Mixed Waste Treatment Facility Design

(Based on a previous report by Tanya Oakley, Matthew Rollins, Lindsey Stinson, and Catherine Cheng)

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Abstract

This report illustrates a design of a low-level mixed waste treatment facility. A specified amount of waste in known concentrations must be processed in a twenty year period using only nonthermal treatment technologies. Several companies must make bids on the design of this type of facility. The total design must include researching various remedial technologies and developing a total removal scheme. A series of mass balance calculations are then made to size equipment and develop equipment costs. Operating costs and products costs can then be calculated. Finally, a return on investment calculation is then made to estimate the yearly expenditure that the company requesting this design must make.

The removal scheme involves dechlorination to separate the chlorines from the chlorinated organics, thermal desorption to remove all organics from the waste, incineration to destroy those organics, acid extraction to remove heavy metals and radioactive components from the waste, and ion exchange to treat those radioactive and metal components. This treatment scheme has a total present value cost of 1.4 billion dollars. In addition, the DOE has developed a study of nonthermal treatment technologies that could remove some of the waste in question. Since this is the only known study of this kind, then a comparison between this scheme and the DOE technologies would be warranted.

Table of Contents

List of Figures

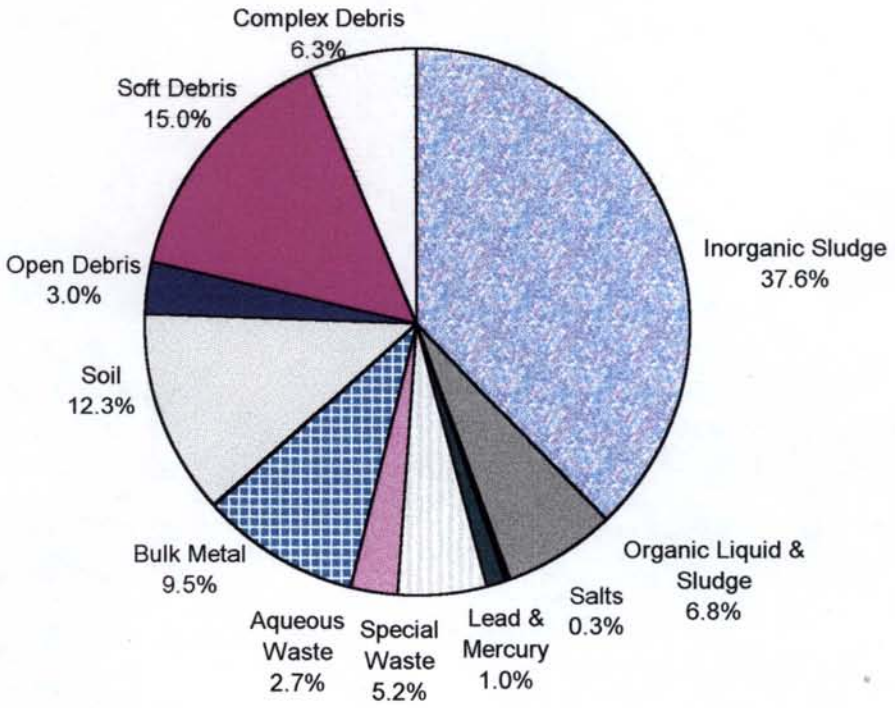
List of Tables

Background

Recently, due to public opinion, many companies have begun to develop strategies that not only increase environmental awareness, but also mandate environmental compliance. Numerous regulations and requirements have existed including the Clean Air Act and Clean Water Act, but compliance with those regulations has just now started to increase. The basis for environmental awareness/compliance is to thoroughly evaluate actions and implement those actions which have the least significant environmental impact. However, even careful planning and execution cannot eliminate all waste streams. Therefore, the RCRA (Resource Conservation and Recovery Act) and EPA provide guidelines for the treatment and storage of wastes.

Many types of wastes can be produces by different processes including hazardous wastes, organic wastes, radioactive wastes, and various other combinations. The US Department of Energy complex currently stores mixed low-level waste consisting of organic and inorganic solids and liquids contaminated with radioactive substances. The following chart lists the compositional breakdown of these wastes (Rptd. in Bahar 13).

Figure 1: Average Composition of Low-Level Mixed Waste in DOE Complex



A facility that can treat low-level mixed waste is therefore warranted.

Introduction

The US Department of Energy is searching for a company to effectively treat a major percentage of their mixed wastes in the forms of process residues and soils. As mentioned previously, a real need for a design of this type of facility clearly exists. However, the design criteria including the concentrations and types of wastes that is required by the DOE is uncertain. They do, however, reflect general categories of wastes in appropriate proportions that an actual facility may treat.

Mixed waste treatment is a cumbersome, expensive process that involves either the separation of radioactive wastes from hazardous wastes or the formation of non-leachable mixed wastes that pass EPA tests for not being considered toxic. Hazardous waste is any solid waste that can either be listed as hazardous or considered corrosive, ignitable, reactive, or toxic. Radioactive waste, on the other hand, contains radioactive nuclei.

A major part of the design is the total compliance with the aforementioned EPA regulations. Some of the pertinent regulatory conditions include the classification of hazardous wastes, Resource Recovery and Conservation Act (RCRA) limits for the contaminates present in those wastes, and disposal requirements. A listing of relevant disposal requirements and a summary of waste classification follows.

Pertinent disposal requirements:

- Non-explosive or reactive at normal pressures and temperatures
- Not contain or capable of generating toxic gases or vapors
- Must not be pyrophoric
- Packaged pressure not to exceed 1.5 ATM at 20 °C

Table 1: Classification of Waste (curies/m^3 unless otherwise noted)

Radionuclide	Class A	Class B	Class C
Long-lived			
C-14	$\leq .8$		$> .8$ and ≤ 8
C-14 in activated metal	≤ 8		> 8 and ≤ 80
Ni-59 in activated metal	≤ 22		> 22 and ≤ 2200
Nb-94 in activated metal	$\leq .02$		$> .02$ and $\leq .2$
Tc-99	$\leq .3$		$> .3$ and ≤ 30
I-129	$\leq .008$		$>.008$ and $\leq .08$
Alpha emitting transuranic nuclides of half-life > 5 yrs	$\leq 1 \times 10^{-8}$ curies/g		$> 1 \times 10^{-8}$ and $\leq 1 \times 10^{-7}$ curies/g
Pu-241	$\leq 3.5 \times 10^{-7}$ curies/g		$> 3.5 \times 10^{-7}$ and $\leq 3.5 \times 10^{-6}$ curies/g
Cm-242	$\leq 2 \times 10^{-6}$ curies/g		$> 2 \times 10^{-6}$ and $\leq 2 \times 10^{-5}$ curies/g

Table 1: Continued

Short-lived			
H-3	≤ 40		
Co-60	≤ 700		
Ni-63	≤ 3.5	> 3.5 and ≤ 70	> 70 and ≤ 700
Ni-63 in activated metal	≤ 35	> 35 and ≤ 700	> 700 and ≤ 7000
Sr-90	≤.04	> .04 and ≤ 150	> 150 and ≤ 7000
Cs-137	≤ 1	> 1 and ≤ 44	> 44 and ≤ 4600

The plant has several design specifications. Approximately 42000 m^3 of process residues and 37000 m^3 of solids must be processed. Also, 5% of the process residues and 1% of the contaminated soils will be generated each year for the twenty year treatment period. The process wastes include inorganic sludges, solidified process residues, inorganic particulates, salt wastes, and organic process residues. The soils are heterogeneous materials including small rocks, clays and fine silica, and dry earth. The facility will have to handle various different contamination levels in both the soils and process residues as shown on the following pages. (Note that the concentrations are averages.)

Concentration of Contaminants in Soils

VOCs	5000 ppm
TCE	100 ppm
PCE	50 ppm
Hydrocarbons	(Remainder of VOCs)
PCBs (Ahlor)	500 ppm
Uranium	1000 ppm
Plutonium	20 ppm
Cesium	20 ppm (100 microCuries/g Cs-137)
Strontium	80 ppm (200 microCuries/g Sr-90)
Calcium	10000 ppm
Nickel	2000 ppm
Iron	8000 ppm

Concentration of Contaminants in Process Residues	
Total organic compounds	30 wt.%
VOCs	5 wt.%
PCBs	1 wt.%
Uranium	1 wt.%
Plutonium	50 ppm
Cesium	2 wt.% (1 milliCuries/g)
Strontium	4 wt.% (1 milliCuries/g)
Technetium	100 microCuries/g
Nickel	3 wt.%
Iron	5 wt.%

A design and cost estimate of a suitable facility follows. Several views of the plant are included as well as a flowsheet highlighting each process. Also, a mass and energy balance is included with hand calculations for referral. Cost estimates, including a payment schedule, comprise the final design requirements. Following the design specifications, a comparison analysis of DOE proposed processes and those chosen for this design will be presented.

Selection of the Process

There are many different viable processes available to treat mixed wastes. A major reference that gives a wide range of technologies is an EPA produced computer program called Vendor Information System for Innovative Treatment Technologies (VISITT), see Appendix B. A description of the program is found in the users manual also located in Appendix B. This program not only lists numerous technologies as well as the specifics of each but also gives the different vendors that utilize these technologies. Thus, this program provides the basic knowledge for the selection the different processes.

Before the APEG/KPEG process for removing the chlorinated VOCs and PCBs was chosen, one other process was considered. Commodore Environmental Services was one vendor with a similar type of treatment process. A flowsheet and description of Commodore's system is located in VISITT. This system was also ruled out because of the lack of information on removing the PCBs. The APEG/KPEG process was chosen because it dehalogenates all compounds including the PCBs, therefore making removal of the remaining organics much easier. The chemistry behind this process was well documented and fairly simple to understand. For more information please refer to the EPA engineering bulletin *Chemical Dehalogenation Treatment: APEG Treatment.*

The next process step in our treatment facility involves removing the organics from the soil and sludge. From the beginning, thermal desorption was the only process considered for volatilizing the organics. With all of the chlorines removed from the organics this was the next logical step for full organic removal from the soil/sludge. For more information on thermal desorption please refer to the EPA Applications Analysis Report *Low Temperature Thermal Treatment* in Appendix B. The soil and sludge is fed into an acid extraction system to remove the radioactive and hazardous elements.

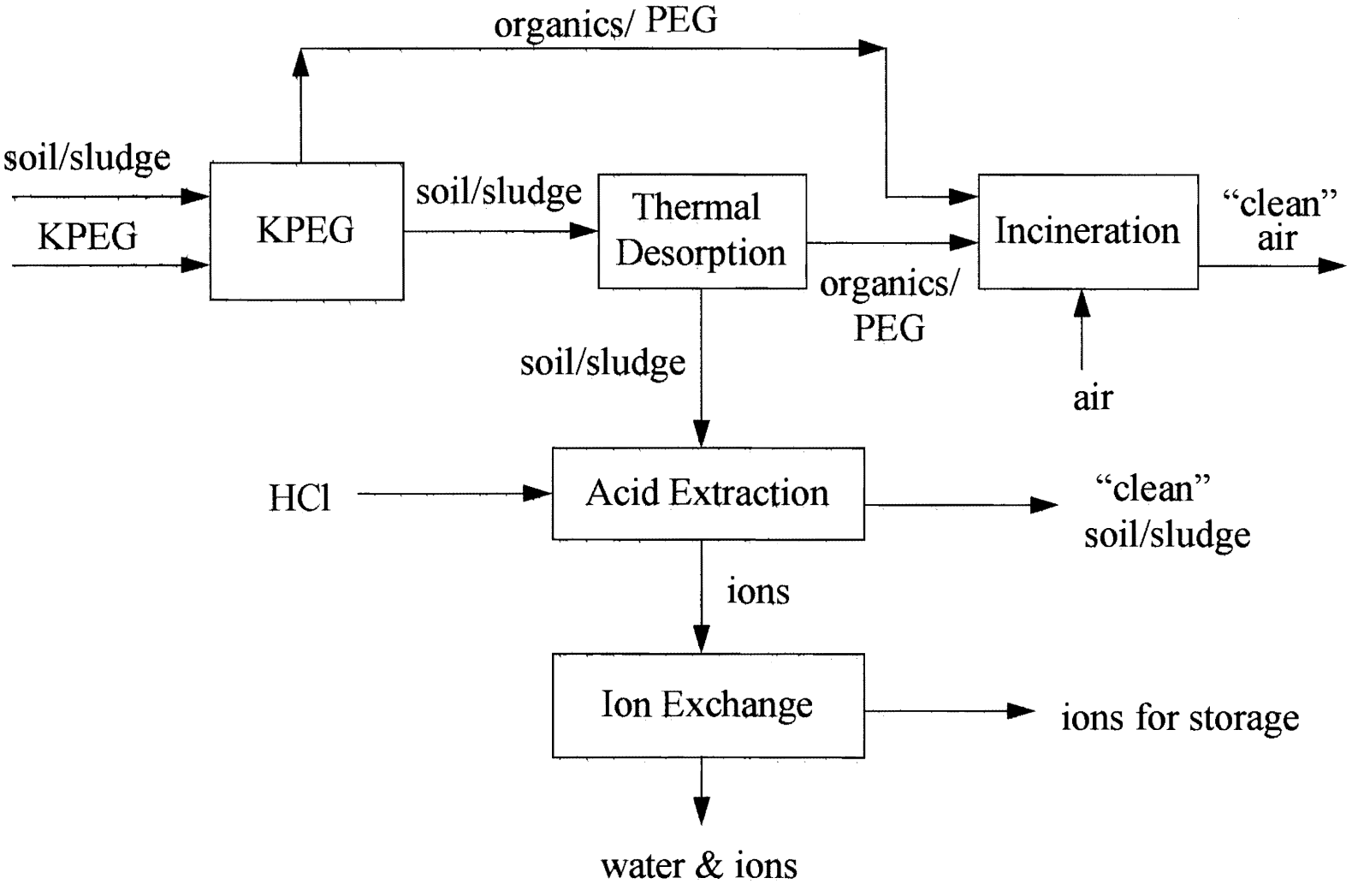
The gaseous stream from thermal desorption containing the organics is fed into an incinerator system. One alternative was to send the dechlorinated organics into PURUS, a VOC removal system. For a description of PURUS please refer to the VISITT program or page 11 of the May 1994 issue of Chemical Engineering Progress located in Appendix B. The PURUS process was ruled out because of the lack of information on removing all organics present. A biodegredation system was also another choice for removing the dechlorinated organics. Bioremediation systems utilize microorganisms to destroy the wastes. Several bioremediation vendors are located in VISITT. It was not chosen, however, because of its high cost. Incineration was chosen because it has an efficiency of 99.9999% for removing all organics and at a much cheaper price than either PURUS or bioremediation..

The next step in the treatment facility is removing the radioactive and hazardous elements from the soil and sludge. Acid extraction has always been the choice for this process. It is assumed the elements enter the acid extraction system in oxide form. This process involves adding a strong acid to the soil and

sludge to remove the aforementioned elements and place them in solution of only cations. In addition to the VISITT program, we obtained actual vendor information from *Cognis Corporation* and *Nucon Corporation.* This information is also located in Appendix D.

The final step in the treatment process is removing the radioactive and hazardous elements from solution. The only process considered to remove the ions from solution was ion exchange. The ion exchangers are filled with a calculated amount of DOWEX 50WX8 cation exchange resin. The resin removes the hazardous ions from solution where they are placed in 55 gallon drums for concrete stabilization. Information on the DOWEX resin is also located in Appendix D. For a diagram showing important processes and inputs, refer to the following page.

Figure 2: Outline of Mixed Waste Treatment Facility Processes



Plant Layout

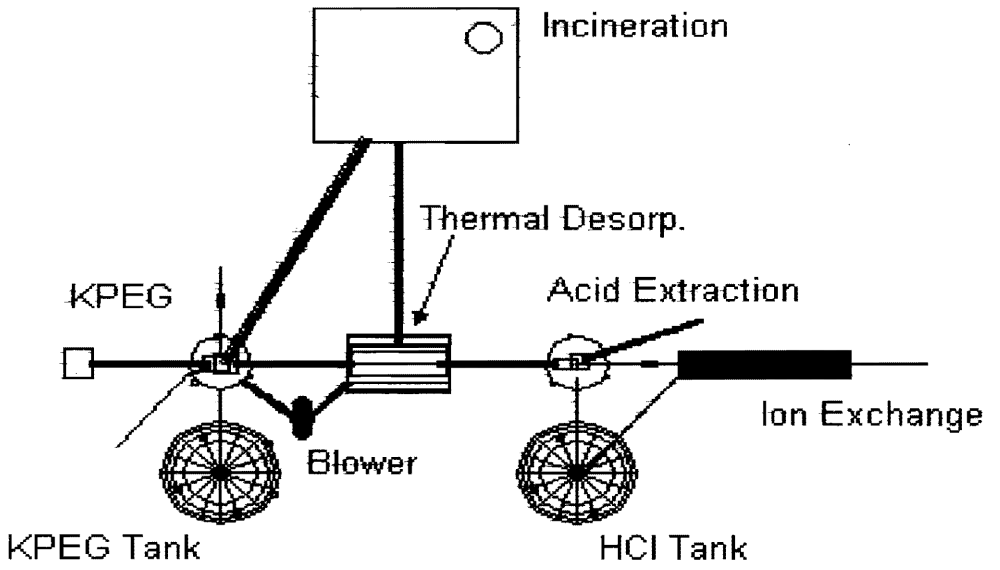
Spacing between processes becomes important when cost estimates are performed. A more accurate idea of the amount of auxiliary equipment such as pipe, conveyors and duct is desirable since the more costs that can be correctly identified leads to a smaller error in the economics of the plant.

Below are two major points guiding the layout of the plant designed thus far:

1. Adequate spacing between processes must be allowed for ease of maintenance. (20' in this case as an estimate)
2. There must be extra spacing between the incinerator and the rest of the plant to minimize the chance of volatilizing or igniting reagents.

Following the above points, a tentative layout was made for all the processes decided upon. What follows is a regular 2 dimensional CAD drawing showing the processes in relation to each other. The drawing is not exactly to scale, since dimensions for the incineration process, pumps and blower were not available. Also, no radiation shielding is shown in any of the drawings of this report so that the processes can be easily identified.

Figure 3: Two-dimensional Drawing of Plant Layout



The following five pages provide different 3 dimensional views of the proposed layout.

Figure 4: Side View Focused on KPEG Process

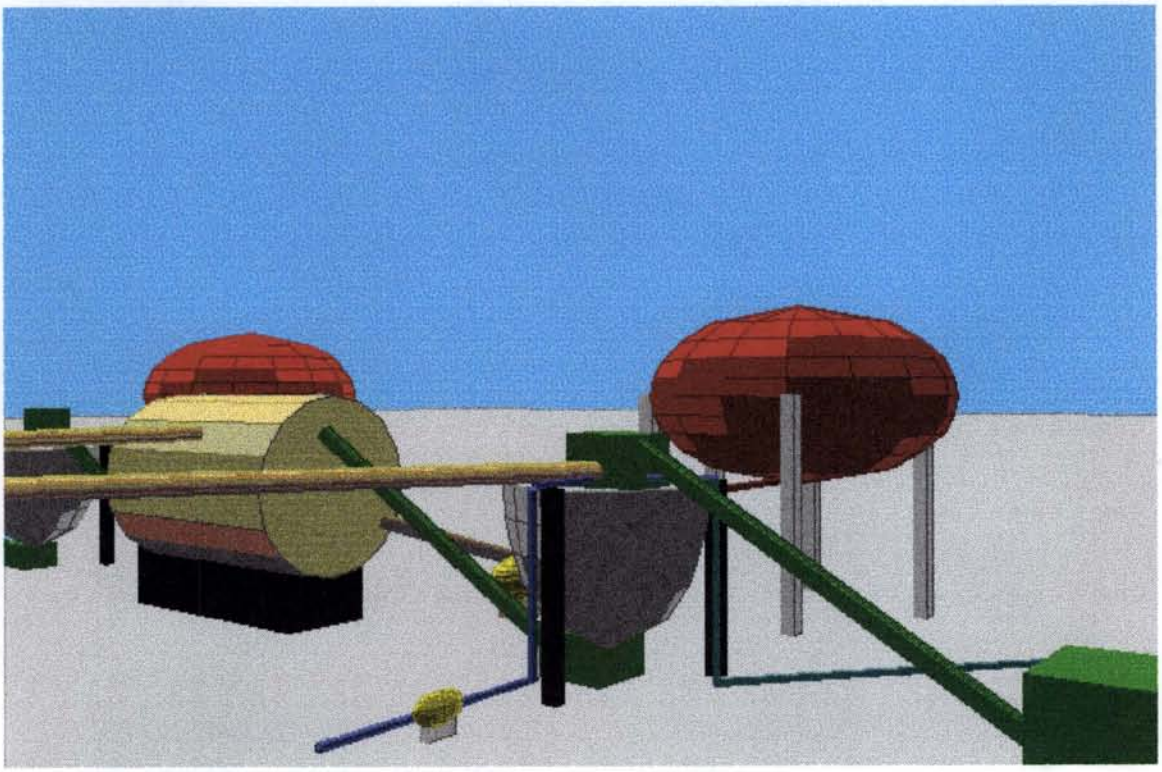


Figure 5: Side View Focused on KPEG and Incinerator

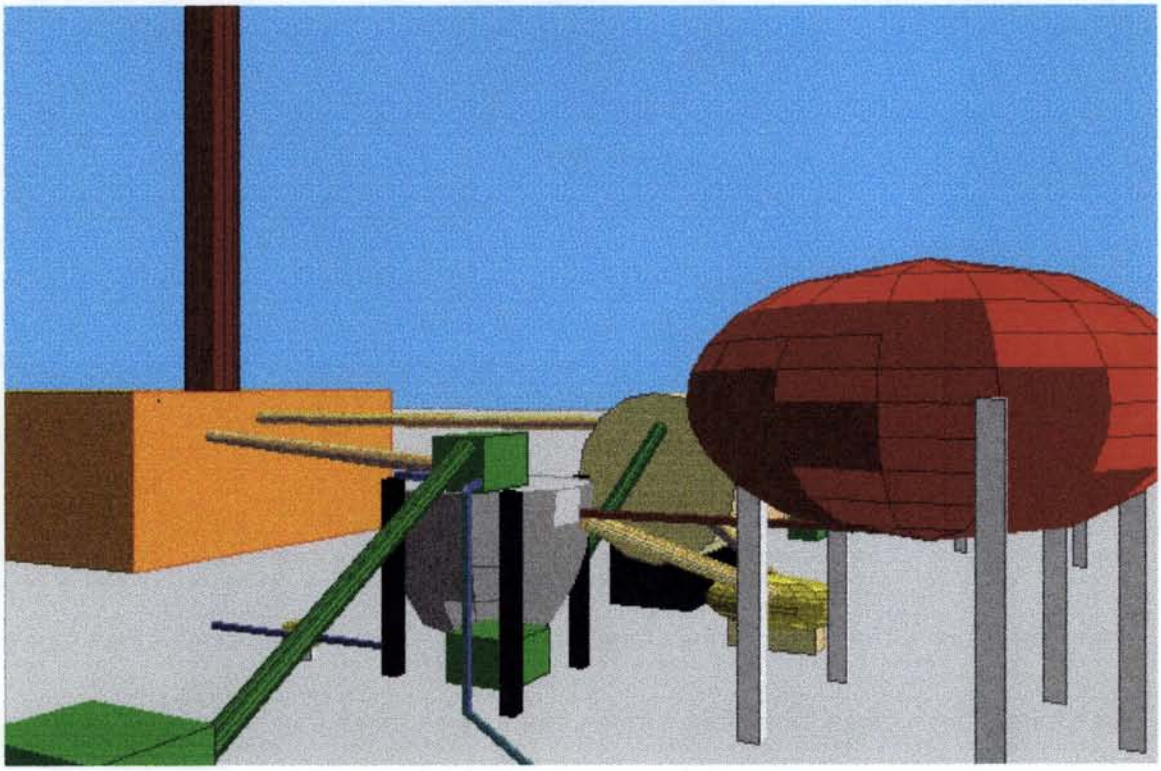


Figure 6: Front view of Thermal Desorption and Incineration

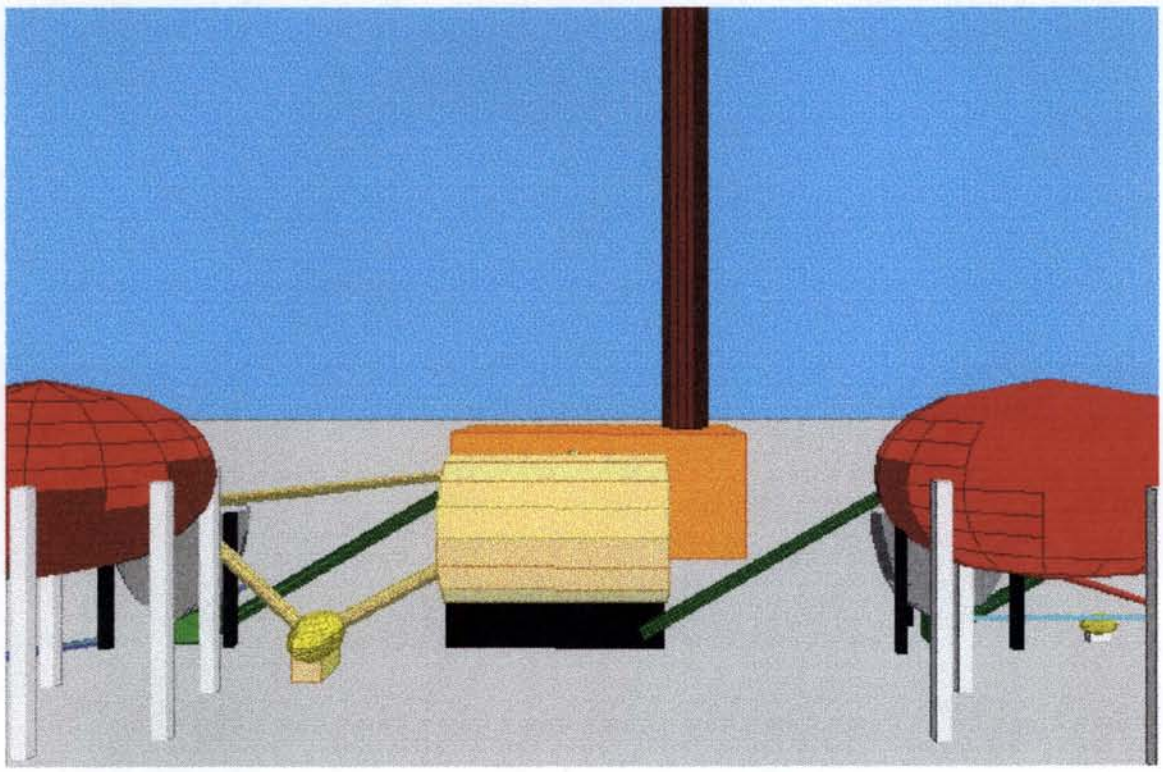


Figure 7: Side View Focused on Ion Exchange and Incineration

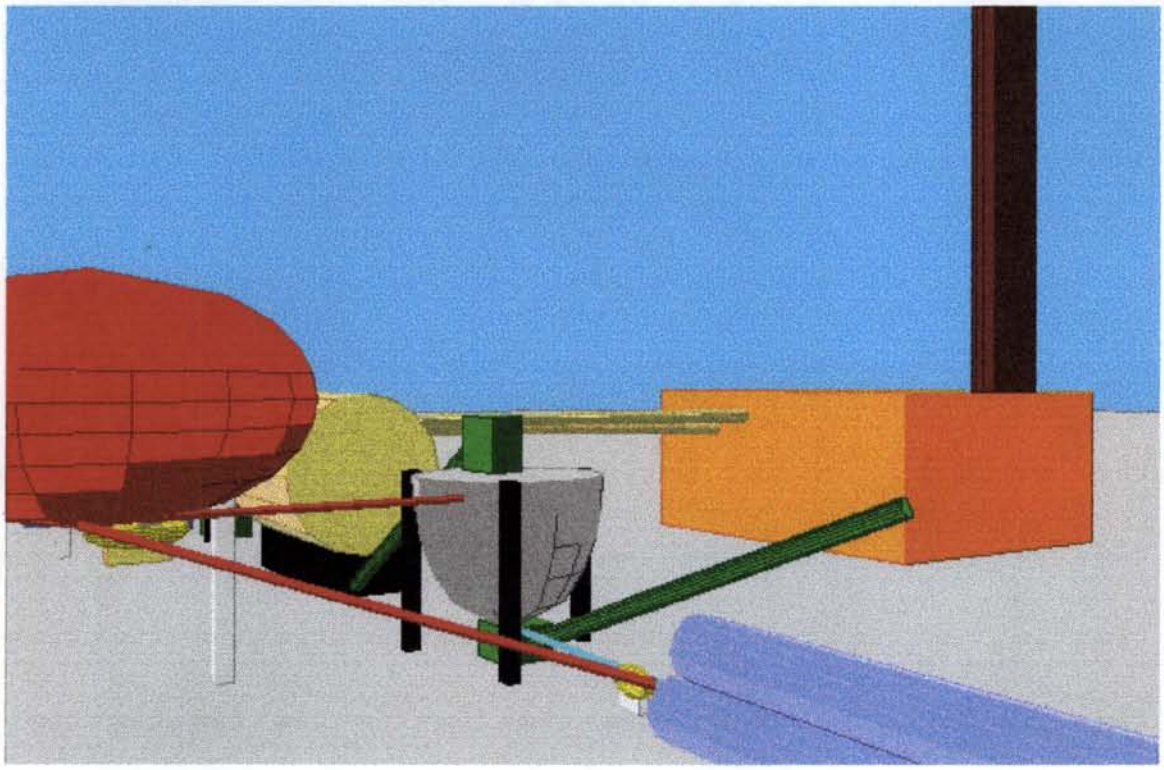
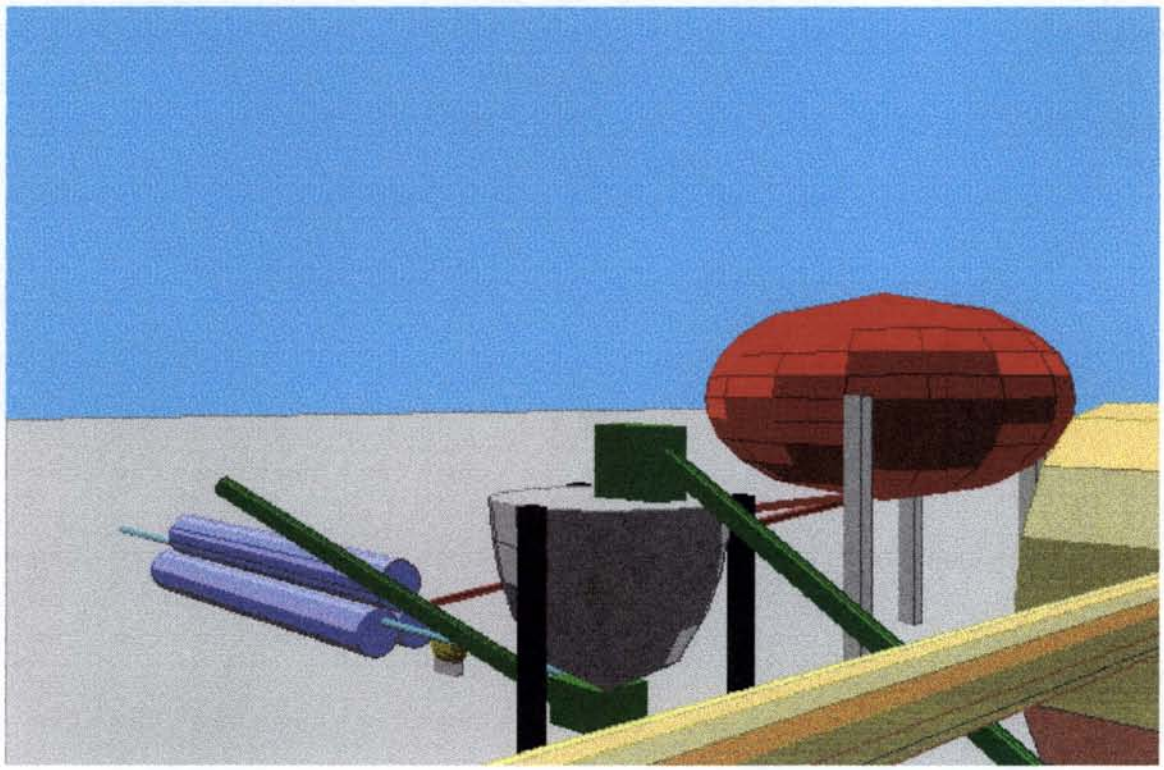


Figure 8: Back View of Thermal Desorption and Ion Exchange



Preliminary Calculations

The calculations that fall under this heading include average throughput or processing capacity and obvious parameters for soil and sludge such as density and heat capacity.

- **Heat Capacities of Soil and Sludge**
  - **-assume heat capacity of soil is approximately that of mica**
  - **-Heat Capacity of Soil**

    Cp_{soil} = 878.64 J/kg K
  - **-Heat Capacity of Sludge**

    given: sludge contains approx. 30% organics & 70% soil

    Can approx. organics with heavy oil.

    Cp_{oil} = 848.7 J/kg K & Cp_{soil} = 878.64 J/kg K

$$Cp_{sludge} = \left(0.30 \cdot 848.7 \frac{J}{kg \cdot K}\right) + \left(0.70 \cdot 878.64 \frac{J}{kg \cdot K}\right) = 869.66 \frac{J}{kg \cdot K}$$

- **Densities of Soil and Sludge**
  - **-Density of Soil**

    given: soil is 55% clay, 5% earth, 40% gravel

    ρ_{clay} = 63 lb/ft^3 ; ρ_{earth} = 95 lb/ft^3 ; ρ_{gravel} = 100 lb/ft^3

$$\rho_{soil} = \left(0.55 \cdot 63 \frac{lb}{ft^3}\right) + \left(0.05 \cdot 95 \frac{lb}{ft^3}\right) + \left(0.40 \cdot 100 \frac{lb}{ft^3}\right) = 79.4 \frac{lb}{ft^3} = 1274.53 \frac{kg}{m^3}$$

  - **-Density of Sludge**

    given: sludge is 30% organics & 70% soil

    Can approx. organics with heavy oil.

    ρ_{oil} = 56 lb/ft^3 ; ρ_{earth} = 95 lb/ft^3

$$\rho_{sludge} = \left(0.30 \cdot 56 \frac{lb}{ft^3}\right) + \left(0.70 \cdot 95 \frac{lb}{ft^3}\right) = 83.3 \frac{lb}{ft^3} = 1334.32 \frac{kg}{m^3}$$

- **Average Throughput**

  given: 45,000 m^3 sludge and 37,000 m^3 soil in storage.

  20 yr. processing period.

  5% sludge and 1% soil generated per yr.

  -sludge/year [m^3/yr]

$$\frac{45000 m^3}{20 yr} + \left(\frac{0.05}{yr} \cdot 45000 m^3\right) = 4500 \frac{m^3}{yr} \text{ sludge}$$

  -soil/year [m^3/yr]

$$\frac{37000 m^3}{20 yr} + \left(\frac{0.01}{yr} \cdot 37000 m^3\right) = 2220 \frac{m^3}{yr} \text{ soil}$$

-assume plant operates 8100 hours per year (batch process)

-sludge/hour [m^3/hr]

$$4500\frac{m^3}{yr}\cdot\frac{yr}{8100hr}=0.556\frac{m^3}{hr}\text{ sludge}$$

-sludge/hour [kg/hr]

$$0.556\frac{m^3}{hr}\cdot 1334.32\frac{kg}{m^3}=741.88\frac{kg}{hr}\text{ sludge}$$

-soil/hour [m^3/hr]

$$2220\frac{m^3}{yr}\cdot\frac{yr}{8100hr}=0.274\frac{m^3}{hr}\text{ soil}$$

-soil/hour [kg/hr]

$$0.274\frac{m^3}{hr}\cdot 1274.53\frac{kg}{m^3}=349.3\frac{kg}{hr}\text{ soil}$$

Dechlorination -- APEG / KPEG Process

This process involves adding KPEG reagent and heat to the soil / sludge slurry and allowing the following (conceptual) reaction to occur:

Requirements for the process state that the soil / sludge be made into a slurry.

Inputs

-Soil & Sludge

These values are already calculated as the throughputs in the Preliminary Calculations section of this report.
Soil [kg/hr] = 349.3
Sludge [kg/hr] = 741.88

Amounts of contaminates are calculated from concentration values in project description. Below is an example:

-Total Organics from Soil

given: Soil is on average 5000 ppm organics.

$$349.3\frac{kg}{hr}\cdot\frac{5000}{10^6}=1.747\frac{kg}{hr}$$ organics from soil

Table 2: Relevant Contaminate Flows into KPEG Process

Contaminate	flow [kg/hr]
Total Organics from Soil	1.747
Total Organics from Sludge	222.387
PCB's from Soil	0.17466
PCB's from Sludge	7.4129
TCE form Soil	0.03493
PCE from Soil	0.01746

-Water Required for Process

Since the soil needs to be made into a slurry (assuming that the sludge already is a slurry), water must be added. An adjustable wt.% of soil was set at 1/4 for the water added.

$$349.3\frac{kg}{hr}\text{soil}\cdot 0.25\frac{kg\ \text{water}}{kg\ \text{soil}}=87.33\frac{kg}{hr}$$ water added

-Amount KPEG needed

Referring to the reaction of KPEG reagent with halogenated compounds, it is seen that 1 KPEG is needed for 1 Cl atom.

-Total Cl atoms to be stripped

Below is an example of how the number of chlorine atoms to be stripped was determined:

given: PCB's can be assumed to have an average of 6 Cl atoms.

$$(0.17466 + 7.4129)\frac{kg}{hr}PCB \cdot \frac{1000g}{kg} \cdot \frac{mol}{360.7g} \cdot \frac{6Cl}{mol} = 126.214 \quad mol/hr$$

Total Cl atoms: 127.432 mol/hr

Since mol KPEG required equals mol Cl...

Amount PEG required = (127.432 mol/hr)*(399 g/mol) / (1000 g/kg)
= 50.846 kg/hr

Amount KOH required = 7.148 kg/hr

-Energy Input

Temp. of complete KPEG reaction is approximately 150 deg C.

-Energy needed for Soil

Energy = mass*heat capacity*change in temperature

given: Starting temp. = 25 deg C.
Ending temp. = 150 deg C.
Heat Capacity Soil = 878.64 J/kg K

$$349.3\frac{kg}{hr} \cdot 878.64\frac{J}{kgK} \cdot 125K = 3.836x10^{7}\frac{J}{hr}$$

-Energy needed for Sludge

Energy needed for sludge = $8.0647x10^{7}$ J/hr

-Energy needed for Water

Energy = mass*Cp*delta T (to 100 C) + heat of vaporization*mass

$$\left(87.33\frac{kg}{hr} \cdot 4180\frac{J}{kgK} \cdot 75K\right) + \left(1.5884x10^{6}\frac{J}{kg} \cdot 87.33\frac{kg}{hr}\right) = 1.6609x10^{8}\frac{J}{hr}$$

-Total Energy required (neglecting KPEG reagent)

Total Energy for KPEG Process = $2.851x10^{8}$ J/hr.

-Output to Incineration

A possibility exists for some of the more volatile organics to escape when heat is applied in this process. An analytical method for determining this amount could not be found, so a percentage of the total organics was used.

assumed: 0.5% of organics escape to off gas
All PEG reacts and becomes part of organics.
PCB's become part of organics, but don't volatilize at the temperature used.

$$(1.747 + 222.387 + 50.846)\frac{kg}{hr} \cdot 0.005 = 1.375\frac{kg}{hr} \text{ organics}$$

-Output of Air

Since the organics do volatilize, an air stream must be added. It is possible to approximate organics with heavy oil ($C_{16}H_{34}$). At 150 deg C, the vapor pressure of $C_{16}H_{34}$ is .02 ATM. From mass balance, 290 mol of air needed for 5.9 mol of organics including PEG.

-Output to Atmosphere

Reaction time for the KPEG process averages around 1 hr. At a temperature of around 150 deg C, all water is evaporated and sent to atmosphere (no organics are present)
Water to Ion Exchange = Water in = 87.33 kg/hr

-Output to Thermal Desorption

All inputs to KPEG, with the exception of water, a small amount of organics, and the chlorines that are stripped off travel on into thermal desorption. The amounts of PCB and PEG, however, are converted into organics.

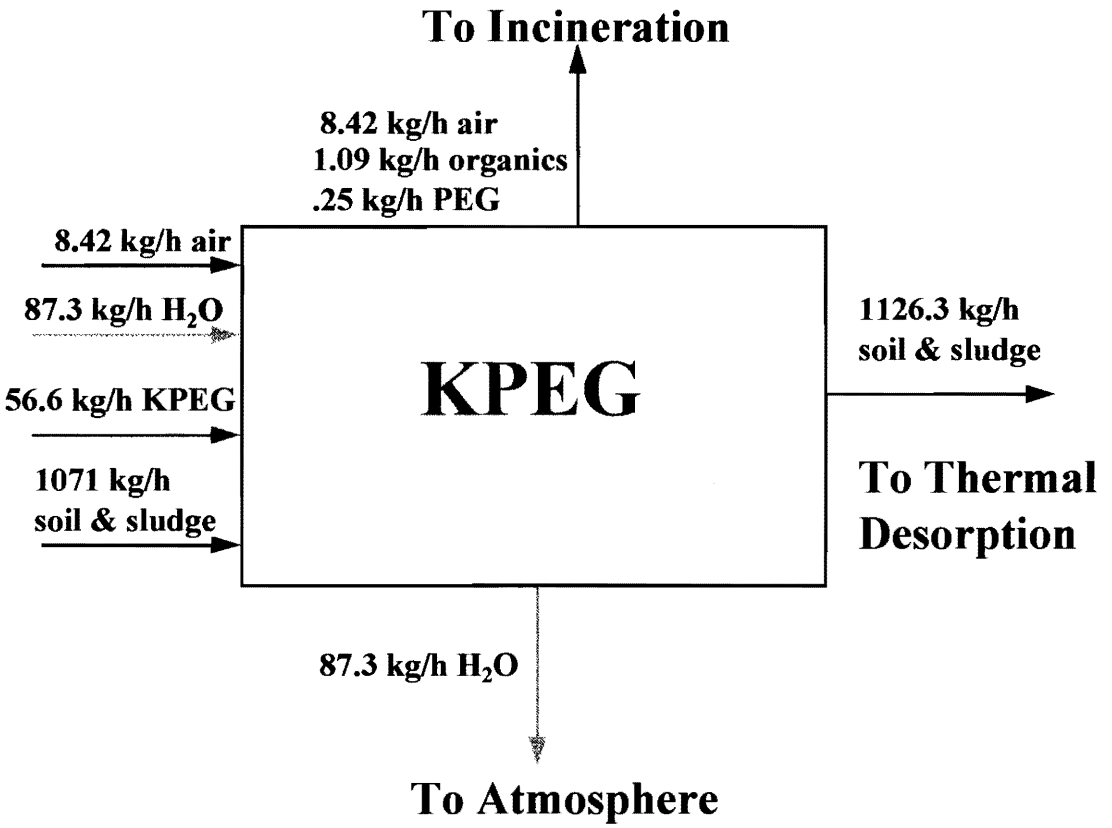
-Organics

$$(1.747 + 216.60 + 50.486 + 0.1747 + 7.4129 - 4.39)\frac{kg}{hr} - 1.375\frac{kg}{hr} = 269.0\frac{kg}{hr}$$

The above equation says that all organics entering plus all newly made organics minus organics leaving for incineration minus the chlorines that are stripped off equals amount headed for thermal desorption.

A stream summary for the KPEG process follows. Space requirements limit the amount of individual components that can be listed on the figure, so only those that change are shown. For a complete listing of all components in the process, refer to Appendix A.

Figure 9: Detail of KPEG Process



Thermal Desorption

Thermal desorption involves heating the soil & sludge to a high enough temperature as to volatilize all organics. To ensure good separation, the soil / sludge mixture is also agitated.

Nothing other than the soil / sludge coming from the KPEG process is added (except energy). Most of the organics are sent to incineration leaving a small amount in the soil destined for acid extraction. An adjustable organics removal efficiency was used to determine the destination of all organics.

-Inputs

-Soil with organics

Soil with organics = Soil leaving KPEG process = 349.3 kg/hr
(This number is the amount of soil with organics in KPEG process minus amount of organics in soil lost to carbon bed.)

-Sludge with organics

(Calculated the same way as for soil w/ organics.)
Sludge with organics = 747.59 kg/hr

-PEG (now part of total organics)

PEG = PEG into KPEG - 0.5% PEG lost to Carbon Bed
PEG = 50.846 kg/hr - 0.2542 kg/hr = 50.5914 kg/hr

-Total Organics (including PEG)

Total organics in = 269.0 kg/hr

-Energy Input (for heating from 75 C to 260 C)

These calculations are done the same way as for the KPEG process (E = mass*Cp*delta T). The same values for the heat capacities of soil and sludge were used since the compositions of both did not change much in the preceding step.

Energy for Soil = 5.678×10^7 J/hr
Energy for Sludge = 1.203×10^8 J/hr
Total Energy Needed (Neglecting KPEG reagent) = 1.77×10^8 J/hr

-Output to Incineration

-Organics

Organics out = organics in*removal efficiency (99.5%)

$$269.0\frac{kg}{hr} \cdot 0.995 = 268\frac{kg}{hr}$$

-Air

given: Can approx. organics with heavy oil ($C_{16}H_{34}$, MW = 226)
Vapor pressure of oil = 0.5 ATM at 260 C.
Air required (mol) for above conditions = Mol organics.

$$268\frac{kg}{hr}\cdot 1000\frac{g}{kg}\cdot\frac{mol}{226g}=1185.8\frac{mol}{hr}\ \text{Air}$$

Air leaving thermal desorption

$$1185.5\frac{mol}{hr}\cdot\frac{29g}{mol}\cdot\frac{kg}{1000g}=34.4\frac{kg}{hr}\ \text{Air}$$

-Output to Acid Extraction

-Soil & Sludge

At this point it is easier to consider soil and sludge together, since most of the organics are removed. Both soil and sludge now have the same approximate heat capacity, that of soil.

Soil & Sludge (dry, no organics) = (347.57+ 518)kg/hr = 866.5kg/hr

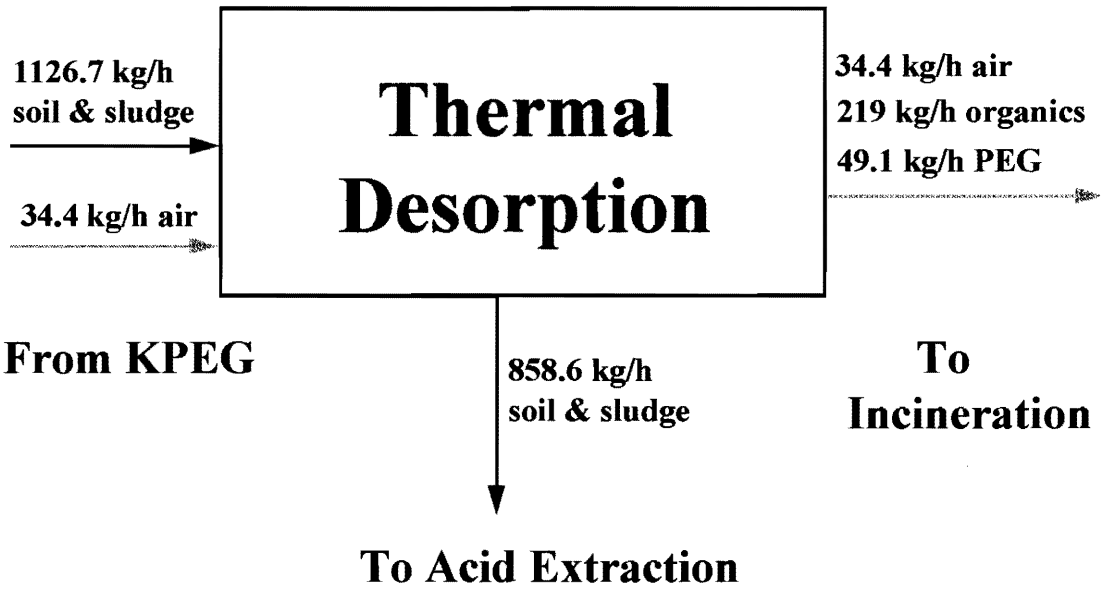
-Total Organics left in soil

This value is just the 0.5% of organics not going to burn.

Organics left in soil = 281.0 kg/hr * 0.005 = 1.405 kg/hr

All other components into thermal desorption leave with soil to acid extraction. A simplified diagram of the thermal desorption process follows on the next page.

Figure 10: Detail of Thermal Desorption Process



Incineration

In the incineration process the organic vapor and air from thermal desorption are burnt to release carbon dioxide and water vapor. The efficiency of the unit is taken from Callidus Corporation, ~ 100 %. The organics are approximated by $C_{16}H_{34}$ in the burning reaction:

$$C_{16}H_{34} + 24.5\ O_2 \rightarrow 16\ CO_2 + 17\ H_2O$$

-Inputs

-Organic Vapor

Total organics in = 269.595 kg/hr (from thermal desorp. and KPEG)

Mol. organics = 1192.5 mol/hr (calculated earlier)

-Air (from thermal desorption & KPEG)

Air = 1192.15 mol/hr + 290 mol/hr

Oxygen = 0.21*1482.15 mol/hr = 311.3 mol/hr

Nitrogen = 0.79*1482.15 mol/hr = 1170.78 mol/hr = 32.8/hr

-Oxygen needed for burning

-Burned organics (burning efficiency*mol organics in)

Burned organics = 1*1192.5 mol/hr = 1192.5mol/hr

Oxygen needed = 24.5*1192.5 mol/hr = 29217mol/hr

Oxygen needed for makeup air = 29217 - 311.3 = 28905mol/hr

-Air from makeup stream

Makeup air = (28905mol/0.21)*(29g/mol)/(1000g/kg)=3991.7/hr

Makeup Nitrogen = 1.082×10^5 mol/hr = 3030kg/hr

-Output to Air

Total Nitrogen = 3030 kg/hr

Oxygen = 0 (assuming all consumed in burning)

Unburnt organics = 0

Carbon Dioxide = 16*1192.5 mol/hr = 19080 mol/hr = 835 kg/hr

Water Vapor = 17*1192.5 mol/hr = 20272.5 mol/hr = 363.7kg/hr

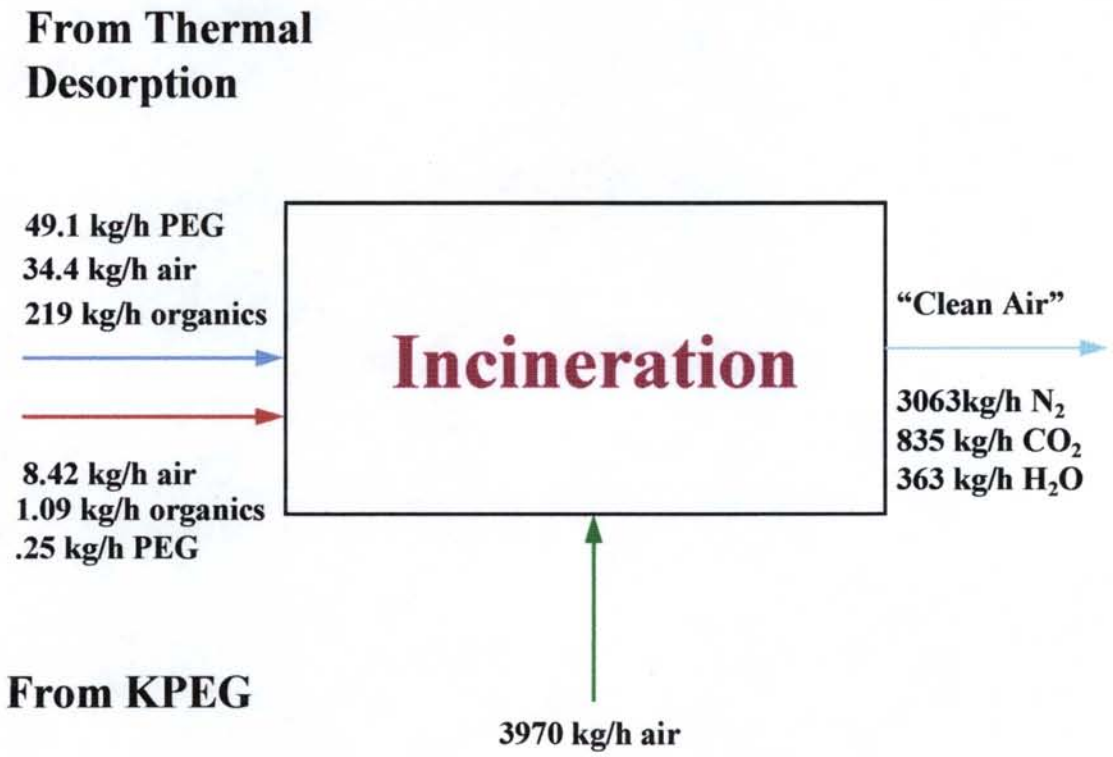
-Heat Generated

Heat of combustion for $C_{16}H_{34}$: 2577kCal/mol

$$\left(\frac{1192.5\,\text{mol/hr}}{1}\right)\left(\frac{2577\,\text{kCal}}{\text{mol}}\right)\left(\frac{1000\,\text{Cal}}{1\,\text{kCal}}\right)\left(\frac{4.184\,\text{J}}{1\,\text{Cal}}\right) \quad 1.28\text{x}10^{10}\,\text{J/hr}$$

The following page contains the flow diagram for the incineration process.

Figure 11: Detail of Incineration Process



Acid Extraction Process

This process utilizes hydrochloric acid which separates the heavy metals and radioactive elements from the soil and sludge into their respective cation forms in a solution. A major assumption is that all of the reactions go to completion, thus forming the ions. The KOH from the KPEG treatments would neutralize the acid, therefore an excess of HCl must be added. Also, to control the pH of the solution, the amount of water needed to achieve a specific pH must be calculated.

The following chemical reaction equations summarize the acid extraction process:

1). $8HCl + TcO_4^{2-} \rightarrow 4H_2O\ 8Cl^- + Tc^{6+}$

2). $4HCl + SrO_2^{2-} \rightarrow 2H_2O + 4Cl^- + Sr^{4+}$

3). $6HCl + UO_3^{2-} \rightarrow 3H_2O + 6Cl^- + U^{4+}$

4). $2HCl + NiO \rightarrow H_2O + 2Cl^- + Ni^{2+}$

5). $3HCl + Fe(OH)_3 \rightarrow 3H_2O + 3Cl^- + Fe^{3+}$

6). $6HCl + PuO_3^{2-} \rightarrow 3H_2O + 6Cl^- + Pu^{4+}$

7). $2HCl + Cs_2O \rightarrow H_2O + 2Cl^- + 2Cs^+$

8). $2HCl + CaO \rightarrow + 2Cl^- + Ca^{2+}$

The following sample calculation describes the procedure for calculating the amount of hydrochloric acid required to separate these oxides:

- **The mass flow rate of UO_3^{2-} equals .349 kg/hr in soil**

- **The molar flow rate of UO_3^{2-} equals**

$$\left(\frac{.349 kg/hr}{286 g/mol}\right)\left(\frac{1000\ g}{kg}\right) = 1.2214\ \frac{mol}{hr}$$

- **The molar flow rate of HCl equals**

$$\left(6 \times 1.2214 \frac{mol}{hr}\right) = 7.3282 \frac{mol}{hr}$$

- **The molar flow rate of H_2O equals**

$$\left(3 \times 1.2214 \frac{\text{mol}}{\text{hr}}\right) = 3.6642 \frac{\text{mol}}{\text{hr}}$$

The stoichiometric coefficients in the above equations determine the amount of HCl required and water generated for the reactions(see Appendix B for the other related calculations). Total amount of HCl and water needed are **117 kg/hr** and **38.8 kg/hr.** More HCl is required and more water is produced for the neutralization of KOH. Those calculations follow.

- **pH Calculations**

$KOH + HCl \rightarrow H_2O + K^+ + Cl^-$

- **KOH from KPEG process = 6.97 kg/hr**

- **Molar flow rate of KOH**

$$\left(\frac{6.97\text{kg/hr}}{56.1\text{g/mol}}\right)\left(\frac{1000\text{g}}{\text{kg}}\right) = 124 \frac{\text{mol}}{\text{hr}}$$

- **Excess HCl needed for neutralization of KOH**

$$1 \times 124 \frac{\text{mol}}{\text{hr}} = 124 \frac{\text{mol}}{\text{hr}}$$

- **For pH = 2**

$$[H^+] = 0.01 \frac{\text{mol}}{\text{L}}$$

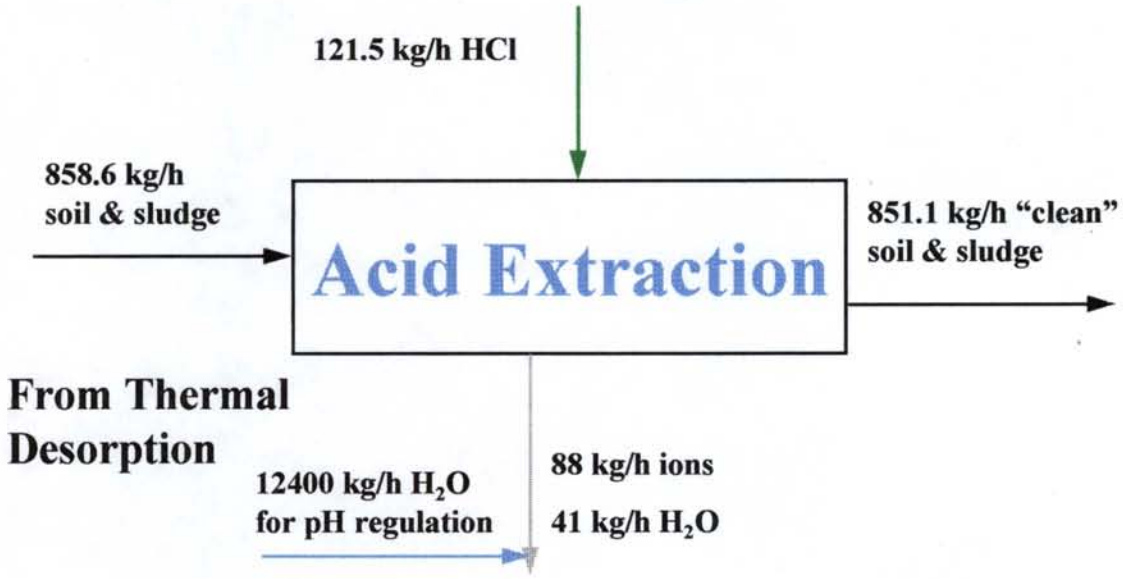
- **Amount of water needed**

$$(1.24\text{mol})\left(\frac{\text{L}}{0.01\text{mol}}\right) = 12{,}400\text{L}$$

Note: the water produced from the neutralization and the acid extraction reactions are negligible.

Figure 11 on the following page shows details of the Acid Extraction Process.

Figure 12: Detail of Acid Extraction Process



Ion Exchange Process

The purpose of ion exchange is to remove and recover the heavy metal and radioactive ions. A solution containing those heavy metals as well as potassium and chloride ions are introduced into ion exchange resins. The resins picked for the process are DOWEX 50WX8, 50-100 mesh, H base cation exchange resins. The major assumption for this process is all metals exchanged with sodium ion as exemplified by the following formula:

$$HR + Na^{+} \rightarrow NaR + H^{+}$$

The amount of sodium ions, resin and hydrogen ion required are calculated from the preceding chemical reaction equations.

- **Na^{+} Calculation for Exchange in Resin**
- **Mass flow rate of UO_3^{2-} in sludge = 7.22 kg/hr**
- **Number of mols of Na^{+} needed equals:**

$$\left(\frac{7.22\text{kg/h}\ UO_3^{-2}}{1000\text{g/1kg}}\right)\left(\frac{1\text{mol}UO_3^{-2}}{286\text{g}}\right)\left(\frac{1\text{mol}U^{+4}}{1\text{mol}UO_3^{-2}}\right)\left(\frac{4\text{mol}Na^{+}}{1\text{mol}U^{4+}}\right)$$

= 100.97 mol Na^{+}

- **The total amount of Na^{+} required is found by the same procedure for the other metal and radioactive ions which equals 3120 mols/hr**
- **The mols of resin and hydrogen ions required are also equal to 3120 mols/hr**
- **Calculation of the amount of DOWEX resin:**

$$\left(\frac{3120\text{ mol}}{\text{hr}}\right)\left(\frac{1\text{g}}{4.8\text{x}10^{-3}\text{ eq.}}\right) = \textbf{6500 kg/hr}$$

- **For three resin beds: (3)(6500kg/h) = $1.95\text{x}10^{6}$ kg/hr**
- **For regeneration every hour:**
  Amount of Hydrochloric Acid needed is the amount of H^{+} lost:

$$\left(\frac{3120\text{mol/hr}\ H^{+}}{1}\right)\left(\frac{1\text{mol HCl}}{1\text{mol}H^{+}}\right)\left(\frac{36.5\text{g HCl}}{1\text{mol HCl}}\right)\left(\frac{1\text{kg}}{1000\text{g}}\right) = \textbf{114 kg/hr}$$

- **pH Regulation**

- **Since 3120 mols/hr of hydrogen ions are produced, the molar amount of hydroxide required to neutralize is also 3217 mols/hr:**

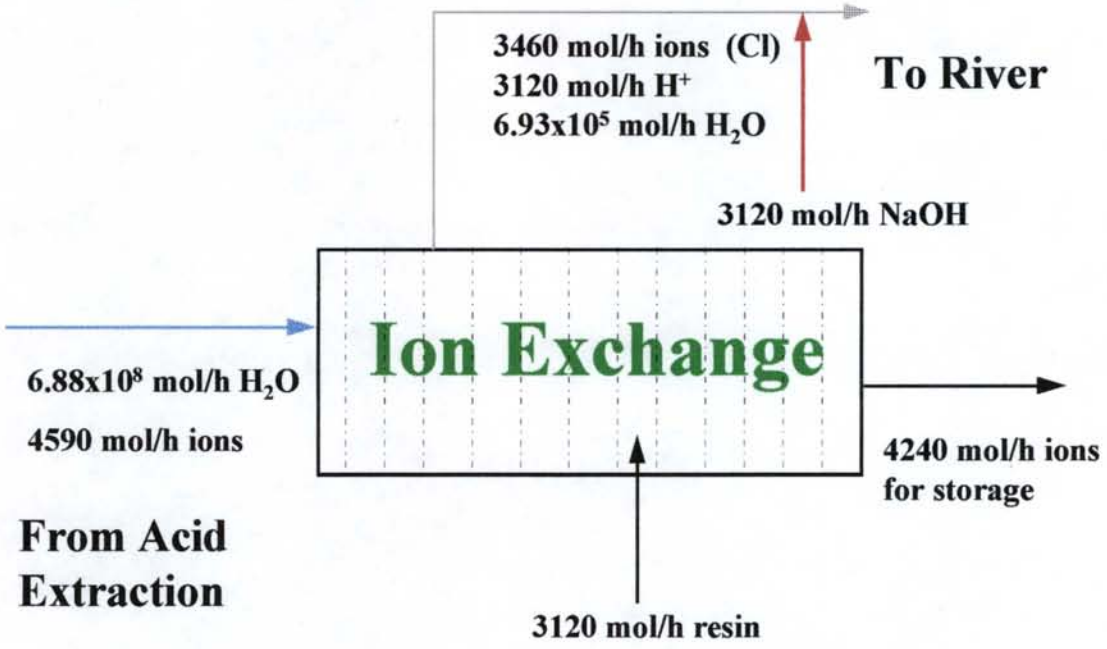
$$\left(\frac{3120\text{mol/hr NaOH}}{1}\right)\left(\frac{40\text{g}}{1\text{mol NaOH}}\right)\left(\frac{1\text{kg}}{1000\text{g}}\right) = \textbf{124.8 kg/hr}$$

- **Therefore, 3120 mols/hr of water is produced:**

$$\left(\frac{3120\text{mol/hr } H_2O}{1}\right)\left(\frac{18\text{g}}{1\text{mol } H_2O}\right)\left(\frac{1\text{kg}}{1000\text{g}}\right) = \textbf{56.2 kg/hr}$$

Figure 12 on the following page summarizes the materials balance on the Ion Exchange process.

Figure 13: Detail of Ion Exchange Process



Equipment Sizing & Pricing

The next logical step after materials & energy balances is to size the equipment decided upon at the beginning of the project. Other equipment items, such as conveyors, are now included for the transport of material from process to process. Auxiliary equipment such as pumps and blowers are sized according to the requirements of each process. Components, after being sized, are then priced using the correlations found in *Peters & Timmerhaus*: *Process Design and Economics for Chemical Engineers*. The prices thus found are in 1990 values and must be brought to 1996 terms. This is done using Marshall & Swift indices found in *Chemical Engineering*, July 1996.

To list the procedure for every process would be unduly repetitive, so an example using the first process in our flowsheet, KPEG, is used to illustrate the steps involved.

Into KPEG:

1. Soil ------ (349 kg/hr) / (1274 kg/m^3) x (264.17 gal/m^3) = 72.367 gal / hr
2. Sludge --- (722 kg/hr) / (1299 kg/m^3) x (264.17 gal/m^3) = 146.829 gal /hr
3. PEG ------ (49.6 kg/hr) / (1000 kg/m^3) x (264.17 gal/m^3) = 13.103 gal / hr
4. KOH ----- (6.97 kg/hr) / (1000 kg/m^3) x (264.17 gal/m^3) = 1.841 gal / hr
5. Water ----- (87.3 kg/hr) / (1000 kg/m^3) x (264.17 gal/m^3) = 23.062 gal / hr

Total: 257.202 gal /hr

Since our processes have approximately 1 hr residence times, this total is the approximate volume needed for the reactor. A volume of 300 gal was decided upon to facilitate increasing throughput and allow ample volume for vapor removal.

A holding tank for 1 week's supply of the KPEG reagent was deemed necessary. Using the total volume of PEG & KOH above, a total volume for the tank was found:

(13.103 + 1.841) gal/hr x (8100 hr/yr.) / (52 weeks/yr.) = 2327 gal/wk.

The volume for the tank was taken at 3000 gal. Another tank for hydrochloric acid was sized in the same manner.

To transport the materials (soil & sludge) between processes a conveyor is needed. A screw type conveyor was thought to be best suited for this task due to the fact that a contained transport system would help keep cleanup to a minimum. The criteria for sizing the conveyor is as follows: Distance to the next process is approximately 20 feet; a transport time of approximately 1 minute is desirable; some empty space in the conveyor tube is desirable due to the gravely nature of the soil. These criteria lead to the selection of a conveyor length of 20' and diameter of the tube of 14".

Pricing the above equipment yields the following values:

Table 3: Equipment Prices for KPEG Process (Installation Included)

Equipment	1990 Price	1996 Price
Jacketed steel, glass lined reactor (300 gal)	$30,000	$34,064.94
Glass lined tank (3000 gal)	$100,000	$113,549.78
Screw conveyor (20' length , 14" diameter)	$8,000	$9,083.98

A few processes required special treatment with regards to sizing and pricing. The first of these is the incineration process. An applicable cost correlation could not be found, so an alternate source of information was needed. This information was found by calling the firm of Callidus Corp. in Oklahoma. Their quoted price was based on the material being incinerated (heavy hydrocarbon approximation $C_{16}H_{34}$), throughput, and phase of incinerated material. The price including instrumentation and installation was $3,000,000.

An air blower was needed for the removal of water vapor from the KPEG process and removal of hydrocarbons from the thermal desorption process. From materials balances the required throughput of air into these processes (total) was: 42.8 kg/h. A blower rated at 2500 ft^3/min was selected. The price (1996) was $2498.10.

Two pumps were needed for the plant: one for transporting water from the KPEG process and one for removing the ion solution from acid extraction. The volumes to be transported were 10 gal / min and 23 gal / min respectively. The volumes were calculated on the per batch (or hour) basis and set to the 1 min transfer time. Total 1996 prices for the pumps turned out to be $4,541.99.

Ion exchange bed sizing was done by first finding the amount of resin needed based on the throughput of ions to be removed, the exchange capacity of the resin, and the time between regeneration. Next, the volume of the tower needed was found by the density of the resin and its expansion factor. The tower diameter was set by setting the maximum length and finding the diameter of a cylinder that gives the correct volume. Three towers of resin are needed for each separate ion exchange process: one being the primary adsorber, one to catch the lag in the breakthrough curve of the primary, and one to be regenerated while the other two are in active use.

Disposal consisted of the following: disposal of soil from acid extraction and disposal of ions from ion exchange. For both processes, 55 gallon drums were used as the disposal apparatus. Encasing of the drums is required for ion

exchange, but the cost associated with it is included in the fixed capital investment as illustrated in the section concerning return on investment.

A complete listing of all equipment with costs is found below.

Table 4: Equipment Costs

		$1990	$1996
KPEG	Reactor	30,000.00	34,064.94
	Holding Tank	100,000.00	113,549.78
	Screw Conveyor	8,000.00	9,083.98
Thermal Desorption	Rotary Dryer	12,000.00	13,625.97
	Screw Conveyor	8,000.00	9,083.98
Incinerator (1996) cost		3,000,000.00	3,000,000.00
Acid Extraction	Reactor	11,400.00	12,944.68
	Screw Conveyor	8,000.00	9,083.98
	Used 55 gallon drums for "clean' soil	339,129.60	385,080.93
	HCl holding tank	100,000.00	113,549.78
Blower		2,200.00	2,498.10
Ion Exchange	(2)Pump	4,000.00	4,541.99
	Resin for 3 beds	310,732.50	352,929.46
	15' towers (3)	67,500.00	76,646.10
	55 Gallon drums (ions)	25,053.30	28,447.97
	Total	4,026,015.40	4,165,131.65

Miscellaneous	Pipe	
	Sch. 40 4"	4640
	Duct 1' Diam.	13440

Economic Analysis

After the mixed waste treatment system is sized cost estimates are performed. The economics of the facility determine if it will be constructed or not. In today's market if your not economically competitive you will not remain in business. The following are extensive cost estimates on every phase of the mixed waste treatment plant.

Utilities

There are three different components under utility costs, electricity, natural gas, and water. The total electrical costs is found by adding 10% of the total product cost to 10% of the total equipment cost see Table 4 and Table 7. For cost per unit and total amount of natural gas and water needed refer to the Table 4 below. All costs in Table 4 and Table 7 are per year in **1996 dollars**.

Table 5: Utility Costs Per Year

	Energy Needed/hr	Hours/yr	Energy Needed [BTU/yr]	Price [$/BTU]	Cost /yr [$]
Electrical		8.10E+03	0	2.05E-05	416,309
Natural Gas	4.35E+05	8.10E+03	3.52E+09	0.000004	14,099
	Needed [gal/hr]	Hours/yr	Needed [gal/yr]	Price [$/gal]	Cost [$]
Water	3.30E+03	8.10E+03	2.67E+07	8.00E-04	21,381
				TOTAL	451,788

Raw Materials

There are four different components under Raw Material (see Table 5) costs, HCl, PEG, NaOH, and KOH. The price per unit are in 1996 dollars from sargent-welch home page on the world wide web. The amount of HCl needed below includes the specific amount needed for acid extraction process as well an extra 125 units for storage. The KOH and PEG is the amount needed for the KPEG process. The NaOH is the amount of base required to neutralize the HCl solution leaving acid extraction to a pH of 2.00 before entering ion exchange.

Table 6: Raw Material Costs in 1996 Dollars

	Units/hr	Hours/yr	Needed units/yr	Price/unit	Cost /yr [$]
HCl	242	8,100	1,960,200	6.52	12,780,504
KOH	8.75	8,100	70,875	23.80	1,686,825
PEG	47.55	8,100	385,155	12.22	4,706,296
NaOH	71.76	8,100	581,256	21.90	12,729,506
				TOTAL	31,903,132

Labor

The next item on the economic analysis agenda is labor cost. The cost for the helpers and workers was taken from *Plant Design and Economics for Chemical Engineers* by Peters and Timmerhaus. The process plant will operate three eight hour shifts or 2700 hours per shift each year. The number of helpers and workers for each shift along with their hourly and yearly costs can be found below.

Table 7: Labor Costs in 1996 Dollars

		Number	Wage - $ per hr	Hours / worker	Cost $
Helpers	Helpers	6.00	15.00	2,700.00	243,000.00
Operators	Batch Reactor (2)	6.00	20.00	2,700.00	324,000.00
	Incinerator	6.00	20.00	2,700.00	324,000.00
	Thermal Desorption	2.00	20.00	2,700.00	108,000.00
				Total	999,000.00

The plant is operating three full shifts so six helpers are needed, two for each shift. Six batch reactor and incinerator operators are needed to handle the three shift load. Finally, only half an operator per shift is required for thermal desorption. The extra operator can be used other places if he/she is not needed for thermal desorption.

Fixed and Total Capital Investment

By definition the fixed-capital investment is the amount of money needed to supply the necessary manufacturing and plant facilities. Included in the fixed-capital investment are direct costs, indirect costs, working capital, and contingencies. The total fixed-capital investment iterated with the working capital, which is 20% of the total capital investment, is the total capital investment. For this project there are four different major categories under direct costs

Table 8: Fixed and Total Capital Investment in 1996 Dollars

Direct Costs		
A	Equipment	4,165,131.65
	Instrumentation (20% of Eq.)	833,026.33
	Piping	4,640.00
	Duct	13,440.00
	Electrical (10% Equip. Cost)	416,513.16
B	Building (30% Equip. Cost)	1,249,539.49
C	Service Facilities & Yard Improvements (40% Equip. Cost)	1,666,052.66
D	Land (4% Equip. Cost)	166,605.27
	Direct Cost Total	8,514,948.56
Indirect Costs		
A	Engineering & Supervision (5% Direct Cost)	425,747.43
B	Construction expense & Contractor's Fee (20% Direct Cost)	1,702,989.71
	Indirect Cost Total	2,128,737.14
Preliminary Fixed Capital Investment	(Direct + Indirect)	10,643,685.70
	Contingency (5% of Fixed Capital Inv.)	532,184.28
Fixed Capital Investment	Prelim. F.C.I. + Contingency	11,175,869.98
Working Capital	(20% of TOTAL CAPITAL INVEST.)	2,793,967.49
TOTAL CAPITAL INVESTMENT	Fixed + Working Capital	13,969,837.47

Total Product Cost

The total product cost is the manufacturing cost plus plant overhead cost plus general expense cost. The manufacturing cost is broken down into two categories, total production cost and fixed charges. The total production cost contain raw material cost, operating labor cost, direct supervisory and clerical labor cost, utility cost, maintenance and repair cost, operating supplies cost, and laboratory charges. Direct supervisory and clerical labor is 10% of the operating labor. A breakdown of the operating labor is located in Table 6. A breakdown of the utility costs is located in Table 4. The maintenance and repair cost and operating supply cost are 5% and 0.5% of the fixed-capital investment cost, respectively. Finally, laboratory charges are 15% of the operating labor. The fixed charges section of the manufacturing cost contains two costs, local taxes and insurance. Local taxes is 2% of the fixed-capital investment cost while insurance is 1% of the fixed-capital investment cost. Plant overhead, 10% of the total product cost, is determined by iterating the total product costs. The third part of the total product cost is general expenses. General expenses also contains two costs, administrative and research and development. Administrative and research and development costs are determined by iterating 2% and 5% respectively of the total product cost . The table below illustrates the above explanations of the total product cost.

Table 9: Total Product Cost in 1996 Dollars

Manufacturing Cost		$ 1996 dollars
A	Direct Production Cost	
	1) Raw Materials 1996 dollars	
	HCl	12,780,504.00
	KOH	1,686,825.00
	PEG	4,706,296.50
	NaOH	12,729,506.40
	2) Operating Labor	999,000.00
	3) Direct Supervisory & Clerical Labor (10% Operat. Labor)	99,900.00
	4) Utiltities	451,788.17
	5) Maintenance (5% Fixed Capital Investment)	558,793.50
	6) Operating Supplies (0.5% Fixed Capital Investment)	55,879.35
	7) Lab Charges (15% Operating Labor)	149,850.00
	Total Direct Production Costs	34,218,342.92
B	Fixed Charges	
	1) Local Taxes (2% Fixed Capital Investment)	223,517.40
	2) Insurance (1% Fixed capital Investment)	111,758.70
	Total Fixed Charges	335,276.10
C	Plant Overhead (10% Total Product Cost)	4,163,086.63
	Total Manufacturing Cost	38,716,705.65
General Expenses		
A	Administrative Costs (2% Total Product Cost)	832,617.33
B	Research & Development (5% Total Prod. Cost)	2,081,543.31
	Total General Expenses	2,914,160.64
Total Product Cost	Manufacturing + General Expenses	41,630,866.29

Present Value and Return On Investment

The last part of the economic analysis involves entering all of the above costs into a structured spreadsheet. The spreadsheet model chosen for this project can be found on the next page. The first year of the economic analysis period is planning cost. The amount of 1.4 million dollars is the amount put forth to design the waste treatment facility. The 1.4 million dollars is payment for 20 engineers at 70,000 dollars a piece. It will take two years to build the facility at a cost of over 28.3 million dollars. A safety factor of 3 (above the total required for operation) is included in the total fixed capital investment for radiation handling and storage. This figure comes from half of the fixed-capital investment multiplied by three for safety factors (see Line 3 of spreadsheet on next page). Lines 5 through 6-T of the spreadsheet are filled in directly from the above tables into years 4 through 23. Lines 7 through 16 are calculated from formulas in the *Plant Design and Economics for Chemical Engineers* by Peters and Timmerhaus. Line 8 or operating income is just line 4-7 (annual income minus total product cost). Line 10 (income before tax) is equal to line 8 (operating income) because there is not any depreciation. Line 11 (income after tax) is simply Line 10 (income before tax) multiplied by 0.66 because of 34% income tax. Line 12 (annual cash income) is simply equal to Line 11 because of the lack of depreciation. Line 13 (annual cash flow) is equal to Line 12 (annual cash income) since total capital investment applies only to the second and third years. Line 14 or annual discount factors are found by the following formula: $(1+i)^{-n}$ where: i = interest rate of 35% and n = number of years. Line 15 (annual present value),equals Line 13 (annual cash flow) multiplied by Line 14 (annual discount factors). All of the outlays including planning costs and total capital investment are discounted from year one. The plant is not receiving any payments until the end of the fourth year. However, the payments run through year 23. The annual payments, are calculated by iterating until the total of the annual payments is equal to the total of the expenditures.

For 35% return on investment, the DOE must pay over 69 million a year for twenty years. The total amount paid will near 1.4 billion dollars. For specific numbers please refer to the tables on the following pages.

Table 10: Present Value and ROI Until Year 5

		Design	Building			
	Year	1	2	3	4	5
Line	Item Numbers in ( ) designate line	1996 1	1997	1998	1999	2000
	Planning Costs	-1,400,000.00				
1	Fixed-capital investment		-5,587,934.99	-5,587,934.99		
2	Working capital		-1,396,983.75	-1,396,983.75		
3	Total capital investment (1+2)		-20,954,756.21	-20,954,756.21		
4	Annual income (sales)	-1,400,000.00			69,072,009.27	69,072,009.27
5	Annual Manufacturing cost					
	(a) Raw Materials					
	(ai) HCl				12,780,504.00	12,780,504.00
	(ai) PEG				4,706,296.50	4,706,296.50
	KOH				1,686,825.00	1,686,825.00
	NaOH				12,729,506.40	12,729,506.40
	(b) Labor				1,098,900.00	1,098,900.00
	(c) Utilities				451,788.17	450,512.20
	(d) Maintenance and repairs				558,793.50	497,462.72
	(e) Operating Supplies				55,879.35	49,746.27
	(f) Laboratory charges				149,850.00	149,850.00
	(g) Local taxes and insurance				335,276.10	298,477.63
	(h) Plant overhead				4,163,086.63	4,150,371.17
5-T	Total of line 5				38,716,705.65	38,598,451.90
6	Annual general expenses					
	(a) Administrative				832,617.33	830,074.23
	(c) Research and development				2,081,543.31	2,075,185.59
6-T	Total of line 6				2,914,160.64	2,905,259.82
7	Total Product cost (5-T + 6-T)	0	0	0	41,630,866.29	41,503,711.72
8	Annual operating income (4-7)	-1,400,000.00	0.00	0.00	27,441,142.98	27,568,297.55
10	Income before tax (8 since no depr.)	-1,400,000.00	0.00	0.00	27,441,142.98	27,568,297.55
11	Income after 34% tax (0.66*10)	-1,400,000.00	0	0	18111154.37	18195076.38
12	Annual cash income (11 since no depr.)	-1,400,000.00	0.00	0.00	18,111,154.37	18,195,076.38
13	Annual cash flow (3+12)	-1,400,000.00	-20,954,756.21	-20,954,756.21	18,111,154.37	18,195,076.38
14	Discount factors for 30% interest	0.740740741	0.548696845	0.406442107	0.301068226	0.223013502
15	Annual present value (13*14)	-1,037,037.04	-11,497,808.62	-8,516,895.28	5,452,693.15	4,057,747.70
16	TOTAL present value of annual cash flows (sum of line 15 not including 0 year =	-1,037,037.04	-11,497,808.62	-8,516,895.28	5,452,693.15	4,057,747.70

Table 11: Present Value and ROI From Year 6 Until 12

6	7	8	9	10	11	12
2001	2002	2003	2004	2005	2006	2007
69,072,009.27	69,072,009.27	69,072,009.27	69,072,009.27	69,072,009.27	69,072,009.27	69,072,009.27
12,780,504.00	12,780,504.00	12,780,504.00	12,780,504.00	12,780,504.00	12,780,504.00	12,780,504.00
4,706,296.50	4,706,296.50	4,706,296.50	4,706,296.50	4,706,296.50	4,706,296.50	4,706,296.50
1,686,825.00	1,686,825.00	1,686,825.00	1,686,825.00	1,686,825.00	1,686,825.00	1,686,825.00
12,729,506.40	12,729,506.40	12,729,506.40	12,729,506.40	12,729,506.40	12,729,506.40	12,729,506.40
1,098,900.00	1,098,900.00	1,098,900.00	1,098,900.00	1,098,900.00	1,098,900.00	1,098,900.00
450,512.20	450,512.20	450,512.20	450,512.20	450,512.20	450,512.20	450,512.20
497,462.72	497,462.72	497,462.72	497,462.72	497,462.72	497,462.72	497,462.72
49,746.27	49,746.27	49,746.27	49,746.27	49,746.27	49,746.27	49,746.27
149,850.00	149,850.00	149,850.00	149,850.00	149,850.00	149,850.00	149,850.00
298,477.63	298,477.63	298,477.63	298,477.63	298,477.63	298,477.63	298,477.63
4,150,371.17	4,150,371.17	4,150,371.17	4,150,371.17	4,150,371.17	4,150,371.17	4,150,371.17
38,598,451.90	38,598,451.90	38,598,451.90	38,598,451.90	38,598,451.90	38,598,451.90	38,598,451.90
830,074.23	830,074.23	830,074.23	830,074.23	830,074.23	830,074.23	830,074.23
2,075,185.59	2,075,185.59	2,075,185.59	2,075,185.59	2,075,185.59	2,075,185.59	2,075,185.59
2,905,259.82	2,905,259.82	2,905,259.82	2,905,259.82	2,905,259.82	2,905,259.82	2,905,259.82
41,503,711.72	41,503,711.72	41,503,711.72	41,503,711.72	41,503,711.72	41,503,711.72	41,503,711.72
27,568,297.55	27,568,297.55	27,568,297.55	27,568,297.55	27,568,297.55	27,568,297.55	27,568,297.55
27,568,297.55	27,568,297.55	27,568,297.55	27,568,297.55	27,568,297.55	27,568,297.55	27,568,297.55
18195076.38	18195076.38	18195076.38	18195076.38	18195076.38	18195076.38	18195076.38
18,195,076.38	18,195,076.38	18,195,076.38	18,195,076.38	18,195,076.38	18,195,076.38	18,195,076.38
18,195,076.38	18,195,076.38	18,195,076.38	18,195,076.38	18,195,076.38	18,195,076.38	18,195,076.38
0.165195187	0.122366805	0.090642078	0.06714228	0.049735022	0.036840757	0.02728945
3,005,739.04	2,226,473.36	1,649,239.53	1,221,658.91	904,932.53	670,320.39	496,533.62
3,005,739.04	2,226,473.36	1,649,239.53	1,221,658.91	904,932.53	670,320.39	496,533.62

Table 12: Present Value and ROI From Year 13 Until 18

13	14	15	16	17	18
2008 13th	2009 14th	2010 15th	2011 16th	2012 17th	2013 18th
69,072,009.27	69,072,009.27	69,072,009.27	69,072,009.27	69,072,009.27	69,072,009.27
12,780,504.00	12,780,504.00	12,780,504.00	12,780,504.00	12,780,504.00	12,780,504.00
4,706,296.50	4,706,296.50	4,706,296.50	4,706,296.50	4,706,296.50	4,706,296.50
1,686,825.00	1,686,825.00	1,686,825.00	1,686,825.00	1,686,825.00	1,686,825.00
12,729,506.40	12,729,506.40	12,729,506.40	12,729,506.40	12,729,506.40	12,729,506.40
1,098,900.00	1,098,900.00	1,098,900.00	1,098,900.00	1,098,900.00	1,098,900.00
450,512.20	450,512.20	450,512.20	450,512.20	450,512.20	450,512.20
497,462.72	497,462.72	497,462.72	497,462.72	497,462.72	497,462.72
49,746.27	49,746.27	49,746.27	49,746.27	49,746.27	49,746.27
149,850.00	149,850.00	149,850.00	149,850.00	149,850.00	149,850.00
298,477.63	298,477.63	298,477.63	298,477.63	298,477.63	298,477.63
4,150,371.17	4,150,371.17	4,150,371.17	4,150,371.17	4,150,371.17	4,150,371.17
38,598,451.90	38,598,451.90	38,598,451.90	38,598,451.90	38,598,451.90	38,598,451.90
830,074.23	830,074.23	830,074.23	830,074.23	830,074.23	830,074.23
2,075,185.59	2,075,185.59	2,075,185.59	2,075,185.59	2,075,185.59	2,075,185.59
2,905,259.82	2,905,259.82	2,905,259.82	2,905,259.82	2,905,259.82	2,905,259.82
41,503,711.72	41,503,711.72	41,503,711.72	41,503,711.72	41,503,711.72	41,503,711.72
27,568,297.55	27,568,297.55	27,568,297.55	27,568,297.55	27,568,297.55	27,568,297.55
27,568,297.55	27,568,297.55	27,568,297.55	27,568,297.55	27,568,297.55	27,568,297.55
18195076.38	18195076.38	18195076.38	18195076.38	18195076.38	18195076.38
18,195,076.38	18,195,076.38	18,195,076.38	18,195,076.38	18,195,076.38	18,195,076.38
18,195,076.38	18,195,076.38	18,195,076.38	18,195,076.38	18,195,076.38	18,195,076.38
0.020214407	0.014973635	0.011091581	0.008215986	0.006085916	0.004508086
367,802.68	272,446.43	201,812.17	149,490.50	110,733.70	82,024.96
367,802.68	272,446.43	201,812.17	149,490.50	110,733.70	82,024.96

Table 13: Present Value and ROI From Year 19 Until Final Year

19	20	21	22	23	
2014 19th	2015 20th	2016 21st	2017 22nd	2018 23rd	Totals
69,072,009.27	69,072,009.27	69,072,009.27	69,072,009.27	69,072,009.27	1,381,440,185.34
12,780,504.00	12,780,504.00	12,780,504.00	12,780,504.00	12,780,504.00	
4,706,296.50	4,706,296.50	4,706,296.50	4,706,296.50	4,706,296.50	
1,686,825.00	1,686,825.00	1,686,825.00	1,686,825.00	1,686,825.00	
12,729,506.40	12,729,506.40	12,729,506.40	12,729,506.40	12,729,506.40	
1,098,900.00	1,098,900.00	1,098,900.00	1,098,900.00	1,098,900.00	
450,512.20	450,512.20	450,512.20	450,512.20	450,512.20	
497,462.72	497,462.72	497,462.72	497,462.72	497,462.72	
49,746.27	49,746.27	49,746.27	49,746.27	49,746.27	
149,850.00	149,850.00	149,850.00	149,850.00	149,850.00	
298,477.63	298,477.63	298,477.63	298,477.63	298,477.63	
4,150,371.17	4,150,371.17	4,150,371.17	4,150,371.17	4,150,371.17	
38,598,451.90	38,598,451.90	38,598,451.90	38,598,451.90	38,598,451.90	
830,074.23	830,074.23	830,074.23	830,074.23	830,074.23	
2,075,185.59	2,075,185.59	2,075,185.59	2,075,185.59	2,075,185.59	
2,905,259.82	2,905,259.82	2,905,259.82	2,905,259.82	2,905,259.82	
41,503,711.72	41,503,711.72	41,503,711.72	41,503,711.72	41,503,711.72	
27,568,297.55	27,568,297.55	27,568,297.55	27,568,297.55	27,568,297.55	
27,568,297.55	27,568,297.55	27,568,297.55	27,568,297.55	27,568,297.55	
18195076.38	18195076.38	18195076.38	18195076.38	18195076.38	
18,195,076.38	18,195,076.38	18,195,076.38	18,195,076.38	18,195,076.38	
18,195,076.38	18,195,076.38	18,195,076.38	18,195,076.38	18,195,076.38	
0.003339323	0.002473572	0.001832276	0.001357241	0.001005364	
60,759.23	45,006.84	33,338.40	24,695.11	18,292.67	Solver
60,759.23	45,006.84	33,338.40	24,695.11	18,292.67	0.00

Results and Discussion

This mixed waste facility does meet the requirements that the DOE has mandated. The plant consists of five different process steps: KPEG treatment, thermal desorption, incineration, acid extraction, and ion exchange. Each process is essential for complete removal of hazardous and/or radioactive wastes.

The first process step is the KPEG treatment. KPEG is an EPA approved treatment process that dechlorinates organic compounds to form ions in solution. KPEG involves mixing the soil and residues with water and KPEG reagent (potassium hydroxide + polyethylene glycol) and heating this mixture to 150 °C for one hour. The PEG and the PCBs become part of the organics while the potassium and chlorine become ions in solution. There is a possibility that the lighter organics may volatile and escape. Therefore, an air stream is introduced into the process. A fair estimate of the amount of organics that escape is roughly .5% Also, this process is assumed to be 100% efficient, i.e., 100% of the organics are dechlorinated. KPEG is an important step because if the chlorines are totally removed, then the remaining organics can be burned, drastically decreasing cost and increasing effectiveness.

Several different costs are associated with this process: a reactor, a holding tank for the reagent, a screw conveyer to transport wastes, and raw materials including reagent and water. As illustrated previously, the cost for this process is fairly expensive. The equipment is not the major factor with the total cost of $159,000. Instead, KPEG reagent contributes to the majority of the cost at approximately $6,400,000/year/ Still this process is still the most effective way of ensuring that all organics including those chlorinated can be removed, and it meet with EPA approval.

After the organics are dehalogenated, the stream is sent to a thermal desorption unit. This technology has proven to be one of the primary methods of removing organics from soil/process wastes. This process involves heating the soil and process wastes to a high enough temperature (240 °C) to volatilize the organics. The efficiency of this process is estimated based on previous reports at 99.5%.

The cost of this process is not nearly as expensive as KPEG, due mainly to the lack of any type of reagent requirements. The thermal desorption unit resembles a rotary dryer which is estimated at only approximately $14,000. The costs due to heating requirements are not that high with only $14,000 covering the heating requirements for all processes. Therefore, thermal desorption is an efficient, effective process for removing organics.

Incineration is the next step in treating the organics. The organics volatilized in the KPEG process as well as the organics from thermal desorption are sent to incineration. From a vendor, Callidus Corporation, the estimated

removal efficiency for this specific concentration of organics is approximately 100%. Therefore, this would be the ideal next step in removing organics. Also, Callidus provided a cost estimate of approximately $3,000,000 including blowers and all other required equipment. This cost may seem fairly expensive, but no other costs aside from utilities are incurred per year.

The soil and process residues are sent to an acid extraction system. This process involves introducing hydrochloric acid to the soil/sludges. The acid changes all the heavy and radioactive metal from their oxide forms into cations. Based on stoichiometric coefficients, the amount of HCl, ions generated including chlorine and metals, and water generated can all be calculated. Also, since hydroxide is still present from the KPEG process, a calculated amount of excess acid will have to be added for neutralization. The solution leaving will be extremely acidic, therefore pH regulation measures are undertaken. The remaining soil will then be disposed of in 55 gallon drums.

The cost associated with this process is extremely high. Like KPEG, the equipment does not contribute much to the overall cost. The reactor, acid holding tank, conveyer, and drums only total approximately $520,000. The acid, though, is approximately $7,000,000/year. (Note the cost of HCl in table 5 is for all processes.) Since this process is the only known way to change the hazardous metal oxides into ions, the price does not seem that exorbitant.

The final step in this treatment facility is ion exchange. Dowex 50WX8 is a cation exchanger that fits the characteristics required for this process. By knowing the amount of ions present, the exchange capability of the resin, and the amount of water retention of the resin, the amount of resin required can be calculated. The ion exchange system uses a series of three beds: on is the primary exchanger, the other catches the lag in the breakthrough curve, and the last is used for regeneration. For best use, the ion exchanger is regenerated every hour.

This is the most expensive process in the facility. The resins are fairly expensive at approximately $350,000 for 3, but the towers holding the exchangers as well as the disposal apparatus are moderately priced. Again, the major cost is in the use of reagents, and acid for regeneration and a base for neutralization of the resulting stream. These cost total to an estimated $18,000,000/year. Also, disposal costs of drum encasement would ordinarily be included, but these costs are included in the safely scaleup factor in fixed capital investment.

The total cost of the facility includes fixed capital costs, working capital, manufacturing costs, and various other expenses. By summing the various costs which are discounted to present value and maintaining a return on investment of 35 %, the total cost of the plant is approximately 1.4 billion dollars. Each year for twenty year the DOE would therefore have to spend about $69,000,000. The number is quite feasible. Other high-level waste treatment centers have proposed costs in the 100 billion dollar range. This facility is guaranteed to meet the requirements warranted by DOE at a moderate cost with absolutely no risk to personal safety.

Conclusions

This treatment facility utilizes five processes: KPEG, thermal desorption, incineration, acid extraction and ion exchange. Each process is extremely efficient and moderately priced. All processes are at least 99.5% effective, with some being even closet to 100%. Due to the high cost of reagent, KPEG, acid extraction, and ion exchange seem relatively expensive. But, when compared to other processes which are not as efficient therefore requiring other process steps, they probably save money. As for thermal desorption and incineration, these are the best known processes that eliminate volatile organics, therefore they are the best choices even if they were not as moderately priced. Each process used safely precautions, therefore the liabilities associated with this facility are small.

The Department of Energy will need to distribute 69 million dollars a year for this facility. After twenty years of those annual payments, the total paid by DOE will be roughly 1.4 billion dollars, the total cost of the plant. Is this and exorbitant amount for a facility that will fulfill all the requirements insisted upon by DOE? With all the safety factors and the reliabilities of the technologies, this estimate is quite fair.

Comparisons To DOE Treatment Technologies

The Department of Energy commissioned a study on nonthermal treatment technologies for the aforementioned MLLW present at the DOE complex. Numerous technologies were considered for this study but eventually only five different cases were thoroughly examined. These cases were labeled debris grout (System 1), vacuum desorption (System 2), washing system (System 3), acid digestion (System 4), and catalytic wet oxidation (System 5). The following paragraphs explain each system.

In System 1, vacuum desorption treats process residue and inorganic sludge. The organic liquids and sludges can be destroyed using silver MEO (mediated electrochemical oxidation). MEO uses electric energy to react with organics and break them down to CO_2 and H_2O. Debris is grouted (mixing waste with grout) for organic removal and stabilization. Polymer stabilization is used to stabilize salts and treated process residues.

System 2 incorporates vacuum desorption for residues, debris and soil. Catalytic Wet Oxidation (CWO) is used to destroy organic liquids and sludges. Like System 1, grout is the primary stabilization procedure and polymer stabilization is secondary.

System 3 only incorporates soil, sludge, and debris washing. Organic liquids and sludges can be destroyed by silver MEO as in System 1. Grout and polymer are the stabilization media.

System 4 is a combination of the first 3 systems with additional innovative technologies. Open debris and soil are washed, complex debris is grouted, and inorganic sludges are vacuum desorbed. Organic liquid and sludges and soft debris will be treated with acid digestion. Stabilization occurs through phosphate bonded ceramic primarily and polymer secondly.

System 5 is identical to System 4 except CWO is used for soft debris and organics. Also, the primary stabilization device is grout instead of phosphate bonded ceramic.

Two subsystems occur in each system: off-gas treatment and aqueous waste treatment. All off gas streams pass through a condenser to condense organics which would then be sent to organic destruction. Aqueous waste treatment consists of ion exchange, precipitation followed by filtration, and carbon filtration to remove dissolved solids or organics prior to discharge.

The main focus of these technologies is organic removal and subsequent organic destruction. Metal and radioactive components are only removed as a result of the primary organic removal schemes: washing and thermal desorption. In other words, some metal and radioactive components are removed but only as a result of trying to remove organics. The treated or untreated final waste containing these metals and radioactive components is then stabilized by the various methods illustrated previously. Table 14 illustrates the fate of the metals and radioactive components for each system.

Table 14: Final Waste Form For DOE Technologies

System 1	System 2	System 3	System 4	System 5
Highest contaminant concentration including metals and radionuclides	Metals and radionuclides remain within the waste	Soluble metals and radionuclides are removed, precipitated, and sent to polymer stabilization	Same as System 3	Same as System 3

The costs associated with these systems is quite high, approximately 3.5-3.7 billion dollars. But, this cost estimate incorporates a myriad of costs including administrative, inspection, and even NEPA. A more detailed cost estimate such as this will no doubt result in a higher total cost. Also, the costs detailed only represent the minimum cost required to remove the specified wastes. For a company bidding on this project the cost estimate would be significantly higher due to the rerun the company wished to make on its investment.

The following table illustrates a direct comparison between these technologies and the removal scheme presented in this report. Thermal desorption is a common technology in both several cases for removing organics. However, one major difference is that no specific technology in the DOE study was introduced to specifically remove metal and radioactive components. Ion exchange is a similar technology for both schemes, but the DOE study only illustrates it as a secondary removal technology. The DOE study incorporates an off-gas treatment subsystem, while this study uses incineration which does not require and off-gas treatment because all organics are removed.

These comparisons illustrate the various techniques available to treat mixed low-level waste. Different removal schemes can only be chosen once sufficient research is completed and appropriate pilot scale tests run. Interpretations of various laws and other opinions relating to disposal characteristics contribute to the selection of the total removal scheme. For instance, the DOE study was almost entirely concerned with organic removal and destruction. If, however, the main focus was on total contaminant removal with less risk for environmental impacts, then the DOE study would not be comprehensive enough. So, both the DOE study and the study in this report represent the different interpretations of regulations involving environmental risk. Ultimately the agency or company bidding on these designs will decide which path to follow.

Table 15: Comparison To DOE Technologies

Removal Scheme	Organic Removal	Organic Destruction	Metal and Radionuclide Removal	Metal and Radionuclide Treatment	Off-gas Treatment	Aqueous Waste Treatment	Cost (billions)
This System	Thermal Desorption	Incineration	Acid Extraction	Ion Exchange	None Required	None Required	1.4
System 1 (DOE)	Vacuum Thermal Desorption	MEO	None Removed	Stabilization	Condenser, Photooxidation, Filters	Ion Exchange, Filtration	3.55
System 2 (DOE)	Vacuum Thermal Desorption	CWO	None Removed	Stabilization	Condenser, Photooxidation, Filters	Ion Exchange, Filtration	3.51
System 3 (DOE)	Wash	MEO	Soluble, Precipitation	Stabilization	Condenser, Photooxidation, Filters	Ion Exchange, Filtration	3.66
System 4 (DOE)	Wash, Vacuum Thermal Desorption	Acid Digestion	Soluble, Precipitation	Stabilization	Condenser, Photooxidation, Filters	Ion Exchange, Filtration	3.72
System 5 (DOE)	Wash, Vacuum Thermal Desorption	CWO	Soluble, Precipitation	Stabilization	Condenser, Photooxidation, Filters	Ion Exchange, Filtration	3.69

Nomenclature

C_p ---------- Heat Capacity ---------- J/kg K
E ---------- Energy ---------- J
T ---------- Temperature ---------- C or K

Δ ---------- difference ---------- unitless
ρ ---------- density ---------- kg / m^3

Units

Energy
- J ---------- Joule

Length
- m ---------- meter

Mass
- g ---------- gram
- kg ---------- kilogram
- mol ---------- mole

Volume
- L ---------- liter

Temperature
- K ---------- degrees Kelvin
- C ---------- degrees Celsius

Time
- hr ---------- hour
- yr ---------- year

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VISITT-Vendor Information System for Innovative Treatment Technologies. EPA, Solid Waster and Energy Response, July 1994.

Other References

Direct Vendor Pamphlets from Cognis, Dow, and Nucon.

Cognis; 2331 Circadian Way; Santa Rosa, CA 95407
Dow Chemical Company; Midland, Michigan 48674
Nucon International, Inc.; P.O. Box 29151; Columbus, Ohio 43229

Some Raw Material Prices found via Internet:
http://www.sargentwelch.com/ezchem/html#P (Laboratory Chemical Prices)

Appendix A

Spreadsheet Calculations

		APEG / KPEG	APEG / KPEG	APEG / KPEG	APEG / KPEG
CONTAMINATE or SPECIE CONC. (wt fract. soil/sludge @ start)	kg/hr	IN	OUT TO THERMAL DESORP.	OUT TO ATMOSPHERE	OUT TO INCINERATION
	soil(with organics)	3.49E+02	3.49E+02		
5.00E-03	VOC's (Total)	1.75E+00	1.77E+00		8.73E-03
1.00E-04	TCE (out of organics)	3.49E-02			
5.00E-05	PCE (out of organics)	1.75E-02			
	Hydrocarbons	1.69E+00			
	soil(no organics)	3.48E+02	3.48E+02		
5.00E-04	PCB's	1.75E-01			
1.00E-03	UO_3	3.49E-01	3.49E-01		
2.00E-05	PuO_3	6.99E-03	6.99E-03		
2.00E-05	Cs_2O	6.99E-03	6.99E-03		
8.00E-05	SrO_2	2.79E-02	2.79E-02		
1.00E-02	CaO	3.49E+00	3.49E+00		
2.00E-03	NiO	6.99E-01	6.99E-01		
8.00E-03	$Fe(OH)_3$	2.79E+00	2.79E+00		
	Sludge(w/organics)	7.22E+02	7.21E+02		
3.00E-01	Organics (total, no PEG)	2.17E+02	2.18E+02		1.08E+00
5.00E-02	VOC's (out of organics)	3.61E+01			
	sludge(no organics)	5.05E+02	5.05E+02		
1.00E-02	PCB's	7.22E+00			
1.00E-02	UO_3	7.22E+00	7.22E+00		
5.00E-05	PuO_3	3.61E-02	3.61E-02		
2.00E-02	Cs_2O	1.44E+01	1.44E+01		
4.00E-02	SrO_2	2.89E+01	2.89E+01		
3.00E-02	NiO	2.17E+01	2.17E+01		
5.00E-02	$Fe(OH)_3$	3.61E+01	3.61E+01		
	TcO_4	3.47E+00	3.47E+00		
	PEG	4.96E+01	4.93E+01		2.48E-01
	Cl ION		4.39E+00		
	KOH	6.97E+00	6.97E+00		
	AIR	8.42E+00			8.42E+00
	WATER	8.73E+01		8.73E+01	

	THERMAL DESORPTION	THERMAL DESORPTION	THERMAL DESORPTION
kg/hr	IN	OUT TO INCINERATION	OUT TO ACID EXTRACTION
soil(with organics)	3.49E+02		3.48E+02
VOC's (Total from soil)	1.77E+00	1.76E+00	8.83E-03
soil(no organics)	3.48E+02		3.48E+02
UO_3	3.49E-01		3.49E-01
PuO_3	6.99E-03		6.99E-03
Cs_2O	6.99E-03		6.99E-03
SrO_2	2.79E-02		2.79E-02
CaO	3.49E+00		3.49E+00
NiO	6.99E-01		6.99E-01
$Fe(OH)_3$	2.79E+00		2.79E+00
Sludge(w/organics)	7.21E+02		5.04E+02
Organics (total, no PEG)	2.18E+02	2.17E+02	1.09E+00
sludge(no organics)	5.05E+02		5.05E+02
UO_3	7.22E+00		7.22E+00
PuO_3	3.61E-02		3.61E-02
Cs_2O	1.44E+01		1.44E+01
SrO_2	2.89E+01		2.89E+01
NiO	2.17E+01		2.17E+01
$Fe(OH)_3$	3.61E+01		3.61E+01
TcO_4	3.47E+00		3.47E+00
PEG	4.93E+01	4.91E+01	2.47E-01
Cl ion	4.39E+00		4.39E+00
AIR	3.44E+01	3.44E+01	
KOH	6.97E+00		6.97E+00

		INCINERATION	INCINERATION
	kg/hr	IN	OUT TO Air
	VOC's (Total from soil)	1.76E+00	0.00E+00
	Organics (total from sludge)	2.17E+02	0.00E+00
	PEG	4.91E+01	0.00E+00
	AIR PRIMARY	4.28E+01	
	O_2 PRIMARY	9.93E+00	
	N_2 PRIMARY	3.27E+01	3.27E+01
makeup	O_2 SECONDARY	9.20E+02	
	N_2 SECONDARY	3.03E+03	3.03E+03
	AIR SECONDARY	3.97E+03	
	CO_2 TOTAL		8.35E+02
	WATER VAPOR		3.63E+02

		ACID EXTRACTION	ACID EXTRACTION	ACID EXTRACTION
Molecular Weights	kg/hr	IN	OUT TO ION EXCHANGE	"CLEAN SOIL"
2.86E+02	UO_3	3.49E-01		0.00E+00
2.92E+02	PuO_3	6.99E-03		0.00E+00
2.81E+02	Cs_2O	6.99E-03		0.00E+00
1.20E+02	SrO_2	2.79E-02		0.00E+00
5.61E+01	CaO	3.49E+00		0.00E+00
7.47E+01	NiO	6.99E-01		0.00E+00
1.07E+02	$Fe(OH)_3$	2.79E+00		0.00E+00
	soil(with organics)	3.48E+02		3.40E+02
	VOC's (Total from soil)	8.83E-03		8.83E-03
	soil(no organics)	3.48E+02		3.40E+02
2.86E+02	UO_3	7.22E+00		0.00E+00
2.92E+02	PuO_3	3.61E-02		0.00E+00
2.81E+02	Cs_2O	1.44E+01		0.00E+00
1.20E+02	SrO_2	2.89E+01		0.00E+00
7.47E+01	NiO	2.17E+01		0.00E+00
1.07E+02	$Fe(OH)_3$	3.61E+01		0.00E+00
1.62E+02	TcO_4	3.47E+00		0.00E+00
	Sludge(w/organics)	5.04E+02		3.92E+02
	Organics (total from sludge)	1.09E+00		1.09E+00
	sludge(no organics)	5.05E+02		3.91E+02
	PEG	2.47E-01		2.47E-01
5.61E+01	KOH	6.97E+00		
	WATER		3.88E+01	
	HCL	1.17E+02		
	EXCESS HCL	4.53E+00		
	IONS (total) mol/hr		4.59E+03	
2.38E+02	U		2.65E+01	
2.44E+02	Pu		1.48E-01	
1.33E+02	Cs		1.03E+02	
8.76E+01	Sr		2.42E+02	
5.86E+01	Ni		2.99E+02	
5.58E+01	Fe		3.64E+02	
9.80E+01	Tc		2.14E+01	
3.55E+01	Cl		3.46E+03	
3.91E+01	K		4.86E+00	
4.01E+01	Ca		6.23E+01	

	ION EXCHANGE	ION EXCHANGE	ION EXCHANGE	pH REGULATION	pH REGULATION
	IN	TO 55 GALLON DRUMS	OUT TO RIVER OR RECYCLE	IN	OUT
TOTAL WATER (including Cl)	1.25E+04		1.25E+04		
IONS (total) mol/hr	7.71E+03	4.22E+03	3.46E+03		
U	2.65E+01	2.65E+01	0.00E+00		
Pu	1.48E-01	1.48E-01	0.00E+00		
Cs	1.03E+02	1.03E+02	0.00E+00		
Sr	2.42E+02	2.42E+02	0.00E+00		
Ni	2.99E+02	2.99E+02	0.00E+00		
Fe	3.64E+02	3.64E+02	0.00E+00		
Tc	2.14E+01	2.14E+01	0.00E+00		
Cl	3.46E+03	0.00E+00	3.46E+03		
Ca	6.23E+01	6.23E+01	0.00E+00		
K	4.86E+00	4.86E+00	0.00E+00		
Na	3.12E+03	3.12E+03	0.00E+00		
H			3.12E+03	3.12E+03	
OH				3.12E+03	
H_2O					3.12E+03