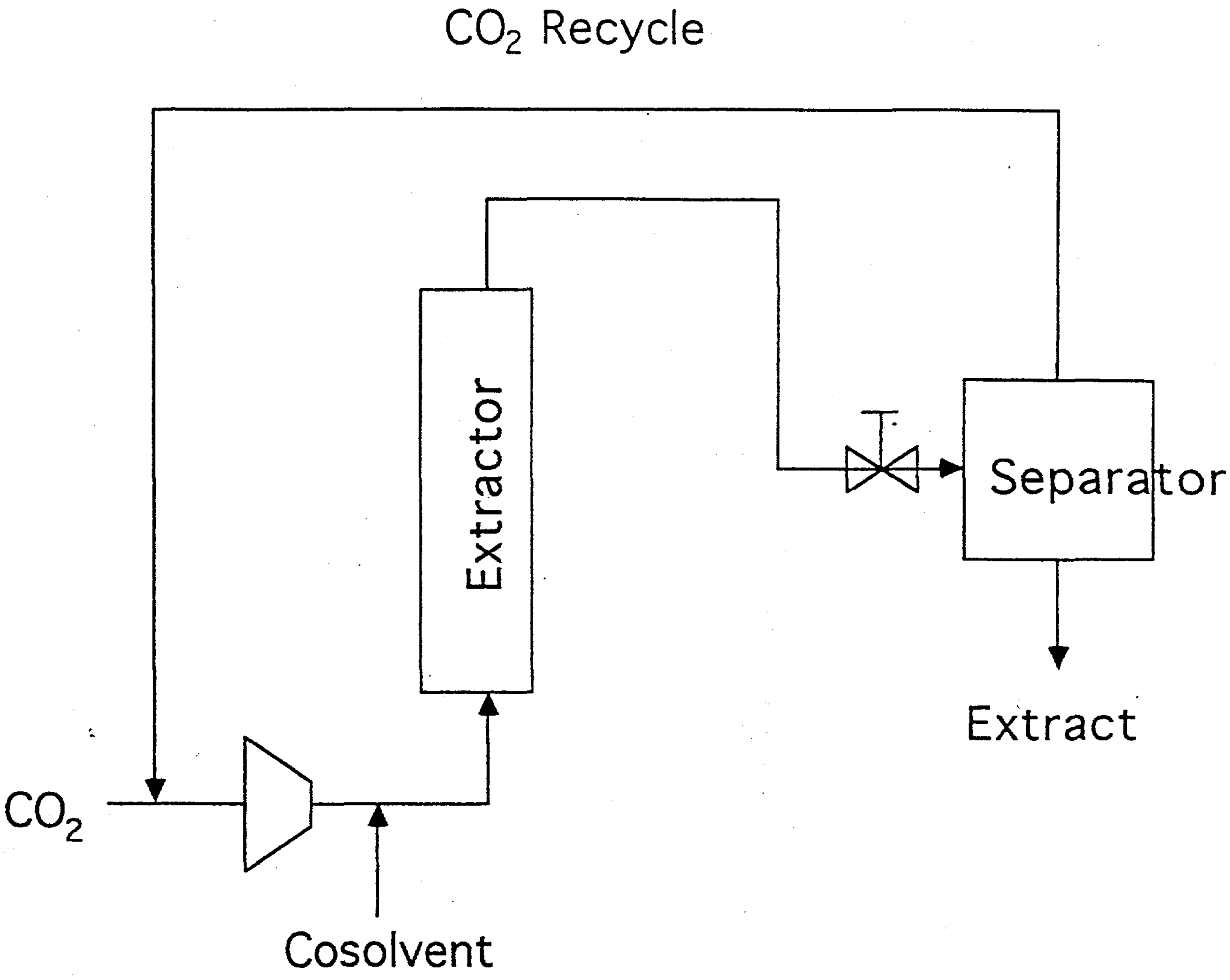

Figure A-1: Schematic of supercritical fluid extraction system

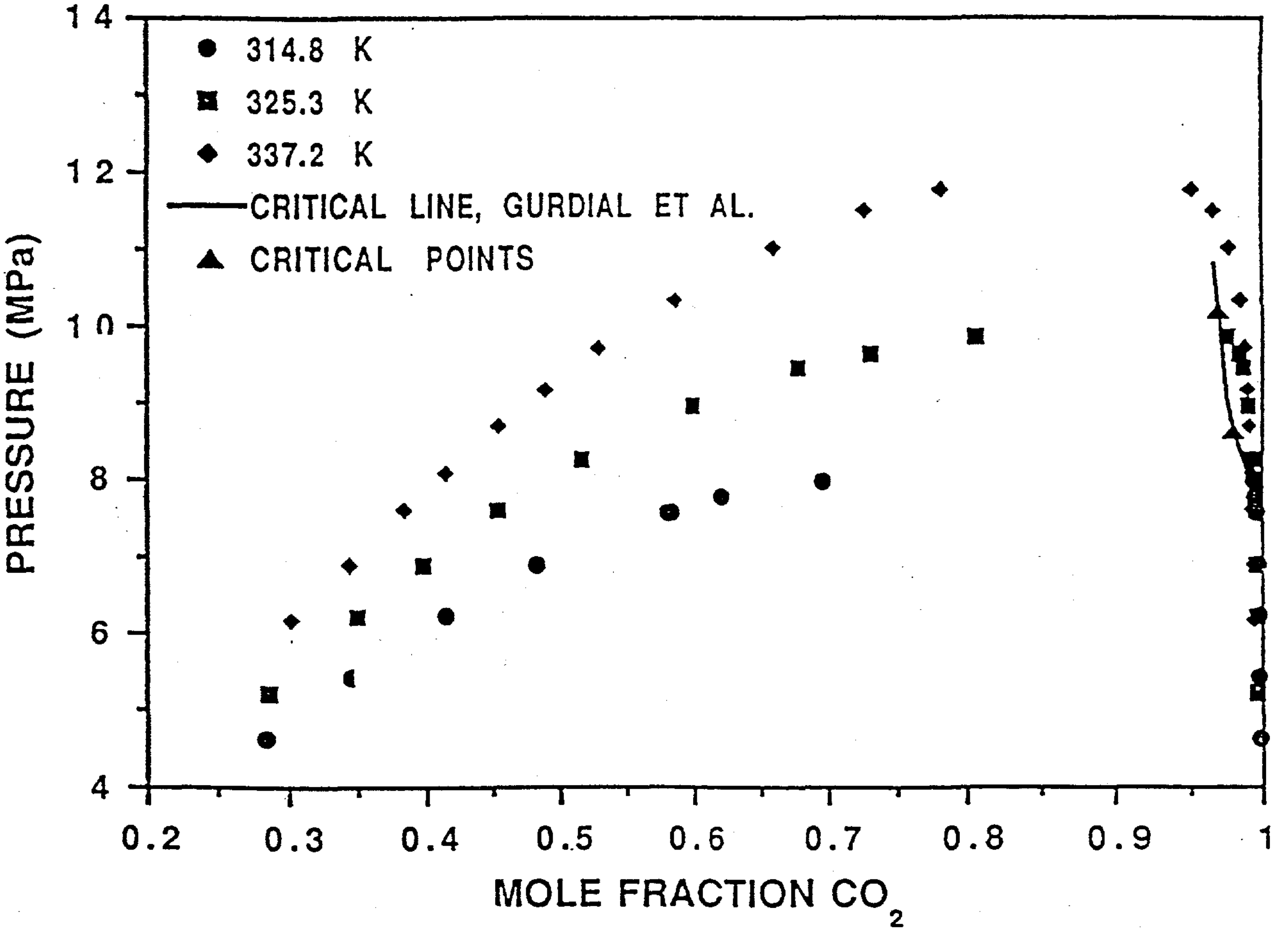

Figure A-2: Critical locus/phase envelope for CO_2-1-butanol (Jennings *et al.* 1993)

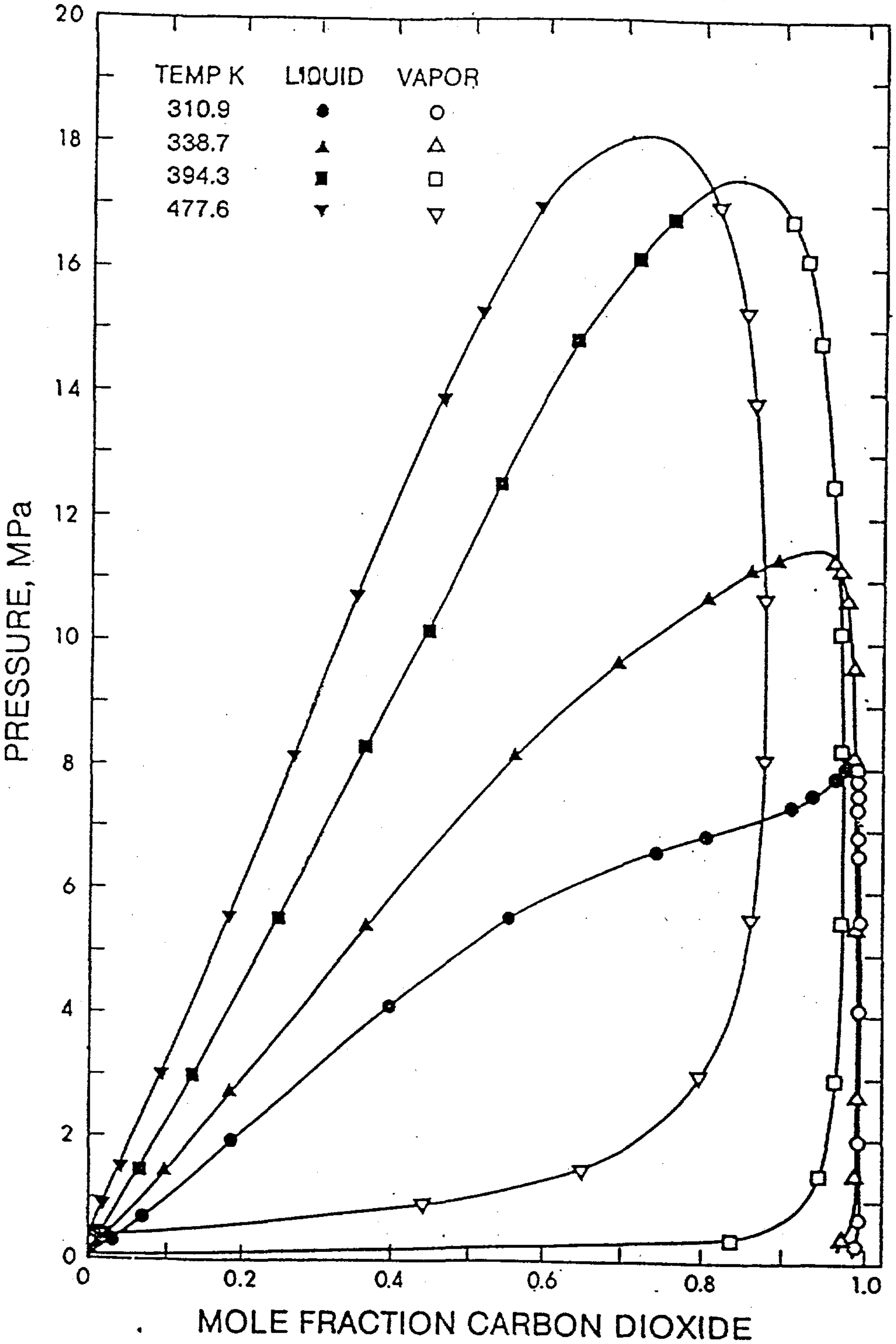

Figure A-3: Pressure-equilibrium phase composition diagram for CO_2-m-xylene (Ng *et al.* 1982)

APPENDIX B: HANFORD HIGH-MERCURY SUBCATEGORY WASTE SUMMARY ANALYSIS

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Hanford High-Mercury Subcategory Waste Summary Analysis

A detailed analysis of the Hanford High-Mercury subcategory wastes, which are recommended for supercritical fluid extraction, is contained within this appendix.

Table B-1 contains the summarized federal hazardous waste codes applicable to the waste packages. Table B-2 provides a correlation of waste codes to waste constituents. Table B-3, Table B-4, and Table B-5 summarize the physical, volumetric, and mass characteristics of the waste packages. The total waste mass is expected to be 4368kg and have a total volume of 4.7904m^3.

Table B-6 provides a summary of radioactive contamination of the waste packages while Table B-7a and Table B-7b and Table B-8a and Table B-8b detail isotopic distributions of reported and current activity, respectively. The radioactivity of the material, although all 'contact-handled,' will limit physical manipulation of the waste materials.

Table B-9a and Table B-9b and Table B-9c and Table B-9d detail hazardous metal and organic masses and compositions of the waste packages, respectively. The mercury content is such (< 260 ppm) that federal land disposal restrictions require a mercury retort in treatment. As such a retort is a relatively low temperature operation, the organic contaminants, normally requiring a high temperature incineration for treatment, would not be adequately treated if they remain in the waste when it is processed through the retort. Thus, the combination of these waste characteristics is the basis for proposing the application of supercritical carbon dioxide extraction upon the waste material.

Table B-1: Federal Waste Code Designations

Hazardous Waste Code Summary	
High Mercury Subcategory Wastes	
Package	Suspected RCRA Waste Codes
ANL93-MW-00001	D006 D007 D008 D009 D010 D039 D040 F001 F002 F003 F004 F005
ANL93-MW-00002	D006 D007 D008 D009 D010 D039 D040 F001 F002 F003 F004 F005
ANL93-MW-00003	D006 D007 D008 D009 D010 D039 F001 F002 F003 F004 F005
ANL93-MW-00004	D006 D007 D008 D009 D010 D039 D040 F001 F002 F003 F004 F005
ANL93-MW-00005	D006 D007 D008 D009 D010 D039 D040 F001 F002 F003 F004 F005
ANL93-MW-00006	D006 D007 D008 D009 D010 D039 D040 F001 F002 F003 F004 F005
ANL93-MW-00007	D006 D007 D008 D009 D010 D039 D040 F001 F002 F003 F004 F005
ANL93-MW-00008	D006 D007 D008 D009 D010 D039 D040 F001 F002 F003 F004 F005
ANL93-MW-00009	D006 D007 D008 D009 D010 D039 D040 F001 F002 F003 F004 F005
ANL93-MW-00010	D006 D007 D008 D009 D010 D039 D040 F001 F002 F003 F004 F005
ANL93-MW-00011	D006 D007 D008 D009 D010 D039 D040 F001 F002 F003 F004 F005
ANL93-MW-00012	D006 D007 D008 D009 D010 D039 D040 F001 F002 F003 F004 F005
ANL93-MW-00013	D006 D007 D008 D009 D010 D039 D040 F001 F002 F003 F004 F005
ANL93-MW-00014	D006 D007 D008 D009 D010 D039 D040 F001 F002 F003 F004 F005
ANL93-MW-00015	D006 D007 D008 D009 D010 D039 D040 F001 F002 F003 F004 F005
ANL93-MW-00016	D006 D007 D008 D009 D010 D039 D040 F001 F002 F003 F004 F005
ANL93-MW-00017	D006 D007 D008 D009 D010 D039 D040 F001 F002 F003 F004 F005
ANL93-MW-00018	D006 D007 D008 D009 D010 F001 F002 F003 F005 D018
ANL93-MW-00019	D006 D007 D008 D009 D010 F001 F002 F003 F005 D018
ANL93-MW-00020	D006 D007 D008 D009 D010 F001 F002 F003 F005 D018
ANL93-MW-00047	D006 D007 D008 D009 D010 F001 F002 F003 F004 D018 F005
ANL93-MW-00048	D006 D007 D008 D009 D010 F001 F002 F003 F004 D018 F005
221T-92-000100	D008 D009 D040 F001 F002

Table B-2: Hazardous Constituent Waste Codes

Hazardous Waste Constituents		
Chemical	Listed Codes	TC Codes
Arsenic		D004
Barium		D005
Cadmium		D006
Chromium		D007
Lead		D008
Mercury		D009
Selenium		D010
Silver		D011
Methylene Chloride	F001 F002	
Tetrachloroethylene	F001 F002	D039
Trichloroethylene	F001 F002	D040
Xylene	F003	
Acetone	F003	
Nitrobenzene	F004	D036
Methyl ethyl ketone	F005	D035
Toluene	F005	
Benzene	F005	D018

Table B-3: Waste Physical Description

Component	Waste Description
Comp. 1	Absorbent/Kity Ltr/Vermiculite
Comp. 2	Cloth/Rags/Nylon
Comp. 3	Hazardous Constituents
Comp. 4	Plastic/Polyurethane
Comp. 5	Sludges
For 221T-92	
Comp. 2	Dirt/Soil/Diatomaceous Earth
Comp. 4	+Foam/styrofoam/pyrofoam
Comp. 5	Glass/Lime/slaked lime

Table B-4: Waste Volumetric Composition

Content Description Volume %							
Package	Waste Wt. (kg)	Volume (cu.m)	Comp. 1	Comp. 2	Comp. 3	Comp. 4	Comp. 5
ANL93-MW-00001	167.8	0.2082	4%	1%	2%	4%	89%
ANL93-MW-00002	168.7	0.2082	3%	1%	2%	5%	89%
ANL93-MW-00003	172.3	0.2082	3%	1%	2%	5%	89%
ANL93-MW-00004	175	0.2082	3%	1%	2%	5%	89%
ANL93-MW-00005	201.8	0.2082	3%	1%	2%	5%	89%
ANL93-MW-00006	198.7	0.2082	3%	1%	2%	5%	89%
ANL93-MW-00007	179.1	0.2082	3%	1%	2%	5%	89%
ANL93-MW-00008	185.9	0.2082	3%	1%	2%	5%	89%
ANL93-MW-00009	179.1	0.2082	3%	1%	2%	5%	89%
ANL93-MW-00010	207.8	0.2082	3%	1%	2%	5%	89%
ANL93-MW-00011	197.8	0.2082	3%	1%	2%	5%	89%
ANL93-MW-00012	187.8	0.2082	3%	1%	2%	5%	89%
ANL93-MW-00013	220	0.2082	3%	1%	2%	5%	89%
ANL93-MW-00014	198.7	0.2082	3%	1%	2%	5%	89%
ANL93-MW-00015	199.6	0.2082	4%	1%	2%	4%	89%
ANL93-MW-00016	205.9	0.2082	3%	1%	2%	4%	90%
ANL93-MW-00017	152.3	0.2082	4%	1%	2%	4%	89%
ANL93-MW-00018	222.3	0.2082	4%	1%	2%	4%	89%
ANL93-MW-00019	253.2	0.2082	3%	1%	2%	4%	90%
ANL93-MW-00020	197.8	0.2082	4%	1%	2%	4%	89%
ANL93-MW-00047	172.3	0.2082	4%	1%	2%	4%	89%
ANL93-MW-00048	225	0.2082	4%	1%	2%	4%	89%
221T-92-000100	99.1	0.21	17%	22%	50%	6%	3%
Total	4368	4.7904					

Table B-5: Waste Mass Composition

Content Description Mass (kg)							
Package	Waste Wt. (kg)	Volume (cu.m)	Comp. 1	Comp. 2	Comp. 3	Comp. 4	Comp. 5
ANL93-MW-00001	167.8	0.2082	6	1	4.4078	6	150.3922
ANL93-MW-00002	168.7	0.2082	6	1	4.5191	6	151.1809
ANL93-MW-00003	172.3	0.2082	6	1	4.6395	6	154.6605
ANL93-MW-00004	175	0.2082	6	1	4.6535	6	157.3465
ANL93-MW-00005	201.8	0.2082	6	1	5.4121	6	183.3879
ANL93-MW-00006	198.7	0.2082	6	1	5.4032	6	180.2968
ANL93-MW-00007	179.1	0.2082	6	1	4.7852	6	161.3148
ANL93-MW-00008	185.9	0.2082	6	1	5.2794	6	167.6206
ANL93-MW-00009	179.1	0.2082	6	1	4.7852	6	161.3148
ANL93-MW-00010	207.8	0.2082	6	1	5.6597	6	189.1403
ANL93-MW-00011	197.8	0.2082	6	1	5.2997	6	179.5003
ANL93-MW-00012	187.8	0.2082	6	1	5.0328	6	169.7672
ANL93-MW-00013	220	0.2082	6	1	5.9251	6	201.0749
ANL93-MW-00014	198.7	0.2082	6	1	5.401	6	180.299
ANL93-MW-00015	199.6	0.2082	6	1	5.411	6	181.189
ANL93-MW-00016	205.9	0.2082	6	1	5.5447	6	187.3553
ANL93-MW-00017	152.3	0.2082	6	1	4.0265	6	135.2735
ANL93-MW-00018	222.3	0.2082	6	1	3.3628	6	205.9372
ANL93-MW-00019	253.2	0.2082	6	1	3.856	6	236.344
ANL93-MW-00020	197.8	0.2082	6	1	2.9849	6	181.8151
ANL93-MW-00047	172.3	0.2082	6	1	3.3879	6	155.9121
ANL93-MW-00048	225	0.2082	6	1	4.4508	6	207.5492
221T-92-000100	99.1	0.21	16.86	52.36	5.0122	12.14	12.7278
Total	4368	4.7904	148.86	74.36	109.2401	144.14	3891.4

Table B-6: Waste Activity Summary

High Mercury Subcategory Wastes
Activities (Ci)

	Current	10/12/95	Reported				
Package	Total Alpha	Total Beta-Gamma	Total Alpha	Total Beta-Gamma	Decay Date	Dose (mrem/hr)	Thermal Power (w/cu.m)
ANL93-MW-00001	1.02 E-03	2.42 E-03	1.02 E-03	2.59 E-03	04/23/93	5	3.53
ANL93-MW-00002	1.02 E-03	2.42 E-03	1.02 E-03	2.59 E-03	04/23/93	10	3.53
ANL93-MW-00003	1.06 E-03	2.60 E-03	1.06 E-03	2.79 E-03	04/20/93	9	3.53
ANL93-MW-00004	1.09 E-03	2.61 E-03	1.09 E-03	2.80 E-03	04/23/93	5	3.53
ANL93-MW-00005	1.27 E-03	3.01 E-03	1.27 E-03	3.23 E-03	04/23/93	8	3.53
ANL93-MW-00006	1.23 E-03	3.01 E-03	1.24 E-03	3.23 E-03	04/23/93	7	3.53
ANL93-MW-00007	1.09 E-03	2.61 E-03	1.10 E-03	2.80 E-03	04/23/93	5	3.53
ANL93-MW-00008	1.16 E-03	2.81 E-03	1.17 E-03	3.01 E-03	04/23/93	7	3.53
ANL93-MW-00009	1.09 E-03	2.61 E-03	1.10 E-03	2.80 E-03	04/23/93	8	3.53
ANL93-MW-00010	1.30 E-03	3.20 E-03	1.31 E-03	3.43 E-03	04/23/93	10	3.53
ANL93-MW-00011	1.23 E-03	3.01 E-03	1.24 E-03	3.23 E-03	04/23/93	8	3.53
ANL93-MW-00012	1.16 E-03	2.81 E-03	1.17 E-03	3.01 E-03	04/23/93	9	3.53
ANL93-MW-00013	1.20 E-03	3.41 E-03	1.21 E-03	3.65 E-03	04/23/93	8	3.53
ANL93-MW-00014	1.23 E-03	3.01 E-03	1.24 E-03	3.23 E-03	04/23/93	7	3.53
ANL93-MW-00015	1.23 E-03	3.01 E-03	1.24 E-03	3.23 E-03	04/23/93	8	3.53
ANL93-MW-00016	1.27 E-03	3.02 E-03	1.27 E-03	3.24 E-03	04/23/93	8	3.53
ANL93-MW-00017	9.15 E-04	2.21 E-03	9.19 E-04	2.39 E-03	04/23/93	7	3.53
ANL93-MW-00018	8.27 E-04	3.55 E-03	8.30 E-04	4.08 E-03	04/23/93	0.7	3.53
ANL93-MW-00019	9.36 E-04	4.09 E-03	9.39 E-04	4.71 E-03	04/23/93	8	3.53
ANL93-MW-00020	7.19 E-04	3.27 E-03	7.22 E-04	3.75 E-03	04/23/93	0.6	3.53
ANL93-MW-00047	2.16 E-03	1.14 E-02	2.16 E-03	1.24 E-02	04/23/93	47	3.53
ANL93-MW-00048	2.89 E-03	1.51 E-02	2.90 E-03	1.65 E-02	04/23/93	8	3.53
221T-92-000100	0.00	6.63 E-07	0.00	7.07 E-07	11/12/92	0.5	3.53
Total	2.71 E-02	8.51 E-02	2.72 E-02	9.27 E-02			

Table B-7a: Reported Isotopic Activity

High Mercury Subcategory Wastes						
Activities (Ci)						
Isotopic Activity (Ci)						
Package	Na-22	Co-60	Sr90	Sb-125	Te-125m	Cs137
ANL93-MW-00001	1.50 E-06	2.20 E-04		3.10 E-05	7.16 E-06	1.20 E-03
ANL93-MW-00002	1.60 E-06	2.20 E-04		3.10 E-05	7.16 E-06	1.20 E-03
ANL93-MW-00003	1.60 E-06	2.20 E-04		3.20 E-05	7.39 E-06	1.30 E-03
ANL93-MW-00004	1.60 E-06	2.30 E-04		3.20 E-05	7.39 E-06	1.30 E-03
ANL93-MW-00005	1.90 E-06	2.60 E-04		3.80 E-05	8.78 E-06	1.50 E-03
ANL93-MW-00006	1.90 E-06	2.60 E-04		3.70 E-05	8.55 E-06	1.50 E-03
ANL93-MW-00007	1.70 E-06	2.30 E-04		3.30 E-05	7.62 E-06	1.30 E-03
ANL93-MW-00008	1.70 E-06	2.40 E-04		3.40 E-05	7.85 E-06	1.40 E-03
ANL93-MW-00009	1.70 E-06	2.30 E-04		3.30 E-05	7.62 E-06	1.30 E-03
ANL93-MW-00010	1.90 E-06	2.70 E-04		3.90 E-05	9.01 E-06	1.60 E-03
ANL93-MW-00011	1.80 E-06	2.60 E-04		3.70 E-05	8.55 E-06	1.50 E-03
ANL93-MW-00012	1.70 E-06	2.40 E-04		3.50 E-05	8.09 E-06	1.40 E-03
ANL93-MW-00013	2.10 E-06	2.90 E-04		4.10 E-05	9.47 E-06	1.70 E-03
ANL93-MW-00014	1.90 E-06	2.60 E-04		3.70 E-05	8.55 E-06	1.50 E-03
ANL93-MW-00015	1.90 E-06	2.60 E-04		3.70 E-05	8.55 E-06	1.50 E-03
ANL93-MW-00016	1.90 E-06	2.70 E-04		3.80 E-05	8.78 E-06	1.50 E-03
ANL93-MW-00017	1.40 E-06	1.90 E-04		2.80 E-05	6.47 E-06	1.10 E-03
ANL93-MW-00018		1.10 E-03		2.10 E-04	4.85 E-05	1.40 E-03
ANL93-MW-00019		1.30 E-03		2.40 E-04	5.54 E-05	1.60 E-03
ANL93-MW-00020		1.00 E-03		1.80 E-04	4.16 E-05	1.30 E-03
ANL93-MW-00047		2.00 E-03		7.90 E-05	1.82 E-05	5.30 E-03
ANL93-MW-00048		2.70 E-03		1.10 E-04	2.54 E-05	7.00 E-03
221T-92-000100			2.04 E-07		0.00	6.80 E-08
Total	2.98 E-05	1.23 E-02	2.04 E-07	1.41 E-03	3.26 E-04	4.04 E-02

Table B-7b: Reported Isotopic Activity

High Mercury Subcategory Wastes							
Activities (Ci)							
Isotopic Activity (Ci)							
Package	Eu-152	Eu-154	Eu-155	Pt-195m	Np-237	Am-241	Pu-241
ANL93-MW-00001					3.10 E-05	9.94 E-04	0.00
ANL93-MW-00002					3.10 E-05	9.94 E-04	0.00
ANL93-MW-00003					3.17 E-05	1.03 E-03	0.00
ANL93-MW-00004					3.24 E-05	1.06 E-03	0.00
ANL93-MW-00005					3.74 E-05	1.23 E-03	0.00
ANL93-MW-00006					3.59 E-05	1.20 E-03	0.00
ANL93-MW-00007					3.31 E-05	1.06 E-03	0.00
ANL93-MW-00008					3.45 E-05	1.13 E-03	0.00
ANL93-MW-00009					3.31 E-05	1.06 E-03	0.00
ANL93-MW-00010					3.88 E-05	1.27 E-03	0.00
ANL93-MW-00011					3.66 E-05	1.20 E-03	0.00
ANL93-MW-00012					3.45 E-05	1.13 E-03	0.00
ANL93-MW-00013					4.16 E-05	1.17 E-03	0.00
ANL93-MW-00014					3.66 E-05	1.20 E-03	0.00
ANL93-MW-00015					3.74 E-05	1.20 E-03	0.00
ANL93-MW-00016					3.88 E-05	1.23 E-03	0.00
ANL93-MW-00017				2.80 E-05	2.75 E-05	8.91 E-04	0.00
ANL93-MW-00018					4.16 E-05	7.88 E-04	0.00
ANL93-MW-00019					4.79 E-05	8.91 E-04	0.00
ANL93-MW-00020					3.66 E-05	6.86 E-04	0.00
ANL93-MW-00047					1.41 E-04	2.02 E-03	0.00
ANL93-MW-00048					1.90 E-04	2.71 E-03	0.00
221T-92-000100	2.27 E-08	4.54 E-08	9.83 E-08		0.00	0.00	4.54 E-08
Total	2.27 E-08	4.54 E-08	9.83 E-08	2.80 E-05	1.05 E-03	2.62 E-02	4.54 E-08

Table B-8a: Current Isotopic Activity

High Mercury Subcategory Wastes						
Current Activities (Ci)						
	Decay Date		10/12/95			
halflife(s)	8.22 E+07	1.66 E+08	9.18 E+08	8.70 E+07	5.01 E+06	9.52 E+08
Isotope	Na-22	Co-60	Sr90	Sb-125	Te-125m	Cs137
ANL93-MW-00001	7.78 E-07	1.59 E-04	0	0.000017	0.000004	1.13 E-03
ANL93-MW-00002	8.29 E-07	1.59 E-04	0	0.000017	0.000004	1.13 E-03
ANL93-MW-00003	8.28 E-07	1.59 E-04	0	0.000017	0.000004	1.23 E-03
ANL93-MW-00004	8.29 E-07	1.66 E-04	0	0.000017	0.000004	1.23 E-03
ANL93-MW-00005	9.85 E-07	1.88 E-04	0	0.00002	0.000005	1.42 E-03
ANL93-MW-00006	9.85 E-07	1.88 E-04	0	0.00002	0.000005	1.42 E-03
ANL93-MW-00007	8.81 E-07	1.66 E-04	0	0.000018	0.000004	1.23 E-03
ANL93-MW-00008	8.81 E-07	1.73 E-04	0	0.000018	0.000004	1.32 E-03
ANL93-MW-00009	8.81 E-07	1.66 E-04	0	0.000018	0.000004	1.23 E-03
ANL93-MW-00010	9.85 E-07	1.95 E-04	0	0.000021	0.000005	1.51 E-03
ANL93-MW-00011	9.33 E-07	1.88 E-04	0	0.00002	0.000005	1.42 E-03
ANL93-MW-00012	8.81 E-07	1.73 E-04	0	0.000019	0.000004	1.32 E-03
ANL93-MW-00013	0.000001	2.10 E-04	0	0.000022	0.000005	1.61 E-03
ANL93-MW-00014	9.85 E-07	1.88 E-04	0	0.00002	0.000005	1.42 E-03
ANL93-MW-00015	9.85 E-07	1.88 E-04	0	0.00002	0.000005	1.42 E-03
ANL93-MW-00016	9.85 E-07	1.95 E-04	0	0.00002	0.000005	1.42 E-03
ANL93-MW-00017	7.26 E-07	1.37 E-04	0	0.000015	0.000003	1.04 E-03
ANL93-MW-00018	0	7.95 E-04	0	0.000113	0.000026	1.32 E-03
ANL93-MW-00019	0	9.40 E-04	0	0.000129	0.00003	1.51 E-03
ANL93-MW-00020	0	7.23 E-04	0	0.000097	0.000022	1.23 E-03
ANL93-MW-00047	0	1.45 E-03	0	0.000042	0.00001	5.01 E-03
ANL93-MW-00048	0	1.95 E-03	0	0.000059	0.000014	6.61 E-03
221T-92-000100	0	0	1.90 E-07	0	0	6.36 E-08
Total	1.54 E-05	8.85 E-03	1.90 E-07	7.59 E-04	1.75 E-04	3.82 E-02

Table B-8b: Current Isotopic Activity

High Mercury Subcategory Wastes							
Current Activities (Ci)							
	Decay Date		10/12/95				
halflife(s)	4.25 E+08	2.71 E+08	1.49 E+08	3.47 E+05	6.75 E+13	1.37 E+10	4.45 E+08
Isotope	Eu-152	Eu-154	Eu-155	Pt-195m	Np-237	Am-241	Pu-241
ANL93-MW-00001	0	0	0	0	3.10 E-05	9.90 E-04	0
ANL93-MW-00002	0	0	0	0	3.10 E-05	9.90 E-04	0
ANL93-MW-00003	0	0	0	0	3.17 E-05	1.02 E-03	0
ANL93-MW-00004	0	0	0	0	3.24 E-05	1.06 E-03	0
ANL93-MW-00005	0	0	0	0	3.74 E-05	1.23 E-03	0
ANL93-MW-00006	0	0	0	0	3.59 E-05	1.19 E-03	0
ANL93-MW-00007	0	0	0	0	3.31 E-05	1.06 E-03	0
ANL93-MW-00008	0	0	0	0	3.45 E-05	1.13 E-03	0
ANL93-MW-00009	0	0	0	0	3.31 E-05	1.06 E-03	0
ANL93-MW-00010	0	0	0	0	3.88 E-05	1.26 E-03	0
ANL93-MW-00011	0	0	0	0	3.66 E-05	1.19 E-03	0
ANL93-MW-00012	0	0	0	0	3.45 E-05	1.13 E-03	0
ANL93-MW-00013	0	0	0	0	4.16 E-05	1.16 E-03	0
ANL93-MW-00014	0	0	0	0	3.66 E-05	1.19 E-03	0
ANL93-MW-00015	0	0	0	0	3.74 E-05	1.19 E-03	0
ANL93-MW-00016	0	0	0	0	3.88 E-05	1.23 E-03	0
ANL93-MW-00017	0	0	0	7.99 E-73	2.75 E-05	8.88 E-04	0
ANL93-MW-00018	0	0	0	0	4.16 E-05	7.85 E-04	0
ANL93-MW-00019	0	0	0	0	4.79 E-05	8.88 E-04	0
ANL93-MW-00020	0	0	0	0	3.66 E-05	6.83 E-04	0
ANL93-MW-00047	0	0	0	0	1.41 E-04	2.01 E-03	0
ANL93-MW-00048	0	0	0	0	1.90 E-04	2.70 E-03	0
221T-92-000100	1.95 E-08	3.59 E-08	6.40 E-08	0	0	0	3.94 E-08
Total	1.95 E-08	3.59 E-08	6.40 E-08	7.99 E-73	1.05 E-03	2.60 E-02	3.94 E-08

Table B-9a: Waste Package Hazardous Metal Masses

High Mercury Subcategory Wastes								
Hazardous Waste Components (kg)								
TC Codes	D004	D005	D006	D007	D008	D009	D010	D011
Package	Arsenic	Barium	Cadmium	Chromium	Lead	Mercury	Selenium	Silver
ANL93-MW-00001	0.013	0.045	0.014	3.5	0.41	0.16	0.011	0.0057
ANL93-MW-00002	0.013	0.045	0.014	3.6	0.41	0.17	0.011	0.0058
ANL93-MW-00003	0.014	0.046	0.014	3.7	0.42	0.17	0.011	0.0059
ANL93-MW-00004	0.014	0.047	0.015	3.7	0.43	0.17	0.011	0.006
ANL93-MW-00005	0.016	0.055	0.017	4.3	0.5	0.2	0.013	0.007
ANL93-MW-00006	0.016	0.054	0.017	4.3	0.49	0.2	0.013	0.0069
ANL93-MW-00007	0.014	0.048	0.015	3.8	0.44	0.18	0.011	0.0062
ANL93-MW-00008	0.015	0.05	0.016	4	0.46	0.18	0.012	0.0064
ANL93-MW-00009	0.014	0.048	0.015	3.8	0.44	0.18	0.011	0.0062
ANL93-MW-00010	0.017	0.056	0.017	4.5	0.52	0.21	0.018	0.0072
ANL93-MW-00011	0.016	0.053	0.017	4.2	0.49	0.2	0.013	0.0068
ANL93-MW-00012	0.015	0.051	0.016	4	0.46	0.19	0.012	0.0065
ANL93-MW-00013	0.018	0.06	0.019	4.7	0.55	0.22	0.014	0.0077
ANL93-MW-00014	0.016	0.054	0.017	4.3	0.49	0.2	0.013	0.0069
ANL93-MW-00015	0.016	0.054	0.017	4.3	0.5	0.2	0.013	0.0069
ANL93-MW-00016	0.017	0.056	0.017	4.4	0.51	0.21	0.013	0.0072
ANL93-MW-00017	0.012	0.04	0.012	3.2	0.37	0.15	0.0096	0.0052
ANL93-MW-00018	0.0071	0.084	0.029	2.7	0.33	0.18	0.021	
ANL93-MW-00019	0.0082	0.096	0.033	3.1	0.38	0.2	0.025	
ANL93-MW-00020	0.0063	0.074	0.025	2.4	0.29	0.16	0.019	
ANL93-MW-00047	0.004	0.1	0.08	2.3	0.47	0.4	0.016	0.01
ANL93-MW-00048	0.0053	0.13	0.11	3	0.63	0.53	0.021	0.014
221T-92-000100				0.0009	0.04	0.04		0.0013
Total	0.2869	1.346	0.546	81.8009	10.03	4.7	0.3116	0.1358

Table B-9b: Waste Package Hazardous Metal Mass Fractions

High Mercury Subcategory Wastes								
Hazardous Waste Components								
Mass Fractions								
Package	Arsenic	Barium	Cadmium	Chromium	Lead	Mercury	Selenium	Silver
ANL93-MW-00001	7.75 E-05	2.68 E-04	8.34 E-05	2.09 E-02	2.44 E-03	9.54 E-04	6.56 E-05	3.40 E-05
ANL93-MW-00002	7.71 E-05	2.67 E-04	8.30 E-05	2.13 E-02	2.43 E-03	1.01 E-03	6.52 E-05	3.44 E-05
ANL93-MW-00003	8.13 E-05	2.67 E-04	8.13 E-05	2.15 E-02	2.44 E-03	9.87 E-04	6.38 E-05	3.42 E-05
ANL93-MW-00004	8.00 E-05	2.69 E-04	8.57 E-05	2.11 E-02	2.46 E-03	9.71 E-04	6.29 E-05	3.43 E-05
ANL93-MW-00005	7.93 E-05	2.73 E-04	8.42 E-05	2.13 E-02	2.48 E-03	9.91 E-04	6.44 E-05	3.47 E-05
ANL93-MW-00006	8.05 E-05	2.72 E-04	8.56 E-05	2.16 E-02	2.47 E-03	1.01 E-03	6.54 E-05	3.47 E-05
ANL93-MW-00007	7.82 E-05	2.68 E-04	8.38 E-05	2.12 E-02	2.46 E-03	1.01 E-03	6.14 E-05	3.46 E-05
ANL93-MW-00008	8.07 E-05	2.69 E-04	8.61 E-05	2.15 E-02	2.47 E-03	9.68 E-04	6.46 E-05	3.44 E-05
ANL93-MW-00009	7.82 E-05	2.68 E-04	8.38 E-05	2.12 E-02	2.46 E-03	1.01 E-03	6.14 E-05	3.46 E-05
ANL93-MW-00010	8.18 E-05	2.69 E-04	8.18 E-05	2.17 E-02	2.50 E-03	1.01 E-03	8.66 E-05	3.46 E-05
ANL93-MW-00011	8.09 E-05	2.68 E-04	8.59 E-05	2.12 E-02	2.48 E-03	1.01 E-03	6.57 E-05	3.44 E-05
ANL93-MW-00012	7.99 E-05	2.72 E-04	8.52 E-05	2.13 E-02	2.45 E-03	1.01 E-03	6.39 E-05	3.46 E-05
ANL93-MW-00013	8.18 E-05	2.73 E-04	8.64 E-05	2.14 E-02	2.50 E-03	1.00 E-03	6.36 E-05	3.50 E-05
ANL93-MW-00014	8.05 E-05	2.72 E-04	8.56 E-05	2.16 E-02	2.47 E-03	1.01 E-03	6.54 E-05	3.47 E-05
ANL93-MW-00015	8.02 E-05	2.71 E-04	8.52 E-05	2.15 E-02	2.51 E-03	1.00 E-03	6.51 E-05	3.46 E-05
ANL93-MW-00016	8.26 E-05	2.72 E-04	8.26 E-05	2.14 E-02	2.48 E-03	1.02 E-03	6.31 E-05	3.50 E-05
ANL93-MW-00017	7.88 E-05	2.63 E-04	7.88 E-05	2.10 E-02	2.43 E-03	9.85 E-04	6.30 E-05	3.41 E-05
ANL93-MW-00018	3.19 E-05	3.78 E-04	1.30 E-04	1.21 E-02	1.48 E-03	8.10 E-04	9.45 E-05	0.00
ANL93-MW-00019	3.24 E-05	3.79 E-04	1.30 E-04	1.22 E-02	1.50 E-03	7.90 E-04	9.87 E-05	0.00
ANL93-MW-00020	3.19 E-05	3.74 E-04	1.26 E-04	1.21 E-02	1.47 E-03	8.09 E-04	9.61 E-05	0.00
ANL93-MW-00047	2.32 E-05	5.80 E-04	4.64 E-04	1.33 E-02	2.73 E-03	2.32 E-03	9.29 E-05	5.80 E-05
ANL93-MW-00048	2.36 E-05	5.78 E-04	4.89 E-04	1.33 E-02	2.80 E-03	2.36 E-03	9.33 E-05	6.22 E-05
221T-92-000100	0.00	0.00	0.00	9.08 E-06	4.04 E-04	4.04 E-04	0.00	1.31 E-05
			Hg content (ppm)		Max	2356		
					Min	404		

Table B-9c: Waste Package Hazardous Organic Compound Masses

High Mercury Subcategory Wastes										
Hazardous Waste Components (kg)										
Listed Codes	F001 F002	F001 F002	F001 F002	F003	F003	F004	F005	F005	F005	
TC Codes		D039	D040			D036	D035		D018	Sum (kg)
Package	Methylene Chloride	Tetrachloro ethylene	Trichloro ethylene	Xylene	Acetone	Nitro benzene	Methyl ethyl ketone	Toluene	Benzene	
ANL93-MW-00001		0.23	0.002	0.0015	0.0046	0.01	0.0002	0.0008		4.4078
ANL93-MW-00002		0.23	0.002	0.0016	0.0047	0.011	0.0002	0.0008		4.5191
ANL93-MW-00003		0.24	0.0002	0.0016	0.0048	0.011	0.0002	0.0008		4.6395
ANL93-MW-00004		0.24	0.0021	0.0016	0.0048	0.011	0.0002	0.0008		4.6535
ANL93-MW-00005		0.28	0.0024	0.0019	0.0056	0.013	0.0002	0.001		5.4121
ANL93-MW-00006		0.28	0.0024	0.0019	0.0056	0.013	0.0024	0.001		5.4032
ANL93-MW-00007		0.25	0.0022	0.0017	0.005	0.011	0.0002	0.0009		4.7852
ANL93-MW-00008		0.26	0.26	0.0017	0.0052	0.012	0.0002	0.0009		5.2794
ANL93-MW-00009		0.25	0.0022	0.0017	0.005	0.011	0.0002	0.0009		4.7852
ANL93-MW-00010		0.29	0.0025	0.0019	0.0058	0.013	0.0003	0.001		5.6597
ANL93-MW-00011		0.28	0.0024	0.0018	0.0055	0.013	0.0002	0.001		5.2997
ANL93-MW-00012		0.26	0.0023	0.0017	0.0052	0.012	0.0002	0.0009		5.0328
ANL93-MW-00013		0.31	0.0027	0.0021	0.0062	0.014	0.0003	0.0011		5.9251
ANL93-MW-00014		0.28	0.0024	0.0019	0.0056	0.013	0.0002	0.001		5.401
ANL93-MW-00015		0.28	0.0024	0.0019	0.0056	0.013	0.0002	0.001		5.411
ANL93-MW-00016		0.29	0.0025	0.0019	0.0058	0.013	0.0003	0.001		5.5447
ANL93-MW-00017		0.21	0.0018	0.0014	0.0042	0.0094	0.0002	0.0007		4.0265
ANL93-MW-00018	0.0001	0.0001			0.0004		0.0001		0.011	3.3628
ANL93-MW-00019	0.0001	0.0001			0.0005		0.0001		0.013	3.856
ANL93-MW-00020	0.0001	0.0001			0.0004		0.0001		0.0099	2.9849
ANL93-MW-00047	0.0004				0.0001	0.0073			0.0001	3.3879
ANL93-MW-00048	0.0005				0.0002	0.0097			0.0001	4.4508
221T-92-000100			0.03							0.1122
Total	0.0012	4.4603	0.3245	0.0298	0.0908	0.2204	0.0062	0.0156	0.0341	104.3401

Table B-9d: Waste Package Hazardous Organic Mass Fractions

High Mercury Subcategory Wastes									
Hazardous Waste Components									
Mass Fractions									
Package	Methylene Chloride	Tetrachloro ethylene	Trichloro ethylene	Xylene	Acetone	Nitro benzene	Methyl ethyl ketone	Toluene	Benzene
ANL93-MW-00001	0	1.37 E-03	1.19 E-05	8.94 E-06	2.74 E-05	5.96 E-05	1.19 E-06	4.77 E-06	0
ANL93-MW-00002	0	1.36 E-03	1.19 E-05	9.48 E-06	2.79 E-05	6.52 E-05	1.19 E-06	4.74 E-06	0
ANL93-MW-00003	0	1.39 E-03	1.16 E-06	9.29 E-06	2.79 E-05	6.38 E-05	1.16 E-06	4.64 E-06	0
ANL93-MW-00004	0	1.37 E-03	1.20 E-05	9.14 E-06	2.74 E-05	6.29 E-05	1.14 E-06	4.57 E-06	0
ANL93-MW-00005	0	1.39 E-03	1.19 E-05	9.42 E-06	2.78 E-05	6.44 E-05	9.91 E-07	4.96 E-06	0
ANL93-MW-00006	0	1.41 E-03	1.21 E-05	9.56 E-06	2.82 E-05	6.54 E-05	1.21 E-05	5.03 E-06	0
ANL93-MW-00007	0	1.40 E-03	1.23 E-05	9.49 E-06	2.79 E-05	6.14 E-05	1.12 E-06	5.03 E-06	0
ANL93-MW-00008	0	1.40 E-03	1.40 E-03	9.14 E-06	2.80 E-05	6.46 E-05	1.08 E-06	4.84 E-06	0
ANL93-MW-00009	0	1.40 E-03	1.23 E-05	9.49 E-06	2.79 E-05	6.14 E-05	1.12 E-06	5.03 E-06	0
ANL93-MW-00010	0	1.40 E-03	1.20 E-05	9.14 E-06	2.79 E-05	6.26 E-05	1.44 E-06	4.81 E-06	0
ANL93-MW-00011	0	1.42 E-03	1.21 E-05	9.10 E-06	2.78 E-05	6.57 E-05	1.01 E-06	5.06 E-06	0
ANL93-MW-00012	0	1.38 E-03	1.22 E-05	9.05 E-06	2.77 E-05	6.39 E-05	1.06 E-06	4.79 E-06	0
ANL93-MW-00013	0	1.41 E-03	1.23 E-05	9.55 E-06	2.82 E-05	6.36 E-05	1.36 E-06	5.00 E-06	0
ANL93-MW-00014	0	1.41 E-03	1.21 E-05	9.56 E-06	2.82 E-05	6.54 E-05	1.01 E-06	5.03 E-06	0
ANL93-MW-00015	0	1.40 E-03	1.20 E-05	9.52 E-06	2.81 E-05	6.51 E-05	1.00 E-06	5.01 E-06	0
ANL93-MW-00016	0	1.41 E-03	1.21 E-05	9.23 E-06	2.82 E-05	6.31 E-05	1.46 E-06	4.86 E-06	0
ANL93-MW-00017	0	1.38 E-03	1.18 E-05	9.19 E-06	2.76 E-05	6.17 E-05	1.31 E-06	4.60 E-06	0
ANL93-MW-00018	4.50 E-07	4.50 E-07	0	0	1.80 E-06	0	4.50 E-07	0	4.95 E-05
ANL93-MW-00019	3.95 E-07	3.95 E-07	0	0	1.97 E-06	0	3.95 E-07	0	5.13 E-05
ANL93-MW-00020	5.06 E-07	5.06 E-07	0	0	2.02 E-06	0	5.06 E-07	0	5.01 E-05
ANL93-MW-00047	2.32 E-06	0	0	0	5.80 E-07	4.24 E-05	0	0	5.80 E-07
ANL93-MW-00048	2.22 E-06	0	0	0	8.89 E-07	4.31 E-05	0	0	4.44 E-07
221T-92-000100	0	0	3.03 E-04	0	0	0	0	0	0

APPENDIX C: ROCKY FLATS STORED LOW LEVEL MIXED WASTE STREAM DETAIL

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Table C-1: ROCKY FLATS STORED LOW LEVEL MIXED WASTE STREAMS AND TARGETED TREATMENT TECHNOLOGIES

ROCKY FLATS STORED LOW LEVEL MIXED WASTE STREAMS AND TARGETED TREATMENT TECHNOLOGIES

MWIR #	Mixed Waste Description	IDC	IDC Description	Constituents	Volume (M^3)	Primary Treatment (1,2,3)	Secondary Treatment
RF-W003	Cemented Composit Chips	327	Cemented Composit Metal	Vol	95.4	SCDE	
RF-W005	Metal	480	Light Metal	Vol, Metals, Cy, Hg	152.59	SCDE	LCE, Polymer Macro
RF-W005	Metal	480	Light Metal	React	0.21	Polymer Macro	
RF-W005	Metal	480	Light Metal	Vol, Metals, Cy, Leach	9.07	SCDE	LCE, Polymer Macro
RF-W005	Metal	480	Light Metal	Metals	1.26	Polymer Macro	
RF-W006	Combustibles	325	Mixed IDCs (Outside PA)	Metals	10.83	Polymer	
RF-W006	Combustibles	325	Mixed IDCs (Outside PA)	Vol, Metals, Cy, Leach	60.23	Multiple	
RF-W006	Combustibles	325	Mixed IDCs (Outside PA)	Ignit, React, Corrsv, Hg, Cy, Metals	10.88	Multiple	
RF-W006	Combustibles	325	Mixed IDCs (Outside PA)	Ignit, Vol	4.62	SCDE	
RF-W006	Combustibles	325	Mixed IDCs (Outside PA)	Vol	8.93	SCDE	
RF-W006	Combustibles	325	Mixed IDCs (Outside PA)	Vol, Hg	1.89	SCDE	
RF-W006	Combustibles	325	Mixed IDCs (Outside PA)	Vol, Metals, Hg	0.84	SCDE	Polymer Macro
RF-W006	Combustibles	325	Mixed IDCs (Outside PA)	Vol, Metals	0.32	SCDE	Polymer Macro
RF-W006	Combustibles	851	Combustibles, Dry	Vol, Metals, Cy, Leach	773.82	Multiple	
RF-W006	Combustibles	851	Combustibles, Dry	Vol	102.69	SCDE	
RF-W006	Combustibles	851	Combustibles, Dry	Metals	19.78	Polymer Macro	
RF-W006	Combustibles	851	Combustibles, Dry	Vol, Metals	10.94	SCDE	Polymer Macro
RF-W006	Combustibles	851	Combustibles, Dry	Vol, Metals, Cy	12.69	SCDE	LCE, Polymer Macro
RF-W006	Combustibles	851	Combustibles, Dry	Vol, Hg	0.21	SCDE	
RF-W006	Combustibles	851	Combustibles, Dry	Vol, Metals, Cy, Hg	6.02	Multiple	
RF-W006	Combustibles	852	Combustibles, Wet	Vol, Metals, Cy, Hg	14.07	Multiple	
RF-W006	Combustibles	852	Combustibles, Wet	Vol	77.32	SCDE	
RF-W006	Combustibles	852	Combustibles, Wet	Vol, Metals, Cy, Leach	20.39	Multiple	
RF-W006	Combustibles	852	Combustibles, Wet	Metals	10.5	Polymer Macro	
RF-W006	Combustibles	852	Combustibles, Wet	Vol, Metals	34.29	SCDE	Polymer Macro
RF-W006	Combustibles	852	Combustibles, Wet	Vol, Metals, Cy	0.42	SCDE	LCE, Polymer Macro
RF-W006	Combustibles	852	Combustibles, Wet	Vol, Metals, Hg	0.63	SCDE	Polymer Macro
RF-W006	Combustibles	852	Combustibles, Wet	Vol, Hg	0.21	SCDE	
RF-W006	Combustibles	852	Combustibles, Wet	Metals, Hg	0.21	Polymer Macro	
RF-W006	Combustibles	852	Combustibles, Wet	Vol, Cy	0.21	SCDE	LCE, Polymer Macro
RF-W006	Combustibles	853	Plastic	Vol, Metals, Cy, Hg	4.62	SCDE	LCE, Polymer Macro
RF-W006	Combustibles	853	Plastic	Vol, Metals, Cy, Leach	3.99	Multiple	
RF-W006	Combustibles	853	Plastic	Vol, Metals	0.21	SCDE	Polymer Macro
RF-W006	Combustibles	863	Plastic	Metals	1.68	Polymer Macro	

Table D-1: ROCKY FLATS STORED LOW LEVEL MIXED WASTE STREAMS AND TARGETED TREATMENT TECHNOLOGIES, continued

ROCKY FLATS STORED LOW LEVEL MIXED WASTE STREAMS AND TARGETED TREATMENT TECHNOLOGIES							
MWIR #	Mixed Waste Description	IDC	IDC Description	Constituents	Volume (M^3)	Primary Treatment (1,2,3)	Secondary Treatment
RF-W006	Combustibles	853	Plastic	Vol	12.01	SCDE	
RF-W006	Combustibles	853	Plastic	Hg	1.59	SCDE	
RF-W006	Combustibles	853	Plastic	Vol, Metals, Cy	19.06	SCDE	LCE, Polymer Macro
RF-W006	Combustibles	337	Plastic (PTFE, PVC, PE, etc.)	Vol	0.42	SCDE	
RF-W007	Roaster Oxide	69	Roaster Oxide	Vol	66.36	SCDE	
RF-W009	Solidified Bypass Sludge	1	Aqueous Sludge	Vol, Metals, Cy, Hg	0.21	SCDE	LCE, Polymer Micro
RF-W009	Solidified Bypass Sludge	807	Bypass Sludge - Bldg 374	Vol, Metals, Cy, Leach	457.17	SCDE	LCE, Polymer Micro
RF-W015	FBI Oil	X106	FBI Oil	Vol, PCB	0.42	CCO	
RF-W015	FBI Oil	X106	FBI Oil	Vol, PCB	37.85	CCO	
RF-W017	PCB Liquids	299	Misc. Sludge/PCB	Vol, PCB	0.31	SCDE or CCO	
RF-W017	PCB Liquids	544P	Excess Chemicals - Liquids/PCB	Ignit, PCB	0	CCO	
RF-W017	PCB Liquids	X106P	FBI Oil/PCB	Ignit, Vol, PCB	37.85	CCO	
RF-W017	PCB Liquids	544P	Organics - Discard Level/PCB	Vol, Metals, PCB	0.42	CCO	
RF-W017	PCB Liquids	533P	Organics - Discard Level/PCB	Ignit, Vol, Metals, Hg, PCB	0.42	CCO	
RF-W020	Beryllium Fines	870	Beryllium Fines	Vol, Metals	1.05	SCDE	Polymer Micro
RF-W020	Beryllium Fines	870	Beryllium Fines	Metals	2.1	Polymer Micro	
RF-W022	Incinerator Ash	420	Pulverized Incinerator Ash	Vol, Metals, Hg	0.21	SCDE	Polymer Micro
RF-W022	Incinerator Ash	425	Fluid Bed Ash	Vol, Metals	10.71	SCDE	Polymer Micro
RF-W023	Lead	321	Lead	Metals	34.69	Polymer Macro	
RF-W024	Ground Glass	444	Ground/Leaded Glass	Metals	2.1	SCDE	Polymer Micro
RF-W024	Ground Glass	444	Ground/Leaded Glass	Vol, Metals, Hg	2.73	SCDE	Polymer Micro
RF-W024	Ground Glass	855	Ground Glass	Hg	5.46	SCDE	
RF-W025	Used Absorbents	375	Oil Dri	Vol	0.25	SCDE	
RF-W025	Used Absorbents	375	Oil Dri	Metals	0.04	Polymer Micro	
RF-W027	Paints	529	Miscellaneous Organic Liquid/Solution	Ignit, Vol, Metals	0.31	CCO	
RF-W027	Paints	529	Miscellaneous Organic Liquid/Solution	Ignit, Vol	0.63	CCO	
RF-W027	Paints	531	Miscellaneous Organic Sludge	Vol	0.21	SCDE or CCO	
RF-W030	Leaded Gloves	339	Leaded Drybox Gloves	Metals	3.57	Polymer Macro	
RF-W031	Leaded Gloves-Acid	341	Leaded Drybox Gloves/Acid Contam	Metals	0.21	Polymer Macro	
RF-W035	Glovebox Parts - Lead	488	Glovebox Parts With Lead	Metals	0.42	Polymer Macro	
RF-W042	Heavy Metal (Non-SS)	320	Heavy Metal (Non-SS)	Metals	0.84	Polymer Macro	
RF-W042	Heavy Metal (Non-SS)	320	Heavy Metal (Non-SS)	Hg	0.29	SCDE	
RF-W043	Glass	440	Glass (except Raschig Rings)	Metals, Hg	0.42	SCDE	Polymer
RF-W043	Glass	440	Glass (except Raschig Rings)	Hg	2.1	SCDE	

Table D-1: ROCKY FLATS STORED LOW LEVEL MIXED WASTE STREAMS AND TARGETED TREATMENT TECHNOLOGIES, continued

ROCKY FLATS STORED LOW LEVEL MIXED WASTE STREAMS AND TARGETED TREATMENT TECHNOLOGIES

MWIR #	Mixed Waste Description	IDC	IDC Description	Constituents	Volume (M^3)	Primary Treatment (1,2,3)	Secondary Treatment
RF-W045	Insulation	438	Insulation	Vol, Metals, Cy, Leach	1.47	SCDE	LCE, Polymer
RF-W045	Insulation	438	Insulation	Vol, Metals, Cy, Hg	1.47	SCDE	LCE, Polymer
RF-W046	Organics Discard Level	533	Organics -Discard Level	Vol	34.92	CCO	
RF-W046	Organics Discard Level	533	Organics -Discard Level	Ignit, Vol	2.96	CCO	
RF-W046	Organics Discard Level	533	Organics -Discard Level	Ignit, Corrsv, Vol, Metals,Cy, Hg	9.97	CCO	
RF-W046	Organics Discard Level	535	Organics Solution (Lab Quantities)	Ignit, Vol, Metals	3.36	CCO	
RF-W046	Organics Discard Level	533	Organics -Discard Level	Vol, Metals	1.47	CCO	
RF-W046	Organics Discard Level	533	Organics -Discard Level	Ignit, Vol, Metals, React	1.68	CCO	
RF-W049	Miscellaneous Liquids	530	Misc. aqueous/Organic Liquid Mixture	Vol, Corrsv	0.21	CCO	
RF-W049	Miscellaneous Liquids	530	Misc. aqueous/Organic Liquid Mixture	Ignit, Vol, Corrsv	0.21	CCO	
RF-W049	Miscellaneous Liquids	530	Misc. aqueous/Organic Liquid Mixture	Ignit, Vol, Metals	0.42	CCO	
RF-W049	Miscellaneous Liquids	530	Misc. aqueous/Organic Liquid Mixture	Vol, Corrsv, Metals	0.21	CCO	
RF-W049	Miscellaneous Liquids	599	N.O.L. Solutions	Vol, Metals	0.22	Specialized Chemistries	
RF-W049	Miscellaneous Liquids	505	Miscellaneous Neutral Waste Solution	Metals	0.25	CCO	
RF-W049	Miscellaneous Liquids	505	Miscellaneous Neutral Waste Solution	Metals, Cy	0.02	Specialized Chemistries	
RF-W049	Miscellaneous Liquids	527	Misc. Basic Solutions	Hg	0.21	Specialized Chemistries	
RF-W049	Miscellaneous Liquids	X107	Miscellaneous Liquids	Vol	0.42	Specialized Chemistries	
RF-W049	Miscellaneous Liquids	X107	Miscellaneous Liquids	Ignit, Vol	0.21	Specialized Chemistries	
RF-W050	Soil & Cleanup Debris	374	Blacktop, Concrete, Dirt and Sand	Vol, Metals, Cy, Hg, Leach	90.81	Multiple	
RF-W050	Soil & Cleanup Debris	374	Blacktop, Concrete, Dirt and Sand	Vol, Metals, Cy, Leach	3.27	Multple	
RF-W050	Soil & Cleanup Debris	374	Blacktop, Concrete, Dirt and Sand	Vol, Metals, Cy	0.21	SCDE	LCE, Polymer
RF-W050	Soil & Cleanup Debris	374	Blacktop, Concrete, Dirt and Sand	Metals	0.04	Polymer	
RF-W050	Soil & Cleanup Debris	374	Blacktop, Concrete, Dirt and Sand	Vol	311.72	SCDE	
RF-W054	Cyanides	X104	Cyanides	Cy	0.42	Specialized Chemistries	
RF-W055	Turnings	871	Titanium Turnings	React	0.42	Specialized Chemistries	
RF-W062	Solidified Organics	801	Solidified Organics -Bldg 774	Vol, Metals, Cy, Hg	0.21	SCDE	LCE, Polymer Micro
RF-W062	Solidified Organics	801	Solidified Organics - Bldg 774	Vol	0.21	SCDE	
RF-W071	Particulate Sludge	813	RCRA Regulated Sludge - OU1	Vol	64.05	SCDE	
RF-W071	Particulate Sludge	332	Oily Sludge	Ignit.	0.84	SCDE or CCO	
RF-W071	Particulate Sludge	532	Miscellaneous Inorganic Solids	Metals	4.74	SCDE	Polymer Micro
RF-W071	Particulate Sludge	292	Incinerator Sludge	Ignit, Vol, Met	1.26	SCDE	Polymer Micro
RF-W071	Particulate Sludge	371	Fire Brick	Vol, Metals, Hg	2.1	SCDE	Polymer
RF-W071	Particulate Sludge	812	Carbon Filter Media	Leach	1.89	CCO organic, LCE inorg.	Polymer inorganics
RF-W071	Particulate Sludge	813	RCRA Regulated Sludge - OU1	Vol, Metals, Cy	12.72	SCDE	LCE, Polymer Micro

Table D-1: ROCKY FLATS STORED LOW LEVEL MIXED WASTE STREAMS AND TARGETED TREATMENT TECHNOLOGIES, continued

ROCKY FLATS STORED LOW LEVEL MIXED WASTE STREAMS AND TARGETED TREATMENT TECHNOLOGIES							
MWIR #	Mixed Waste Description	IDC	IDC Description	Constituents	Volume (M^3)	Primary Treatment (1,2,3)	Secondary Treatment
RF-W074	Cemented Filters	338	Filter Media	Ignit, Vol	0.21	SCDE	
RF-W074	Cemented Filters	338	Filter Media	Vol	3.93	SCDE	
RF-W075	Filters and Media	328	Filter, Fulflo, From Incinerator	Corrsv, Vol	0.21	SCDE	
RF-W075	Filters and Media	342	Absolute Drybox Filters/Acid Contam	Vol	1.68	SCDE	
RF-W075	Filters and Media	335	Absolute Drybox Filters	Ignit, Vol, Metals, Cy, Leach	0.21	Multiple	
RF-W075	Filters and Media	490	HEPA Filters	Vol, Metals	0.21	SCDE	
RF-W075	Filters and Media	491	Pre-Filters	Vol, Metals,Hg	0.21	SCDE	
RF-W081	PCB Solids-Combustibles	330P	Combustibles, Dry.PCB	Vol, PCB	10.81	SCDE or CCO	
RF-W082	PCB Solids-Metal	481P	Light Metal (non-SS)/PCB	Vol, PCB	0.52	SCDE	
RF-W047	Analytical Lab Solutions		Analytical Lab Solutions	Misc	6.05	Specialized Chemistries	
RF-W083	Excess Chemicals		Excess Chemicals Organometallic Lab Packs	Misc	6.69	Specialized Chemistries	
RF-W084	Excess Chemicals		Excess Chemicals Organic Lab Packs	Misc	4.26	Specialized Chemistries	
RF-W085	Excess Chemicals		Excess Chemicals Non-Lab Packs W/Mercury	Misc	2.94	Specialized Chemistries	
RF-W086	Excess Chemicals		Excess Chemicals Non-Lab Packs Other	Misc	3.38	Specialized Chemistries	
RF-WXXX	Excess Chemicals		Excess Chemicals Uncategorized	Misc	30.13	Specialized Chemistries	
					2781.06		

Table C-2: Waste Code Descriptions and Notes

Notes:		
Abbreviation	Name	EPA Code
Corrsv	Corrosivity	D002
Ignit	Ignitiability	D001
React	Reactivity	D003
Vol	Volitiles	F001-F005
Cy	Inorganic Cyanide	F006-F012, P029, P030, P098, P104, P106, P121
Hg	Mercury	D009, P092, U151
Leach	Leachate	F039
Metals	Toxic Metals	D004-D011
SCDE	Supercritical Carbon Dioxide Extraction	
CCO	Catalytic Chemical Oxidation	
Polymer Micro	Polymer Microencapsulation	
Polymer Macro	Polymer Macroencapsulation	
Polymer	Macro and/or Micro depending on partical size	
LCE	Liquid Chemical Extraction (Cyanide Removal)	
Multiple	Four or more processes	
1 Organics extracted by SCDE will be treated by CCO		
2 CCO process solution will be solidified by polymer microencapsulation		
3 Washing solutions will be treated by cyanide destruction		

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