DRAFT

CHEMICAL WASTES
DISPOSED OF BY DEEP WELL INJECTION
AND THEIR SUBSURFACE REACTIONS

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U.S. Environmental Protection Agency
Office of Drinking Water
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INTRODUCTION

More than 8.6 billion gallons of liquid industrial waste is disposed of by deep-well injection each year (Mankin and Moffett, 1987). This constitutes more than half of the approximately 15 billion gallons of liquid hazardous waste that must be disposed. About 90 percent of these wastes are injected into deep aquifers in the Gulf Coast Region (Gordon and Bloom, 1986). In recent years the proportion of waste managed by deep well injection has increased because of the limitations on other methods of disposal such as landfills, surface impoundments, and mixing with surface soil. Therefore, until methods of waste minimization adequately limit the production of liquid hazardous waste, deep well injection is a much needed method for disposal.

Recent legislation limits deep well injection unless the injector demonstrates that there will be no migration of hazardous constituents from the injection zone for as long as the waste remain hazardous (Federal Register 40 FR 146). To prove that injected waste does not migrate from the vicinity of the well bore it must be shown that the fluid, or chemical constituents in the fluid, are immobile or that the hazardous material degrades to a nonhazardous form before the fluid migrates from the area. It is unlikely that fluids are immobile in deep Texas aquifers, as is indicated by the large gradients in fluid potential produced around injection zones (Kreitler et al., 1988). In addition, improperly sealed abandoned wells and deep growth faults, which are both common in the Gulf Coast area, can provide unexpected pathways to the surface. It needs to be shown instead that the hazardous chemicals are immobilized through reactions with the sediments or are transformed to nonhazardous substances.

At present little is known of the chemical compositions of waste streams disposed of by deep well injection and of the chemical reactions that limit the mobility and degradation of hazardous materials in these complex waste streams (cf. Strycker and Collins, 1987; and Appendices I and II). The majority of the research on waste degradation has been conducted on chemical compounds that are contaminants because of surface and near surface disposal and usage, such as pesticides, solvents and metals. Studies that include chemicals commonly disposed of by deep well injection generally only consider surface or shallow aquifer conditions of ambient temperature, atmospheric pressure, and oxygenated fluids with aerobic microbial activity. In addition, these studies generally consider reactions in simple waste solutions containing only the compound of interest, and do not consider the effects of other constituents commonly present in the waste solution that could control aqueous reactions, or of the effect of interactions with the aquifer material.

In this report the compositions of the industrial waste injected into the 98 active on-site class I industrial waste disposal wells in Texas are compiled. Texas waste streams were selected for this compilation because they represent 70% of the industrial wastes disposed of by deep well injection in the U.S. (based on data from Knape, 1984) , and, therefore, are representative of the majority of the wastes disposed of in the U.S. In addition, the compositions and injection volumes of Texas waste streams were available for study in the Underground Injection Control files of the Texas Water Commission.

From the compilation of waste stream compositions the more significant hazardous chemicals and chemical groups injected (by weight) and their potential for degradation and adsorption in the deep subsurface are determined. The chemical environment of subsurface injection is presented in the context of reactions and mixing with formation fluid and reactions with the aquifer material, and the degradation of significant hazardous materials in this environment is discussed. The success of experimental and numerical simulations of this environment are discussed in contrast to field experimentation, and suggestions for future work are given.

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SIGNIFICANT CHEMICAL WASTES INJECTED INTO CLASS I HAZARDOUS WASTE DISPOSAL WELLS

Hundreds of chemical constituents, both hazardous and nonhazardous, are disposed of by deep well injection each year. Therefore, to augment a study of the chemical reactions of injected wastes in the subsurface the compositions of 98 Texas waste streams are compiled, yearly injection masses calculated, and the chemical character of these wastes compared so as to determine the more significant wastes and waste groups. The purpose of this report is to review the data used in selection of these significant wastes and waste groups.

Waste Stream Compositions

The chemical compositions of liquid-waste streams injected into all the on-site Class I industrial waste disposal wells in Texas are compiled and listed in Appendix III. A Class I well is used to dispose of hazardous waste and nonhazardous industrial and municipal waste below the deepest underground sources of drinking water. An on-site hazardous-waste injection well is owned and operated by the waste generator and is located at the site of the generating facility. Commercial (off-site) injectors, which comprise only a small fraction of Class I wells in Texas with seven active injectors, were not included in this compilation because of the wide range of waste compositions injected into these wells.

Although, the U.S. Environmental Protection Agency (EPA) Office of Drinking Water (ODW) has compiled a list of waste compositions (D. Morganwalp, personal communication, 1987), this EPA-ODW list includes only 68 of the 98 active on-site Class I injection wells in Texas, and for several of the wells on the EPA-ODW list the reported waste compositions do not include a complete listings of the organic constituents injected. The majority of the 30 wells not included in the preliminary EPA listing are used for injection of toxic organic wastes.

Information on the waste composition is important in the regulation of hazardous waste. Numerous organic compounds that are currently injected have not yet been evaluated as a potential hazardous waste. In addition, a complete chemical composition of a waste stream must be considered in prediction of degradation reactions because degradation of hazardous components in a waste stream can be affected by all the chemical constituents in solution.

This compilation can be accessed as a DBASE-III Plus (Ashton-Tate Corp.) data base file using an IBM personal computer or compatible operating system. Methods used in compiling this data base and a complete listing of its contents are included below.

Data Retrieval

Data on the chemical compositions of wastes injected into Class I injection wells in Texas were taken from the Underground Injection Control (UIC) files of the Texas Water Commission. The UIC files include copies of the original permit application and supporting data reports, annual permit reports, permit amendments, correspondence between the injector and members of the UIC staff, and repermit reports as required by recent EPA regulations.

Compositions of the waste streams reported by the injectors in the UIC files were often generalized and incomplete, particularly the compositions and concentrations of organic compounds that should be present in the waste given the nature of the manufacturing process. In addition, the waste streams are often chemically treated prior to injection, however, permit reports do not generally indicate whether the reported analysis of the waste stream was made before or after injection pretreatment. Analytic methods used to determine the chemical concentration are not reported, and most of the waste compositions reported represent analyses of a single sample in most cases collected and analyzed at the time of initial permitting. This single initial analysis is then included repeatedly as the waste composition to fulfill annual reporting and repermitting requirements. Although UIC and EPA regulations require that a chemical analysis of the waste stream be provided, we recommend that this requirement be more explicit and better enforced.

Concentrations of chemical components in the waste stream are reported in the data base as minimum and maximum values. The number of significant digits on the reported values should be taken as the number of non-zero digits both before and after the decimal. There are excess zeros after the decimal that are not significant in almost all the reported values. These trailing zeros are an artifact of the data base management system used to compile this listing.

Waste compositions as reported by the injector generally do not include minimum and maximum values. For those cases, a representative minimum and maximum concentration for each chemical constituent is selected from all available waste analyses found in the UIC files. When only one concentration was reported for an element or compound, even if it was reported as an average concentration, that single value is used in the data base as both the minimum and the maximum concentration. When both average and maximum concentrations were provided by the injector, the average concentration reported by the injector appears in the data base as the minimum concentration, and the maximum concentration as reported by the injector is listed in the data base as the maximum concentration. If several waste analyses were provided by the injector, then the minimum and maximum concentrations as reported are used as such in the data base.

Several injectors report analyses for multiple waste streams but do not provide an analysis of the combined injection stream, nor do they provide the ratio with which the streams are mixed. In this case, the minimum and maximum values reported in the data base are derived from the assumption that each of the waste streams comprises either 0 to 100 percent of the combined waste stream.

Often the concentrations in solution are reported by the injector as less than the lower limit of analytic detection. If the only analysis reported by the injector for a chemical constituent is less than the analytic detection limit, then the detection limit is used as the maximum concentration and zero as the minimum concentration in the data base. When multiple analyses were available and at least one of the analyses was above the detection limit and one below, the highest concentration reported by the injector is included in the data base as the maximum concentration, and half the detection limit reported by the injector is included in the data base as the minimum concentration.

Chemical pretreatment of the waste stream by the addition of a scale inhibiter to increase formation compatibility, or by addition of an acid or base to adjust the pH to within the limits set by the UIC permit, is common. None of the injectors, however, listed the composition of the scale inhibiter used, and few listed the composition of the chemicals used to adjust pH.

Injection Wells and Waste Production

The compilation in Appendix III includes the compositions of waste streams injected into the 98 active on-site Class I waste disposal wells in Texas. These 98 noncommercial wells constitute just over 50 percent of the 187 industrial hazardous-waste injection wells active in the U.S. in 1987 (U.S. General Accounting Office, 1987).

Class I waste disposal wells are used to inject hazardous waste into a formation that is below the deepest underground source of drinking water within one-quarter mile of the disposal well. This category includes disposal wells operated in conjunction with uranium mining activities. On-site wells are used by the hazardous-waste generator to inject material produced at the disposal site, and off-site (commercial) waste disposal wells are used by operators of hazardous waste management facilities to dispose of waste brought to the site by the waste generator. Off-site waste disposal wells are not included in this compilation because the compositions of the waste streams injected into these wells changes daily depending on the generator that submits waste for disposal on any given day. There are currently only 7 active off-site Class I wells in Texas.

A brief description of the waste producing processes and the waste streams for the 98 wells included in this report are listed in Table 1. The gallons of waste injected into each well in 1985 and 1986 are also included in Table 1. The 1985 listing of gallons of waste injected is nearly complete with injection volumes included for all but 1 of the 98 wells. The 1986 listing of gallons of waste injected, however, is relatively incomplete with injection volumes included for only 43 of the 98 wells. Injection volumes in 1986 for these 43 wells were not available at the time of this compilation. Comparison of the volumes of waste injected into the 54 wells with injection volumes available for both 1985 and 1986, shows that similar volumes of waste were injected in both years. Thus, 1985 injection volumes are probably representative of what was injected in 1986, and possibly in the future. The more complete 1985 data, therefore, are used in the following discussion of injection volumes and masses.

The processes that result in the production of the waste streams injected, and the general waste character, are also listed in Table 1. Waste streams containing organic compounds derived predominantly from chemical manufacturing are injected into 71 of the 98 waste streams, and comprise 4.09 billion of the 5.10 billion gallons injected each year (80%). Waste streams containing low-level radioactive material from uranium in-situ mining operations are injected into 18 wells at 0.69 billion gallons a year (14%), and a wide range of waste streams containing metals, chloride brine, acid, and ammonia are injected into the remaining 9 wells at 0.32 billion gallons a year (6%).

Waste Groups

The chemical constituents analyzed for and found as present in Texas waste streams, and the minimum and maximum masses injected in 1985 and 1986 are listed in Table 2. These yearly injection masses are calculated from a compilation of the compositions of hazardous waste streams disposed of in Texas as reported in Appendix III. In this report, hazardous constituents are taken as those constituents listed as hazardous by the Environmental Protection Agency (EPA) in the Federal Register 40CFR part 261 subpart D as of 1987. The chemical constituents are subdivided into inorganic and organic, and the organic constituents are further subdivided by functional groups and molecular structures. The compositions, relative injection masses, hazardous character and reactivities of each of these groups are then discussed and compared and from these the most significant wastes and waste groups are selected.

The chemicals listed in Table 2 are by no means all the chemicals that are injected as constituents in these waste streams, they include only what was analyzed for. Most of the waste stream analyses available in the Underground Injection Control Files were incomplete with only selected elements and compounds having been analyzed for. Hazardous chemicals, as listed in the U.S. Federal Register 40CRF part 261 subpart D, are noted in Table 2 by superscripts indicating if the chemical is an acute hazard, a toxic waste, a toxic waste only because of ignitability, a hazardous constituent of concern as listed in Appendix VIII of FR-40CRF, or having EP toxicity (determined toxic by the extraction procedure listed in the Federal Register).

The yearly minimum and maximum masses of each chemical compound injected were calculated as the sum of the product of the minimum or maximum concentration of the compound in the waste stream times the yearly injection volume for that well (with the units adjusted assuming the fluid density is 1 g/cm^3). The minimum and maximum waste stream compositions for each well used in this study are listed in Appendix III, which includes a discussion of the generalizations and assumptions used in determining representative minimum and maximum values.

Of the compounds analyzed for in these waste streams 42 are inorganic and 138 are organic. Inorganic constituents are subdivided in Table 2 into primary and secondary inorganic constituents based on their occurrence in natural ground water, and organic compounds are subdivided according to functional groups and structure such that compounds within each subdivision have similar properties and behave similarly in chemical reactions.

Primary inorganic constituents include inorganic elements that are commonly present in ground waters and are generally not considered hazardous unless present in high concentrations, such as sodium and chloride. Secondary inorganic constituents include all the remaining inorganic compounds, eight of which are EPA listed hazardous wastes having EP toxicity, while one, cyanide, is listed as an acute hazard. A number of the remaining secondary constituents such as ammonia, nitrate and phosphate, although not listed as hazardous in the Federal Register 40CFR, are hazardous if present in drinking water in elevated concentrations. Possibly hazardous constituents not listed in the Federal Register 40CFR are not included in the calculated masses of hazardous wastes.

The total mass of all (hazardous and nonhazardous) secondary inorganic constituents injected, 144 to 446 x 10^6 kg/yr, is similar to the total mass of all (hazardous and nonhazardous) organic compounds injected, 80 to 565 x 10^6 kg/yr. Of the primary inorganic elements injected

chloride	96 to 201 x 10^6 kg/yr,
sodium	77 to 171 x 10^6 kg/yr, and
bicarbonate	14 to 22 x 10^6 kg/yr

have the larger injection masses. Of the secondary inorganic constituents, nitrogen compounds are the dominant constituents injected with

ammonia	3 to 132 x 10^6 kg/yr,
nitrate	15 to 47 x 10^6 kg/yr, and
nitrogen	17 to 23 x 10^6 kg/yr,

followed by sulfur compounds with

sulfate	93 to 183 x 10^6 kg/yr,
sulfide	0.6 to 24 x 10^6 kg/yr, and
sulfite	5 to 9 x 10^6 kg/yr.

The groups of organic compounds having the greater mass of hazardous and nonhazardous compounds injected include:

all alcohols	12 to 129 x 10^6 kg/yr
carboxylic acids	15 to 108 x 10^6 kg/yr
nitriles	10 to 92 x 10^6 kg/yr.

Ten to thirteen percent (22 to 128 x 10^6 kg/yr) of the organic and inorganic constituents injected are hazardous according to the EPA criteria. Organic compounds alone comprise 72 to 90% (16 to 115 x 10^6 kg/yr) of this hazardous material. Some 42 to 48% (7 to 55 x 10^6 kg/yr) of the hazardous organic compounds are considered hazardous only because of their ignitability. The significant waste groups selected will be used in a study to predict degradation of hazardous substances in the subsurface, therefore, the hazardous wastes of greatest concern in this report are the 52 to 58% that are hazardous for reasons other than their ignitability (referred to as nonignitable in Table 2).

The organic waste groups listed above with the largest injection masses are not the waste groups with the largest mass of hazardous materials injected. The organic waste group with the largest mass of nonignitable hazardous compounds injected is

phenols	2 to 41 x 10^6 kg/yr,

which is followed in importance by

organo halogens	3 to 8 x 10^6 kg/yr,
ketones-aldehydes	2 to 4 x 10^6 kg/yr,
nitriles	2 x 10^6 kg/yr,

and finally

carboxylic acids	0.1 to 1.1 x 10^6 kg/yr,

all of which have injection masses of more than 1 million kg/yr. Of the hazardous inorganics only

cyanide	5 to 8 x 10^6 kg/yr, and
nickel	0.5 to 5.6 x 10^6 kg/yr

have injection masses greater than 1 million kg/yr. Six nonignitable-toxic organic wastes have injection masses of more than 1 million kg/yr, the two with higher masses are phenols,

phenol	1.8 to 15.2 x 10^6 kg/yr	phenol
cresol	0.0 to 6.7 x 10^6 kg/yr	phenol,

followed in mass by

butanone	0.5 to 2.3 x 10^6 kg/yr	ketone
formaldehyde	1.3 to 1.8 x 10^6 kg/yr	aldehyde,
acetonitrile	1.0 to 1.4 x 10^6 kg/yr	nitrile
formic acid	0.1 to 1.1 x 10^6 kg/yr	carboxylic acid.

The injected masses of the ignitable wastes,

methy alcohol	1.5 to 18.6 x 10^6 kg/yr, and
butyl alcohol	0.4 to 23.2 x 10^6 kg/yr,

exceed the masses of all of the above listed nonignitable wastes, however, as discussed above ignitable wastes are not considered in this study as important for their hazardous character.

Chemical Properties of Injected Wastes and Waste Groups

Hazardous chemical constituents injected into subsurface aquifers can be transformed to nonhazardous substances through chemical reactions with other constituents in the solution. It is also possible that nonhazardous constituents could be transformed into hazardous constituents. In the discussion below the controls on the chemical compositions, structures and reactivities of the more significant hazardous compounds injected are briefly reviewed. The focus is on organic materials because they comprise the greatest proportion (72 to 90%) of the hazardous material injected. The properties of significant nonhazardous organic compounds are also discussed because the influence of some of these nonhazardous organic compounds, such as carboxylic acids, on the properties of the solution and thereby the reactivities of hazardous compounds can be considerable.

Organic compounds are organized in Table 2 and in this discussion into families of compounds according to their primary functional groups. Compounds with the same functional group form a homologous series having similar chemical properties, behave similarly in chemical reactions, and often exhibit a regular gradation in physical properties with increasing molecular weight. These similarities allow determination of the reactivities of compounds for which thermodynamic data are not available from the reactivities of other compounds with the same functional group for which data are available or for which reactions in an analogous situation have been described through field or laboratory experiments.

Functional groups, however, do not behave the same in reactions independent of the molecule on which they are attached, therefore, the functional groups listed in Table 2 are in some cases further subdivided into structural groups. Reactions taking place at the functional group are influenced by the rest of the molecule. This includes isomers that have the same molecular formula but different structures. Sometimes the influence of the molecule attached to the functional group can result in great enough differences to cause the reaction not to take place or to proceed in an entirely different direction. Even when the styles of reactions are the same, two different molecules with the same functional group may undergo the same reactions but the rates and equilibrium concentrations usually differ. The greatest differences are noted in organic compounds that have more than one functional group.

In the discussion below formulas for organic compounds are in most cases written in their structure form, for generalized representations of structural groups an R is used to indicate an alkyl (carbon chain) or aryl (aromatic ring) group, Ar indicates only an aryl group, and Ph indicates a phenolic group. The sources of information on the structure and reactivity of organic compounds found below are taken from March (1977), Meislich et al. (1977), and Wade (1987).

Alkanes

Alkanes are hydrocarbons in which the carbons are connected by single bonds. Both cyclic and straight chain alkanes are extremely weak acids. They are the least reactive class of organic compounds not reacting with strong acids or bases or with most other reagents. Because of their nonpolar and unreactive nature alkanes are used as solvents, fuels and lubricants. Alkanes are referred to as hydrophobic because they do not dissolve in water. Alkanes are less dense than water with densities on the order of 0.7 g/cm^3 at 20°C compared to the density of water of approximately 1.0 g/cm^3 at the same temperature. Insoluble alkanes injected with water, therefore, will generally rise relative to the water once in the formation.

Straight chain (normal) and cyclic alkanes resemble one another in their properties and chemistry. Cycloalkanes are also nonpolar and relatively inert compounds. Cycloalkanes are held in a more compact cyclic shape than aliphatic alkanes and therefore have physical properties more similar to the compact, branched alkanes.

Most alkane reactions take place under high temperature conditions. Thermal cracking of large hydrocarbons gives smaller hydrocarbons in the form of alkanes and alkenes. In the presence of water, hydrocracking at high temperatures gives saturated hydrocarbons. Given the proper high temperature conditions alkanes can halogenate through reactions with halogens to form alkyl halides.

Straight chain alkanes

Propane: $CH_3CH_2CH_3$

Cycloalkanes

Cyclohexane: C6H12 - (toxic waste because of ignitability)

The relative unreactive nature of alkanes combined with their comprising less than 3% of all the organic compounds injected and less than 1% of the hazardous organic compounds injected, allow for this group not to be considered further in the study of waste degradation.

Alcohols

The structure of an alcohol resembles the molecular structure of water, with an alkyl group replacing one of the hydrogen atoms of water. There is a wide variety of alcohols with the only common characteristic being that each has at least one hydroxyl group (-OH) bonded to one of its carbon atoms. Each alcohol is classified by the type of carbon atom that is bonded to the -OH group. Primary alcohols have the -OH bonded to a carbon atom that is attached to only one other carbon atom, secondary alcohols have the -OH group bonded to a carbon atom that is attached to two other carbon atoms, and tertiary alcohols have the -OH group bonded to a carbon atom that is attached to three other carbon atoms. Primary, secondary, and tertiary alcohols react differently.

Aliphatic alcohol with single carbon-carbon bonds:

methyl alcohol: CH_3OH - (toxic waste because of ignitability)
ethyl alcohol: CH_3CH_2OH
propyl alcohol: $CH_3(CH_2)_2OH$ (1^o or 2^o)
butyl alcohol: $CH_3(CH_2)_3OH$ (1^o or 2^o) (toxic waste because of ignitability)
pentyl alcohol: $CH_3(CH_2)_4OH$ (1^o)
hexanol: $CH_3(CH_2)_5OH$ (1^o)

The compositions of propyl and butyl alcohols are reported in the Underground Injection Control permits without a designation as to whether they are primary (1^o) or secondary (2^o). Pentyl alcohol and hexanol are inferred to be primary from how they are reported. None of these alcohols were injected with the tertiary structure.

The electron pair on the oxygen makes alcohols Lewis bases, thus it is the O and the H on the OH that dominate reactions. However, the larger the R group on the alcohols (ROH) the more the alcohol begins to resemble the hydrocarbon in reactions than the alcohol. Hydrogen bonding occurs with alcohols with C/OH ratios less than or equal to 4 making them generally soluble in water. In contrast, the hydrogen bonding with alcohols with C/OH ratios greater than 4 is insignificant by comparison making the them less soluble in water.

The H of OH is very weakly acidic. The order of decreasing acidity is (Meislich et al., 1977)

$$H_2O > ROH(1^o) > ROH(2^o) > ROH(3^o) > RC{\equiv}CH >> RCH_3 .$$

A strong base (B^-) can remove the hydroxyl proton of an alcohol to give an alkoxide ion.

R-O-H (alcohol) + B^- = R-O^- (alkoxide ion) + B-H
ie.) CH_3-O-H(methanol) + B^- = CH_3-O^-(methoxide ion) + B-H

The acidity of alcohols varies according to their structure, generally ranging from as acid as water for primary alcohols to three orders of magnitude less acid for tertiary alcohols. The more highly substituted alkyl group inhibits solvation of the alkoxide ion thereby inhibiting dissociation of the alcohol. The 1^o and 2^o alcohols have at least one H on the carbinol C and are oxidizable to carbonyl compounds.

Aliphatic alcohol with double carbon-carbon bond

Allyl alcohol: $H_2C{=}CH{-}CH_2OH$ (acute hazard)

Alkyne (acetylene) alcohol - aliphatic with triple carbon-carbon bond

The acetylene alcohols listed below are straight chain alkynes such that they have a triple carbon-carbon bond in the aryl group and are alcohols with an OH group replacing a H on the main carbon chain. Although these wastes are alkynes they are listed with the alcohols because the OH group on the alkyne chain is expected to have properties similar to those of the OH group on alcohols. Also, similar to other alcohols, the smaller the R group the less the compound acts like an alkyne in reactions. The two alkyne alcohol wastes listed have low C/OH ratios of 3 and 4.

Hydroxymethylacetylene (propargyle alcohol) : $H-C\equiv C-CH_2OH$ (acute hazard)

Butynediol: is structurally either $CH_3-CHOH-C\equiv C-H$ which reacts like a secondary alcohol, or $HOCH_2-CH_2-C\equiv C-H$ which reacts like a primary alcohol.

The more distinctive property of the alkyne chain is its acidity, which results from the nature of the $\equiv C-H$ bond. Deprotonation of alkynes forms **acetylide ions** ($R-C\equiv C-^{-}$). Terminal alkynes, those with the triple bond at the end of the carbon chain, are the most readily deprotonated. Both the alkyne wastes listed below are terminal. The acetylenic proton is removed by a very strong base, hydroxide and alkoxide ions are not strong enough to do this at low temperatures. Acetylide ions are strong nucleophiles, and therefore form alkyne salt. The salt can be a cation such as sodium or in some cases metals such as Ag^+ and Cu^+. Metal salts of alkynes are relatively insoluble and in most solutions form precipitates. Alkynes having physical properties similar to the corresponding alkanes and alkenes, are relatively nonpolar and thus insoluble in water. Alkynes are quite soluble in most organic solvents.

Cyclic (nonaromatic)

Cyclohexanol: cyclo-$C_6H_{11}OH$

Diols

Diols are alcohols with two -OH groups.

Vicinal diols (glycols) - are 1,2 diols, with the two hydroxy groups on adjacent carbon atoms. None of the vicinal diols are listed as hazardous.

Triols

Triols are alcohols with three -0H groups.

Glycerol

Pentaerythritols

Pentaerythritol

Di pentaerythritol

Oxirane-ether alcohol (heterocyclic nonaromatic)

Glycidol (oxiranemethanol) - $H_2C-O-CHCH_2OH$

Other nonaromatic alcohols

Trimethylol propane

Ditrimethylol propane

Trimethylol propane mono cyclic formal

Bis-trimethylol propane mono layer formal

Phenol-alcohols

Alcohols with the -OH group bonded directly to a carbon atom in a benzene ring are phenols. Some phenol-alcohols have properties similar to those of other alcohols, while other properties are derived from their aromatic character. Phenols can be more acidic because of the influence of the aromatic ring. In this section the alcohol like properties of phenols are considered. In the section on benzene derivatives the aromatic properties of the phenols are discussed, and other nonalcohol phenol wastes are listed.

α-methy benzyl alcohol - CH_3-Ph-CH_2OH (Ph denotes C_6H_5 benzene ring structure)

Alcohols are the dominant group of both nonhazardous (15-29%) and hazardous (13-37%) organic wastes injected (phenols are grouped separately from the alcohols discussed here). Aliphatic, diol and triol alcohols include the majority of the alcohols injected, with all of the hazardous alcohols being aliphatic. Hazardous alcohols are methyl, butyl and allyl alcohols. Methly and butyl alcohol, the hazardous compounds with the largest injection masses, are hazardous only because of their ignitability and therefore are not of major importance to this study. Allyl alcohol is acutely toxic but is only injected in very small amounts of less than 0.05 x 10^6 kg/yr. Alcohols, therefore, will be considered in the study of degradation reactions for the effects the presence of alcohol in the solution may have on the degradation of other hazardous constituents in solution, rather than for the of degradation of hazardous alcohols.

Ethers

Like alcohols ethers are relatives of H_2O with alkyl or aryl (benzene ring) groups (R) replacing the hydrogens.

H-O-H	R-O-H	R-O-R'
water	alcohol	ether

Although ethers are quite polar with large molecular dipole moments, they are relatively unreactive. Ethers lack the OH of alcohols, instead the oxygen has nonbonding electrons that act as a solvate pair. The O of ethers is able to undergo H-bonding with the H of H2O. Ethers are very volatile because the absence of intermolecular hydrogen bonding. Ethers are basic because of the unshared electron pair on the O, they are also extremely flammable.

Heterocyclic nonaromatic ethers - tetrahydrofuran (toxic waste because of ignitability) and dioxane (toxic waste) are polar, nonhydrous solvents that are miscible in water. These compounds have one oxygen substituted for a carbon in a 5 carbon ring (single bonds) and two oxygens substituted for 2 carbons in a 6 carbon ring (single bonds), respectively. Trioxane is a metaformaldehyde with an oxygen substituted for every other carbon in a six carbon ring. Tetroxane has 4 oxygens substituted on a 6 carbon ring.

Epichlorohidrin is an oxirane (epoxide) ether but is listed under another functional group with mono- and dichlorohydrin because the concentrations of these three compounds in the waste streams were reported as a single concentration by the injector. Epichlorohidrin is not listed as hazardous.

Gycidol, an oxirane alcohol, is listed with the alcohols.

Ethers are relatively unreactive and comprise only a small component of both the hazardous and nonhazardous organic wastes injected and, therefore, will not be considered in the determination of waste degradation reactions.

Benzene and Benzene Derivatives

Electrophilic aromatic substitution is the most important mechanism involved in the reactions of aromatic compounds. Substitutions on the ring influences its reactivity toward electrophilic aromatic substitution and the positional orientations found in the products. The overall reaction is the substitution of an electrophile for a proton (H^+) on the aromatic ring. This is the process of halogenation to ArBr (bromination), ArCl (chlorination), and ArI (iodination), nitration to $ArNO_2$, sulfonation to $ArSO_3H$ (benzene sulfonic acid), and others. Ar in the structural formulas indicates the aryl group (an aromatic ring), which in this discussion is always a phenyl group (benzene ring).

Benzene: C_6H_6 (toxic waste) the benzene ring is unusually stable which is marked by its inability to undergo typical alkene reactions.

Benzene derivatives are composed of a benzene ring with one or more hydrogens substituted with a functional group

ethyl benzene: $C_6H_5\text{-}CH_2\text{-}CH_3$

styrene (vinyl benzene): $C_6H_5\text{-}CH{=}CH_2$

anisole (methoxybenzene): $C_6H_5\text{-}O\text{-}CH_3$

phenyl borate: The phenyl group is an aryl group composed of a benzene ring with one hydrogen atom replaced so as to attach the ring to any one of a wide range of compounds containing boron, hydrogen and oxygen such as $B(OH)_4^-$ or BO_3.

trichlorobenzene: (member of a general class of hazardous compounds) $C_6H_3Cl_3$, is composed of a benzene ring with every other hydrogen replaced by a chloride.

dichloroanisole (dicholoromethoxybenzene): (member of a general class of hazardous compounds) $Cl_2\text{-}C_6H_3\text{-}O\text{-}CH_3$, is composed of a benzene ring with every other hydrogen replace twice by a chloride ion and the third by $\text{-}O\text{-}CH_3$.

Phenols

Phenols are benzene derivatives with a hydroxyl group (OH) bound directly to a carbon atom in the benzene ring. Phenols are more acidic than normal alcohols because of the influence of the aromatic ring.

phenol: (toxic waste) $C_6H_5\text{-}OH$, is a benzene ring with one of the hydrogens replace by -OH. Phenol is acidic in character and under the proper conditions it can ionize in water as follows:

$C_6H_5OH = C_6H_5O^- + H^+$

cresols (methylphenol, cresylic acid): (toxic waste) $OH\text{-}C_6H_4\text{-}CH_3$. Cresols have a methyl group and hydroxyl group bound directly to a benzene ring. There are three possible cresols depending on the positions of the methyl and hydroxyl groups.

dichlorophenol: (toxic waste) $Cl_2\text{-}C_6H_3\text{-}OH$, is a benzene ring with every other hydrogen ion replace by either a chloride or an OH group..

triphenylborane: three phenyl groups attached to a boron atom.

hydroquinone (1,4 benzenediol; 1,2 dihydroxybenzene): $OH\text{-}C_6H_4\text{-}OH$, is a benzene ring with two opposing hydrogens replaced by -OH groups.

tertiary butyl cathecol: $CH_3(CH_2)_3\text{-}C_6H_3\text{-}(OH)_2$, is composed of a butyl group ($CH_3(CH_2)_3$) and two hydroxy groups (OH) replacing hydrogen ions on a benzene ring.

Phenols will be given primary consideration in the study of degradation reactions because they constitute the group with largest mass of hazardous material injected each year, with phenol and cresol having the largest yearly injection masses of all other nonignitable toxic wastes.

Ketones - Aldehydes

A ketone contains a carbonyl group (C=O) with the carbon attached to two alkyl groups (R-CO-R'), and an aldehyde contains a carbonyl group attached to an alkyl group and a hydrogen atom (R-CO-H). Ketones and aldehydes react similarly whether aliphatic, cyclic, or aromatic (benzene derivatives) because it is the the oxygen atom of the carbonyl group that reacts and it is the bond between the oxygen and carbon atom in the carbonyl group that is most readily distorted and broken. The alkyl groups attached to the carbonyl group are less reactive. Ketones and aldehydes are weak bases.

KETONES:

butanone (methyl ethyl ketone): (toxic waste) $CH_3CH_2\text{-}CO\text{-}CH_3$

acetone (dimethyl ketone): (hazard because of ignitability) $CH_3\text{-}CO\text{-}CH_3$

Cyclic Ketone

cyclohexanone: (toxic waste) C_6H_8O

Aromatic (Benzene derivative) Ketone

acetophenone (methyl phenyl ketone): (toxic waste) $CH_3\text{-}CO\text{-}Ph$

ALDEHYDES:

formaldehyde (methanal): (toxic waste) H-CO-H

acetaldehyde (ethanal, "aldehyde"): (ignitable hazard) $CH_3\text{-}CO\text{-}H$

acrolein (propenal): (acute hazard) $CH_2\text{=}CH\text{-}CO\text{-}H$

Chlorinated Aldehydes

chloroaldehyde: C_2H_3ClO

dichloroaldehyde: $C_2H_2Cl_2O$

trichloroaldehyde: C_2HCl_3O

Ketones-aldehydes will be given secondary consideration in the determination of degradation of hazardous compounds because hazardous compounds from this group are comparable with organo halogens and carboxylic acids as having the second highest mass of hazardous material injected. In addition, butanone and formaldehyde which are two of the six toxic wastes having yearly injection masses of more than one million kg/yr, are a ketone and an aldehyde, respectively, and acrolein which is one of four wastes injected in Texas that is acutely toxic is an aldehyde.

Carboxylic acids

Carboxylic acids have the carboxyl group COOH attached to an alkyl or aryl group (R-COOH or Ar-COOH). The carboxyl group is comprised of an oxygen attached to the carbon by a double bond (C=O and an OH group with the oxygen attached to the carbon by a single bond (C-OH).

All of the carboxylic acids injected with Texas waste streams are straight chain carboxylic acids. The majority have only single carbon-carbon bonds and with the alkyl (R) group in RCOOH having 1 (formic acid), 2 (acetic acid), 3 (propionic acid), 4 (butyric acid), 5 (valeric acid) and 6 (caproic acid) carbon atoms. Hydroxycaproic acid has 6 carbons with single bonds in the alkyl group with one of the hydrogens substituted by OH, and acrylic acid has 2 carbon atoms in the alkyl group bound by a double carbon-carbon bond. Only carboxylic acids with five or fewer carbon atoms are highly soluble in water.

The H on the carboxyl group (CO-OH) is acidic. Acid carboxylation of carboxylic acids (R-CO-OH) produces carboxylate ions ($RCOO^-$).

$$RCOOH + H_2O = RCOO^- + H^+$$

Salts of carboxylate ions are relatively stable.

$$\text{ie. } RCOO^- + K^+ = RCOOK$$

Na, K, Li, NH_4 salts are water soluble, whereas, most other salts, particularly Ca, Mg, and Fe, are generally insoluble and will deposit from solution (ie. soap scum that forms in the bath tub).

Carboxylic acids are more acidic than alcohols (ROH). The relative strengths of acids can be accounted for in terms of their conjugate bases. The weaker (more stable base) has the stronger acid. Since the electron density in the carboxyl ion ($RCOO^-$) is dispersed to both oxygens, $RCOO^-$ is more stable and a weaker base than RO^-, whose charge is localized on only one oxygen.

Hazardous carboxylic acids are comparable with organo halogens and ketones-aldehydes for having the second largest mass of injected hazardous organic compounds. Degradation of hazardous carboxylic acids will therefore be included in the study of waste reactions. Because carboxylic acids are the second most significant group of organic compounds injected in waste streams, and because of the importance of carboxylate ions on the mobility and reactivity of other compounds in solution, carboxylic acids will be given a primary importance in the study of waste degradation. The importance of this is enhanced by the occurrence of carboxylic acids in 17 of the 71 organic waste streams injected in Texas in addition to the addition of carboxylic acids to solution from decomposition of dicarboxylic acids and carboxylic acid derivatives (see discussion below).

Dicarboxylic acids

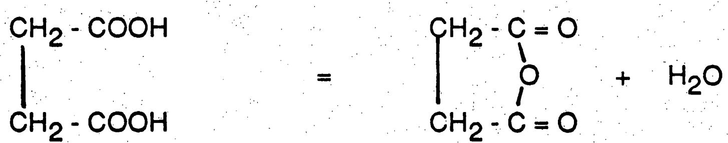
Heating of dicarboxylic acids results in the following reactions (Meislich et al., 1977). Short chained carboxylic acids with 3 or less carbons undergo decarboxylation to carboxylic acids and CO_2.

oxalic acid: $HOOC\text{-}COOH = CO_2 + H\text{-}COOH = CO_2 + CO + H_2O$

malonic acid: $HOOC\text{-}CH_2\text{-}COOH = CO_2 + CH_3COOH$

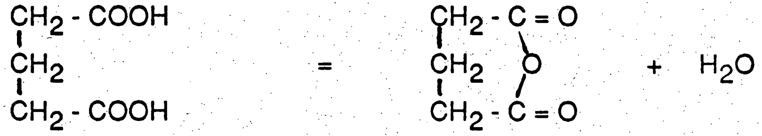
Dicarboxylic acids with 4 to 5 carbons undergo intramolecular dehydration and ring formation to an anhydride:

succinic acid:



succinic acid succinic anhydride

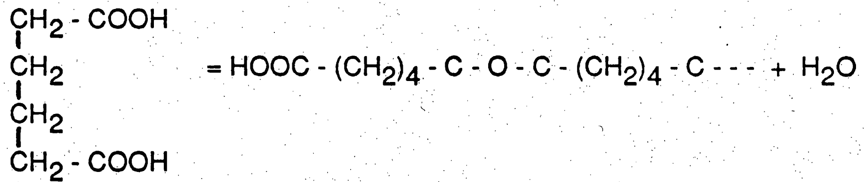
glutaric acid:



glutaric acid glutaric anhydride

Longer chain dicarboxylic acids undergo intermolecular dehydration on heating to form long-chain polymeric anhydrides.

adipic acid:



$$CH_2\text{-}COOH\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}COOH = HOOC\text{-}(CH_2)_4\text{-}C\text{-}O\text{-}C\text{-}(CH_2)_4\text{-}C\text{---} + H_2O$$

Reactivities of dicarboxylic acids will only be considered for their similarity to carboxylic acids, in that their presence in solution effects degradation and mobilities of hazardous materials similar to carboxylic acids.

Carboxylic Acid Derivatives

Esters, amides and nitriles are carboxylic acid derivatives, which means they contain a functional group that is converted to a carboxylic acid by simple acidic or basic hydrolysis. Carboxylic acid derivatives generally hydrolyze to carboxylic acids in high-temperature acid or basic aqueous solutions. The presence of carboxylic acid derivatives in waste streams, therefore, is important because of the possible role of carboxylic acid carboxyl ions in solution. Carboxylic acid derivatives are generally insoluble in water, unless they have very short chains, and they act as good polar solvents.

Esters

Esters are composed of a carboxylic acid and an alcohol with the loss of a molecule of water (R-CO-O-R'). Esters are a carboxylic acid derivative and, therefore, in an acidic aqueous solution esters hydrolyze to a carboxylic acid and an alcohol.

Esters will not be considered in the study of degradation reactions because their injection mass of both hazardous and nonhazardous organic compounds is relatively low. The importance of esters would be their transformation to a carboxylic acid.

Amides

Amides are composed of a carboxylic acid and an amine, with an NH and an alkyl group replacing the OH of the carboxyl (R-CO-NH-R'). Amides are a carboxylic acid derivative, thus they are converted to a carboxylic acid by simple acidic or basic hydrolysis. Amides are only weakly basic and are considered neutral functional groups. A concentrated acid is needed to protonate an amide, and when it does protonation occurs on the carbonyl oxygen rather than the nitrogen atom.

acrylamide: (toxic waste) $CH_2=CH-CO-NH_2$ is a primary aliphatic amide composed of acrylic acid and an amine.

Similar to esters, degradation reactions of hazardous amides will not be study because the comprise such a small group. The presence of amides, however, could be significant because of their potential to transform to a carboxylic acid and, thereby, contribute a carboxylate ion to solution.

Nitriles

Nitriles ($R-C \equiv N$) contain the cyano group, $-C \equiv N$. Nitriles, although they do not contain the carbonyl group of carboxylic acids, are considered derivatives of carboxylic acids because they hydrolyze to carboxylic acids,

$$\underset{\text{nitrile}}{R-C \equiv N} + H_2O = \underset{\text{primary amide}}{R-CO-NH_2}$$

under basic conditions followed by

$$\underset{\text{primary amide}}{R-CO-NH_2} + H_2O = \underset{\text{carboxylate ion}}{R-CO-O^-} + NH_3 + H^+$$

or under acid conditions followed by

$$\underset{\text{primary amide}}{R-CO-NH_2} + H^+ + H_2O = \underset{\text{carboxylic acid}}{R-CO-OH} + NH_4^+$$

In the presence of ammonia and heat, however, carboxylic acids can synthesis to nitriles.

As with other carboxylic acid derivatives, nitriles are generally insoluble in water, with the smaller nitriles being somewhat soluble. Nitriles are generally highly polar solvents. Nitrates are not very basic despite a lone pair of electrons on the nitrogen and, therefore, do not protonate very readily making them good organic solvents.

dinitrile (dicyano compounds): $N{\equiv}C\text{-}R\text{-}C{\equiv}N$ (R is an aryl chain)

acetonitrile (ethanenitrile): (toxic waste) $CH_3\text{-}C{\equiv}N$ Acetonitrile is only 10% water soluble at 25°C, and is a highly polar solvent that solvates ions almost as well as water, with relatively unreactive O-H and N-H groups that will not donate protons or act as nucleophiles. Deprotonation of acetonitrile produces the carbanion

$$\underset{\text{acetonitrile}}{CH_3\text{-}C{\equiv}N} \quad = \quad \underset{\text{carbanion}}{{}^{-}CH_2\text{-}C{\equiv}N} + H^+$$

acrylonitrile: (toxic waste) $CH_2{=}CH\text{-}CN$

succinonitrile: $COOH\text{-}(CH_2)_2\text{-}C{\equiv}N$

maleonitrile: $COOH\text{-}CH{=}CH\text{-}C{\equiv}N$

fumaronitrile: $COOH\text{-}CH{=}CH\text{-}C{\equiv}N$

phthalonitrile: $1,2\text{-}C_6H_4\text{-}(COOH)\text{-}CN$

nicotinonitrile: $C_6H_5N\text{-}C{\equiv}N$

Lactames

Lactames are heterocyclic nonaromatic amides. The are formed from amino acids, where the amino group and the carboxyl group have joined to form an amide. Caprolactam is an aminohexanoic acid lactam. Lactams comprise only a very small proportion of the organic wastes injected and caprolactam is not hazardous, therefore, lactams will not be considered in the study of degradation reactions.

Amines

Amines are derivatives of ammonia with one or more alkyl or aryl groups bonded to the nitrogen atom. Amines encourage biological activity by providing a food source. Amines react differently whether they are one, two, three or four substituted.

tertiary butylamine: $(CH_3)_3\text{-}C\text{-}NH_2$

quaternary ammonium salts: have four alkyl or aryl groups replacing the hydrogens on the $NH4^+$ ion, with the addition of a halogen to create a neutral compound.

Pyridines: $C_5H_5\text{-}N$ have a benzene ring with nitrogen substitution for a carbon on the ring. Pyridine protonates to pyridinium ion in acid solutions with a hydrogen attaching to the nitrogen on the ring giving an aromatic positively charged ion ($C_5H_5\text{-}NH^+$).

Pyrrolidones: $O{=}C_4H_8\text{-}NH$ are five member heterocyclic rings with a nitrogen substituted for one of the carbons on the ring, and an oxygen replacing the two hydrogens bound to one of the carbons on the ring.

Amines comprise only a small fraction of both the hazardous and nonhazardous organic compounds injected and therefore are not a focus of the study of degradation reactions. Because amides may be used as a food source they may contribute to microbiologic reactions and therefore will be considered in that context.

Organo Halogens

The reactivities of the alkyl, vinyl, and aryl halides differ because their bonding and hybridization are different.

Alkyl Halides

Alkyl halides have a halogen atom bonded to an alkyl group. Halogen atoms are the functional groups. Reactions with this group are a result of the polarization of the carbon-halogen bond. The halogen atom can be eliminated or replaced by a wide variety of functional groups.

Freon 113: (flourinated alkyl halide) a refrigerant

Carbon tetrachloride: (toxic waste) CCl_4, a halo methane, a solvent

Vinyl Halides

Vinyl halides have a halogen atom bonded to one of the carbon atoms of an alkene.

Tetrachloroethylene: (toxic waste) $Cl_2C{=}CCl_2$

Aryl Halides

Aryl halides have a halogen atom bonded to one of carbon atoms of an aromatic ring.

Polychorinated biphenyl (PCB): (member of a group of compounds that are considered hazardous)

Organo halogens share the position of second highest mass of hazardous material injected with ketones-aldehydes and carboxylic acids. More than 99% of the mass of waste injected in this organo halogen group, however, is reported as chlorinated organics or chlorinated hydrocarbons, rather than as individual compounds. Organo halogen reactions differ widely depending on the structure and composition of the compound. Therefore, despite the large mass of organo halogens injected, organo halogens will not be a focus of the study of waste degradation because the reactions of each organo halogen must be considered individually and individual compositions are not available. In addition, for those organo halogens in which individual compositions are available the individual compounds do not comprise a large enough proportion of the total mass of all hazardous materials injected and therefore are not significant in the context of this compilation.

Polymers

A polymer is a large molecule composed of many smaller repeating units (the monomers) bonded together.

Hydrophilic

Contain hydroxyl groups that allow them to form hydrogen bonds and thus they are well associated with water.

polyglycerols
polyvinyl alcohol

Condensation

polyesters

Inorganic Nitrogen Compounds

Inorganic nitrogen compounds comprise the largest proportion of the secondary inorganics including the EPA listed acutely hazardous compound cyanide (CN^-). Ammonium (NH_4^+), nitrate (NO_3^-), and nitrogen are not listed as hazardous in the Federal Register 40CFR. Nitrate concentrations in excess of 10 mg/l as N_2, however, are considered unacceptable in drinking water (FR 40CFR). Microbes commonly use nitrogen for nutrients, therefore the injection of these nitrogen compounds into the subsurface could possibly enhance microbiologic reactions and degradation. Thus the presence of these nitrogen compounds and their possible effects on hazardous waste reactions should be considered.

Cyanide

Cyanide, CN^-, is the dominant hazardous inorganic injected and second only to phenol when compared to the mass of hazardous organic compounds injected. The CN^- group resembles halogens in reactions. Because of its large injection mass and acute hazardous character, cyanide will be considered in the study of waste reactions.

Nickel

Nickel is the second most injected inorganic. The general class of nickel compounds are listed as hazardous in the Federal Register 40CFR. Thus, the immobilization of nickel and nickel compounds through interaction with the sediments must be considered rather than their chemical transformations.

Selection of Significant Waste Groups

In the selection of significant waste groups for study of subsurface chemical reactions of injection waste there are essentially two subdivisions. The first subdivision is that of waste groups that are significant because large masses of hazardous waste from those groups are injected. The second subdivision is that of waste groups that are significant, not because of their hazardous character, but because they are very reactive and are injected in large masses and, therefore, will strongly influence the reactions that take place in the solution, and between the solution and the enclosing sediments.

Of the waste groups that are significant because they include large masses of hazardous compounds injected, the phenol group is the most significant followed by cyanide, ketone-aldehydes, and nitriles. Hazardous organo halogens and nickel, although injected in large masses, are not selected for the focus of the study of waste reactions because individual compounds in these groups will react differently, and because the actual natural of the individual compounds that comprise these groups are unknown.

Carboxylic acids are the most significant waste group selected because of their strong influence on reactions in solutions in which they are contained and because they are injected in high concentrations. The contribution of additional carboxylic acids to solution through the decomposition of dicarboxylic acids and carboxylic acid derivatives will also be considered. Nitrogen compounds are also significant, particularly in their ability to influence microbiologic reactions. Alcohols, although injected in the greatest amount, are given a lesser priority because they are much less reactive than carboxylic acids.

The waste streams injected are generally complex inorganic and organic solutions that have been diluted with sodium chloride rich ground water, treated with an acid or base to alter pH, and, in some cases, an organic surfactant to inhibit scale formation (Appendix III). In the study of waste degradation, therefore, the influence of the other components in the complex waste stream on degradation of the hazardous material of interest will also be considered.

SUBSURFACE WASTE REACTIONS

Subsurface degradation of hazardous materials results from chemical reactions within the waste stream in response to temperature, pressure, oxidation/reduction, pH and other chemical changes as the waste stream mixes with the aquifer fluid, interacts with the sediments, and is used as a nutrient source in microbial activity. The significant hazardous waste groups disposed of by deep well injection are all organic compounds, except for cyanide which in some cases reacts similarly to the organic nitrile compounds, therefore, organic and microbiologic reactions are the focus of the discussion on degradation reactions below. Inorganic reactions can shift the fluid composition and, thereby, affect chemical transformations, sorption, and microbiologic degradation of the hazardous organics. Therefore, the consequences of interactions of both inorganic and organic compounds with the aquifer material and with the formation fluid will be considered in the discussions below.

Formation Fluid and Aquifer Material

Most injection operations use porous, saline sandstone aquifers along the Gulf Coast, namely the Frio, Yequa, Catahoula, Oakville, Wilcox, and undifferentiated Miocene sandstones (Kreitler and Richter, 1986). Sediments in the Gulf Coast are predominantly shale with the sandstone component being as little as 15 volume % (Boles and Franks, 1979). Injection occurs within a depth range of 2,000 to 8,500 ft (610 to 2600 m) below land surface, with most injection within a range of 4,000 to 7,000 ft (1,200 to 2100 m).

Most water in sandstone aquifers of the Gulf Coast at the depth of injection are sodium chloride in character and have dissolved solids contents ranging from 30,000 to 80,000 mg/l (Kreitler and Richter, 1986). At these depths pore water is generally anoxic, reducing, has a pH of near to neutral to slightly acidic, has a temperature ranging from 50 to 80^{o}C (over the depth range of 1,200 to 2100 m with a thermal gradient ranging from 20 to 30^{o}/km), and has a pressure less than or near equivalent to hydrostatic (Kharaka, 1979; Hanor, 1979; Kreitler et al., 1988; Capuano, 1988). Fluids at the depths of deep well injection are within the hydrostatic, and in some cases underpressured, section of Gulf Coast sediments.

The mineralogy of Tertiary units along the Gulf Coast is surprisingly uniform. Quartz is the major component comprising up to 95 volume %, followed by feldspar and rock fragments which generally comprise from 5 to 50 volume % of the total rock (Loucks et al., 1979). With increased depth in the sedimentary column the sandstone clay content increases, and the clay composition changes with smectite giving way to illite at depths on the order of 9,000 ft (Loucks et al., 1979). Smectite, therefore, is the dominant clay mineral present in sandstones at the depths of deep well injection. Carbonate cementation, which occurs predominantly as calcite at the depths of deep well injection (Boles, 1978; Land, 1984), is common in these deep Gulf Coast sandstones, with the Frio sandstone averaging 5 volume % (Land, 1984). Organic material is generally present in the clay rich shale units, and averages 0.6 wt % (Siebert et al., 1984).

Hydrogeology of the Injection Environment

Upon injection of the waste solution, increases in temperature and pressure, and chemical transformations resulting from waste/rock and waste/formation fluid interactions should result in significant changes in the types of chemical and biological reactions that could degrade or immobilize hazardous compounds.

Thermal and chemical zonation between the point of injection and the sediments containing original formation fluid results in a zonation of chemical degradation reactions. The injection solution is generally cooler, more oxidizing than the formation fluid, and has extreme pH values that are lower or higher than the near neutral pH of the formation fluid. The zone of mixing of these two chemically distinct fluids in a porous media does not produce a sharp contact but generally occurs over a measurable distance with a gradational change in the composition of one end member to the composition of the other. This gradational change is documented by the passage of a mixed waste/formation fluid past a monitor well that takes several hours to days (cf. Ehrlich et al., 1979).

Introduction of the waste stream into the formation also results in reactions with the aquifer material that ultimately chemically neutralize and reduce the waste stream. In turn the aquifer material in the vicinity of the well bore is altered through the process of reducing the waste solution, resulting in dissolution of mineral phases containing elements in their reduced state, such as pyrite and biotite, and precipitation of minerals containing these elements in their oxidized form, such as hematite or magnetite. Reactions of acid waste solutions with the arkosic sandstones commonly used for disposal results in dissolution of minerals such as feldspars and carbonates, and ultimately in an increase in the solution pH to near neutral (cf. Capuano 1977; Roy et al., 1988). Reactions of alkaline waste solution with these sandstones results in dissolution of silica grains which comprise a large fraction of the sediment, but does not result in reduction of the pH to near neutral (cf. Roy et al., 1988). In addition the waste plume is heated to subsurface temperatures as it gains heat conductively from the formation and through mixing with the higher temperature formation fluid.

All these processes act to create three chemically distinct environments in which degradation or immobilization of hazardous chemicals can take place: 1) oxidized lower temperature conditions characteristic of the original waste stream in the immediate vicinity of the well bore that expands with increased injection, 2) a mixed zone in which the waste plume and formation fluid are mixing, 3) an outer zone of formation fluid containing hazardous compounds from diluted waste but the chemical character of the fluid is more like that of the original formation fluid. The presence of these different environments and their effects on inorganic and organic reactions are documented in deep-well injection field experiments, laboratory experimentations and numerical simulations, which are discussed below.

Biofilm Simulation

Production of zones of changing microbiologic degradation processes in the subsurface are predicted by Bouwer and McCarthy (1984) through calculation of subsurface biotransformations using biofilm theory (Rittmann and McCarty, 1980a, 1980b) combined with the results of laboratory flow-through column experiments. It is apparent from their work that a progression in subsurface biologic activity can develop from the point of introduction of a contaminant plume into the formation. The change in biologic activity will progress from aerobic heterotrophic respiration in the vicinity of the injection well where waste fluids still maintain oxygenated conditions, to a zone of denitrification, then sulfate respiration, and finally methanogenesis on the outer margins. Methanogenesis and sulfate reduction can occur on the outer margins of the mixed zone where sulfate and carbon dioxide available in the formation fluid can drive the activity.

Zoning in the concentration of inorganics in the waste and waste/formation fluid mixture also accompanies this biologic zoning. The oxidation potential of the waste stream is decreased into the formation with the consumption of available oxygen in the zone of aerobic respiration, to the consumption of nitrate in the zone of denitrification, to the consumption of sulfate in the zone of sulfate respiration. This biologic activity can also shift the pH of the solution, particularly from the consumption of carbon dioxide if the outer methanogenic zone is active.

There is a lower limit on the concentration of the primary substrate (nutrient) below which the biologic activity ceases (Bouwer and McCarthy, 1984). Thus biologic activity will not proceed beyond the zone of primary mixing and does not completely consume the organic compounds being degraded. Organic compounds used as the secondary substrate, however, can be consumed to much lower concentrations but at a much slower rate, therefore, they can also persist beyond the zone of biologic activity (Bouwer and McCarthy, 1984).

Carboxylic Acid Waste

In this example an acid (pH = 4) waste stream containing predominantly carboxylic acids, formaldehyde, methanol and aromatic dicarboxylic acids was injected into a sandstone aquifer at approximately 850 to 1000 ft near Wilmington, North Carolina by Hercules Chemical, Inc. (Leenheer and Malcom, 1973; Leenheer et al., 1976a, 1976b). Fluid samples collected from observation wells confirmed the passage of a front containing evidence of chemical zonation induced by waste rock reactions and biological activity. These observation wells where located from 1400 to 2700 ft (427 to 823 m) from the point of injection and waste fluid sampled from these wells was predicted to have a post injection residence time of 2 to 4 years.

Leenheer et al. (1976b) defined several reactions zones between the waste plume and the waste front. The outermost zone, referred to as the dilute zone, contained waste in concentrations too dilute to support microbiologic activity, and also lacked evidence of any waste transformations.

The next zone toward the well is referred to as the microbial zone. From the data presented by Leenheer et al. (1976a and 1976b) this microbial zone can be further subdivide. It appears that the outermost zone of microbiologic activity encountered showed evidence of methanogensis as marked the presence of methane gas and reduction in dissolved organic carbon (DOC). The next zone of microbial activity showed evidence of sulfate reduction by the formation of black sulfide precipitates and the presence of hydrogen sulfide gas, suggested by (Leenheer et al, 1976a) to be evidence of microbiologic sulfate reduction. Methanogenesis was still evident in this second zone, and as noted later in this report these two processes can occur simultaneously. Fluids in the next zone toward the well showed evidence of increased concentration of nitrogen gas and decreased methane production, possibly marking a zone of denitrification. Analyses of the organic carbon fraction of fluids sampled from all these microbial zones showed that concentrations of formic acid were below those expected for the ratio of waste/formation fluid mixing at that time indicating degradation, whereas concentrations of acetic acid showed little degradation.

Inside the microbial zone Leenheer et al. (1976b), is the transition zone, in which the concentrations of organic compounds are toxic to microbial activity and formation fluid nitrogen which is needed for the microbial activity is consumed. In this transition zone the waste solution has already been neutralized by waste/rock reactions that occurred closer to the injection well and, therefore, there are limited waste transformations in this zone.

Inside the transition zone, referred to by Leenheer et al. (1976b) as the fast reaction zone is where waste/rock reactions result in significant chemical changes in the inorganic composition of the waste fluid. In this fast reaction zone the pH of the waste solution is neutralized, calcium in solution is increased and carbon dioxide is evolved as silicate and carbonate minerals are dissolved. The next zone toward the injection well supports slow waste/rock reactions resulting in relatively insignificant changes in the waste fluid composition and finally with the innermost zone being composed of unaltered waste fluid.

Nitrile Waste

The mobility of an organonitrile waste injected 400 m into a limestone aquifer by American Cyanamide near Pensacola, Florida, was monitored at a well 132 m away (Ehrlich et al., 1979; Vecchioli et al., 1984). The waste stream was acidic, pH = 5.8, and contained several organic compounds, of which only nitrate, acetone, cyanide, and methyl alcohol were analyzed for. Within 300 to 800 days of injection a zone of mixed formation fluid and waste passed by the monitor well. Chemical reactions in this mixed waste/formation fluid were evident by a zone of elevated bicarbonate concentration and reduced pH between 400 to 600 days of injection (Figure 6, Ehrlich et al., 1979), with organic nitrogen concentrations (Figure 7, Ehrlich et al. 1979) below those expected if simple mixing had occurred suggest that biologic activity was active in the mixed waste/formation fluid.

After 800 days the unmixed waste plume reached the monitor well. Although the waste plume that arrived at the monitor well after 800 days was determined to be unmixed based on the presence of the conservative tracers SCN and Cl, it was chemically altered, changes in pH, organic nitrogen, ammonia, and gas concentrations were interpreted by Ehrlich et al. (1979) and Vecchioli et al. (1984) to indicate that microbiologic activity had altered the plume composition. Higher calcium concentrations in the waste plume, 15 mg/l in contrast to the 0 mg/l injected, also suggest that reactions between the limestone and the waste have altered the waste plume composition. These results also support the development of zones in the chemical composition and waste degradation reactions between the waste plume and aquifer fluid.

Comparison of the zones present in the Wilmington carboxylic acid waste stream, with those produced by this nitrile waste stream, suggests that the zones present at the carboxylic acid site, if present at the nitrile site are compressed. In the nitrile waste stream the zone of microbial activity appears to overlap the zone of water/rock interactions and neutralization (the fast reaction zone) defined by the acid waste stream. This overlaping of zones is probably a result of the slower reactivity of components such as alcohol in the nitrile waste stream with the carbonates in the formation to neutralize the solution, compared to the greater reactivity of the carboxylic acids. In addition, the microbiologic activity in the nitrile waste stream was denitrification, which occurs closer to the source of injection than methanogenesis (Bouwer and McCarthy, 1984) the dominant form of microbial activity in the carboxylic acid waste stream.

Other Chemical Environments

There are two other subsurface processes in which the degradation and retention of hazardous compounds should be considered, the mobility of waste fluid in the overlaying shale beds and in faults that are hydrologically connected to shallow aquifers. Studies of the affects of these hydrologic conditions on waste degradation were not available.

Shale units overlaying disposal aquifers are generally rich in clays and organic material and act as imperfect seal which retard the vertical mobility of fluids. The clay and organic material in these sediments can also act as sorbants to retard waste mobility. In addition, the chemical environment in the shale units differs from that in the injection aquifer, and thus could encourage additional degradation reactions.

The degradation or retardation of waste which escapes the disposal aquifer through faults is difficult to document. The pressure and temperature decrease attendant upward fluid flow could result in precipitation of mineral phases that either seal these faults or incorporate the hazardous material. It is possible that these favorable processes could be encouraged through chemical pretreatment of the waste stream.

It is apparent from the field studies, laboratory experiments and calculations of subsurface reactions discussed above that interactions of the waste solution with the reservoir rock, formation fluid, and microbes produces a complex series of reactions that are specific to the composition of the waste solution and to a lesser extent to the composition of the reservoir rock. In addition, that all three processes waste/rock reactions, microbial activity and waste/formation fluid mixing play a role in the types and extent of the reactions that will occur.

GEOCHEMISTRY OF WASTE REACTIONS

There are a number of review studies that address the mobility of contaminants in ground water (cf. Appendices I and II). Most of these studies, however, focus on the problems of the mobility of contaminants under near surface conditions resulting from the infiltration of toxins into the ground water system from surface disposal (cf. Cherry et al., 1984) or from shallow disposal at less than a couple of hundred meters. Many of these review studies also focus on the mobility of metals, rather than organic compounds which are shown above to be the dominant component of hazardous material disposed of by deep well injection, or focus on pesticides (halogenated organics), fertilizers, and other organics that are common surface contaminants rather than the industrial contaminants that are the concern of this study. In addition, these studies generally report on the chemical reactivity of the hazardous material but do not address how other contaminants in solution might effect its mobility.

The purpose of this section is to present waste degradation processes in the context of the reactions that are important to the degradation and the retardation of the mobility of the hazardous chemicals disposed of in significant amounts into deep subsurface aquifers. First chemical and biologic process that affect the stability of organic compounds are reviewed, and then the effects of these process on the significant waste groups are presented.

Organic Reactions

Sorption

Binding of hazardous organics to humic substances and clay mineral present in the disposal aquifer and confining shale beds can act to immobilize toxic material keeping it in the vicinity of the injection zone possibly for the 10,000 yr time period set by the EPA, or for sufficient time to degrade to a nonhazardous form. Extensive work has been done on the sorption of toxic materials (cf. Appendices I and II) and for some organic compounds it has a significant effect on mobility while for others it is not a significant process.

Several factors that limit sorption must be considered in predicting its effect on hazardous compound mobilities. These include the temperature and pH of the solution, the presence of other possible sorbants in solution that could compete for the hazardous material that must be retarded, and the composition and quantity of sorbing material in the sediments.

Gulf Coast sandstones generally contain at most a few percent clay and little or no organic material, probably cannot sorb large quantities of hazardous material (Loucks et al., 1979). Clay rich shale units which comprise up to 90% of Gulf Coast basin sediments, however can contain dominantly clay and average 0.6 wt % organic material (Siebert et al., 1984) and, therefore, are better retardants to waste mobility. Sorption by shales can, therefore, act to retard vertical migration of wastes.

Oxidation-Reduction

Oxidation of inorganic chemicals is defined as the loss of electrons and an increase in oxidation number. A definition that covers oxidation and reduction of most organic compounds defines oxidation as the gain of oxygen or loss of hydrogen (ie. hydrogenation), and reduction as the loss of oxygen or gain of hydrogen (ie. dehydrogenation) (Rinehart, 1973). This definition, however, can be ambiguous for reactions in which both oxygen and hydrogen are either gained or lost. Oxidation of organic chemicals is not so easily defined because of the complexity of oxidation of elements in the molecules. Redox reactions are generally slow and mediated by organisms (Morel, 1983). Some types of bacteria that mediate reducing reactions are aerobic organisms (O_2/H_2O), denitrifiers (NO_3^-/N_2), and sulfate reducers ($SO_4^=$).

Injection of waste into deep aquifers will effect the oxidizing conditions in the aquifer. Industrial waste streams are generally exposed to the atmosphere and, therefore, will be oxidizing in character unless a reduced phase has been added to the solution during production. Whereas, fluids in deep aquifers are reducing and minerals in the deep sediments contain elements in their reduced form. Introduction of the oxidized waste stream into the reduced subsurface environment will act to reduce the waste stream. There are numerous field examples where this subsurface reduction in oxidation of the injection solution is documented (cf. Ragone et al., 1973, Leenheer et al., 1976b; Ehrlich et al., 1979). It is expected, therefore, that oxidation reactions will occur only near the injection well, whereas, reduction predominates beyond the inner plume environment.

Hydrolysis

Many organic compounds hydrolyze in aqueous solutions to simpler compounds. Hydrolysis, therefore, is an important mechanism in the degradation of hazardous organic compounds. Unfortunately hydrolysis in some cases result in the transformation of a nonhazardous compound to a hazardous compound.

Hydrolysis of organic compounds usually results in the exchange of a leaving group (X) for a hydroxyl group (OH).

$$RX + H_2O \Rightarrow ROH + HX$$

Rates of hydrolysis can vary widely, ranging from half lives of a few seconds to thousands of years (Mabey and Mill, 1978), and are dependent on pH, temperature and ion concentrations in solutions. Hydrolysis of an organic compound is generally fastest at the extremes in acidity and basicity with the rate of hydrolysis decreasing to a minimum at some intermediate pH. Hydrolysis rates increase with increased temperature. Elevated concentrations of non-nucleophilic salts (ie. NaCL, LiBr) in solution can act to either increase or decrease the rates of hydrolysis, although very high concentrations change the rate constant by no more than 30 to 40% (Mabey and Mill, 1978). The addition of nucleophilic anions (ie. acetate, phosphate) to solution accelerate the rate of hydrolysis, and in some cases effect the displacement of the leaving group (X) more rapidly than water and, thereby, catalyze the process

$$RX + A^- \Rightarrow RA + X^-,$$

$$RA + H_2O \Rightarrow ROH + HA$$

where,

$$(HA + X^- \Leftrightarrow A^- + HX).$$

Because hydrolysis products and rates are dependent on the solution pH and temperature, it can be expected that hydrolysis reactions will change with distance from the point of injection. Hydrolysis rates would be expected to decrease, and reactions may change, as the generally acid or basic waste plume is neutralized with increased distance from the injection well. In contrast, hydrolysis rates would increase with distance from the injection well because of heating of the generally ambient temperature waste. Calculation of hydrolysis rates and reactions should consider the effects of this subsurface zoning.

Microbial Activity

Biodegradation includes several distinctly different kinds of processes which are reviewed by Alexander (1980). Microbial decomposition of organic compounds can occur as mineralization or cometabolism. Cometabolism, when the microbe transforms the organic during metabolism, but does not use the organic compound as a source of nutrition, is less favored. In cometabolism the population density of the responsible species does not increase because the species is not using the organic compound as a nutrient and therefore is not given a selective advantage. Therefore, without an increase in the population of the responsible species, cometabolism does not result in an increase in degradation with an increase in the introduction of the chemical to the environment. Another disadvantage of cometabolism which is derived from its byproducts. Cometabolism does not break down the organic compound to an inorganic form such as CO_2, but instead transforms it into another organic molecule which in some cases is more toxic and resistant to degradation than the original compound. Because of this cometabolism is a significant mechanism of activation, the production of a hazardous compound from a nonhazardous one.

An example of cometabolism resulting in activation is the processes in which microbial activity has been found to convert organic molecules to nitrosammines (RR'N-N=O) (Alexander, 1980), which are carcinogenic, mutagenic and teratogenic. The immediate precursors of nitrosamines are secondary amines and nitrite. Secondary amines are commonly injected and can also form microbiologically from primary, tertiary and quaternary amines, all hazardous wastes disposed of by well injection. Nitrite, which is not commonly injected with organic waste streams, is formed from oxidation of ammonia or reduction of nitrate which are common components of organic waste streams. This is another example indicating that the presence of nonhazardous substances in the injection solution can be significant and should be included in studies of hazardous waste degradation because of their influence on subsurface reactions and possible transformations to hazardous materials.

Mineralization is the most favored type of microbial activity. During mineralization microbes consume the organic as a nutrient. The presence of this nutrient allow the selected microbial population flourish, which in turn increases degradation. Thus, mineralization is a more effective mechanism for degradation of organic compounds than cometabolism. Furthermore, mineralization results in the transformation of the organic compound to a nonhazardous inorganic.

Most studies of biodegradation of hazardous waste consider the reactions of aerobic bacteria (cf. Stryker and Collins, 1987). It has only been in the last decade that anaerobic degradation has been realized as a mechanism that can contribute significantly to contaminant transformations (cf. Bouwer et. al., 1981; Kobayashi and Fittmann, 1982, Young, 1984).

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The presence and activity of microbiologic activity in the deep subsurface has been documented only recently. Populations of sulfate reducing and fermentative bacteria have been found in sediments at depths up to 410 m by White et al. (1985), and of sulfate reducing and enteric bacteria at depths up to 1000 ft in the Tuscaloosa aquifer of South Carolina (Wobber, 1986). The sulfate reducing and enteric bacteria populations present down 1,000 ft in the Tuscaloosa aquifer showed a general decrease in the population density with increased depth, with the highest numbers in the permeable sandstone and the lowest numbers in the less permeable clays at a given depth (Wobber, 1986). Evidence of microbiologic degradation of organic compounds at depths of up to 7,000 ft in Gulf Coast sediments has been indicated by the presence of degraded hydrocarbons and lack of organic acids in formation fluids (Kreitler et al., 1988).

Reduced conditions in the deep subsurface favor anaerobic activity. For biologic oxidation of organic compounds by anaerobic bacteria under oxygen poor conditions, aqueous complexes of nitrate, sulfate or carbonate are used as the source of oxygen (Young, 1984). Recent work by Suflita et al. (1988) suggests that oxygen in water is also used in anaerobic degradation reactions. In deep Gulf Coast aquifer fluids at the depth of deep well injection nitrogen is generally present in the reduced form as ammonia, whereas sulfate concentrations range from 0 to 1000 mg/l, and carbonate from 100 to 2000 mg/l (Kreitler and Richter, 1986). Under these conditions anaerobic degradation in Gulf Coast sediments would involve sulfate reduction, methanogenesis or transformation of water. Sulfate reduction and methanogenesis can occur simultaneously, but when they do sulfate reduction predominates (Oremland and Taylor, 1978).

The toxic waste stream disposed of by deep well injection often contain organic compounds in high concentrations that can be toxic to microbial populations. Microbes, however, that are feeding on the hazardous material become resistant to its toxic effects and instead become more active in the presence of the toxic material. This suggests that if microbial degradation is the method of waste degradation than introduction of a waste stream of the same composition over long periods of time is preferred over the injection of multiple waste stream compositions as is the case for commercial injection wells.

The zoning of microbial activity as seen at the Wilmington, N.C., injection site indicates that an inner zone of high waste concentration can remain toxic to microbial activity, with an outer zone where waste is diluted with formation fluid being the location of greatest microbial activity (Leenheer et al., 1976b).

REACTIONS OF SIGNIFICANT HAZARDOUS WASTE GROUPS

Phenols

Phenols can undergo reactions that involve the benzene ring or the functional group (OH). Although phenols (ArOH) and alcohols (ROH) are similar in structure they differ considerably in chemical reactions and therefore are considered separately. The most favored chemical transformations of phenols are 1) ionization in which the H on the OH group is removed leaving a negatively charged phenoxy ion (ArO^-), 2) oxidation in which the H on the OH group is lost and the remaining O forms a double bond with the C on the benzene ring and a H attached directly to the benzene ring is replace by a double bonded O, forming a quinone ($O{=}C_6H_4{=}O$) and 3) electrophylic substitution in which a halogen, nitrate, sulfate or other ion is substituted for a H on the benzene ring. Other possible degradations can be the result of microbial activity. Phenol mobility is retarded by sorption onto clay surfaces and biofilms.

Ionization

The acid dissociation constant, pK_a, for phenol dissociation

$$Ar{=}OH \Leftrightarrow Ar{=}O^- + H^+$$

equals

$$pK_a = [Ar{=}O^-]\,[H^+]$$

where $[Ar{=}O^-]$ and $[H^+]$ are the activities of the ions in solution. At $pH > pK_a$ the dissociated phenoxy ion is dominant in solution over the undissociated parent phenol compound. The pK_a of the phenol group compounds is generally over 7 at ambient temperatures, with values of 9.8 for cresol, and 9.8 and 13 for the two phenolic groups in catechol (Thurman, 1985). The chlorinated phenols have much lower pK_a values at ambient temperatures ranging from 4.75 to 9, with the higher chlorinated phenols having lower values (Schwarzenbach and Westall, 1985). For example $pK_a = 4.75$ for pentachlorophenol, 5.40 for 2,3,4,6 tetrachlorophenol, 6.35 for 2,3,4,5,-tetrachlorophenol, and 6.94 for 2,4,5-trichlorophenol.

Sorption

Phenol mobility in subsurface aquifers is inhibited by adsorption on clays and organic surfaces. Ionization of phenols, as with other inonizable (anionic) hydrophobic compounds such as amines and carboxylic acids, decreases adsorption on natural organic carbon in sediments (Schwarzenbach and Westall, 1985). At $pH\text{-}pK_a<2$ the unionized form predominates but in more basic solutions, $pH\text{-}pK_a>2$, the negatively charged phenolate ion is the predominate ion in solution. The phenolate ion forms from the release of H from the OH functional group common to all phenols. At low pH solutions where the phenol is present in its unionized form sorption is highest and decreases with increased pH in the region of $pH - pK_a = 0$ to $pH - pK_a = 2$. Sorption is lowest in solutions with $pH - pK_a > 2$, in which phenoxy ions dominate. In these basic solutions sorption becomes ionic strength dependent with increased sorption in higher ionic strength solutions.

Phenol sorption on Frio sandstone samples collected from Gulf Coast sediments at a depth commonly used for deep well injection, 7,155 ft, was tested by Collins and Croker (1988). These phenol sorption tests were conducted at temperatures of 38^{o} and $60^{o}C$ and pressures equivalent to hydrostatic at the depth from which the samples were collected. The sorbant in the Frio sand would be the kaolinite that was present as 3 wt % of the sediment. Flow through experimental results indicate that phenol sorption increases with increased phenol concentration in solution, and decreases with increased temperature. A kg of the Frio sandstone with 36% porosity could adsorb 13% (at $38^{o}C$) to 7% (at $60^{o}C$) of the phenol from pore fluid containing 500 mg/l phenol, and 22% (at $38^{o}C$) and 19% (at $60^{o}C$) of the phenol from pore fluid containing 10,000 mg/l phenol. The pH of the solutions in these flow through experiments started at 5.7 and shifted to a final pH of 8.1 during the experiment. Although phenol sorption on organic material was found to be pH dependent (Schwarzenbach and Westall, 1985), the pH dependence of phenol sorption on clay minerals, as in the Frio sample, has not been determined and was not considered by Collins and Crocker (1988).

A flow through experiment conducted to test the desorption of the phenol adsorbed by the Frio sandstone showed the phenol not to be desorbed by a dilute sodium chloride solution (Collins and Crocker, 1988). This desorption experiment, however, does not test for the possible desorption of phenol by more complex solutions.

The results of these experiments on the adsorption of phenolic compounds by clay minerals and organic material indicate that sorption can act to retard phenolic compound mobility in the deep subsurface, and that the lack of phenolic desorption suggests that retardation may be permanent. The efficiency of this process is dependent on the amount of sorbing surface, on temperature, on the concentration of the phenolic compound in solution, and on the lack of other aqueous compounds that might be preferentially adsorbed.

Oxidation

Phenols oxidize readily, and since the hydroxyl (OH) group in phenols is attached to a benzene ring rather than a hydrocarbon chain as in alcohols, phenols oxidize more readily than alcohols (Rinehart, 1973). Although there are many products of the oxidation of phenols, phenols commonly oxidize to the corresponding quinone.

$$\underset{\text{phenol}}{C_6H_5\text{-}OH} + O^{+2} \Rightarrow \underset{\text{quinone}}{C_6H_4{=}O} + H^{+} + e^{-}$$

Quinones exist as a redox couple with phenols at a redox potential of approximately -0.7 volts (Thurman, 1985). Using the relationship between Eh and pH at $25^{o}C$ for this coupling,

$$Eh = E^{o} + 0.059\,pH \text{ (see Garrels and Christ, 1965)}$$

indicates that the oxidation of phenols to generally nonhazardous quinones is favored in shallow reduced ground waters. Equilibrium relationships at the high temperatures present in the formations of deep well injection were not determined because of the lack of available thermochemical data for the calculations. This data suggests, however, that phenol oxidation to quinones will proceed in injected waste stream at least until the solution becomes reduced by this reaction and other reduction reactions resulting from reactions with reduced phases in the aquifer material and mixing with the reduced formation fluid. Information on the rate of phenol oxidation was not located but in general oxidation reactions tend to proceed more rapidly in the presence of bacteria. Thus phenol degradation by bacterial consumption and oxidation would be enhanced by introduction of oxygen into the disposal formation. The effects on other precipitation reactions such as the formation of gypsum resulting from the transformation of sulfide to sulfate must be considered, and subsequent sealing of the formation.

A common phenol group oxidation sequence is autoxidation which produces the resonance-stabilized phenoyx radical (C_6H_5-O^-) which attacks benzene rings giving coupling products which can be further oxidized (Rinehart, 1973).

Microbial Degradation

Microbial degradation of phenolic compounds in waste treatment water, and water in surficial and near surface environments is well studied (Table 1). From this work it is well established that phenolic compounds are readily degraded by aerobic bacteria (Chapman et al., 1972), and that these reactions require oxygen for the hydroxylation and ring cleavage reactions (Chapman et al., 1972). Microbial degradation is a favored method of hazardous waste treatment of phenolic compounds because the common products of microbiologic degradation of phenolic compounds are generally nonhazardous carboxylic acids and catechols.

Batch experiments of anaerobic microbial degradation of pentachlorophenol by shallow ground waters, collected from depths down to the water table at 24 ft, within pentachlorophenol contaminated sediments, suggest that low concentrations of pentachlorophenol, 0.1 mg/l, are microbially degraded in the shallow subsurface at a rate of 10 to 15% a week (Lee et al., 1984).

Because of the lack of oxygen in the deep subsurface environment of deep well injection, anaerobic degradation would be favored over aerobic. Recent work on the anaerobic degradation of phenolic compounds indicates that they are successfully degraded by methanogenesis and sulfate reduction under anaerobic conditions in subsurface aquifers (Healy and Young, 1978; Suflita et al., 1988). This work indicates that upon introduction of the phenolic compounds to the subsurface environment there is an acclimation period that takes from 30 day to a year before anaerobic biodegradation begins. The success of methanogenesis has been found to be dependent on pH and temperature (Beeman and Suflita, 1988). Over a pH range of 5 to 9 and temperature range from 5 to 45°C the optimum conditions for methanogenic degradation of phenolic compounds ar pH 8 and 35°C. These results suggests that much additional work is needed to understand the conditions most favorable for anaerobic degradation of phenolic compounds.

Degradation of phenolic compounds in the subsurface by biologic activity and the retardation of the mobility of phenolic compounds by adsorption are the most likely methods of purifying phenolic waste solutions. The experimental work discussed above suggest that both phenol biodegradation and adsorption can be enhanced by adjustment of the solution pH, temperature and composition. Phenol biodegradation could occur both in the aerobic subsurface environment in the vicinity of the injection well and in the anaerobic environment beyond. Because of the time necessary for the a bacterial population that favors phenolic compounds to accumulate in the subsurface sediments, phenolic degradation should be the most successful around injection wells in which the phenolic waste stream is injected continuously at a constant composition in a well that is dedicated to the disposal of only that waste stream.

Cyanide

Cyanide, CN^-, is a negatively charged ion that is a prototype of the cyano group, -CN (Rappaport, 1970), and, therefore, its reactivity is in part related to that of the nitriles. The cyanide ion acts similar to halogen ions, such as Cl^-, in solution, readily forming complexes with cations, particularly those of the transition metals (Sharpe, 1976). Cyanide forms hydrogen cyanide in basic aqueous solutions with pK_a's of 9.63, 9.21, and 8.88 at 10, 25, and 40°C respectively (Sharpe, 1976).

Information on the reactivity of cyanide in aqueous solutions indicates few mechanisms of its transformation. Oxidation of cyanide to cyanogen or cyanate is favored at ambient temperatures

$$HCN \Leftrightarrow 0.5C_2N_2 + H^+ + e \qquad E^o = -0.37V$$

$$CN^- + H_2O \Leftrightarrow OCN^- + 2H^+ + 2e \qquad E^o = +0.14V$$

(Sharpe, 1976). Oxidation in the reduced injection environment, however, is unlikely. Cyanide transformation to hydroxynitriles is favored upon injection with a ketone-aldehyde organic waste stream (Roberts and Caserio, 1979). Hydrolysis of these hydroxynitriles to ammonium and the corresponding hydroxy-carboxylic acid is then favored.

Not only are there few mechanisms for cyanide degradation, but the addition of cyanide to a complex waste stream can increase the mobility of hazardous metals or inhibit the microbiologic degradation of hazardous organic compounds. Cyanide complexes readily with transitions metals which inhibits the sorption of these metals on clays and organic material and thereby increasing their mobility. Experiments on the denitrification of alcohols (methanol and propanol) and caboxylic acids (acetic acid) indicates that the presence of cyanide inhibits this proces (Lewandowski, 1984). The inhibition of acetic acid biodegradation by cyanide ultimately limits the anaerobic degradation of phenolic compounds. While the anaerobic biodegradation of phenolic compounds takes place in the presence of cyanide, the greater the presence of cyanide in solution the slower the phenolic degradation (Fedorak et al., 1986). In the process of anaerobic degradation of phenols, a first group of microbes degrade the phenolic compound to acetic acid and a second group of methanogenic bacteria convert the acetate to methane. The first step, the degradation of phenolic compounds, occurs uninhibited in the presence of cyanide, however, it was found that the second step, the methanogenic degradation of the acetic acid product, was inhibited by the presence of cyanide. Phenolic biodegradation was, therefore, slowed in the presence of cyanide because of the accumulation of the acetic acid byproduct in solution.

In contrast, the denitrification of a ketones and aldehydes in the presence of cyanide is uninhibited and results in removal of the ketone or the aldehyde and cyanide (Lewandowski, 1984). Ketone-aldehyde biodegradation in the presence of cyanide is displayed in experimental work on acetone degradation in cyanide contaminated solutions (Lewandowski, 1984). In this work acetone-cyanide reactions to produce hydroxynitriles are credited with permitting the biologic degradation of ketones despite the inhibiting qualities of cyanide, and with the removal of cyanide from the solution. Biodegradation of acetone in the presence of cyanide was also found to be pH dependent because of the pH dependence both of hydroxynitrile formation from acetone/cyanide reactions and of the hydrolysis of the resulting hydroxynitrile. Biodegradation of acetone by denitrifying bacteria was favored in more acid solutions, pH < 7.9 at 25°C, in which the reaction of acetone with cyanide to form a hydroxynitrile and hydroxynitrile hydrolysis are favored. Whereas in basic solutions acetone biodegradation was unsuccesful.

The effect of cyanide, present in concentrations less than 10 mg/l, on biodegradation of nitriles is also minimal as evidenced by a field study of subsurface nitrile degradation (Ehrlich et al., 1979; Vecchioli et al., 1984).

In this study not only did the nitriles degrade, but a reduction in cyanide in recovered waste solution indicates that cyanide also degraded.

These results suggests that cyanide degradation is unlikely unless injected with organic compounds such as ketones, aldehydes, or nitriles, that will include cyanide in their biodegradation reactions. On the other hand cyanide will inhibit the biodegradation of organic compounds when ketones, aldehydes or nitriles are not components in the waste stream. In addition, undegraded cyanide will increase the mobility of hazardous metals through the formation of complexes that inhibit metal sorption. Cyanides potentially detrimental effects on subsurface degradation of hazardous industrial wastes can be significant, because cyanide is not only injected in relatively high concentrations it is a component in 26 of the 98 industrial waste streams injected into Texas aquifers.

Nitriles

Hydrolysis

This amide then hydrolyzes to a carboxylic acid and ammonia which are the more common end products of nitrile hydrolysis (March, 1977). Although data on the rate of nitrile hydrolysis to carboxylic acids was not available, nitrile hydrolysis is favored at high temperatures (American Cyanamide Company, 1959) and therefore is expected to be an active mechanism of degradation in the deep aquifer environment.

Sorption

Sorption of nitriles onto clay minerals or organic material is not significant at low temperatures (Sanchez et al., 1972; Callahan et al, 1979). Information on sorption at the elevated temperatures of the deep well injection environment is limited. Short chain n-alkyl nitriles were found to have limited adsorption after 1 week of contact with montmorillonite at 60°C, while other organic nitrogen compounds were significantly adsorbed (Charlesworth, 1986). It is unlikely, therefore, that nitrile sorption will significantly reduce nitrile mobility in deep aquifers.

Biodegradation

Although aerobic degradation of nitriles is well documented (cf. Smith and Cullimore, 1974; DiGeronimo and Antoine, 1976), there is little experimental work on anaerobic nitrile degradation. Subsurface degradation, at 400 m, of organonitrile compounds (the only one identified was acetonitrile) by denitrifying bacteria under anaerobic conditions was documented in a backflush experiment at a waste injection site into a limestone aquifer at Pensacola Florida (Ehrlich et al., 1979; Vecchioli et al., 1984). Acetonitrile concentrations were reduced by half in the 107 hours that the waste solution remained in the aquifer. Flow through tests conducted at the same site showed that with longer residence time, 900 days over a travel distance of 312 m, denitrification ceased. Analysis of organo nitrile concentrations in the fluids collected from the long term flow test were not reported and therefore the completness of the degradation reactions is uncertain. Cyanide injected with this waste stream degraded and appeared not to prevent the activity of denitrifying bacteria, probably because of the presence of the ketone acetone in the waste stream (see discussion above).

Degradation of nitriles by hydrolysis and denitrifying bacteria in subsurface aquifers appear to be adequate processes to treat deep well injected waste and prevent the mobility of nitriles out of the injection zone.

Ketones-Aldehydes

Chemical Reactions

Ketones and aldehydes can react as both an acid and a base (Wade, 1987). The carbonyl oxygen, -COH, which is double bond to the carbon atom and has two nonbonding pairs of electrons, can act as a base and either attack a proton or electrophile to form a new bond. Otherwise the carbonyl acts as an acid with a strong nucleophile attaching to the carbon and leaving a negative charge on the oxygen atom of the carbonyl group. Thus the presence of other organic compounds in solution can have significant limitations or enhancements on the transformation of hazardous ketones and aldehydes to nonhazardous substances in the aqueous environment and at the elevated temperaturea of subsurface injection. Despite the reactivity of ketones and aldehydes in aqueous solution the results of these reactions in deep injection aquifers on the degradation of hazardous ketones and aldehydes have not been considered.

Sorption

Sorption of ketones and aldehydes by both clays and organic material in sediments can be a significant retardant to the mobility of these compounds provided that the sediments contain sufficient amounts of the sorbing material (Donaldson et al., 1975; Khan et al., 1979; Briggs, 1981; and Southworth and Keller, 1986). Experimental work on the sorption of the formaldehyde (an aldehyde) at 25°C in an acid waste solution, pH = 4, containing several carboxylic acids onto sandstone aquifer material, however, showed that formaldehyde did not sorb while the carboxylic acids were strongly sorbed from the solution (Leenheer et al., 1976b).

Biodegradation

Most of the research on biodegradation of ketones and aldehyes considers aerobic activity rather than anaerobic as is present in subsurface aquifers (cf. Grula and Grula, 1975). Anaerobic denitrification of ketone and aldehydes in the presence of cyanide has been documented by Lewandowski (1984). Acetone (a ketone) injected into a subsurface aquifer in a nitrate/nitrile/cyanide waste stream, however, was not consumed by denitrifying bacteria that consumed the nitrate, nitrile and cyanide as evidenced in the backflush solution (Ehrlich et al., 1979). In contrast, heptaldehyde (an aldehyde) injected in a waste stream that did not include nitriles or cyanide into a subsurface aquifer, where anaerobic conditions prevailed (Roberts et al., 1978), was found to biodegrade by 69% in the 12 hours it took the injection fluid to reach a nearby monitor well (Rittman et al., 1980). Roberts et al. (1978) concluded that the heptaldehyde was used as a secondary substrate by the bacteria, which accounted for the incomplete degradation. Thus biodegradation of ketones and aldehydes in complex waste streams or in the absence of cyanide is uncertain. It appears that ketones and aldehydes may complete unsuccesfully for microbial attention when injected with other chemical compounds, such as those that contain nitrogen, that are more acceptable to the subsurface microbes for nutrition.

Degradation of ketones and aldehydes in deep subsurface aquifers is possible through both biodegradation and chemical transformations, and their mobilities can be retarded through adsorption on organic material and clays in the aquifer matrix. To ascertain that the necessary degradation reactions will take place, however, precautions must be taken as the the compositions of other organic and inorganic compounds in the waste stream. Review of the available literature indicates that more information is needed on the influence of other chemicals on ketone-aldehyde degradation, before improvements in the design of waste injection can be made to enhance their degradation.

REACTIONS OF SIGNIFICANT NONHAZARDOUS WASTE GROUPS

Carboxylic Acids

Carboxylic Acid Derivatives as a Source of Carboxylic Acids

The affect of carboxylic acids on waste reactions can be considerable, therefore, the hydrolysis of carboxylic acid derivatives as a source of carboxylic acid will be discussed briefly.

Alliphatic esters hydrolyze to give alcohols and carboxylic acids

$$RCOOR' + H_2O \Rightarrow RCOOH + R'OH$$

at 25^{o}C and pH 7, the hydrolysis half life for the simple alliphatic esters ranges from 1 to 10 years (Mabey and Mill, 1978). The esters injected into Texas aquifers are all alliphatic and, therefore, the production of a carboxylic acid and an alcohol as a result of hydrolysis will proceed rapidly enough so as to be consideration a source of carboxylic acids in consideration of waste degradation.

All the esters injected into Texas aquifers are acetate esters and, therefore, produce acetic acid, a nonhazardous carboxylic acid, upon hydrolysis. The alcohols produced during this reaction include methyl, ethyl, propyl, butyl, and vinyl alcohols. Of these alcohols, methyl and butyl alcohol are listed as hazardous only for their ignitability, and the remaining three are not listed as hazardous. The contribution of alcohols to solution could also effect aqueous complexing and, thereby, chemical reactions.

Amides hydrolyze to carboxylic acids and amines

$$RCONR'R'' + H_2O \Rightarrow RCOOH + R'R''NH\ .$$

Most amides, except for a few halogenated acetamides, hydrolyze to carboxylic acids extremely slow at 25^{o}C and pH 7, with half lives measuring in centuries, from over 4,000 to 11,000 yrs (Mabey and Mill, 1978). Acrylamide, a toxic waste and the only amide injected into Texas aquifers, hydrolyzes to acrylic acid and ammonia

$$\underset{\text{acrylamide}}{CH_2{=}CH\text{-}CO\text{-}NH_2} + H_2O \Rightarrow \underset{\text{acrylic acid}}{CH_2{=}CH\text{-}COOH} + NH_3\ .$$

Acyrlic acid is listed as a hazardous waste only because of its ignitability, ammonia is not listed. Acrylamide is a type of amide that would have an extremely long half life and, therefore, does not produce carboxylic acid rapidly enough to effect other reactions in the waste stream, and may persist in solution beyond the 10,000 year limitation for degradation, unless there is another degradation process in addition to hydrolysis that transforms it into a nonhazardous substance.

Nitriles also hydrolyze to a carboxylic acid and ammonia. Data on the rate of nitrile hydrolysis are not available, excepting that this reaction is favored at elevated temperatures or in acid solutions (American Cyanamid Company, 1952).

Affects of Carboxylic Acids on Waste Reactions

A comprehensive study of subsurface reactions of a carboxylic-dicarboxylic acid laden waste solution injected into a sandstone aquifer near Wilmington, North Carolina, by Leenheer et al. (1976a, 1976b) indicates that carboxylic and dicarboxylic acids in a waste solution result in significant waste/rock reactions and microbial activity. Upon injection the waste solution dissolved carbonate and silicate material in the formation which resulted in increased calcium, production of carbon dioxide gas, neutralization of the pH. Beyond this zone of active water/rock reactions where the waste becomes significantly diluted with the formation fluid, these carboxylic and dicarboxylic acids act as a substrate for microbial activity which also results in production of carbon dioxide, methane and hydrogen sulfide gases.

Calculations of fluid/mineral reactions between a carboxylic acid laden waste stream and a sandstone aquifer by Drez (1988) confirm the inorganic reactions that result in carbonate and silicate dissolution near the injection well, with subsequent changes in the chemical character of the solution that were documented in the Wilmington field test.

In determining the possible degradation of hazardous materials disposed of in a waste stream containing carboxylic acids, the rapid neutralization of pH must be considered in calculating rates of hydrolysis, sorption coefficients and the progress of other chemical transformation reactions that are pH dependent. In addition, because of the affinity of carboxylic acids as a microbial substrate, the possiblity that carboxylic acids will be consumed as a primary substrate rather that the hazardous material that must be degraded should also be taken into account.

Carboxylic acids occuring in ionic form in neutral to basic solutions can act as a vehicle to transport hazardous metals from the injection zone as complexes with carboxylate ions (cf. Loch and Lagas, 1985).

Alcohols

Alcohols do not appear to have as significant an affect on waste reactions as carboxylic acids, however, little work has been done to confirm their affects on reactions of other hazardous materials. Because they are so often injected as a component of waste solutions and are relatively reactive their affect on degradation reactions of complex waste solutions should not be considered insignificant without consideration of the possible effects.

From this review of the possible degradation pathways of the significant waste groups disposed of by deep well injection, it is apparent that in most cases subsurface degradation of the hazardouse compounds of concern is possible and could be enhanced by pretreatment of the aquifer or the waste stream. The preferred pathway for each waste group appears to differ from that of the others. For example ketones-aldehydes are degraded by denitrifying bacteria, whereas, phenols are favored by methanogenic and sulfate reducing bacteria. Additional work to determine the most favorable conditions such as temperature, pH and solution composition, the composition of the aquifer material, and composition of the microbial population that are necessary to optimize waste degradation. This is particularly important for complex waste streams that contain hazardous wastes from different functional and structural groups.

APPROACHES FOR PREDICTION AND VALIDATION OF SUBSURFACE WASTE REACTIONS

NUMERICAL SIMULATION

Thermodynamic data bases and programs that permit the calculation of inorganic fluid/mineral equilibria and water/rock reactions in multicomponent systems under the conditions of elevated temperature and pressure present in aquifers used for deep well injection have been available for the past decade (Helgeson, 1970; Helgeson et al., 1978; Wolery, 1983, 1984). The thermochemical data bases available, however, do not contain data for organic compounds and ions, other than for a few naturally occurring carboxylic acids such as acetic acid. In the proposed research geochemical modeling was to be completed using existing data bases. Because the data needed to calculate transformations of organic compounds in the multicomponent organic waste solutions most often deep well injected are presently not compiled into a data base, hazardous waste reactions were not calculated.

Little work has been done by other researchers on the calculation of organic transformations and organic waste/rock reactions in the subsurface, particularly for the complex organic-inorganic waste streams most often injected. The affects of a carboxylic acid waste stream on mineral precipitation and dissolution in the injection aquifer were calculated by Drez (1988) after adding the metal-acetate complexes to the preexisting predominantly inorganic thermochemical data base for the reaction pathway code EQ3/6 (Wolery, 1983, 1984). The results of Drez's calculations, as discussed in the previous section on the affects of carboxylic acids on waste reactions, appear to agree with the transformations that occurred upon injection of a carboxylic acid laden waste stream into a sandstone aquifer near Wilmington, North Carolina as described by Leenheer et al. (1976a, 1976b). Upon injection of the carboxylic acid waste stream, a "fast reaction zone" developed where the pH of the originally acid waste stream was neutralized, calcium increased and carbon dioxide evolved as carbonate and silicate minerals dissolved.

The majority of the computer codes used for calculation of chemical transformations in solution and fluid/mineral reactions do not calculate adsorption reactions or biologic transformations, which are important in the degradation of hazardous materials and in the retardation of their mobility. There are numerical models available for the calculation of the results of adsorption (cf. Morel et al., 1981) and of biologic transformations using biofilm kinetics (Rittmann and McCarty, 1980a, 1980b), and combined inorganic reactions and denitrification (Sorek and Braester, 1988). Similar to the data bases for the water/rock reaction codes, sorption reaction codes generally contain data only for inorganic species and, therefore, have not been tested to predict sorption of the hazardous materials of concern in this study. The numerical models for predicting biologic transformation have been used successfully to predict results from laboratory flow-through experiments (Bouwer and McCarthy, 1984).

Although reaction codes have not yet been tested in predicting subsurface waste transformations and waste/rock reactions for complex inorganic and organic waste streams, their ability to simulate experimental results and to predict reaction path sequences found in natural systems suggests that they are useful tools in predicting waste degradation. A limiting factor appears to be the quality of thermochemical data used in the calculations and the ready availability of this data in an internally consistent data base that contains all the inorganic and organic elements and compounds that can contribute to reaction in the complex waste stream of interest. In addition reactions kinetics for slower reactions, such as organic hydrolysis reactions, must be considered. If all the necessary data are not available, calculations of equilibrium reactions should at lease assist in predicting the controls on chemical transformations found in field and laboratory experiments.

NATURAL AND ARTIFICIAL ANALOGS

Because of the great depth of deep well injection aquifers it is generally not possible to study the effects of subsurface degradation first hand. The use of monitor wells to document reactions is not always advisable because the high expense of drilling and because monitor wells increase the possibility of leakage of the waste into shallower aquifers. In addition, it is not possible to determine long term degradation because deep well injection has only been used as a method of disposal for many hazardous organic compounds during the last 10 to 20 years. Natural and artificial analogs of subsurface waste reactions would, therefore, be useful in predicting the geochemical processes active in deep injection aquifers and in the degradation pathways that can be expected. Natural analog environments might include diagenetic sediments and marine sediments, and artificial analog environments might include landfills or injection into a shallow aquifer.

The common trait of the landfill and marine sediment environments with the deep well injection environment is that in all three oxygenated fluid is introduced to an anoxic environment. The chemical environment around a landfill and in marine sediments and their similarities are described by Baedecker and Back (1979a, 1979b). They find that the lateral zonation of aqueous species in landfills is similar to the vertical zonation in marine sediments, and attribute this similarity to a reaction sequence that includes initial oxidation of the sediments at the source of the foreign fluid, with reduction of the fluid as it migrates from its source into the sediments. Fluid reduction is initially indicated by nitrate and sulfate being reduced and further from the source by production of methane and ammonia as products of the fermentation of organic compounds. The pH in the reactions zones is buffered at near neutral in both environments. This zonation in oxidation potential of the solutions is similar to the zones described above in the discussion of the hydrogeology of the injection environment present in aquifers around wells used for deep well injection. The presence of an aerated zone around an injection well in aquifer sediments is further documented by a study of the injection of tertiary-treated sewage 418 to 480 ft (127 to 146 m) into a sandstone aquifer on Long Island, New York (Ragone et al., 1973). Waste fluid collected from a series of monitor wells showed evidence of the oxidation of pyrite in the sandstone and subsequent deposition of ferric hydroxide minerals.

The sequence in chemical species described by Baedecker and Back (1979a, 1979b) in landfills and marine sediments also suggests a zonation in microbial activity similar to that expected around injection wells as described by Bouwer and McCarthy (1984), which includes a progression from aerobic heterotrophic respiration in the vicinity of the injection well to a zone of denitrification, then sulfate respiration, and finally methanogenesis on the outer margins. There are significant dissimilarities between landfill and marine sediment environments and that of deep well injection, however, the most important being the elevated temperature and pressure common in deep well injection aquifers, and that fluids in landfills and marine sediments generally lack the organic compounds or group of organic compounds that are significant hazardous wastes disposed of by deep well injection (cf. Appendices I and II; Moore and Ramamoorthy, 1984; Thurman, 1985).

Shallow well injection is the most analogous situation to deep well injection with the most significant difference being the lower temperature and pressure present in the shallow aquifer. These thermal and pressure differences, however, can be significant in the determination of the rate and magnitude of organic transformations, sorption and water/rock reactions, and in predicting the activity and composition of bacterial populations which are highly sensitive to both temperature and pressure (cf. Wobber, 1986).

Diagenesis of sediments at the depths, temperatures, and pressures of deep well injection aquifers could give information on the degradation reactions to expect. The chemical and microbial transformations of sedimentary organic compounds released from the thermal decomposition of sedimentary organic material during diagenesis can be determined through examination of the present day mineral alteration suites and pore fluids. The organic compounds present in natural pore fluids exposed to thermally degraded organic material are generally not the same hazardous organic compounds deep well injected. The natural organic compounds, however, are in some cases from similar organic chemical groups as the hazardous organics injected and, therefore, may react similarly. A case in which natural diagenetic reactions were used to derive information on reactions in aquifers used for deep well injection is one in which Kreitler et al. (1988) used the presence of degraded hydrocarbons and lack of organic acids in pore fluids as evidence of microbial degradation at 7,000 ft (2134 m) in Gulf Coast aquifers. The diagenetic environment is not clearly analogous to deep well injection because deep well injection is the introduction of oxygenated fluids that are clearly out of equilibrium with the subsurface environment that then mixes with the pore fluids which have a distinctly different composition. Diagenesis, therefore, is similar to the other analogous situations in that it only gives pieces of information on possible deep well injection reactions.

This review of the processes controlling reactions in each of the possibly analogous environments indicates that, while each of these analogs represents some aspects of the deep well injection geochemical environment, none of these analogs represents the deep well injection environment fully. Each analog lacks a key element such as elevated temperature, pressure, or for the natural analogs, presence of the contaminants of interest, which allows the use of analogs as a tool to assist in defining some of the controls on degradation reactions but does not fully represent the types and rates of degradation reactions or sorption that will occur in the deep well injection environment.

LABORATORY EXPERIMENTS

Batch and flow through experiments of waste degradation have been used extensively to predict sorption, biodegradation, and the effects of waste/rock reactions. Comparison of the number of laboratory experimental studies in contrast to the number of field experiments and numerical simulations listed in Appendix II, it is apparent that to date laboratory experiments, particularly batch experiments, are the most used method of studying degradation reactions.

There are numerous problems inherent in simulating subsurface conditions in the laboratory that must be accounted for. Batch experiments reflect natural aquifer conditions much less than flow through experiments. Batch experiments, however, can be useful in providing information on reaction paths and are used extensively to study microbial activity and less extensively to study organic and inorganic reactions (cf. Appendices I and II). Results from both batch and flow through experiments to study the biodegradation of hazardous wastes (microcosm studies), however, indicated that for prediction of subsurface biodegradation the the behavior of compounds must be verified by direct experimentation for each compound and each site of interest, rather than predicted from the behavior of compounds in material from the surface (Wilson et al., 1985).

Batch experiments conducted by Roy et al. (1988) on the effects of inorganic acid and alkaline waste streams reacting with a sandstone, siltstone and dolomite were successful in predicting the neutralization of the acid waste solution, reduction of Eh, and dissolution of carbonate minerals, and that the alkaline waste solution would dissolve silica, and result in Eh reduction, but would not be neutralized. Their batch experiments were run over a temperature range of 25$^{\text{o}}$ to 55$^{\text{o}}$C at hydrostatic pressures for the depth at which those temperatures are achieved. They did not confirm their experimental results through comparison with an actual site, however, they did simulate their reactions using the fluid/mineral equilibria computer codes WATEQ2 and SOLMNEQF. They concluded that the calculations of fluid/mineral reactions, although unsuccessful in exactly duplicating the experimental results, were a useful tool when used in conjunction with the experimental results reaction to determine the controls on reactions.

Flow through experiments, although used much less extensively, duplicate natural conditions more accurately than batch experiments. The protocol for designing flow through experiments to study subsurface inorganic-organic reactions at the temperatures and pressures of injection aquifers is presented by Collins and Crocker (1988). In their experimental setup, however, it is not indicated that the core should be sterilized to prevent biodegradation reactions, the possibility of sorption on the rubber lining material was not tested, nor were their experimental results tested against the results from a natural system.

Flow through experiments to test microbial activity were tested at low temperatures and pressures by Wilson et al. (1985). Their work indicates that for a laboratory study of subsurface microbial degradation it is important to have a sample from the subsurface that contains the native flora. In their flow through experiments they did not test for reactions other than the loss of the hazardous wastes of concern. Studies of biodegradation at high temperature and pressure using flow through experimental apparatus were not available.

FIELD STUDIES

A number of field studies have been conducted to test subsurface degradation reactions, and are already discussed elsewhere in this report, particularly in the section on the hydrogeology of subsurface injection, and are listed under Case Studies in Appendix II. The majority of these field studies were conducted at active injection sites rather than having been designed specifically to study degradation reactions. As is apparent from the discussion on the hydrogeology of subsurface injection, field tests are invaluable in predicting the sequence, types and rates of transformations of hazardous organics in the subsurface.

In field testing information can be derived either backflushing the injection well or sampling nearby monitor wells. The combination of both of these types of samples is the most favored. Both backflush and flow through experiments were conducted at the Pensacola, Florida, waste disposal site where an organonitrile waste stream was injected 400 m into a limestone aquifer by the American Cyanide Company (Ehrlich et al., 1979; Vecchioli et al., 1984). The results of these tests already discussed above show that a unique suite of information is derived from each type of test. That the backflush experiment was the most useful in documenting reactions in the immediate vicinity of the injection well. These near well bore reactions were completed by the time the fluid reached the monitor well only 132 m away. Biologic reactions appeared to proceed more rapidly than the waste/rock reactions and, therefore, the biologic reactions were characterized from data from the backflush experiment and waste/rock reactions were characterized from the monitor well data.

In contrast, backflush and flow through data were collected at the Wilmington, N.C., waste disposal site where a carboxylic acid waste stream was injected into a sandstone aquifer by Hercules Chemical, Inc. (Leenheer and Malcom, 1973; Leenheer et al., 1976a, 1976b). Again the results from both types of test were useful in determining waste reactions in all the transition zones from the waste plume to the unaltered formation fluid (Leenheer et al., 1976a, 1976b). However for this test case the backflush data gave information on waste/rock reactions and the monitor well data gave information on microbial degradation.

Although field experiments are the most reliable method of determining subsurface waste transformations, if thermochemical calculations and laboratory experiments are not used to support these results in order to determine the chemical controls on reactions a field test would have to be conducted at each geologically distinct site for every combination of waste solution, formation fluid composition, and reservoir temperature and pressure.

RECOMMENDATIONS

REPORTING OF WASTE STREAM COMPOSITIONS

In compilation of the chemical compositions of industrial waste streams injected into Texas aquifers from injection well reports submitted to the Texas Water Commission as required by Texas Underground Injection Control Regulations, it became apparent that requiring a chemical analyses of the waste stream composition is not all that is needed to assure that adequate data on the waste stream compositions are available to determine subsurface degradation reactions. The majority of the injectors responded to this broad requirement by reporting an incomplete list of major inorganic cations and anions, and organic compounds. Rather than requiring a chemical analysis in general, specific analysis should be requested and in some cases the preferred analytic methods should be stated. The injector should be required to ascertain that all major and minor constituents are analyzed for by using standard inorganic and organic wet chemical procedures such as comparing the total anion and cation concentrations to the analysis of total dissolved solids, and total organic and inorganic carbon analyses to the total reported concentrations of organic compounds and alkalinity.

PREFERRED WASTE STREAM COMPOSITIONS

Review of the methods of waste degradation indicates that for many waste streams a significant method of degradation is microbial activity. For waste streams containing hazardous compounds in which biodegradation is the favored method of degradation, it is best to dispose of these waste streams in a well that is dedicated to disposal of that waste stream alone and that the waste stream composition is kept uniform and injected continuously. The reason for this is that it allows a population of microbes that consumed the injected hazardous compounds to flourish with a constant food supply. Injection of a uniform composition waste prevents injection in toxic concentrations or concentrations too low to support the population. Injection of other waste streams should be prevented because those streams may be toxic to the microbes already developed.

For the case in which chemical transformations are the favored methods of degradation, injection of multiple waste stream compositions could possibly be used to encourage degradation. Similarly, multiple waste stream compositions could be used to enhanced sorption, or could possibly result in later desorption of hazardous compounds sorped from the previous waste stream. More work needs to be done on this issue in studying subsurface waste degradation.

CHEMICAL ANALYSES OF LABORATORY AND FIELD TEST SAMPLES

Geochemical processes are interrelated, such that a shift in equilibrium in solution effects all components in solution. All aqueous species that could indicate the results of reactions or affect other reactions in solution, should be analyzed for and studied. That includes all major and minor inorganic and organic compounds, gases and microbial populations in of fluid samples collected from laboratory and field experiments. Isotopic analysis could, also, prove useful in predicting reaction mechanisms. Analysis for only the hazardous compound of interest and a couple of major cations and anions does not permit prediction of chemical transformations, water/rock reactions, microbial activity, and sorption. Reporting of complete chemical analyses permits predictions of chemical interactions from the field testing conducted on the carboxylic waste stream injected near Wilmington, N.C. discussed above (Leenheer et al., 1976a, 1976b). In this study of the carboxylic waste reactions, for example, without complete chemical analyses it would have been difficult to discern waste loses from chemical transformation, microbial activity and sorption, and the source of gases as from [6~er/rock reactions or microbial activity. The majority of the experimental work on waste transformations reported in the literature lack complete chemical data sets and, therefore, the reported conclusions as to waste transformations are in many cases inferred and not verified by the data reported.

THERMOCHEMICAL CALCULATIONS

Chemical equilibrium and reactions in mixed organic-inorganic waste solutions are interrelated and, therefore, to predict the results of these reactions or interpret reactions documented by experimental results for individual waste streams and injection environments is by thermochemical calculations. Programs for doing these types of calculations are available and are presented in the above discussions. For these calculations, however, a thermochemical data base including all chemical species in solution that could effect reaction pathways is needed. A data base is already available for inorganic species and precipitates (Helgeson et al., 1978), organic species of interest to industrial waste disposal problems need to be added to the data bases. This is a sizeable task because 1) much of the data for aqueous organic ions and compounds is not available and needs to be calculated from other available data (cf. Shock, 1987), and 2) data available or calculated must be evaluated and adjusted to assure internal consistency within the data base (ie. all experiments and calculation used the same standard states, etc.). Therefore, compilation of a thermochemical data base containing equilibrium constants for the dissociation reactions for organic compounds and ions commonly disposed of by deep well injected and their product phases in conjunction with already available data for inorganic species needs to be compiled.

EXPERIMENTAL DESIGN FOR PREDICTING WASTE DEGRADATION REACTIONS

There are several approaches to predicting subsurface waste reactions, theoretically with coupled thermochemical calculations and numerical simulation of chemical and biological reactions, batch and flow through laboratory experiments, and injection-backflow and flow through field tests. As is evident from the above presentation of validation methods, none of these approaches can be used alone to adequately predict subsurface waste activities.

Thermochemical calculations alone cannot adequately predict hazardous waste reactions at subsurface conditions, particularly for the most commonly injected waste stream, which consists of a concentrated solution enriched in a suite of organic compounds and in some cases trace metals. Thermochemical data necessary for calculation of organic, organic-inorganic, and biochemical reactions that control degradation in complex waste streams are generally not available. In addition, ion interaction models for calculation of the behavior of organic compounds and trace metals in high-ionic-strength solutions, common to both the injectate and formation fluids, have not yet been developed. Thermochemical calculations alone that are limited to those chemical constituents for which thermochemical data are available may not adequately predict degradation reactions because chemical reactions in solution are affected by all components in the solution.

Laboratory experiments are plagued with problems also, preventing adequate prediction of waste degradation reactions without being augmented with thermochemical calculations and field verification. An important limitation on laboratory experiments is the unknown contribution of microbiologic activity on waste degradation. Although preliminary data suggest microbes are present and active at the depths of deep-well injection (Wobber, 1986), not enough information is available to duplicate this microbe activity in the laboratory. If subsurface conditions are not closely duplicated, controls on degradation reactions could be misrepresented.

The favored approach is to combine field testing of a tracer laden waste stream with monitor well samples, and injection well backflush samples, with thermochemical calculations to document inorganic and organic reactions augmented by laboratory experiments to document microbial activity, and organic reactions and sorption for which thermochemical data are lacking. Monitor wells are seldom available at deep well injection disposal sites. For cases in which monitor wells are not available, injection-backflow testing, augmented by thermochemical calculations and laboratory experiments, could be used to predict waste reactions, with the injection-backflow test data giving information on subsurface reactions that can be used to guide the theoretical calculations and laboratory experiments.

CONCLUSION

The compilation of waste stream compositions included in this report indicate that the majority of the wastes and hazardous materials injected are organic compounds, and that the majority of the waste streams contain an array of toxic and nontoxic organic compounds and trace metals. Three of the more significant hazardous waste groups are organic, phenols, ketones-aldehydes and nitriles, and one inorganic, cyanide. The most significant nonhazardous waste groups include carboxylic acids and alcohols.

Subsurface degradation of wastes is generally accomplished by more than one process, and involves all components in solution. A sequence of reactions develop starting at the point of injection and progress out into the formation. Chemical zoning includes shifts from oxidized to reduced conditions, a zone of biologic activity and water/rock reactions. In studies of subsurface disposal aquifers, it is apparent that each of these process is generally active in a disposal aquifer, however, they can overlap with their order of occurrence being dependent on the waste composition and aquifer conditions. Nonhazardous components in the waste stream, such as carboxylic acids, can have significant effects on subsurface reactions and, therefore, the presence of all reactant species in the waste stream should also be considered in the prediction of toxic waste degradation.

Microbial degradation appears to be the overall most active method of subsurface waste degradation, however, very little is known of this process in the deep subsurface. Chemical transformations, such as hydrolysis, oxidation-reduction ect., of hazardous materials also result in degradation, although they are different for each waste group and are favored by different chemical conditions. Similarly subsurface sorption of the majority of the significant hazardous wastes is likely but are favored by different chemical conditions. Additional work is needed to determine the optimum conditions for all these process.

In the study of subsurface waste reactions there are a number of approaches that have been taken, theoretical, laboratory experiments and field testing. Because of the deficiencies in thermochemical data for complex organic systems, and the inherent problems of laboratory experiments in duplicating deep subsurface microbial activity, field testing is still necessary to determine the complex suite of reactions occurring upon subsurface degradation.

It is apparent from this study that the majority of hazardous wastes disposed of by deep well injection can be chemically degradation in the subsurface to prevent their long term contamination of ground water. At present, however, disposal practices, waste stream compositions, and waste pretreatment measures are probably not adequate to achieve maximum subsurface degradation. Thermochemical calculations, and laboratory and field verification of subsurface waste degradation reactions can be used to design injection procedures that enhance waste transformations and assure that the greatest possible degradation is taking place.

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REFERENCES

Alexander, M., 1980, Biodegradation of toxic chemicals in water and soil. In Hague, R., ed., Dynamics, Exposure and Hazard Assessment of Toxic Chemicals: Ann Arbour Science, p. 179-190.

American Cyanamid Company, 1959, The chemistry of acrylonitriles, 2nd edition: Petrochemicals Department, American Cyanamid Company, New York., 116p.

Baedecker, M. J. and Back, W., 1979a, Hydrological processes and chemical reactions at a landfill: Ground Water, v. 17, no. 5, p. 429-437.

Baedecker, M. J. and Back, W., 1979b, Modern marine sediments as a natural analog to the chemically stressed environment of a landfill: Journal of Hydrology, v. 43, p. 393-414.

Beeman, R. E. and Suflita, J. M., 1988, Environmental factors influencing methanogenesis in a shallow anoxic aquifer: a field and laboratory study: manuscript in review.

Boles, J. R., 1978, Active ankerite cementation in the subsurface Eocene of southwest Texas: Contributions to Mineralogy and Petrology, v. 68, p. 13-22.

Boles, J. R. and Franks, S. G., 1979, Clay diagenesis in Wilcox sandstones of southwest Texas: Implications of smectite diagenesis on sandstone cement: Journal of Sedimentary Petrology, v. 49, p. 55-70.

Bouwer, E. J., and McCarty, P. L., 1984, Modeling of trace organics biotransformation in the subsurface: Ground Water, v. 22, no. 4, p. 433-440.

Briggs, G. G., 1981, Theoretical and experimental relationships between soil adsorption, octanol-water partition coefficients, water solubilities, bioconcentration factors, and the parachor: Journal of Agriculture and Food Chemistry, v. 29, p. 1050-1059.

Callahan, M. A., Slimak, M. W., Gabel, N. W., May, I. P., Fowler, C. F., Freed, J. R., Jennings, P. Durfee, R. L., Whitmore, F. C., Maestri, B., Mabey, W. R., Holt, B. R. and Gould, C., 1979, Water-Related Environmental Fate of 129 Priority Pollutants, Volumes I and II: EPA-440/4-79-029a and b.

Capuano, R. M., 1977, Chemical Mass Transfer and Solution Flow in Wyoming Roll-Type Uranium Deposits: M.S. thesis, The University of Arizona, Tucson, Arizona, 81p.

Capuano, R. M., 1988, Chemical Equilibria and Fluid Flow during Compaction Diagenesis of Organic-Rich Geopressured Sediments: Ph.D. dissertation, The Unversity of Arizona, Tucson, Arizona, 120p.

Chapman, P. J., 1972, An outline of reaction sequences used for the bacterial degradation of phenolic compounds. In Degradation of Synthetic Organic Molecules in the Biosphere: National Academy of Science, Washington, D.C., p.17-55.

Charlesworth, J. M., 1986, Interaction of clay minerals with organic nitrogen compounds released by kerogen pyrolysis: Geochimica Cosmochimica Acta, v. 50, p. 1431-1435.

Cherry, J. A., Gillham, R. W., and Barker, J. F., 1984, Contaminants in Groundwater; Chemical Processes: in Groundwater Contamination: National Academy Press, Washington, D.C., p. 46-64.

Collins, A. G. and Crocker, M. E., 1988, Laboratory Protocol for Determining Fate of Waste Disposed of in Deep Wells: Environmental Protection Agency Report EPA/600/8-88/008, PB88-166061, 63p.

DiGeronimo, M. J. and Antoine, A. D., 1976, Metabolism of acetonitrile and propionitrile by nocardia rhodochrous LL100-21: Applied and Environmental Microbiology, v. 31, p. 900-906.

Donaldson, E. C., Crocker, M. E., and Manning, F. S., 1975, Adsorption of organic compounds on Cottage Grove Sandstone, Bartlesville Energy Research Center Report BERC/RI-75/4, 16p.

Drez, P. E., 1988, Rock-water interactions between injected waste and host formation fluids and mineralogy during deep well injection (abstr.): Transactions American Geophysical Union, Eos, v. 69, no. 16, p. 350.

Ehrlich, G. G., Godsy, E. M., Pascale, C. A., and Vecchioli, J., 1979, Chemical changes in an industrial waste liquid during post-injection movement in a limestone aquifer, Pensacola, Florida: Ground Water, v. 17, p.562-573.

Fedorak, P. M., Roberts, D. J. and Hrudey, S. E., 1986, The effects of cyanide on the methanogenic degradation of phenolic compounds: Water Resources, v. 20, p. 1315-1320.

Garrels, R. M. and Christ, C. L., 1965, Solutions, Minerals, and Equilibria: Freeman, Cooper and Company, California, 450p.

Gordon W. and Bloom, J., 1986, Deeper problems, limits to underground injection as a hazardous waste disposal method. In Proceedings of the International Symposium on Subsurface Injection of Liquid Wastes: National Water Well Association, Dublin, Ohio, 739p.

Grula, M. M., and Grula, E. A., 1975, Feasibility of microbial decomposition of organic wastes under conditions existing in deep wells; U. S. Department of Mines Report, BERC/RI-76/6, 55p.

Hanor, J. S., 1979, The sedimentary genesis of hydrothermal fluids. In H. L. Barnes, ed., Geochemistry of Hydrothermal Ore Deposits, 2nd ed.: John Wiley, N.Y., p.137-172.

Healy, J. B., Jr. and Young, L. Y., 1978, Catechol and phenol degradation by a methanogenic population of bacteria: Applied Environmental Microbiology, v. 35, p. 216-218.

Helgeson, H. C., 1970, Description and interpretation of phase relations in geochemical processes involving aqueous solutions: American Journal of Science, v. 268, p. 415-438.

Helgeson, H. C., Delany, J. M., Nesbitt, H. W., and Bird, D. K., 1978, Summary and critique of the thermodynammic properties of rock-forming minerals: American Journal of Science, v. 278-A, p. 1-229.

Khan, A., Hassett, J. J., Banwart, W. L., Means, J. C., and Wood, S. G., 1979, Sorption of acetophenone by sediments and soils: Soil Science, v. 128, no. 5, p. 297-302.

Kharaka, Y. K., Lico, M. S., Wright, V. A. and Carothers, W. W., 1979, Geochemistry of formation waters from Pleasant Bayou no 2 well and adjacent areas in coastal Texas. In M. H. Dorfman and W.I L. Fisher, eds., Proceedings of the Fourth U.S. Gulf Coast Geopressured Geothermal Energy Conference: The University of Texas at Austin, Center for Energy Studies, v. 1, p. 168-193.

Knape, B. K., 1984, Underground Injection Operations in Texas: Texas Department of Water Resources, Austin, Texas, Report 291, 197p.

Kobayashi, H. and Rittmann, B. E., 1982, Microbial removal of hazardous organic compounds: Environmental Science and Technology, v. 16, p. 170A-183A.

Kreitler, C. W., Akhter, M. S., Wood, W. T. and Donnelly, A. C. A., 1988, Regional Hydrologic-Hydrochemical characterization of Saline Formations in the Texas Gulf Coast that are used for Deep well Injection of Chemical Wastes: Bureau of Economic Geology The University of Texas at Austin contract report to the U.S. Environmental Protection Agency cooperative agreement no. CR812786-01-0,

Kreitler, C. W. and Richter, B. C., 1986, Hydrochemical Characterization of Saline Aquifers of the Texas Gulf Coast used for Disposal of Industrial Waste: Bureau of Economic Geology The University of Texas at Austin contract report to the U.S. Environmental Protection Agency under contract no. R-812785-01-0, 164p.

Land, L. S., 1984, Frio sandstone diagenesis, Texas Gulf Coast: a regional isotopic study. In D. A. McDonald and R. C. Surdam, eds., Clastic Diagenesis: American Association of Petroleum Geologists Memoir 37, Tulsa, Oklahoma, p. 47-62.

Lee, M. D., Wilson, J. T. and Ward, C. H., 1984, Microbial degradation of selected aromatics in a hazardous waste site: Developments in Industrial Microbiology, v. 25, p. 557-565.

Leenheer, J. A., and Malcolm, R. L., 1973, Case history of subsurface waste injection of an industrial organic waste. In J. Braunstein, ed., Second International Symposium on Underground Waste Management and Artificial Recharge, vol. 1, p. 565-584.

Leenheer, J. A., Malcolm, R. L. and White, W. R., 1976a, Investigation of the reactivity and fate of certain organic components of an industrial waste after deep-well injection: Environmental Science & Technology, v.10, no. 5, p 445-451.

Leenheer, J. A., Malcolm, R. L., and White, W. R., 1976b, Physical, chemical, and biological aspects of subsurface organic waste injection near Wilmington, North Carolina: U. S. Geological Survey Professional Paper 987, 51p.

Lewandowski, Z., 1984, Biological denitrification in the presence of cyanide: Water Resources, v. 18, p. 289-297.

Loch, J. P. G., and Lagas, P., 1985, The mobilization of heavy metals in river sediment by nitrilotriacetic acid (NTA). In E. Arvin, ed., Water Science and Technology, v. 17, no. 9, Degradation, Retention, and Dispersion of Pollutants in Groundwater, p. 101-113.

Loucks, R. G., Dodge, M. M. and Galloway, W. E., 1979, Sandstone consolidation analyses to delineate area of high-quality reservoirs suitable for production of geopressured geothermal energy along the Texas Gulf Coast: The University of Texas at Austin, Bureau of Economic Geology, report prepared for the U. S. Department of Energy, Division of Geothermal Energy, under contract no. EG-77-5-05-5554, 98p.

Mabey W. and Mill, T., 1978, Critical review of hydrolysis of organic compounds in water under environmental conditions: Journal Physical Chemistry Reference Data, v. 7, no. 2, p. 383-415.

Mankin, C. J. and Moffett, T. B., 1987, Should we continue deep well disposal?: Geotimes, v. 32, p. 13-15.

March, J., 1977, Advanced Organic Chemistry: Reactions, Mechanisms and Structure, second edition, McGraw-Hill, 1328p.

Meislich, H., Nechamkin, H. and Sharefkin, J., 1977, Organic Chemistry, McGraw-Hill, 480p.

Moore, J. W. and Ramamoorthy, S., 1984, Organic Chemicals in Natural Waters: Springer-Verlag, 289p.

Morel, F. M. M., 1983, Principles of Aquatic Chemistry: John Wiley, 446p.

Morel, F. M. M., Yeasted, J. G. and Westall, J. C., 1981, Adsorption models: A mathematical analysis in the framework of general equilibrium calculations. In M. A. Anderson and A. J. Rubin, eds., Adsorption of Inorganics at Solid-Liquid Interfaces: Ann Arbour Science, Ann Arbour, Michigan, 357p.

Oremland, R. S., and Taylor, B. F., 1978, Sulfate reduction and methanogenesis in marine sediments: Geochimica Cosmochimica Acta, v. 42, p 209-214.

Ragone, S. E., Vecchioli, J. and Ku, H. F. H., 1973, Short-term effect of injection of tertiary-treated sewage on iron concentration of water in Magothy aquifer, Bay Park, New York. In J. Braunstein, ed.: Second International Symposium on Underground Waste Management and Artificial Recharge, volume 1: The George Banta Company, Inc., Menasha, Wisconsin, p. 273-290.

Rappaport, Z., 1970, The Chemistry of the Cyano Group: John Wiley, 1044p.

Rinehart, K. L., Jr., 1973, Oxidation and Reduction of Organic Compounds: Prentice-Hall, N. J., 148p.

Rittmann, B. E. and McCarty, P. L., 1980a, Model of steady-state biofilm kinetics: Biotech. Bioeng., v. 22, p. 2343-2357.

Rittmann, B. E. and McCarty, P. L., 1980b, Evaluation of steady-state biofilm kinetics: Biotech. Bioeng., v. 22, p. 2359-2373.

Rittmann, B. E., McCarty, P. L. and Roberts, P. V., 1980, Trace-organics biodegradation in aquifer recharge: Ground Water, v. 18, no. 3, p. 236-967.

Roberts, J. D. and Caserio, M. C., 1979, Basic Principles of Organic Chemistry, 2nd ed., Benjamin, Reading, Ma., p. 689.

Roberts, P. V., Leckie, J. O., McCarty, P. L., Parks, G. A., Street, R. L., Young, L. Y., Reinhard, M., Cooper, R. C., 1978, Groundwater recharge by injection of reclaimed water in Palo Alto: Technical Report No. 229; Department of Civil Engineering, Stanford University, Stanford, CA, 35p.

Roy, W. R., Mravik, S. C., Krapac, I. G., Dickerson, D. R., and Griffin, R. A., 1988, Geochemical interactions of hazardous wastes with geological formations in deep-well systems. Final Report Illinois State Geological Survey, report prepared for the Office of Drinking Water WH 550 and the Hazardous Waste Research and Information Center, 95 p., draft copy.

Sanchez, A., Hidalgo, A. and Serratosa, J. M., 1972, Adsorption of nitriles on montmorillonites. In J. M. Serratosa, ed.: Proceedings International Clay Conference, Madrid, 1972, 617-626.

Schwarzenbach, R. P. and Westall, J., 1985, Sorption of hydrophobic trace organic compounds in groundwater systems: Wat. Sci. Tech., v 17, p. 39-55.

Sharpe, A. G., 1976, The Chemistry of Cyano Complexes of the Transition Metals: Academic Press, 302p.

Shock, E. L., 1987, Standard Molal Properties of Ionic Species and Inorganic Acids, Dissolved Gases and Organic Molecules in Hydrothermal Systems: PhD dissertation, University of California, Berkeley, California, 260p.

Siebert, R. M., Moncure, G. K. and Lahann, R. W., 1984, A theory of framework grain dissolution in sandstones. In D. A. McDonald and R. C. Surdam, eds., Clastic Diagenesis: American Association of Petroleum Geologist Memoir 37, Tulsa, Oklahoma, p. 163-175.

Smith, A. E. and Cullimore, D. R., 1974, The in vitro degradation of the herbicide bromoxynil: Canadian Journal Microbiology, v. 20, p. 773-776.

Sorek, S. and Braester, C, 1988, Eulerian-lagrangian formulation of the equations for groundwater denitrification using bacterial activity: Water Resources Research, in review.

Southworth, G. R., and Keller, J. L., 1986, Hydrophobic sorption of polar organics by low organic carbon soils: Water, Air, and Soil Pollution, v. 28, p. 239-248.

Strycker, A. and Collins, A. G., 1987, State-of-the-Art Report of Injection of Hazardous Wastes into Deep Wells: National Institute for Petroleum and Energy research, Bartlesville, Oklahomma, environmental Protection agency Report EPA/600/8-87/013.

Suflita, J. M., Gibson, S. A. and Beeman, R. E., 1988, Anaerobic biotransformations of pollutant chemicals in aquifers: Journal of Industrial Microbiology, v. 3, p. 179-194.

Thurman, E. M., 1985, Organic Geochemistry of Natural Waters, Kluwer Academic Publishers, Hingham, Massachusetts, 497p.

U.S. General Accounting Office, 1987, Hazardous Waste Controls over Injection Well Disposal Operations: Report to the Chairman, Environment, Energy, and Natural Resources Subcommittee, Committee on Government Operations, House of Representatives, August, 1987, GAO/RCED-87-170, 52p.

Vecchioli, J., Ehrlich, G. G., Godsy, E. M. and Pascale, C. A., 1984, Alterations in the chemistry of an industrial waste liquid injected into limestone near Penasacola, Florida. In G. Castany, E. Groba and E. Romijn eds., Hydrogeology of Karstic Terrains, Case History, v. 1, p 217-221.

Wade, L. G., Jr., 1987, Organic Chemistry, Prentice Hall, 1377p.

White, D. C., Nickels, J. S., Parker, J. H., Findlay, R. H., Gehron, M. J., Smith, G. A. and Martz, R. F., 1985, Biochemical measures of the biomass, community structure, and metabolic activity of the ground water microbiota. In C. H. Ward, W. Giger, and P. L. McCarty, eds., Ground Water Quality: John Wiley & Sons, p. 307-329.

Wilson, J. T., Noonan, M. J. and McNabb, J. F., 1985, Biodegradation of contaminants in the subsurface. In C. H. Ward, W. Giger, and P. L. McCarty, eds., Ground Water Quality: John Wiley & Sons, N.Y., p.483-492.

Wobber, F. J., 1986, Microbiology of Subsurface Environments: Proceedings Second Investigators' Meeting -- Savannah River Exploratory Deep Probe: U.S. Department of Energy Office of Energy Research, DOE EER-0312 E 1.99:DE87 013094, 29p.

Wolery, T. J., 1983, EQ3NR, A Computer Program for Geochemical Aqueous Speciation-Solubility Calculations: User's Guide and Documentation: Lawrence Livermore National Laboratory Report UCRL-53414, 191p.

Wolery, T. J., 1984, EQ6, A Computer Program for Reaction-Path Modeling of Aqueous Geochemical Systems: User's Guide and Documentation: Lawrence Livermore National Laboratory Report UCRL-51, 251p.

Young, L. Y., 1984, Anaerobic degradation of aromatic compounds. In D. T. Gibson, ed., Microbial Degradation of Organic Compounds: Marcel Dekker, N. Y., 535p.

Table 1. Waste production process, general waste description, and gallons of waste injected in 1985 and 1986 for active Class-I on-site waste disposal wells in Texas.[a]

No.	Company	Plant	WDW	Process	Waste	1985 (gallons)	1986 (gallons)
1	Amoco	Texas City	80	refinery operation	organic, brine, caustic	13540330	33790
2	Amoco	Texas City	127	refinery operation	organic, brine, caustic	148105360	nd[b]
3	Amoco	Texas City	128	refinery operation	organic, brine, caustic	45947780	nd
4	Arco	Channelview	36	manufacture of synthetic organic chemicals	organic	0	24750327
5	Arco	Channelview	148	manufacture of synthetic organic chemicals	organic	77240689	nd
6	Arco	Channelview	162	manufacture of synthetic organic chemicals	organic	44	nd
7	Asarco	Amarillo Copper	129	electrolytic refining of Cu	acid, metals	69743814	nd
8	Badische	Freeport	51	manufacture of cyclohexanone and caprolactam	organic	33780000	38287000
9	Badische	Freeport	99	manufacture of cyclohexanone and caprolactam	organic	0	0
10	Caithness Mining	Hebbronville	185	in-situ leach for uranium and aquifer restoration	low level radioactive (Ra^{226}-U)	44302504	nd
11	Celanese	Bay City	14	chemical manufacturing	organic	57803040	66307680
12	Celanese	Bay City	32	chemical manufacturing	organic	53062560	37015200
13	Celanese	Bay City	49	chemical manufacturing	organic	5402560	34165440
14	Celanese	Bay City	110	chemical manufacturing	acid, organic	56823840	89974080
15	Celanese	Bishop	211	chemical manufacturing	organic	93793000	nd
16	Celanese	Bishop	212	chemical manufacturing	organic	12355000	nd
17	Celanese	Clear Lake	33	chemical manufacturing	organic	120029200	123720240
18	Celanese	Clear Lake	45	chemical manufacturing	organic	0	319800
19	Chevron	Palangana Dome	134	in-situ leach mining for U	Ra^{226}	15046100	nd
20	Cominco Chem	Borger	115	manufacture of anhydrous ammonia and urea	alkaline ammonia-sulfate	148765918	182640372
21	Conoco	Trevino Mine	189	in-situ leach mining for U	Ra^{226}	63084765	nd
22	Corpus Christi Petro	Olefins	152	manufacture of olefinic hydrocarbons	sulfide waste water from refinery	18017580	nd
23	Corpus Christi Petro	Olefins	153	manufacture of olefinic hydrocarbons	sulfide waste water from refinery	121680	nd
24	Diamond Shamrock	McKee	20	petroleum refinery, natural gas processing, NH3 plant	ammonia, organic	82549300	nd
25	Diamond Shamrock	McKee	102	petroleum refinery, natural gas processing, NH3 plant	ammonia, organic	11973690	11721940
26	Diamond Shamrock	McKee	192	petroleum refinery, natural gas processing, NH3 plant	ammonia, organic	78110500	nd
27	Dupont	Beaumont	100	chemical manufacturing	organic, ammonium sulfate	80600000	80800000
28	Dupont	Beaumont	101	chemical manufacturing	organic, ammonium sulfate	145900000	143900000
29	Dupont	Ingleside	109	manufacture of chlorocarbons and freon	freon alkaline waste	0	154490
30	Dupont	Ingleside	121	manufacture of chlorocarbons and freon	freon alkaline waste	7881120	6830820
31	Dupont	LaPorte	82	manufacture of polyvinyl alcohol and vinyl acetate	acid, organic	48667900	64076118
32	Dupont	LaPorte	83	manufacture of polyvinyl alcohol and vinyl acetate	acid, organic	51258300	62969487
33	Dupont	LaPorte	149	manufacture of polyvinyl alcohol and vinyl acetate	acid, organic	50861400	nd
34	Dupont	Sabine River	54	manufacture of adiponitrile	organic	147576000	134877000
35	Dupont	Sabine River	55	manufacture of adiponitrile	organic	0	0
36	Dupont	Sabine River	56	manufacture of adiponitrile	organic	16137000	28086000
37	Dupont	Sabine River	57	manufacture of adiponitrile	organic	1955000	3473000
38	Dupont	Sabine River	132	manufacture of adipic acid	organic acid	0	0
39	Dupont	Sabine River	191	manufacture of adiponitrile	organic	26708000	nd
40	Dupont	Sabine River	207	manufacture of adipic acid	organic, acid	138140000	nd
41	Dupont	Victoria	4	manufacture of adiponitrile, hexamethylenediamine	organic, cyanide, metals, alkaline	26729280	586704
42	Dupont	Victoria	28	manufacture of adipic acid, dodecanedioic acid, nitric acid	nitric acid, organic, metals	138520000	152447780
43	Dupont	Victoria	29	manufacture of adipic acid, dodecanedioic acid, nitric acid	nitric acid, organic, metals	131222340	138422500

44	Dupont	Victoria	30	manufacture of adipic acid, dodecanedioic acid, nitric acid	nitric acid, organic, metals	132608400	136931220
45	Dupont	Victoria	105	manufacture of adiponitrile, hexamethylenediamine	organic, cyanide, metals, alkaline	12722400	41194080
46	Dupont	Victoria	106	manufacture of adiponitrile, hexamethylenediamine	organic, cyanide, metals, alkaline	40907520	28335600
47	Dupont	Victoria	142	manufacture of adiponitrile, hexamethylenediamine	organic, cyanide, metals, alkaline	72298080	nd
48	Dupont	Victoria	143	manufacture of adiponitrile, hexamethylenediamine	organic, cyanide, metals, alkaline	85126509	nd
49	Dupont	Victoria	144	manf. adiponitrile, hexamethylenediamine; tritotylphosphite degradation	organic, cyanide, metals, alkaline	35848800	nd
50	Dupont	Victoria	145	manufacture of adipic acid, dodecanedioic acid, nitric acid	nitric acid, organic, metals	137275800	nd
51	El Paso Prod	Odessa Petro	16	chemical manufacturing	organic	nd	75300000
52	El Paso Prod	Odessa Petro	88	chemical manufacturing	organic	74419000	88509000
53	El Paso Prod	Odessa Petro	126	chemical manufacturing	organic	99962000	nd
54	El Paso Prod	Odessa Petro	154	chemical manufacturing	organic	37305000	nd
55	Everest Mineral	Hobson Mine	168	in-situ leach mining for U and yellow cake extraction	Ra^{226}	21216830	nd
56	Everest Mineral	Las Palmas Mine	187	in-situ leach mining for U	Ra^{226}	41380709	nd
57	GAF Corp	Texas City	34	organic chemical synthesis; aceteline industrial chemicals	organic	89670000	75370000
58	GAF Corp	Texas City	113	organic chemical synthesis; aceteline industrial chemicals	organic	0	16240000
59	GAF Corp	Texas City	114	organic chemical synthesis; aceteline industrial chemicals	organic	57960000	30800000
60	IEC	Three Rivers	159	in-situ solution mining for U and aquifer restoration	Ra^{226}	22383821	nd
61	Iowa Beef Proc.	Amarillo Hide	120	hide processing	NaCl brine	4232702	4281406
62	Jetco	Amine	117	manufacture of nitriles, and quaternary ammonium chloride	ammonia, ammonium chloride	26204283	23076808
63	Lundberg Ind	Dumas	3	potassium sulfate production	HCl	74632	53332
64	Merichem	Houston	147	hydrocarbon extraction from refinery waste	caustic, organic	85910390	nd
65	Mobil	Corpus Christi	150	in-situ solution mining for U	Ra^{226}	29434896	nd
66	Mobile	Corpus Christi	151	in-situ solution mining for U	Ra^{226}	53875008	nd
67	Mobile	Corpus Christi	197	in-situ solution mining for U	Ra^{226}	68787648	nd
68	Monsanto	Chocolate Bayou	13	organic chemical production	organic	362851000	330004000
69	Monsanto	Texas City	91	chemical manufacturing	organic	74150000	7247
70	Monsanto	Texas City	196	chemical manufacturing	organic	179970000	nd
71	Penwalt	Crosby	122	organic peroxide, nitrogen compound manf.	petrochemical waste, organic	32374078	nd
72	Phillips	Borger	67	Rubber Chemical Complex	organic	4666500	1135500
73	Phillips	Borger	68	manufacturing of polyphenylene sulfide (Ryton)	organic	64225000	62050000
74	Sandoz-Velsicol	Beaumont	125	organic chemical manufacturing	organic	64426834	nd
75	Sandoz-Velsicol	Beaumont	155	organic chemical manufacturing	organic	63217883	nd
76	Shell	Deer Park	172	manufacture of resins, intermediate products, solvents	organic	45232000	nd
77	Shell	Deer Park	173	manufacture of resins, intermediate products, solvents	organic	60889822	nd
78	Standard Oil-Vistron	Port Lavaca	163	petrochemical manufacturing	organic, cyanide	45275153	nd
79	Standard Oil-Vistron	Port Lavaca	164	petrochemical manufacturing	organic, cyanide	62384101	nd
80	Standard Oil-Vistron	Port Lavaca	165	petrochemical manufacturing	organic, cyanide	63412519	nd
81	Tenneco Uranium	Bruni Mine	195	in-situ solution mining for U	Ra^{226}	6290923	nd
82	Tex Tin-Gulf	Texas City	237	smelting and refining	acid inorganic	2312503	nd
83	Texaco	Amarillo	135	gasoline, diesel fuel manufacturing	inorganic sulfate-chloride brine	35802890	nd
84	Texaco	Amarillo	136	gasoline, diesel fuel manufacturing	inorganic sulfate-chloride brine	54590323	nd
85	US Steel	George West	123	in-situ solution mining for U	Ra^{226}	12283269	nd
86	US Steel	George West	124	in-situ solution mining for U	Ra^{226}	66306226	nd
87	US Steel	George West	130	in-situ solution mining for U	Ra^{226}	58606642	nd
88	US Steel	George West	140	in-situ solution mining for U	Ra^{226}	10328192	nd
89	US Steel	George West	141	in-situ solution mining for U	Ra^{226}	68738708	nd
90	US Steel	George West	174	in-situ solution mining for U	Ra^{226}	87861744	nd
91	W R Grace	Deer Park	222	manufacture of nitroparafins	organic	0	nd
92	W R Grace	Deer Park	223	manufacture of nitroparafins	organic	11422200	nd
93	Westinghouse	Bruni Mine	170	in-situ solution mining for U	Ra^{226}	16463084	nd

94	Witco	Houston	111	chemical manufacturing	organic	3365900	14846830
95	Witco	Houston	139	chemical manufacturing	organic	33442400	nd
96	Witco	Marshall	107	manufacture of organic peroxide materials	organic	92000	0
97	Witco	Marshall	180	manufacture of organic peroxide materials	organic	13856000	nd
98	Wyoming Minerals	Three Rivers	156	in-situ solution mining for U	Ra^{226}	1075950	nd
				TOTAL GALLONS OF WASTE INJECTED YEARLY:		5,097,273,866	2,353,694,791[c]

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a. Data compiled from Underground Injection Control files at the Texas Water Commission, Austin, Texas (see Capuano and Kreitler, 1988).

b. nd = total gallons of waste injected for that year not available at the time of this compilation.

c. The total gallons of waste injected in 1986 is well below the actual amount because of the large number of injection volumes not available.

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Table 2. Mass of all chemicals injected in 1985 and 1986.[a]

	1985 Minimum (kg)	1985 Maximum (kg)	1986 Minimum (kg)	1986 Maximum (kg)
INORGANIC				
PRIMARY INORGANIC CONSTITUENTS				
Na	76747308.	171358138.	28557813.	64932221.
K	2258534.	3454078.	9410.	113612.
Ca	1774374.	3438674.	483197.	520052.
Mg	298285.	542896.	83771.	86601.
Si	36215.	159386.	5595.	16234.
Al	4575.	5308.	350.	1002.
Cl	96259080.	200600366.	23110529.	87083934.
$CO_3^=$	7072922.	62959666.	1062981.	2637619.
HCO_3^-	13805726.	21934393.	2419103.	4532835.
SECONDARY INORGANIC CONSTITUENTS				
Ba[c] (100 mg/l)[d]	18017.	20713.	748.	1053.
B	105723.	150358.	27008.	65001.
F	480851.	2574809.	490643.	2611851.
I	454.	6632.	469.	6854.
ammonia	3735694.	132022415.	2486344.	116619300.
nitrate	15435169.	46577313.	8120495.	29051595.
nitrogen	17085767.	23325743.	7296114.	13480671.
HNO_3	161691.	298307.	0	0
PO_4	428735.	4192713.	270486.	5375594.
sulfide	628220.	23514853.	29584.	828590.
sulfate	92764580.	183415974.	56403973.	131410906.
sulfite	4714491.	9489277.	798.	3476.
H_2SO_4	1953168.	4591828.	510509.	2552547.
CN^- (cyanide)[b,c]	5289199.	7509429.	2405308	4437993.
Trace metals:				
Sn	80.	297.	0	0
Pb[c] (5.0mg/l)[d]	76135.	77419.	79.	142.
As[c] (5.0 mg/l)[d]	1153.	76157.	33.	66118.
Sb[e]	113.	131.	0	4.
Bi	77.	140.	0	0
Se[c] (1.0mg/l)[d]	33.	5637.	2.	16.
Zn	4919.	701410.	2254.	1202064.
Cd[c] (1.0 mg/l)[d]	4766.	4788.	39.	53.
Hg[f] (0.2 mg/l)[d]	197.	1728.	258.	2240.
V	33853.	54335.	16194.	32408.
Cr[c] (5.0mg/l)[d]	5057.	10596.	2195.	4693.
Mo	21092.	162399.	3997.	34104.
Mn	2327.	9975.	548.	5212.
Fe	283417.	465495.	33038.	42458.
Co	261.	2776.	246.	2898.
Ni[e]	555893.	5559119.	195724.	6360775.
Cu	552532.	607478.	33058.	72956.
Ag[c] (5.0 mg/l)[d]	55.	91.	2.	23.
Actinide:				
U	9140.	93510.	0	0
Secondary Inorganics Total	144,352,859	445,523,845	78,330,146	314,271,595
Secondary Inorganics Total Toxic	5,950,618	13,265,808	2,604,388	10,873,110

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Table 2. Mass of all chemicals (cont.)

	1985 Minimum (kg)	1985 Maximum (kg)	1986 Minimum (kg)	1986 Maximum (kg)
ORGANIC COMPOUNDS				
Total Organic Carbon	58519665.	102206053.	31065225.	50973887.
Chemical Oxygen Demand	118491827.	317386242.	60736932.	168020305.
Biochemical Oxygen Demand	14162234.	33462510.	8054614.	10788293.
Oil and Grease	346256.	1127565.	81027.	339123.
ALKANES				
Straight chain alkanes				
propane	0	12050132.	0	0
Cycolalkanes				
cyclohexane[i]	131030.	452260.	172189.	548116.
TOTAL	131,030	12,502,392	172,189	548,116
TOTAL TOXIC - ignitable[i]	131,030	452,260	172,189	548,116
ALCOHOLS				
Aliphatic with single carbon-carbon bonds				
methyl alcohol (methanol)[i]	1541679.	18637324.	1310101.	13713809.
ethy alcohol (ethanol)	0	196545.	0	258283.
propyl alcohol (propanol)	0	196545.	0	258283.
butyl alcohol (butanol)[i]	435027.	23218316.	254838.	23813231.
pentyl alcohol (pentanol, amyl alcohol)	0	589,636.	0	774,850.
hexanol	0	655153.	0	860945.
TOTAL	1,976,706	43,493,519	1,564,939	39,679,401
TOTAL TOXIC - ignitable	1,976,706	41,855,640	1,564,939	37,527,040
Aliphatic with a double carbon-carbon bond				
allyl alcohol[b]	0	46165.	0	9367.
TOTAL TOXIC - nonignitable[j]	0	46,165	0	9,367
Alkyne (acetylene) alcohols - alliphatic with triple carbon-carbon bond				
hydroxymethylacetylene (propargyle alcohol)[b]	111755.	558779.	80370.	401853.
butynediol	111755.	558779.	80370.	401853.
TOTAL	223,510	1,117,558	160,740	803,706
TOTAL TOXIC - nonignitable	111,755	558,779	80,370	401,853
Cyclic (nonaromatic)				
cyclohexanol (cyclohexyl alcohol)	127857.	460286.	144916.	521698.

Table 2. Mass of all chemicals (cont.)

	1985 Minimum (kg)	1985 Maximum (kg)	1986 Minimum (kg)	1986 Maximum (kg)
ALCOHOLS (cont.)				
Diols				
Vicinal diols				
ethylene glycol (ethanediol)	454310.	4543105.	469491.	4694915.
diethylene glycol	45431.	22715526.	46949.	23474577.
triethylene glycol	45431.	22715526.	46949.	23474577.
propylene glycol (propanediol)	5082769.	6310759.	1031416.	1280605.
butylene glycol (butanediol)	468746.	3477501.	395487.	3151164.
ethyl propalene glycol (ethyl propanediol)	0	194456.	0	0
neopentyl glycol	52230.	52230.	0	0
TOTAL	6,148,917	60,009,103	1,990,292	56,075,838
TOTAL TOXIC	0	0	0	0
Triols				
glycerol (glycerine, propanetriol)	2169023.	20083554.	0	0
Pentaerythritols				
pentaerythritol	80755.	848940.	0	0
di pentaerythritol	8437.	8437.	0	0
TOTAL	89,192	857,377	0	0
TOTAL TOXIC	0	0	0	0
Oxirane-ether alcohol (heterocyclic nonaromatic)				
glycidol	52217.	52217.	0	0
Other nonaromatic alcohols				
trimethylol propane	15669.	613503.	0	0
ditrimethylol propane	0	1607.	0	0
trimethylol propane mono cyclic formal	10847.	660108.	0	0
bis-trimethylol propane mono layer formal	6026.	18079.	0	0
chlorinated				
chlorohydrin (mono-, di- and epi-)	140584.	140584.	0	0
TOTAL	173,126	1,433,881	0	0
TOTAL TOXIC	0	0	0	0
Phenol-alcohol				
α-methyl benzyl alcohol	1214140.	1671174.	246378.	339121.
ALL ALCOHOLS: TOTAL	12,174,688	129,216,397	4,107,265	97,429,131
TOTAL TOXIC - ignitable	1,976,706	41,855,640	1,564,939	37,527,040
TOTAL TOXIC - nonignitable	111,755	604,944	80,370	411,220

Table 2. Mass of all chemicals (cont.)

	1985 Minimum (kg)	1985 Maximum (kg)	1986 Minimum (kg)	1986 Maximum (kg)
ETHERS - HETEROCYCLIC NONAROMATIC				
tetrahydrofuran (THF)[i]	55877.	558779.	40185.	401853.
bisdioxane[f]	281169.	281169.	0	0
trioxane (metaformaldehyde)	136601.	136601.	0	0
tetroxane	30132.	30132.	0	0
TOTAL	503,779	1,006,681	40,185	401,853
TOTAL TOXIC - ignitable	55,877	558,779	40,185	401,853
TOTAL TOXIC - nonignitable	281,169	281,169	0	0
BENZENE AND BENZENE DERIVATIVES				
benzene[f]	111755.	947335.	80370.	1008475.
ethyl benzene	0	46165.	0	9367.
styrene (vinyl benzene)	0	18466.	0	3747.
anisole (methoxybenzene)	1449.	1449.	0	0
phenyl borates	6214196.	7249895.	1592343.	1857733.
trichlorobenzene[e]	483.	3381.	0	0
dichloroanisoles (dichloromethoxybenzene)[e]	11112.	11112.	0	0
TOTAL	6,338,995	8,277,803	1,672,713	2,879,322
TOTAL TOXIC - nonignitable	123,350	961,828	80,370	1,008,475
PHENOLS				
phenols (group)[g]	358923.	19074232.	8351.	13748269.
phenol[f]	1780902.	15185964.	198569.	2750711.
cresol (cresylic acid)[f]	0	6724024.	0	5973077.
hydroquinone (1,4 benzenediol)	0	114146.	0	96173.
tertiary butyl catechol	0	883135.	0	214893.
triphenyl borane	27137.	54275.	0	0
dichlorophenol[f,e]	31886.	188422.	0	0
TOTAL	2,198,848	42,224,198	206,920	22,783,123
TOTAL TOXIC - nonignitable	2,171,711	41,172,642	206,920	22,472,057

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Table 2. Mass of all chemicals (cont.)

	1985 Minimum (kg)	1985 Maximum (kg)	1986 Minimum (kg)	1986 Maximum (kg)
KETONES-ALDEHYDES				
KETONES				
Aliphatic				
butanone (methyl ethyl ketone)[f]	462546.	2279788.	469491.	2347457.
acetone (dimethyl ketone)[i]	80334.	803342.	0	0
Cyclic				
cyclohexanone[i]	12785.	127857.	14491.	144916.
Aromatic (benzene derivative)				
acetophenone (methyl phenyl ketone)[f]	101563.	286223.	20609.	58081.
TOTAL	657,228	3,497,210	504,591	2,550,454
TOTAL TOXIC - ignitable	93,119	931,199	14,491	144,916
TOTAL TOXIC - nonignitable	564,109	2,566,011	490,100	2,405,538
ALDEHYDES				
aldehydes	228394.	324650.	0	0
formaldehyde (methanal)[f]	1308550.	1755573.	135230.	456713.
acetaldehyde (ethanal)[i]	492132.	2510487.	517578.	2647885.
acrolein (propenal)[b]	28290.	28290.	28066.	28066.
Chlorinated				
chloroaldehyde	454310.	4543105.	469491.	4694915.
dichloroaldehyde	454310.	4543105.	469491.	4694915.
trichloroaldehyde	454310.	2271552.	469491.	2347457.
TOTAL	3,420,296	15,976,762	2,089,347	14,869,951
TOTAL TOXIC - ignitable	492,132	2,510,487	517,578	2,647,885
TOTAL TOXIC - nonignitable	1,336,804	1,783,863	163,296	484,779
KETONES - ALDEHYDES: TOTAL	4,077,524	19,473,972	2,593,938	17,420,405
TOTAL TOXIC - ignitable	585,251	3,441,686	532,069	2,792,801
TOTAL TOXIC - nonignitable	1,900,949	4,349,874	653,396	2,890,317

Table 2. Mass of all chemicals (cont.)

	1985 Minimum (kg)	1985 Maximum (kg)	1986 Minimum (kg)	1986 Maximum (kg)
CARBOXYLIC ACIDS				
organic acids (monobasic acid, carboxylic acid)	0	20600865.	0	18735977.
formic acid (methanoic acid)[f]	63928.	1111274.	72458.	1436334.
acetic acid (ethanoic acid)	4777887.	19474744.	3106507.	18131142.
propionic acid (propanoic acid)[i]	848218.	1894876.	72458.	1436334.
butyric acid (butanoic acid)	1632508.	2679166.	72458.	1436334.
valeric acid (pentanoic acid)	952790.	13890177.	72458.	14913549.
caproic acid (hexanoic acid)	108371.	5158735.	72458.	5796651.
acrylic acid (2-propenoic acid)[i]	3099382.	4916624.	1223813.	3101779.
hydroxycaproic acid	3196432.	38357190.	3622907.	43474888.
TOTAL	14,679,516	108,083,651	8,315,517	108,462,988
TOTAL TOXIC - ignitable	3,947,600	6,811,500	1,296,271	4,538,113
TOTAL TOXIC - nonignitable	63,928	1,111,274	72,458	1,436,334
DICARBOXYLIC ACIDS				
oxalic acid (ethanedioic)	454310.	2271552.	469491.	2347457.
malonic acid	1278573.	3452147.	1449162.	3912739.
succinic acid	3004010.	5505161.	1449162.	4343212.
glutaric acid	4990878.	5318454.	1449162.	1879635.
adipic acid	5404298.	7010448.	4347488.	6227124.
TOTAL	15,132,069	23,557,762	9,164,465	18,710,167
TOTAL TOXIC	0	0	0	0
TRICARBOXYLIC ACIDS				
citric acid (2-hydroxy 1,2,3 propanetricarboxylic acid)	454310.	2271552.	469491.	2347457.
AROMATIC CARBOXYLIC ACIDS (BENZOIC ACID DERIVATIVES)				
Chlorinated				
2,5-dichlorobenzoic acid	109689.	1096893.	89023.	890232.
dichlorosalicylic acid (dichlorohydroxybenzoic acid)	3381.	3381.	0	0
Banvel(methylated dichlorohydroxybenzoic acid)	3865.	72470.	0	0
Dicamba (3,6-dichloro-2-methoxybenzoic acid)	4348.	42032.	0	0
Chorinated and Nitrated				
dichloronitrobenzoic acids	1447898.	20840967.	1175106.	16914408.
TOTAL	1,569,181	22,055,743	1,264,129	17,804,640
TOTAL TOXIC	0	0	0	0

Table 2. Mass of all chemicals (cont.)

	1985 Minimum (kg)	1985 Maximum (kg)	1986 Minimum (kg)	1986 Maximum (kg)
NITRILES (N derivative of carboxylic acid)				
organic nitrile compounds	2175185.	16884004.	255254.	10210188.
dinitrile	0	66423873.	0	115867290.
acetonitrile (ethanenitrile)[f]	969336.	1368839.	355303.	751631.
acrylonitrile[f]	634488.	876247.	177966.	417804.
succinonitrile	2665995.	2665995.	2032897.	2032897.
maleonitrile	1295384.	1295384.	1285089.	1285089.
fumaronitrile	2343566.	2343566.	1747025.	1747025.
phthalonitrile	54867.	54867.	54431.	54431.
nicotinonitrile	351494.	351494.	348700.	348700.
TOTAL	10,490,315	92,264,269	6,256,665	132,715,055
TOTAL TOXIC - nonignitable	1,603,824	2,245,086	533,269	1,169,435
ANHYDRIDES				
acetic anhydride (ethanoic anhydride)	454310.	2271552.	469491.	2347457.
ESTERS (carboxylic acid derivatives)				
methyl acetate (methyl ethanoate)	171219.	1141462.	144260.	961735.
ethyl acetate (ethyl ethanoate)[i]	227155.	2328625.	234745.	2395544.
butyl acetate (butyl ethanoate)	227155.	2328625.	234745.	2395544.
propyl acetate (propyl ethanoate)	454310.	2271552.	469491.	2347457.
vinyl acetate (vinyl ethanoate)	308081.	3983745.	263908.	3790060.
TOTAL	1,387,920	12,054,009	1,347,149	11,890,340
TOTAL TOXIC - ignitable	227,155	2,328,625	234,745	2,395,544
CYCLIC ESTERS (LACTONES, deriv. of carboxylic acid)				
butyrolactone (4-hydroxybutanoic acid lactone)	111755.	558779.	80370.	401853.
OTHER ESTERS				
acrylate esters	454310.	2271552.	469491.	2347457.
sodium acetate	1025041.	4100166.	950359.	3801436.
potassium acetate	0	34243.	0	28852.
dimethyl phthalate (phthalic acid dimethyl ester)[f]	58.	58.	0	0
Banvel methyl esters (dichlorohydroxybenzoic acid methyl ester)	4831.	4831.	0	0
TOTAL	1,484,240	6,410,850	1,419,850	6,177,745
TOTAL TOXIC - nonignitable	58	58	0	0
AMIDES				
acrylamide (primary aliphatic amide)[f]	625198.	637200.	178294.	190201.

Table 2. Mass of all chemicals (cont.)

	1985 Minimum (kg)	1985 Maximum (kg)	1986 Minimum (kg)	1986 Maximum (kg)
LACTAMES (heterocyclic nonaromatic amides)				
caprolactam (aminohexanoic acid lactam)	0	639286.	0	724581.
UREAS				
urea (diamide of carbonic acid)	96184.	101804.	27429.	27429.
AMINES				
Tertiary amines				
tertiary butylamine	96184.	96184.	27429.	27429.
Quarternary ammonium salts				
quarternary ammonium chloride	0	7006302.	0	6170101.
tetra ethylamine (compostion of salt not indicated)	10446.	10446.	0	0
Heterocyclic aromatic amines				
pyridine[f]	0	12002.	0	11906.
methyl pyridine[f]	0	12002.	0	11906.
cyanopyridine	721383.	721383.	205724.	205724.
pyrrolidone (2-pyrrolidone)	111755.	1117559.	80370.	803706.
N-methyl pyrrolidone	923731.	2513501.	885549.	2400780.
vinyl pyrrolidone	111755.	1117559.	80370.	803706.
ALL AMINES : TOTAL	6,212,982	12,606,938	1,279,442	10,435,258
TOTAL TOXIC - nonignitable	0	24,004	0	23,812
IMINES (nitrogen ketones)				
hexamethylene imine	917214.	917214.	1205323.	1205323.
POLYMERS				
Hydropilic				
polyvinyl alcohol (PVA)	5707.	171219.	4808.	144260.
polyglycols (an alcohol)	454310.	2271552.	469491.	2347457.
polyglycerols (an alcohol)	1205013.	1205013.	0	0
Condensation				
polyesters	0	10867870.	0	12317885.
TOTAL	1,665,030	14,515,654	474,299	14,809,602
TOTAL TOXIC	0	0	0	0

Table 2. Mass of all chemicals (cont.)

	1985 Minimum (kg)	1985 Maximum (kg)	1986 Minimum (kg)	1986 Maximum (kg)
ORGANO HALOGENS				
chlorinated organics[g]	577359.	1858831.	912594.	2872153.
chlorinated hydrocarbons[g]	2008355.	6025066.	0	0
Alkyl halides				
freon 113 (a fluorinated alkyl halide)	0	2983.	0	2643.
carbon tetrachloride[f]	0	596.	0	528.
Vinyl halides				
tetrachloroethylene[f]	0	59.	0	52.
Aryl halides				
polychlorinated biphenyl (PCB)[e]	0	59.	0	52.
TOTAL	2,585,714	7,887,594	912,594	2,875,428
TOTAL TOXIC - nonignitable	2,585,714	7,884,611	912,594	2,872,785
MISCELLANEOUS ORGANICS				
Organic sulfur compounds:				
mercaptans	0	3142965.	0	511.
beta mercaptoethanol	0	189611.	0	183190.
sulfonated organics	0	1278573.	0	1449162.
sulfamic acid (amidosulfonic acid)	454310.	2271552.	469491.	2347457.
Sulfolane	0	232152.	0	224290.
Sulfolene	9.	54695.	9.	52843.
carbonyl-bisulfite adduct	0	15218025.	0	0
volatile sulfur compounds	0	13733910.	0	12490651.
Other:				
butyl formcel	454310.	2271552.	469491.	2347457.
H-10 Defoamer	0	28536.	0	24043.
Versenex 80	0	28536.	0	24043.
organic phosphorous compounds	0	6847822.	0	11945081.
TOTAL	908,629	45,297,929	938,991	31,088,728
TOTAL TOXIC	0	0	0	0
ORGANICS : TOTAL	79,961,703	564,833,229	42,596,709	501,328,768
TOTAL TOXIC	16,391,275	114,721,180	6,558,069	80,678,103
TOTAL TOXIC - Ignitable	6,923,619	55,448,490	3,840,398	48,203,467
TOTAL TOXIC - nonignitable	9,467,656	59,272,690	2,717,671	32,474,636

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a) The yearly minimum and maximum masses injected are calculated from the waste stream compositions taken from the Underground Injection Control files of the Texas Water Commission which have been compiled in an earlier report to the EPA (Capuano and Kreitler, 1988). Hazardous wastes are indicated by superscripts which note the toxic character as listed in the Federal Register 40CFR Part 261 Subpart D.

b) Acute hazard as indicated by a "P" listing or an (H) notation in the "U" listing.

c) Compounds of this element are also considered hazardous as indicated by an Appendix VIII listing.

d) EP toxicity.

e) A member of a general class of compounds that are hazardous as indicated by an Appendix VIII listing.

f) Toxic waste as indicated by a "U" listing.

g) Group considered hazardous because contains common hazardous constituents from "U", "P" or Appendix VIII listing.

h) Hazardous constituents as indicated by an Appendix VIII listing.

i) Toxic waste only because of ingnitability.

j) This total includes all wastes in the group that are toxic for reasons other than just ignitability

APPENDIX I.

Selected references of degradation reactions and sorption of hazardous wastes with preference to deep well injection processes.

REFERENCES FOR CHEMICAL REACTIONS OF INTEREST FOR WASTE-WATER INJECTION

Abdul, A. S., Gibson, T. L. and Rai, D. N., 1987, Statistical correlations for predicting the partition coefficient for nonpolar organic contaminants between aquifer organic carbon and water: Hazardous Waste and Hazardous Materials, v. 4, no. 3, p. 211-222.

Abraham, M. H., and Marcus, Y., 1986, The thermodynamics of solvation of ions. Part 1.-The heat capacity of hydration at 298.15 K: Journal of the Chemical Society, Faraday Transactions I, v. 82, p. 3255-3274.

Alexander, M., 1973, Nonbiodegradable and other recalcitrant molecules: Biotechnology and Bioengineering, v. 15, p. 611-647.

Alexander, M., 1980, Biodegradation of toxic chemicals in water and soil; in Haque R., ed., Dynamics Exposure and Hazard Assessment of Toxic Chemicals, Ann Arbour Science, p. 179-190.

Alexander, M., 1981, Biodegradation of chemicals of environmental concern: Science, v. 211, p. 132-21.

Baedecker, M. J. and Back, W., 1979a, Hydrological processes and chemical reactions at a landfill: Ground Water, v. 17, no. 5, p. 429-437.

Baedecker, M. J. and Back, W., 1979b, Modern marine sediments as a natural analog to the chemically stressed environment of a landfill: Journal of Hydrology, v. 43, p. 393-414.

Bailey, R. E., Gonsior, S. J., and Rhinehart, W. L., 1983, Biodegradation of the monochlorobiphenyls and biphenyl in river water: Environmental Science & Technology, v. 17, no. 10, p. 617-621.

Banerjee, S., Howard, P. H., Rosenberg, A. M., Dombrowski, A. E., Sikka, H., and Tullis, D. L., 1984, Development of a general kinetic model for biodegradation and its application to chlorophenols and related compounds: Environmental Science & Technology, v. 18, no. 6, p. 416-422.

Barraclough, J. T., 1966, Waste injection into a deep limestone in Northwestern Florida: Ground Water, v. 4, no. 1, p. 22-24.

Bedient, P. B., Borden, R. C., and Leib, D. I., 1985, Basic concepts for ground water transport modeling; in C. H. Ward, W. Giger, and P. L. McCarty, eds., Ground Water Quality, John Wiley & Sons, Ch. 28, p. 512-531.

Beeman, R. E., and Suflita, J. M., 1987, Microbial ecology of a shallow unconfined ground water aquifer polluted by municipal landfill leachate: Microbial Ecology, v. 14, p. 39-54.

Beeman, R. E., and Suflita, J. M., in press, Environmental factors influencing methanogenesis in a shallow anoxic aquifer: A field and laboratory study: Journal of Industrial Microbiology, in press.

Beland, F. A., Farwell, S. O., and Geer, R. D., 1974, Anaerobic degradation of 1,1,1,2-tetrachloro-2,2-bis(p-chlorophenyl)ethane (DTE): Journal of Agriculture and Food Chemistry, v. 22, no. 6, p. 1148-1149.

Beland, F. A., Farwell, S. O., Robocker, A. E., and Geer, R. D., 1976, Electrochemical reduction and anaerobic degradation of lindane: Journal of Agriculture and Food Chemistry, v. 24, no. 4, p. 753-756

Bengtsson, G., 1985, Microcosm for ground water research; in C. H. Ward, W. Giger, and P. L. McCarty, eds., Ground Water Quality, John Wiley & Sons, Ch 15, p. 330-341.

Boethling, R. S., and Alexander, M., 1979, Microbial degradation of organic compounds at trace levels: Environmental Science & Technology, v. 13, no. 8, p. 989-991.

Borden, R. C., Bedient, P. B., Lee, M. D., Ward, C. H. and Wilson, J. T., 1986, Transport of dissolved hydrocarbons influenced by oxygen-limited biodegradation 2. Field application: Water Resources Research, v. 22, no. 13, p. 1983-1990.

Boucher, F. R., and Lee, G. F., 1972, Adsorption of lindane and dieldrin pesticides on unconsolidated aquifer sands: Environmental Science & Technology, v. 6, no. 6, p. 538-543.

Bouwer, E. J., and McCarty, P. L., 1984, Modeling of trace organics biotransformation in the subsurface: Ground Water, v. 22, no. 4, p. 433-440.

Bouwer, E. J., Rittman, B. E., and McCarty, P. L., 1981, Anaerobic degradation of halogenated 1- and 2-carbon organic compounds: Environmental Science & Technology, v. 15, no. 5, p. 596-599.

Boyer, J. D., Ahlert, R. C., and Kosson, D. S., 1987, Degradation of 1,1,1-trichloroethane in bench-scale bioreactors: Hazardous Waste and Hazardous Materials, v. 4, no. 3, p. 241-.

Briggs, G. G., 1981, Theoretical and experimental relationships between soil adsorption, octanol-water partition coefficients, water solubilities, bioconcentration factors, and the parachor: Journal of Agriculture and Food Chemistry, v. 29, p. 1050-1059.

Briggs, G. G., and Dawson, J. E., 1970, Hydrolysis of 2,6-dichlorobenzonitrile: Journal of Agriculture and Food Chemistry, v. 18, no. 1, p. 97-99.

Britton, L. N., 1984, Microbial degradation of aliphatic hydrocarbons; in D. T. Gibson, ed., Microbial Degradatin of Organic Compounds, Marcel Dekker, Inc., Ch. 5, p 89-129.

Brown, D. S., and Flagg, E. W., 1981, Empirical prediction of organic pollutant sorption in natural sediments: Journal of Environmental Quality, v. 10, no. 3, p. 382-386.

Brownawell, B. J., and Farrington, J. W., 1986, Biogeochemistry of PCB's in interstitial waters of a coastal marine sediment: Geochimica et Cosmochimica Acta, v. 50, p. 157-169.

Callahan, M. A., Slimak, M. W., Gabel N. W., May, I. P., Fowler, C. F., Freed, J. R., Jennings, P., Durfee, R. L., Whitmore, F. C., Maestri, B., Mabey, W. R., Holt, B. R., and Gould, C., 1979, Water-related environmental fate of 129 priority pollutants. Volume 1: Introduction and technical background, metals and inorganics, pesticides and PCBs., Environmental Protection Agency Report EPA-440/4-79-029a, NTIS no. PB80-204373.

Callahan, M. A., Slimak, M. W., Gabel N. W., May, I. P., Fowler, C. F., Freed, J. R., Jennings, P., Durfee, R. L., Whitmore, F. C., Maestri, B., Mabey, W. R., Holt, B. R., and Gould, C., 1979, Water-related environmental fate of 129 priority pollutants. Volume 2: Halogenated aliphatic hydrocarbons, halogenated ethers, monocyclic aromatics, phthalate esters, polycylic aromatic hydrocarbons, nitrosamines, miscellaneous compounds, Environmental Protection Agency Report EPA-440/4-79-029b, NTIS no. PB80-204381.

Chapelle, F. H., and Morris, J. T., 1988, Potential for in situ biodegradation of JP-4 jet fuel at the Defense Fuel Supply Point, Charleston, South Carolina; U. S. Geological Survey administrative report prepared for the Department of the Navy, 20 p.

Chapelle, F. H., Morris, J. T., McMahon, P. B., and Zelibor, J. L. Jr., in press, Bacterial metabolism and the d^{13}C composition of ground water; Floridan aquifer system, South Carolina: Geology, in press.

Charlesworth, J. M., 1986, Interaction of clay minerals with organic nitrogen compounds released by kerogen pyrolysis: Geochimica et Cosmochimica Acta, v. 50, p 1431-1435.

Cherry, J. A., Gillham, R. W. and Barker, J. F., 1984, Contaminants in groundwater: chemical processes: Groundwater Contamination, Studies in Geophysics, National Academy Press, Washington D. C., p.46-66.

Cherry, J. A., Grisak, G. E., and Clister, W. E., 1973, Hydrogeologic studies at a subsurface radioactive-waste-management site in West-Central Canada; in J. Braunstein, ed., Second International Symposium on Underground Waste Management and Artificial Recharge, vol. 1, p. 436-467.

Chiou, C. T., Freed, V. H., Schmedding, D. W., and Kohnert, R. L., 1977, Partition coefficient and bioaccumulation of selected organic chemicals: Environmental Science & Technology, v. 11, no. 5, p. 475-478.

Chiou, C. T., Malcolm, R. L., Brinton, T. I., and Kile, D. E., 1986, Water solubility enhancement of some organic pollutants and pesticides by dissolved humic and fulvic acids: Environmental Science & Technology, v. 20, no. 5, p. 502-508.

Chiou, C. T., Proter, P. E., and Schmedding, D. W., 1983, Partition Equilibria of nonionic organic compounds between soil organic matter and water: Environmental Science & Technology, v. 17, no. 4, p. 227-231.

Collins, A. G., and Crocker, M. E., 1988, Laboratory protocol for determining fate of waste disposed in deep wells; Project Summary, U. S. Environmental Protection Agency, EPA/600/ S8-88/008.

Davis, J. A., and Leckie, J. O., 1979, Speciation of adsorbed ions at the oxide/water interface; in E. A. Jenne, ed., Chemical Modeling in Aqueous Systems, American Chemical Society, Ch 15, p. 299-317.

DiGeronimo, M. J., and Antoine, A. D., 1976, Metabolism of acetonitrile and propionitrile by Nocadaria rhodochrous LL100-21: Applied and Environmental Microbiology, v. 31, no. 6, p. 900-906.

DiTommaso, A., and Elkan, G. H., 1973, Role of bacteria in decomposition of injected liquid waste at Wilmington, North Carolina; in J. Braunstein, ed., Second International Symposium on Underground Waste Management and Artificial Recharge, vol 2., p. 585-599.

Donaldson, E. C., Crocker, M. E., and Manning, F. S., 1975, Adsorption of organic compounds on Cottage Grove Sandstone, Bartlesville Energy Research Center Report BERC/RI-75/4, 16p.

Downes, C. J., 1985, Redox reactions, mineral equilibria, and ground water quality in New Zealand aquifers; in C. H. Ward, W. Giger, and P. L. McCarty, eds., Ground Water Quality, John Wiley & Sons, Ch. 7, p. 94-121.

Drez, P. E., 1988, Rock-water interactions between injected waste and host formation fluids and mineralogy during deep well injection (abstr.): Transactions American Geophysical Union, Eos, v. 69, no. 16, p. 350.

Ehrlich, G. G., Godsy, E. M., Pascale, C. A. and Vecchioli, J., 1979, Chemical changes in an industrial waste liquid during post-injection movement in a limmestone aquifer, Penscaola, Florida: Ground Water, v. 17, no. 6, p. 562-573.

Elkan, G. E., 1975, Role of microorganisms in the decomposition of deep well injected liquid industrial wastes; NSF Report NSF/RA-770107, NTIS no. PB-249 056.

Elkan, G. H., and Horvath, E., 1976, The role of microorganisms in the decomposition of deep well injected liquid industrial wastes; National Science Foundation Report, NTIS no. PB-268 646.

Engelhardt, G., and Wallnofer, P. R., 1978, Metabolism of di- and mono-n-butyl phthalate by soil bacteria: Applied and Environmental Microbiology, v. 35, no. 2, p. 243-246.

Erickson, D. C., Spaniel, K., and Loehr, R. C., 1988, Abiotic loss of chemicals in soil: Hazardous Waste & Hazardous Materials, v. 5, no. 2, p. 121-128.

Fedorak, P. M., Roberts, D. J., and Hrudey, S. E., 1986, The effects of cyanide on the methanogenic degradation of phenolic compounds: Water Research, v. 20, no. 10, p. 1315-1320.

Fliermans, C. B., Balkwill, D. L., Beeman, R. E., Bledsoe, H. W., Bollag, J.-M., Corey, J. C., Dodge, C. J., Francis, A. J., Fredrickson, J. K., Garland, T. R., Ghiorse, W. C., Hicks, R. J., Jones, R. E., McFadden, K., Madsen, E. L., Meglen, B., Phelps, T. J., Sargent, J. L., Suflita, J. M., White, D. C., and Wobber, F. J., in press, Microbial life in the deep terrestrial subsurface: Science, in press.

Freeman, D. H., and Cheung, L. S., 1981, A gel partition model for organic desorption from a pond sediment: Science, v. 214, p. 790-792.

Ghiorse, W. C., and Balkwill, D. L., 1985, Microbiological characterization of subsurface environments; in C. H. Ward, W. Giger, and P. L. McCarty, eds., Ground Water Quality, John Wiley & Sons, Ch. 20, p. 387-401.

Gibson, S. A., and Suflita, J. M., 1986, Extrapolation of biodegradation results to groundwater aquifers: Reductive dehalogenation of aromatic compounds: Appiled and Environmental Microbiology, v. 52, no. 4, p. 681-688.

Goolsby, D. A., 1971, Hydrogeochemical effects of injecting wastes into a limestone aquifer near Pensacola, Florida: Ground Water, v. 9, no. 1, p. 13-19.

Goolsby, D. A., 1972, Geochemical effects and movement of injected industrial waste in a limestone aquifer; in T. D. Cook, ed., Underground Waste Management and Environmental Implications, Americam Association of Petroleum Geologists Memoir No. 18, p. 355-368.

Grenney, W. J., Caupp, C. L., Sims, R. C. and Short, T. E., 1987, A mathematical model for the fate of hazardous substances in soil: model description and experimental results: Hazardous Waste and Hazardous Materials, v. 4, no. 3, p. 223-239.

Grula, M. M., and Grula, E. A., 1976, Feasibility of microbial decomposition of organic wastes under conditions existing in deep wells; U. S. Department of Mines Report, BERC/RI-76/6, 55p.

Gschwend, P. M., and Wu, S., 1985, On the constancy of sediment-water partition coefficients of hydrophobic organic pollutants: Environmental Science & Technology, v. 19, no. 1, p. 90-93.

Gustafson, R. L. and Paleos, J., 1971, Interactions resposnsible for the selective adsorption of organics on organic surfaces; in S. J. Faust and J. V. Hunter, eds., Organic Compounds in Aquatic Environments, Marcel Dekker, p. 213-237.

Guthrie, M. A., Kirsch, E. J., Wukasch, R. F., and Grady, C. P. L. Jr., 1984, Pentachlorophenol biodegradation - II Anaerobic: Water Research, v. 18, no. 4, p. 451-461.

Haan, F. A. M. de and Swerman, P. J., 1976, Pollution of soil; in G. H. Bolt and M. G. M. Bruggenwert, eds.: Soil Chemistry, A. Basic Elements, Elsever, p. 192-271.

Hamlin, S. N., 1987, Hydraulic/chemical changes during ground-water recharge by injection: Ground Water, v. 25, no. 3, p. 267-274.

Haque, R., Falco, J., Cohen, S. and Riordan, C., 1980, Role of transport and fate studies in the exposure, assessment and screening of toxic chemicals; in Haque R., ed., Dynamics Exposure and Hazard Assessment of Toxic Chemicals, Ann Arbour Science, p. 47-67.

Hassett, J. P., and Anderson, M. A., 1979, Association of hydrophobic organic compounds with dissolved organic matter in aquatic systems: Environmental Science & Technology, v. 13, no. 12, p. 1526-1529.

Hassett, J. P., and Anderson, M. A., 1982, Effects of dissolved organic matter on adsorption of hydrophobic organic compounds by river and sewage-borne particles: Water Research, v. 16, p. 681-686.

Healy, J. B. Jr., and Young, L. Y., 1978, Catechol and phenol degradation by a methanogenic population of bacteria: Applied and Environmental Microbiology, v. 35, no. 1, p. 216-218.

Healy, T. W., 1971, Selective adsorption of organics on inorganic surfaces; in S. J. Faust and J. V. Hunter, eds., Organic Compounds in Aquatic Environments, Marcel Dekker, p. 187-212.

Higgins, J., D. Scott, and Hammond, R. C., 1984, Transformation of C_1 compounds by microorganisms; in D. T. Gibson, ed., Microbial Degradation of Organic Compounds, Marcel Dekker, Inc., Ch 4, p 43-87.

Hiraizumi, Y., Takahashi, M., and Nishimura, H., 1979, Adsorption of polychlorinated biphenyl onto sea bed sediment, marine plankton, and other adsorbing agents: Environmental Science & Technology, v. 13, no. 5, p. 580-584.

Hoehn, E., and von Gunten, H. R., 1985, Distribution of metal pollution in groundwater determined from sump sludges in wells; in E. Arvin, ed., Water Science and Technology, v. 17, no. 9, Degradation, Retention and Dispersion of Pollutants in Groundwater, p 115-132.

Horvath, R. S., and Alexander, M., 1970, Cometabolism: a technique for the accumulation of biochemical products: Canadian Journal of Microbiology, v. 16, p. 1131-1132.

Hwang, H. -M., and Hodson, R. E., 1986, Degradation of phenol and chlorophenols by sunlight and microbes in estuarine water: Environmental Science & Technology, v. 20, no. 10, p. 1002-1007.

Jackson, R. E., 1985, Contaminant Hydrology of Toxic Organic Chemicals at a Disposal Site, Gloucester, Ontario, 1. Chemical Concepts and Site Assessment: National Hydrology Research Institute Paper no. 23, Inland Waters Directorate Scientific Series no. 141, Ottawa, Canada, NHRI paper no. 23, 114p.

Jennings, A. A., 1987, Critical chemical reaction rates for multicomponent groundwater contamination models: Water Resources Research, v. 23, no. 9, p. 1775-1784.

Karickoff, S. W., 1980, Sorption kinetics of hydrophobic pollutants in natural sediments; in R. A. Baker, ed.: Contaminants and Sediments, vol. 2 Analysis, Chemistry, Biology, Ann Arbor Science, Ch 11, p. 193-205.

Karickoff, S. W., Brown, D. S., and Scott, T. A., 1979, Sorption of hydrophobic pollutants on natural sediments: Water Research, v. 13, p. 241-248.

Keeley, D. F. and Meriwether, J. R., 1985, Aromatic hydrocarbons associated with brines from geopressured wells; in M. H. Dorfman and R. A. Morton, eds.: Geopressured-Geothermal Energy: Proceedings of the Sixth U.S. Gulf Coast Geopressured-Geothermal Energy Conference, Pergamon, Press, p. 105-113.

Khan, S. U., 1980, Role of humic substances in predicting fate and transport of pollutants in the environment; in Haque R., ed., Dynamics Exposure and Hazard Assessment of Toxic Chemicals, Ann Arbour Science, p. 215-230.

Khan, A., Hassett, J. J., Banwart, W. L., Means, J. C., and Wood, S. G., 1979, Sorption of acetophenone by sediments and soils: Soil Science, v. 128, no. 5, p. 297-302.

Kharaka, Y. K., 1973, Retention of dissolved constituents of waste by geologic membranes; in J. Braunstein, ed., Second International Symposium on Underground Waste Management and Artficial Recharge, vol. 1, p. 420-435.

Kobayashi, H., and Rittman, B. E., 1982, Microbial removal of hazardous organic compounds: Environmental Science & Technology, v. 16, no. 3, p. 170A-183A.

Ku, H. F. H., Katz, B. G., Sulan, D. J. and Krulikas, R. K., 1978, Scavenging of chromium and cadmium by aquifer material - South Farmingdale-Massapequa Area, Long Island, New York: Ground Water, v. 16, no. 2, p. 112-118.

Kuhn, E. P., and Suflita, J. M., in press, Dehalogenation of pesticides by anaerobic microorganisms in soils and ground waters- A review: In Reactins and Movement of Organic Chemicals in Soils, American Society of Agronomy, in press.

Kuhn, E. P., and Suflite, J. M., in press, The sequential reductive dehalogenation of chloroanilines by microorganisms from a methanogenic aquifer: Science, in press.

Leach, F. R., 1984, Biochemical indicators of groundwater pollution; in G. Bitton and C. P. Gerba, eds., Groundwater Pollution Microbiology, John Wiley & Sons, Inc., p. 303-344.

Leach, F. R., Chang, J. C., Howard, J. L., Webster, J. J., Arquitt, A. B., Merz, R., Doyel, E. R., Norton, P. T., Hampton, G. J., and Jackson, J. Z., 1985, Biochemical methods for detection of subsurface contamination/ biomass; in C. H. Ward, W. Giger, and P. L. McCarty, eds., Ground Water Quality, John Wiley & Sons, Ch. 12, p. 241-269.

Lee, M. D., Wilson, J. T., and Ward, C. H., 1984, Microbial degradation of selected aromatics in a hazardous waste site; in Developments in Industrial Microbiology, Proceedings, 40th General Meeting, Society for Industrial Microbiology, Sarasota FL., v. 25, p. 557-565.

Leenheer, J. A., and Malcolm, R. L., 1973, Case history of subsurface waste injection of an industrial organic waste; in J. Braunstein, ed., Second International Symposium on Underground Waste Management and Artificial Recharge, vol. 1, p. 565-584.

Leenheer, J. A., Malcolm, R. L. and White, W. R., 1976a, Investigation of the reactivity and fate of certain organic components of an industrial waste after deep-well injection: Environmental Science & Technology, v.10, no. 5, p 445-451.

Leenheer, J. A., Malcolm, R. L., and White, W. R., 1976b, Physical, chemical, and biological aspects of subsurface organic waste injection near Wilmington, North Carolina: U. S. Geological Survey Professional Paper 987, 51p.

Lettinga, G., de Zeeuw, W., and Ouborg, E., 1981, Anaerobic treatment of wastes containing methanol and higher alcohols: Water Research, v. 15, p. 171-182.

Lewandowski, Z., 1984, Biological denitrification in the presence of cyanide: Water Research, v. 18, no. 3, p. 289-297.

Loch, J. P. G., and Lagas, P., 1985, The mobilization of heavy metals in river sediment by nitrilotriacetic acid (NTA); in E. Arvin, ed., Water Science and Technology, v. 17, no. 9, Degradation, Retention, and Dispersion of Pollutants in Groundwater, p. 101-113.

Loos, M. A., Roberts, R. N., and Alexander, M., 1967, Formation of 2,4-dichlorophenol and 2,4-dichloroanisole from 2,4-dichlorophenoxyacetate by anthrobacter sp.: Canadian Journal of Microbiology, v. 13, p. 691-699.

Mabey, W. and Mill, T., 1978, Critical review of hydrolysis of organic compounds in water under environmental conditions: Journal of Physical and Chemical Reference Data, v. 7, p. 383-415.

MacFarlane, D. S., Cherry, J. A., Gillham, R. W., and Sudicky, E. A., 1983, Migration of contaminants in groundwater at a landfill: A case study 1. Groundwater flow and plume delineation:: Journal of Hydrology, v. 63, p. 1-29.

Mackay, D., and Shiu, W. Y., 1981, A critical review of Henry's Law constants for chemicals of environmental interest: Journal of Physical and Chemical Reference Data, v. 10, no. 4, p. 1175-1199.

Major, D. W., Mayfield, C. I., and Barker, J. F., 1988, Biotransformation of benzene by denitrification in aquifer sand: Ground Water, v. 26, no. 1, p. 8-14.

Mangold, D. C. and Tsang, D. F., 1987, Summary of Hydrologic and Hydrochemical Models with Potential Application to Deep Underground Injection Performance: Lawrence Berkeley Laboratory University of California, Report LBL-23497, UC-11, 53p.

Martell, A. E., 1971, Principles of complex formation; in S. J. Faust and J. V. Hunter, eds., Organic Compounds in Aquatic Environments, Marcel Dekker, p. 239-263.

Masunaga, S., Urushigawa, Y., and Yonezawa, Y., 1986, Biodegradation pathway of o-cresol by heterogeneous culture. Phenol acclimated activated sludge: Water Research, v. 20, no. 4, p. 477-484.

Mathess, G., 1972, Hydrologeologic criteria for the self-purification of polluted groundwater; in International Geologic Congress, 24th session, 1972, section 11, Hydrogeology, p. 296-304.

Mathess, G., and Pekdeger, A., 1985, Survival and transport of pathogenic bacteria and viruses in ground water; in C. H. Ward, W. Giger, and P. L. McCarty, eds., Ground Water Quality, John Wiley & Sons, Ch. 25, p. 472-482.

McCarty, P. L., and Rittman, B. E., 1981, Trace organics in groundwater: Environmental Science & Technology, v. 15, no. 1, p. 40-51.

McNabb, J. F., and Dunlap, W. J., 1975, Subsurface biological activity in relation to ground-water pollution: Ground Water, v. 13, no. 1, p. 33-44.

Means, J. C., Hassett, J. J., Wood, S. G., Banwart, W. L., Ali, S., and Khan, A., 1980, Sorption properties of polynuclear aromatic hydrocarbons and sediments: heterocyclic and substituted compounds, In Bjorseth, A., and Dennis, A. J., eds. Polynuclear Aromatic Hydrocarbons: Chemistry and Biological Effects, p. 395-404.

Means, J. C., and Wijayaratne, R., 1982, Role of natural colloids in the transport of hydrophobic pollutants: Science, v. 215, p. 968-970.

Means, J. C., Wood, S. G., Hassett, J. J., and Banwart, W. L., 1980, Sorption of polynuclear aromatic hydrocarbons by sediments and soils: Environmental Science & Technology, v. 14, no. 12, p. 1524-1528.

Means, J. C., Wood, S. G., Hassett, J. J., and Banwart, W. L., 1982, Sorption of amino- and carboxy-substituted polynuclear aromatic hydrocarbons by sediments and soils: Environmental Science & Technology, v. 16, no. 2, p. 93-98.

Mehran, M., Olsen, R. L. and Rector, B. M., 1987, Distribution coefficient of trichlorethylene in soil-water systems: Ground-Water, v. 25, no. 3, p. 275-280.

Mill, T., 1980, Data needed to predict the environmental fate of organic chemicals; in Haque R., ed., Dynamics Exposure and Hazard Assessment of Toxic Chemicals, Ann Arbour Science, p. 297-322.

Miller, C., Fischer, T. A. II, Clark, J. E., Porter, W. M., Hales, C. H. and Tilton, J. R., 1986, Flow and contamination of injected wastes: Ground Water Monitor Review, v. 6, no. 3, p. 37-48.

Morris, J. T., Whiting, G. J., and Chapelle, F. H., in press, Potential denitrification rates in deep sediments from a drilling site in the Southeastern Coastal Plain: Environmental Science & Technology, in press.

Mortland, M. M., 1985, Interaction between organic molecules and mineral surfaces; in C. H. Ward, W. Giger, and P. L. McCarty, eds., Ground Water Quality, John Wiley & Sons, Ch. 19, p. 370-386.

Nissenbaum, A., Baedecker, M. J., and Kaplan, I. R., 1971, Studies on dissolved prganic matter from interstitial water of a reducing marine fjord; in von Gaertner, H. and Wehner, H eds., Advances in Organic Chemistry, Permagon Press, p. 427-440.

DRAFT

Noorishad, J., Carnahan, C. L. and Benson, L. V., 1987, Development of the Non-Equilibrium Reactive Chemical Transport Code CHMTRNS: Lawrence Berkeley Laboratory Report LBL-22361, Prepared for U.S. Department of Energy under Contract DE-AC03-76SF00098, 231p.

Novak, J. T. and Ramesh, M. S., 1975, Stimulation in anerobic degradation: Water Research, v. 9, p. 963-967.

Novak, J. T., Goldsmith, C. D., Benoit, R. E., and O'Brien, J. H., 1985, Biodegradation of methanol and tertiary butyl alcohol in subsurface systems; in E. Arvin, ed., Water Science and Technology, v. 17, no. 9, Degradation, Retention, and Dispersion of Pollutants in Groundwater, p. 71-85.

O'Connor, J. T., Ghosh, M. M., Banerji, S. K., Piontek, K., Aguado, E., and Prakash, T. M., 1985, Organic groundwater contamination evaluation and prediction; U. S. Department of Interior Report PB85-23006/8

Ogawa, I., Junk, G. A., and Svec, H. J., 1981, Degradation of aromatic compounds in groundwater, and methods of sample preservation: Talanta, v. 28, p. 725-729.

Oremland, R. S., and Taylor, B. F., 1978, Sulfate reduction and methanogenesis in marine sediments: Geochimica et Cosmochimica Acta, v. 42, p. 209-214.

Paque, M. J., 1986, Class I injection well performance survey: Ground Water Monitor Review, v. 6, no. 3, p. 68-69.

Paris, D. F., Lewis, D. L., and Wolfe, N. L., 1975, Rates of degradation of malathion by bacteria isolated from aquatin system: Environmental Science & Technology, v. 9, no. 2, p. 135-138.

Pascale, C. A., and Martin, J. B., 1978, Hydrologic monitoring of a deep-well waste-injection system near Pensacola, Florida, march 1970-March 1977; U. S. Geological Survey Water-Resources Investigation 78-27, 61p.

Patterson, R. J., Jackson, R. E., Graham, B. W., Chaput, D., and Priddle, M., 1985, Retardation of toxic chemicals in a contaminated outwash aquifer; in E. Arvin, ed., Water Science and Technology, v. 17, no. 9, Degradation, Retention and Dispersion of Pollutants in Groundwater, p. 57-69.

Pearlman, R. S., Yalkowsky, S. H., and Banerjee, S., 1984, Water solubilities of polynuclear aromatic and heteroaromatic compounds: Journal of Physical and Chemical Reference Data, v. 13, no. 2, p. 555-562.

Phillips, S. L., Hale, F. V. and Tsang, C.-F., 1987, Groupings of Organic Waste Chemicals Based on Sorption, Biotransformation and Hydrolysis at Standard Conditions for Application to the Deep Subsurface Environment: Lawrence Berkeley Laboratory Report LBL-23848, Report to U.S. EPA and DOE contract no AC03-967SF00098.

Ragone, S. E., Vecchioli, J., and Ku, H. F. H., 1973, Short-term effect of injection of tertiary-treated sewage on iron concentration of water in Magothy aquifer, Bay Park, New York; in J. Braunstein, ed., Second International Symposium on Underground Waste Management and Artificial Recharge, p. 273-290.

Raymond, D. G. M., and Alexander, M., 1971, Microbial metabolism and cometabolism of nitrophenols: Pesticide Biochemistry and Physiology, v. 1, p 123-130.

Rittmann, B. E., McCarty, P. L. and Roberts, P. V., 1980, Trace-organics biodegradation in aquifer recharge: Ground Water, v. 18, no. 3, p. 236-967.

Roberts, P. V., McCarty, P. L., and Roman, W. M., 1978, Direct injection of reclaimed water into an aquifer: Journal of the Environmental Engineering Division, ASCE, v. 104, no. EE5, p. 933-949.

Roberts, P. V., Reinhard, M., Hopkins, G. D., and Summers, R. S., 1985, Advection-dispersion-sorption models for simulating the transport of organic contaminants; in C. H. Ward, W. Giger, and P. L. McCarty, eds., Ground Water Quality, John Wiley & Sons, Ch. 23, p. 425-445.

Roberts, P. V., Schreiner, J., and Hopkins, G. D., 1982, Field study of organic water quality changes during groundwater recharge in the Palo Alto Baylands: Water Research, v. 16, p. 1025-1035.

Roberts, P. V., and Valocchi, A. J., 1981, Principles of organic contaminant behavior during artificial recharge: The science of the Total Environment, v. 21, p. 161-172.

Robertson, J. B., and Barraclough, J. T., 1973, Radioactive- and chemical-waste transport in groundwater at National Reactor Testing Station, Idaho: 20-year case history and digital model; in J. Braunstein, ed., Second International Symposium on Underground Waste Management and Artificial Recharge, p. 291-322.

Rogers, J. E., Riley, R. G., Li, S. W., O'Malley, M. L., and Thomas, B. L., 1985, Microbial transformation of alkylpyridines in groundwater: Water, Air, and Soil Pollution, v. 24, p. 443-454.

Rosenberg, A., and Alexander, M., 1980, Microbial metabolism os 2,4,5-trichlorophenoxyacetic acid in soil, soil suspensions, and axenic culture: Journal of Agriculture and Food Chemistry, v. 28, no. 2, p. 297-302.

Roy, W. R., Mravik, S. C., Krapac, I. G., Dickerson, D. R., and Griffin, R. A., 1988, Geochemical interactions of hazardous wastes with geological formations in deep-well systems. Final Report Illinois State Geological Survey, report prepared for the Office of Drinking Water WH 550 and the Hazardous Waste Research and Information Center, 95 p., Draft Copy.

Russell, J. D., Cruz, M. I., and White, J. L., 1968, The adsorption of 3-amino-triazole by montmorillonite: Journal of Agriculture and Food Chemistry, v. 16, no. 1, p; 21-24.

Sabijic, A., 1987, On the prediction of soil sorption coefficients of organic pollutants from molecular structure: Application of molecular topology model: Environmental Science & Technology, v. 21, no. 4, p. 358-366.

Saltzman, S., Kliger, L., and Yaron, B., 1972, Adsorption-desorption of parathion as affected by soil organic matter: Journal of Agriculture and Food Chemistry, v. 20, no. 6, p. 1224-1226.

DRAFT

Schellenberg, K., Leuenberger, C., and Schwarzenbach, R. P., 1984, Sorption of chlorinated phenols by natural sediments and aquifer materials: Environmental Science & Technology, v. 18, no. 9, p. 652-657.

Schwarzenbach, R. P., and Giger, W., 1985, Behavior and fate of halogenated hydrocarbons in ground water; in C. H. Ward, W. Giger, and P. L. McCarty, eds., Ground Water Quality, John Wiley & Sons, Ch. 24, p. 446-471.

Schwarzenbach, R. P., Giger, W., Hoehn, E., and Schneider, J. K., 1983, Behavior of organic compounds during infiltration of river water to groundwater. Field studies: Environmental Science & Technology, v. 17, no. 8, p. 472-479.

Schwarzenbach, R. P., and Westall, J., 1981, Transport of nonpolar organic compounds from surface water to groundwater. Laboratory sorption studies: Environmental Science & Technology, v. 15, no. 11, p. 1360-1367.

Schwarzenbach, R. P., and Westall, J., 1985, Sorption of hydrophobic trace organic compounds in groundwater systems; in E. Arvin, ed., Water Science and Technology, v. 17, no. 9, Degradation, Retention, and Dispersion of Pollutants in Groundwater, p. 39-55.

Scrivner, N. C., Bennett, K. E., Pease, R. A., Kopatsis, A., Sanders, S. J., Clark, D. M. and Rafal, M., 1986, Chemical fate of injected wastes: Ground Water Monitor Review, v. 6, no. 3, p. 53-58.

Seidel, D. F., and Crites, R. W., 1970, Evaluation of anaerobic denitrification processes: Journal of the Sanitary Engineering Division, ASCE, v. 96, no. SA2, p. 267-277.

Semprini, L., Roberts, P. V., Hopkins, G. D., and Mackay, D. M., 1988, A field evaluation of in-situ biodegradation for aquifer restoration; Project Summary, U. S. Environmental Protection Agency, EPA/600/S2-87/096, 7 p.

Sims, R. C., Doucette, W. J., McLean, J. E., Grenney, W. J., and Dupont, R. R., 1988, Treatment potential for 56 EPA listed hazardous chemicals in soil; Project Summary, U. S. Environmental Protection Agency, EPA/600/S6-88/001, 7 p.

Smith, A. E., 1977, Degradation of the herbicide dichlorfop-methyl in prarie soils: Journal of Agriculture and Food Chemistry, v. 25, no. 4, p. 893-898.

Smith, A. E., and Cullimore, D. R., 1974, The invitro degradation of the herbicide bromoxynil: Canadian Journal of Microbiology, v. 20, p. 773-776.

Smith, G. A., Nickels, J. S., Davis, J. D., Findlay, R. H., Vashio, P. S., Wilson, J. T., and White, D. C., 1985, Indices identifying subsurface microbial communities that are adapted to organic pollution; in N. N. Durham, and A. E. Redlefs, eds., Second International Conference on Ground Water Quality Research, Stillwater, OK, p. 210-213.

Smolenski, W. J., and Suflita, J. M., 1987, Biodegradation of cresol isomers in anoxic aquifers: Applied and Environmental Microbiology, v. 53, no. 4, p. 710-716.

Southworth, G. R., and Keller, J. L., 1986, Hydrophobic sorption of polar organics by low organic carbon soils: Water, Air, and Soil Pollution, v. 28, p. 239-248.

Strycker, A. and Collins, A. G., 1987, State-of-the-Art Report Injection of Hazardous Wastes into Deep Wells: National Institute for Petroleum and Energy Research, Bartlesville, Oklahoma, Environmental Protection Agency Report EPA/600/8-87/013.

Suflita, J. M., Gibson, S. A., and Beeman, R. E., 1988, Anaerobic biotransformations of pollutant chemicals in aquifers: Journal of Industrial Microbiology, p. 179-194.

Suflita, J. M., Robinson, J. A., and Tiedje, J. M., 1983, Kinetics of microbial dehalogenation of haloaromatic substrates in methanogenic environments: Applied and Environmental Technology, v. 45, no. 5, p. 1466-1473.

Suflita, J. M., Smolenski, W. J., and Robinson, J. A., 1987, Alternative nonlinear model for estimating second-order rate coefficients for biodegradationL: Applied and Environmental Microbiology, v. 53, no. 5, p. 1064-1068.

Sutton, P. A., and Barker, J. F., 1985, Migration and attenuation of selected organics in a sandy aquifer - A natural gradient experiment: Ground Water, v. 23, no. 1, p. 10-16.

Suzuki, T., 1977, Metabolism of pentachlorophenol by a soil microbe: Journal of Environmental Science and Health, v. B12, no. 2, p. 113-127.

Tahoun, S. A., and Mortland, M. M., 1966, Complexes of montmorillonite with primary, secondary and tertiary amides: I. Protonation of amides on the surface of montmorillonite: Soil Science, v. 102, p. 248-254.

Tate, R. L. III, and Alexander, M., 1976a, Resistance of nitrosamines to microbial attack: Journal of Environmental Quality, v. 5, no. 2, p. 131-133.

Tate, R. L. III, and Alexander, M., 1976b, Microbial formation and degradation of dimethylamine: Applied and Environmental Microbiology, v. 1, no. 3, p. 399-403.

Tewfik, M. S., and Evans, W. C., 1966, The metabolism of 3,5-dinitro-o-cresol (DNOC) by soil micro-organisms: Biochemical Journal, v. 99, no. 2, p. 31P-32P.

Toerien, D. F., and Hattingh, W. H. J., 1969, Anaerobic digestion I. The microbiology of anaerobic digestion: Water Research, v. 3, p. 385-416.

Turner, J. M., 1966, Microbial metabolism of amino ketones. Aminoacetone formation from 1-aminopropan-2-ol by a dehydrogenase in Escherichia coli, Biochemical Journal, v. 99, p. 427-433.

United States Department of Energy Proceedings D=Second Investigators' Meeting, 1986, Microbiology of subsurface environments; NTIS no. DE87 013094, 29p.

Valocchi, A. J., Street, R. L. and Roberts, P. V., 1981, Transport of ion-exchanging solutes in groundwater: Chromatographic theory and field simulation: Water Resources Research, v. 17, p. 1517-1527.

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Vecchioli, J., Ehrlich, G. G., Godsy, E. M. and Pascale, C. A., 1984, Alterations in the chemistry of an industrial waste liquid injected into limestone near Pensacola, Florida; in, G. Castany, E. Groba and E. Romijn, eds.: Hydrogeology of Karstic Terrains, Case Histories, v. 1, p. 217-221.

Vogel, T. M., Criddle, C. S. and McCarty, P. L., 1987, Transformations of halogenated aliphatic compounds: Environmental Science & Technology, v. 21, no. 8, p. 722-736.

Webster, J. J., Hampton, G. J., Wilson, J. T., Ghiorse, W. C., and Leach, F. R., 1985, Determination of microbial cell numbers in subsurface samples: Ground Water, v. 23, no. 1, p. 17-25.

Westall, J. C., Leuenbeger, C., and Schwarzenbach, R. P., 1985, Influence of pH and ionic strength on the aqueous-nonaqueous distribution of chlorinated phenols: Environmental Science & Technology, v. 19, no. 2, p. 193-198.

White, D. C., Nickels, J. S., Parker, J. H., Findlay, R. H., Gehron, M. J., Smith, G. A., and Martz, R. F., 1985, Biochemical measures of the biomass, community structure, and metabolic activity of the ground water microbiota; in C. H. Ward, W. Giger, and P. L. McCarty, eds., Ground Water Quality, John Wiley & Sons, Ch. 14, p. 307-329.

Wijayaratne, R. D., and Means, J. C., 1984, Sorption of polycyclic aromatic hydrocarbons by natural estuarine colloids: Marine Environmental Research, v. 11, p. 77-89.

Wilson, B. H., Smith, G. B., and Rees, J. F., 1986, Biotransformations of selected alkylbenzenes and halogenated aliphatic hydrocarbons in methanogenic aquifer material: A microcosm study: Environmental Science & Technology, v. 20, no. 10, p. 997-1002.

Wilson, J. T., Enfield, C. G., Dunlap, W. J., Cosby, R. L., Foster, D. A., and Baskin, L. B., 1981, Transport and fate of selected organic pollutants in a sandy soil: Journal of Environmental Quality, v. 10, no. 4, p. 501-506.

Wilson, J. T., McNabb, J. F., Wilson, B. H., and Noonan, M. J., 1982, Biotransformation of selected organic pollutants in ground water; in Developments in Industrial Microbiology, Porceedings of the 39th general Meeting of the Society for Industrial Microbioloby, St. Paul, Minn., v. 24, p. 225-233.

Wilson, J. T., Miller, G. D., Ghiorse, W. C., and Leach, F. R., 1986, Relationship between the ATP content on subsurface material and the rate of biodegradation of alkylbenzenes and chlorobenzene: J. Contam. Hydrol., v. 1, p. 163-170.

Wilson, J. T., Noonan, M. J., and McNabb, J. F., 1985, Biodegradation of contaminants in the subsurface; in C. H. Ward, W. Giger, and P. L. McCarty, eds., Ground Water Quality, Ch. 26, p. 483-492.

Wobber, F. J., and Zachara, J. M., 1987, DOE deep probe- field evaluation and planning workshop, Augusta Landmark Hotel, Augusta, GA; USDOE Office of Energy Research, NTIS no. DE87 012324, 33 p.

Wolfe, N. L., 1985?, Screening Hydrolytic Reactivity of OSW Chemicals: U.S. Environmental Protection Agency report, Environmental Research Laboratory, Athens, Georgia, 25p.

Wolfe, N. L., 1980, Determining the role of hydrolysis in the fate of organics in natural waters; in Haque R., ed., Dynamics Exposure and Hazard Assessment of Toxic Chemicals, Ann Arbour Science, p. 163-177.

Wood, J. M., 1982, Chlorinated hydrocarbons: oxidation in the biosphere: Environmental Science & Technology, v. 16, no. 5, p. 291A-297A.

Wood, P. R., Lang, R. F., and Payan, I. L., 1985, Anaerobic transformation, transport, and removal of volatile chlorinated organics in ground water; in C. H. Ward, W. Giger, and P. L. McCarty, eds., Ground Water Quality, John Wiley & Sons, Ch. 27, p. 493-511.

Yariv, S., Russell, J. D., and Farmer, V. C., 1966, Infrared study of the adsorption of benzoic acid and nitrobenzene in montmorillonite: Israel Journal of Chemistry, v. 4, p. 201-213.

Yoshida, T. and Kojima, H., 1978, Studies on environmental safety of diisopropylnaphthalene (DIPN) Part II Biodegradation of ^{14}C-DIPN with activated sludge: Chemosphere, no. 6, p. 497-501.

Young, L. Y., 1984, Anaerobic degradation of aromatic compounds; in D. T. Gibson, ed., Microbial Degradation of Organic Compounds, hMarcel Dekker, Inc., Ch. 16, p. 487-523.

Yu, C.-C., Booth, G. M., Hansen, D. J., and Long, J. R., 1974, Fate of carbofuran in a model ecosystem: Journal of Agriculture and Food Chemistry, v. 22, no. 3, p. 431-434.

Zettlemoyer, A. C. and Micale, R. J., 1971, Solution adsorption thermodynamics for organics on surfaces; in S. J. Faust and J. V. Hunter, eds., Organic Compounds in Aquatic Environments, Marcel Dekker, p. 165-185.

Zoetman, B. C. J., De Greef, E., and Brinkman, F. J. J., 1981, Persistency of organic contaminants in groundwater, lessons from soil pollution incidents in the Netherlands: The Science of the Total Environment, v. 21, p. 187-202.

Appendix II.

Compilation of research on degradation and sorption reactions for hazardous waste. (references listed in Appendix I.)

ORGANICS

Biological Processes

Phenols

Chemical	Environment	Degradation	References	Notes
Creosote and pentachlorophenol	Unconfined, shallow, sandy aquifer. A spill created a plume in the aquifer.	Biodegradation	Borden et al., 1986	Plume of contaminants was smaller than the Cl plume, indicating retardation. Model was used and simulated this fairly well.
p-nitrophenol	Laboratory study on soil samples	Biodegradation	Raymond and Alexander, 1971	Degraded to 4-nitrocatechol in approximately 48 hours if soil was treated with chloroform (about 20-30% degraded). If the soil was not treated with chloroform, about 50% degraded to nitrite in 4 hours.
n-nitrophenol	Laboratory study on soil samples	Cometabolism	Raymond and Alexander, 1971	Degraded to nitrohydroquinone in 60-72 hours. 50% reduction.
3,5-dinitro-o-cresol	Laboratory study on a pure culture	Biodegradation	Tewfik and Evans, 1966	Showed that biodegradation occurred in a pure culture in the laboratory.
m, o, p- cresols	Laboratory study on shallow, anoxic sand aquifer material	Biodegradation (anaerobic)	Smolenski and Suflita, 1987	All cresols degraded. Cresols degraded at a more rapid rate under sulfate reducing conditions. If sulfate was added, the rate of degradation increased. Lag times of 10 to 100 days of p, m, o- cresols. Eventually all cresols will be completely removed.
Phenolic compounds	Laboratory study with cyanide present.	Biodegradation by phenol degrading and methanogenic bacteria	Fedorak et al., 1986	The presence of cyanide slowed the degradation on the phenols because it inhibits the methanogenic bacteria which degrade acetate (a product of phenol degradation) to methane. An increase in cyanide will decrease the rate of phenol degradation.

o- cresol	Laboratory study on phenol acclimated activated sludge.	Biodegradation	Mesunaga et al., 1986	Cresol disappeared in 1.5 h. Went to three different dihydroxytoluenes.
Pentachlorophenol	Laboratory study	Biodegradation (anaerobic)	Guthrie et al., 1984	Pentachlorophenol (PCP) is anaerobically biodegraded. Acclimation achieved only if the PCP concentration is low during the initial exposure. Removal is complete, and sorption is only a minor removal mechanism. Anaerobic degradation is characterized as "extensive".
Ketone-Aldehydes				
Heptaledhyde, naphthalene	Injection into a shallow well in a sandy aquifer.	Biodegradation/adsorption.	Rittman et al., 1980	Biofilm theory. Bacteria live in thin film on the individual grains in the aquifer. Heptaldehyde was degraded to 31% of its original concentration, but not sure whether it was due to biodegradation or sorption processes. Naphthalene degraded to less than 10%.
Nitriles				
Bromoxynil (a nitrile)	Laboratory study in a basal medium (final pH= 6.6)	Biodegradation	Smith and Cullimore, 1974	After 5 weeks only 5% of the original concentration was left. There was no loss in a sterile experiment.
2,6-dichlorophenylacetonitrile	Laboratory study on surface and subsurface soils.	Biodegradation	Briggs and Dawson, 1970	Rate of disappearance was 23 times faster in non-sterile soils as opposed to sterile soils.
Acetonitrile, propionitrile, acrylonitrile, butenenitrile, hydroacrylonitrile, succinonitrile, benzonitrile	Laboratory study	Biodegradation	DiGeronimo and Antoine, 1976	All but benzonitrile supported bacterial growth. Acetonitrile degraded completely in 15 minutes sequentially to acetamide, acetic acid and ammonia. Propionitrile degraded to approximately 10% original concentration in 100 hours to propionic acid and ammonia.
Carboxylic Acids				
Carboxylic acids	Landfill polluting an aquifer 100-200 ft. below land surface.	Biodegradation	Baedecker and Back, 1979	Acid concentration decreased downgradient, and so did CH_4 concentration produced by the biodegradation of acetic acid. Note; products of biodegradation may be more harmful than the original chemicals.

Alcohols				
Methanol	Laboratory microcosm study on soil samples.	Biodegradation	Novak et al., 1985	Degraded quickly with a concentration of 500 - 1000 mg/l totally gone in about 200 days. Anaerobic degradation occurs, but it is slower.
Methanol and higher alcohols	Laboratory study	Biodegradation (anaerobic)	Lettinga et al., 1981	Higher alcohols degraded immediately and after a lag time of a few days so did the methanol. Process may be very unstable and upset by the presence of one or more trace elements.
Tertiary butyl alcohols	Laboratory microcosm study on soil samples.	Biodegradation	Novak et al., 1985	200 plus days for the tertiary butyl alcohols to degrade. The degradation rate increased as the initial concentration increased.
Other and Mixed Organics				
Chlorinated hydrocarbons (tetrachloroethylene, and 1,4-dichlorobenzene)	Surface (natural infiltration of river water). Batch and column studies also conducted.	Biodegradation, sorption	Schwarzenbach and Giger, 1985	Retardation depends on the size fraction of the aquifer material. 85% of the sorption occurs at size fraction $\phi <$ 125um. Biological processes appear to remove many chlorinated hydrocarbons as the water infiltrates.
Monochlorobiphenyl and biphenyl	Laboratory study on river water (die-away study).	Biodegradation	Bailey et al., 1983	Both chemicals biodegraded, but the biphenyl degraded faster than the monochlor. Both reduced to 50% of the original concentration in less than 5 days. Rate of biodegradation decreased as the concentration of the chemical increased. The rate of biodegradation increased with time.
Dimethylamine, diethylamine, dithanolamine	Laboratory study using trace concentrations (ng level) in stream water.	Biodegradation	Boethling and Alexander, 1979	At trace levels biodegradation decreases. This is because at low levels the bacteria cannot grow and increase in population. Important because natural conditions are often at low levels like this. Density of bacteria is important because if the chemical is present at low concentrations, no more bacteria can grow.
Trihalomethanes, chloroform	Batch laboratory experiments, aerobic and anaerobic conditions.	Biodegradation	Bouwer et al., 1981	No aerobic degradation occurred. The trihalomethanes biodegraded almost completely in less than two weeks. Chloroform also degraded, but at a significantly slower rate.

m-chlorobenzoate and 2,3,6-trichlorobenzoate	Laboratory study	Cometabolism	Horvath and Alexander, 1970	The two were completely converted to other organics (4-chlorocatechol, 3,5-dichlorocatechol)
Naphthalene, fluorene, dibenzofuran, anthracene, and pentachlorophenol	Study in groundwater samples and laboratory study on subsurface soil samples from approximately 24 ft. down.	Biodegradation	Lee et al., 1984	Naphthalene degraded the quickest (up to 100%/week), then dibenzofuran and fluorene. Anthracene and pentachlorophenol degraded the slowest. An increased initial concentration did not seem to have an effect on the rate of biodegradation. In both contaminated and uncontaminated soil samples removed the pollutants at approximately 3.5% per week..
Trichloroethylene	Field site with groundwater contamination by organics. 1.2m thick sand aquifer about 4-5m below ground surface.	Biodegradation by methane consuming bacteria, sorption.	Semprini et al., 1988	Retardation factors for trichloroethylene and trichloroethane estimated at 3 and 7.5 respectively. Trichloroethylene biodegraded 30% in a test case at a field site. Methane and trichloroethylene were added to the aquifer in pulses.
Toluene, styrene, chlorobenzene	Samples used in laboratory study taken from above and below the water table (2-5m depth) at 2 sites.	Biodegradation	Wilson et al., 1983	Toluene degraded 1-3%/week Styrene degraded 2.5-12%/week Chlorobenzene degraded 1-2%/week
Naphthalene, 1-methylnaphthalene	Laboratory study done with soil samples (a sandy loam).	Biodegradation	Sims et al., 1988	Half lives were about 2 days. Degradation was characterized as "extensive".
Chlorinated methane, ethane, and ethenes	Spilling on ground that infiltrates to a shallow aquifer (200' - 300')	Biodegradation	Wood et al., 1985	This paper deals with volatile organics in groundwater. Many of the highly volatile compounds present are due to the biodegradation of tri- and tetrachloroethylene. All parent and daughter compounds studied were susceptible to biodegradation.
Toluene and styrene	Surface and subsurface environments were simulated in microcosm (batch and column) experiments in the laboratory.	Biodegradation	Wilson et al., 1985	Study shows that the amount of biodegradation varies from site to site, and is different in different environments. Concluded that biodegradation in the subsurface cannot be determined by the behavior at the surface.

Naphthalene	Injection into a shallow well in a sandy aquifer.	Adsorbed, then biodegraded.	Rittman et al., 1980	Naphthalene degraded to <10% of its original concentration in less than 12 hours. It was retarded and then biodegraded by bacteria in biofilm.
Toluene	Unconsolidated sediments (0-10 m). Two sites were used, a pristine site in OK, and a site contaminated by a disposal lagoon for wood-creosoting wastes.	Biodegradation	Wilson et al., 1986	Study relates amount of ATP present in the organic to the amount of biodegradation that occurs. As ATP increases in the toluene it becomes more susceptible to biodegradation.
Alkylated and chlorinated benzenes	Field study. Looked at river water infiltrating into groundwater.	Biodegradation	Schwarzenbach et al., 1983	The volatile organics were not adsorbed at all and therefore dispersed if they were not biodegraded. Biodegradation did not occur for chloroform, 1,1,1-trichloroethane, trichloroethylene, or tetrachloroethylene. 1,4-dichlorobenzene biodegraded only in aerobic conditions. Biodegradation occurred for all alkylated benzenes, naphthalenes, and methylnaphthalenes. Eliminated in the first few meters of infiltration and at 5^{o}C. 1,4-dichlorobenzene biodegraded at a slower rate than the others.
Alkylpyridines	Groundwater	Biodegradation (anaerobic and aerobic)	Rogers et al., 1985	Aerobic degradation reduced concentrations to zero in 10-31 days. Anaerobic degradation reduced concentrations 40- 80% in 33 days, notably slower.
Methanol, propanol, sodium acetate, glucose, acetone, cyanide	Laboratory study	Biodegradation	Lewandowski, 1984	Cyanide inhibits denitrification of methanol, propanol and sodium acetate. Doesn't inhibit glucose or acetone degradation because the cyanide reacts to form cyanohydrins, and therefore removes the toxic effect.
Carboxylic acids, alcohols, phenols, ketone-aldehydes, nitriles	Laboratory study at high temperatures and pressures	Biodegradation (aerobic)	Grula and Grula, 1976	Simulated deep well conditions, unfortunately did not do anaerobic degradation. Determined that many wastes did degrade, but under conditions existing in deep wells they will not degrade and therefore that biodegradation should not be relied on.
Alkylbenzenes and halogenated aliphatic hydrocarbons	Laboratory microcosm study	Biodegradation (anaerobic)	Wilson et al., 1986	Biodegradation did occur, but often with a long lag time (many weeks). Alkylbenzenes are not expected to degrade in anoxic waters.

Halogenated organics	Laboratory column studies and a batch model.	Biodegradation (aerobic and methanogenic)	Bouwer and McCarty, 1984	Biofilm model developed to model the secondary utilization of trace pollutants. This occurs when a trace compound is biodegraded by bacteria biodegrading the primary substrate. Study showed up to 95+% removal.
Nitriloacetic acid	River sediment	Biodegradation	Loch and Lagas, 1985	Nitriloacetic acid rapidly disappears due to biodegradation. There is no difference between anoxic and oxic conditions. Complete degradation occurred within 8 days if organisms were present at the start of the experiment, but took one month if bacteria had to be acclimated. Nitriloacetic acid did not effect the metals concentration.

Sorptive Processes

Phenols

Phenol	Laboratory study- flow through model (at 60° C, and 38° C)	Adsorption	Collins and Crocker, 1988	More phenol was adsorbed at 38° C than at 60° C. There was also a larger percent adsorbed at a higher initial concentration. No desorption occurred. No degradation seemed to occur.
Chlorinated phenols (and ionizable hydrophobic compounds: phenols, amines, carboxylic acids)	River sediments	Sorption	Schwarzenbach and Westall, 1985	Sorption increased as pH decreased due to decreased ionization.
Chlorinated phenols	Laboratory study	Sorption	Schellenberg et al., 1984	As pH decreased, sorption increased. There was a correlation between K_{ow} and percent organic carbon in the sorbent. If percent organic carbon decreased then there were small distribution ratios for chlorinated phenols. For some, phenolate sorption is very important, and the degree of sorption depends on the ionic strength of the aqueous solution.
Chlorinated phenols	Laboratory study	Sorption	Westall et al., 1985	Organic-inorganic pairs can be very important in the non-aqueous phase. As the pH and ionic strength increases, chlorophenolate ions in association with K^+ were the dominant species. Distribution of chlorinated phenols between aqueous and non-aqueous phases was shown to depend on pH and ionic strength.

Acetophenone, benzophenone, phenol, 2,4-dichlorophenol	Laboratory	Sorption (and chemical reactions)	Briggs, 1981	Laboratory work determined: Phenol K_{ow}= 1.46 Acetophenone K_{ow}= 1.58 Benzophenone K_{ow}= 3.18 2,4-dichlorophenol K_{ow}= 2.80 and R_f= 0.30
Ketone-Aldehydes				
Camphor, fenchone (ketones)	Waste dump	Sorption	Zoetman et al., 1981	Half lives of camphor and fenchone are 0.3 and 0.6 years. Half life estimates for many more compounds are available in this paper.
Acetophenone	Laboratory study on sediments and soils	Sorption	Khan et al., 1979	K_p (partition coefficients) increase with increasing organic carbon percent in the sediments. If the total organic carbon is low then an increase in montmorillonite causes k_p to increase. As the amount of acetophenone increases the amount adsorbed increases.
Nitriles				
n-butyronitrile, pyridine,2,6-dimethylpyridine, 2,5-dimethylpyrrole, quinoline, inodole, stearonitrile	Petroleum reservoir, studying natural organics (no anthropogenic pollutants). Laboratory work done on clays.	Ion exchange, adsorption onto clays.	Charlesworth, 1986	Neutral and especially basic nitrogen compounds are removed by clay adsorption. Based on the ion exchange capacity of the clays.
2,6-dichlorobenzonitrile	Laboratory study on surface and subsurface soils	Sorption	Briggs and Dawson, 1970	Partition coefficients correlated with the organic matter content. The amount of clay in the sorbent had no effect. There was no difference between the sterile and non-sterile experiments. Half lives were at least 5 months in this closed system.
Other and Mixed Organics				
Chlorobenzene, chloroform, ammonia trihalomethanes	Shallow aquifer (30' - 50')	Sorption	Roberts et al., 1985	Very few details. Shows that chlorobenzene is retarded the most, then bromoform, and the least retarded in their study is chloroform. Retardation is attributed to sorption.
di-, tri-, and tetrachlorophenyls	Shallow (<50cm) marine sediments, polluted by PCB rich harbor waters.	Sorption to organic colloids. Possible biodegradation.	Brownawell and Farrington, 1986	Di-, tri-, and tetrachlorobiphenyls were sorbed to organic colloids and may also have been biodegraded.

Benzene, naphthalene, anthracene	Natural estuarine colloids studied in the laboratory	Sorption	Wijayaratne and Means, 1984	Sorption was greater by an order of magnitude than reported for pond sediments. Suggests that hydrophobic compounds are more strongly bonded to estuarine colloid organic material. K_d's are 920, 4060, and 510000 for benzene, naphthalene and anthracene.
Pyrene, methoxychlor	Laboratory study- studied bottom sediments in different sediment size fractions	Sorption	Karickhoff et al., 1979	Sorption increases with increasing organic carbon content, and with a smaller size fraction (<50 um). Knowing K_{ow} can give a good estimate of the k_{oc} of the sediments.
Nonpolar organics- halogenated alkenes and benzenes	Column and batch experiments	Sorption	Schwarzenbach and Westall, 1981	These are volatile solutes. There is a correlation between the organic carbon content of the sorbent and the K_p of the compounds if the organic carbon content of the sediments is greater than 0.1%. Compounds are very mobile (low K_p) in "organic poor" media. Sorption is reversible for natural conditions.
Pyrene, 7,12-dimethylbenz[α]anthracene, 3-methylcholanthracene, dibenzanthracene	Laboratory study- 11 sediments and 3 soils	Sorption	Means et al., 1980	An increase in the mass of the compound does not control the sorptive properties. The effective chain length does (increase chain length, increase sorption). Pyrene < 7,12-dimeth. < 3,methyl. < dibenz. in sorption.
Naphthalene, anthracene, fluoranthene	Laboratory, modeling	Sorption	Grenney et al., 1987	A model was developed to simulate movement of a hazardous substance in the unsaturated zone. Lab work done with three polynuclear aromatic hydrocarbons show that the model closely simulated the fate and behavior of the three compounds.
Nonionic organic compounds	Laboratory study on a silt loam soil	Sorption	Chiou et al., 1983	Found that the insolubility of the solute in water is the main factor in estimating the octanol-water partition coefficient. The percent organic carbon in the soil is important, but secondary.
1-butanol, phenol, crotonaldehyde, pyridine, 2-butanone, 1,2-dichloroethane, n-hexyamine, 1-nitropropane, propylproponoate	Laboratory study on sandstone core	Sorption	Donaldson et al., 1975	Adsorption increased as initial concentration increased and as temperature decreased. Adsorption controlled by the bulk and internal pore diffusion.

1,4-dioxane, benzene, carbon tetrachloride, diethyl ether, tetrahydrofuran, 1,2-dichloroethane	Landfill leachate in a shallow (approximately 20 ft below the surface) aquifer	Sorption	Patterson et al, 1985	Plumes were different sizes, all were smaller than the Chloride plume. Retardation factors were estimated to be from 1.6 to 23, with carbon tetrachloride being the most retarded, but also severely retarded was benzene and 1,2-dichloroethane.
Phenols, ketones, alcohols	Laboratory study on three soils	Sorption	Southworth and Keller, 1986	No real correlation was found between the amount of sorption and the hydrophobicity. Any estimate on the sorption coefficient is probably imprecise.
		Other Processes		
Cholesterol, 2,2',5,5'-tetrachlorobiphenyl (PCB)	River water.	Association with organics	Hassett and Anderson, 1974 Hassett and Anderson, 1981	Association of cholesterol and PCB with dissolved organic matter inhibits adsorption of these chemicals.
Hydrogen	Study in sediments	Methanogenesis and sulfate reduction	Oremland and Taylor, 1978	Methanogenesis and sulfate reduction are not mutually exclusive.
Acidic waste and alkaline waste	Sandstone and dolomite samples studied in the lab	Neutralization	Roy et al., 1988	The acidic waste reacted with the carbonate and was neutralized. It was only partially neutralized by the sandstone. The alkaline waste remained hazardous after it reacted with the rocks.
Ammonia, chloroform, chlorobenzene, 1,3-dichlorobenzene, 1,4-dichlorobenzene	Injection of reclaimed water into an aquifer approximately 185 feet below the surface.	Biological or chemical reactions	Roberts et al., 1978	Ammonia travels at approximately one fortieth as fast as the front's rate. 1,3- and 1,4-dichlorobenzene were retarded somewhat.
1,1-dichloroethane, chloroform, 1,1,1-trichloroethane	Samples studied in the laboratory on soil samples taken from above and below the water table (2-5m depth) at two sites.	Lack of biodegradation.	Wilson et al., 1983	These compounds did not degrade.

Monohalogenated alkanes	Surface (leaking waste water tank). Batch and column studies also conducted.	Hydrolysis (esp. important for tertiary halides)	Schwarzenbach and Giger, 1985	Hydrolysis seems to be important, especially for the tertiary halides. Hydrolysis depends on the constitution of the compound. Study shows that under anaerobic conditions the alkylhalides can undergo other reactions, such as nucleophobic substitution reactions.

Case Studies of Deep Well Injection

Wilmington, NC

Carboxylic and dicarboxylic acids, formaldehyde, methanol	Deep well injection (850-1000 ft) into unconsolidated sediments (sand and clay) with some interbedded limestones.	Biodegradation, chemical reactions, neutralization. Produced CH_4, CO_2, and H_2S.	Leenheer et al., 1973 Peek, et al., 1973 (for the geology)	Wilmington, NC case study. Study showed that four different types of reactions occurred as the waste front moved into the aquifer; dilution, biodegradation, chemical reactions, and then neutralization.
Carboxylic and dicarboxylic acids, formaldehyde, methanol	Deep well injection (850-1000 ft) into unconsolidated sediments (sand and clay) with some interbedded limestones.	Biodegradation, however at a fairly low efficiency.	DiTommaso et al., 1973	Wilmington, NC case. As the waste front arrived the number of microorganisms in the aquifer increased tremendously, indicating microbial activity. Low efficiency system. Wastefront also appears to cause changes that harm the bacteria.
Carboxylic and dicarboxylic acids, formaldehyde, methanol	Deep well injection (850-1000 ft) into unconsolidated sediments (sand and clay) with some interbedded limestones.	Chemical reactions with aquifer materials, biodegradation, adsorption.	Leenheer et al., 1976a, 1976b	Wilmington, NC case. Acid first reacts with the aquifer to form CO_2. Also dissolves the aluminosilicates, Fe sesquioxide coatings. Fe complex (complexed with phthalic acid) precipitates. Biodegradation of acids produces methane. There appears to be a retention of the waste due to adsorption and anion exchange.

Pensacola, FL- Monsato Co.

Organic acids, nitric acid, amines, ketones	Deep well injection into a limestone aquifer (1000+ feet deep)	Chemical reactions	Goolsby, 1971, Barraclough, 1966 for background and operations	Nitrate reduction occurs. Also neutralization, but not from dissolving $CaCO_3$, rather it is thought to be due to nitric acid reaction with alcohols and ketones. About ten months after injection began, the Ca concentration increased at an observation well 1300 feet away. This was thought to be due to the dissolution of calcite in the limestone.

Alcohols, ketones, acids, esters, nitriles	Deep well injection into a limestone aquifer (1000+ feet deep)	Neutralization and denitrification	Goolsby, 1972	Acidic waste is thought to dissolve the limestone and is therefore neutralized. Denitrification was shown to occur in a backflushing experiment.
Pensacola, FL- American Cyanamid				
Organonitriles, nitrate, cyanide, acetone	Deep well injection into a limestone aquifer (approximately 1300 feet deep)	Biodegradation	Ehrlich et al., 1979 Vecchioli et al., 1984	The organonitriles and nitrate degraded. Back flow test showed that the degradation was complete within 100 meters of the point of injection. Confirmed by monitoring well. Denitrifying bacteria (anaerobic) present. Cyanide also appears to decrease although this is not covered in the report.
Other Studies				
Iron	Deep well injection of reclaimed water into a sand aquifer 420 to 480 feet deep.	Redox reactions	Ragone et al., 1973	Change in the redox conditions caused by the waste causes pyrite to dissolve and therefore the Fe in solution increases. Eventually a ferric hydroxide precipitates and the Fe in solution decreases.
Injected waste (especially acetate)	Deep well injection	Complexing, destabilization of mineral phases	Drez, 1988	Waste can effect formation minerals, especially the organic acids. Acetate is good at complexing some metals and can effect mineral stability, including aluminosilicate minerals.
		Other Case Studies		
Palo Alto, CA				
Fresh water	Aquifer approximately 45 to 55 feet below the surface.	Dilution, dissolution	Hamlin, 1987	As injected fresh water gets into the aquifer, dilution of the formation water occurs. Calcite becomes undersaturated because of the dilution and dissolves.
Injected water	Aquifer approximately 45 to 55 feet below the surface.	Ion exchange	Valocchi et al., 1981	Computer simulation closely agreed with field simulation of fronts of injected ions. Indicates that laboratory determined chemical parameter values can be used in field scale simulations.

Chloroform, chlorobenzene, trihalomethanes, naphthalene	Aquifer approximately 45 to 55 feet below the surface.	Biodegradation	Roberts et al., 1982 Roberts and Valocchi, 1981	Trihalomethanes biodegrade very quickly. Chloroform degrades slightly.
Chlorobenzene, chloroform, bromoform	Aquifer approximately 45 to 55 feet below the surface.	Sorption	Roberts et al., 1982 Roberts and Valocchi, 1981	Chlorobenzene is greatly retarded, followed by bromoform and chloroform which are retarded only slightly. The bulk of the organics are not retarded.
Other Studies				
Butyric acid, phenol, chlorophenol, dimethyl phthalate	Injection into an aquifer 16 to 20 feet below the surface.	Biodegradation	Sutton and Barker, 1985	No sorption occurs. The organic carbon content in the sand is 0.15%. Biodegradation does appear to be occurring. Degrades in the order: Butyric acid >> phenol > chlorophenol > dimethyl phthalate
NH_4^+, CH_4, Fe, Mn	Marine sediments as a natural analog to a landfill.	Biodegradation	Baedecker and Back, 1979	Concluded that it is a good analog. Found three biochemical zones: an anaerobic zone, a transition zone, and an aerobic zone. The boundaries are controlled by dilution and self purification processes.
		INORGANICS		
Sr^{90}, Cs^{137}	Basaltic aquifer, approx. 500' beneath surface.	Sorption, which has a large influence.	Robertson and Barraclough, 1985	All radionucleides. Groundwater motion and mass transport model was developed for this problem, and this proved to be useful, by successfully simulating distribution and transport history of chloride and tritium.

DRAFT

APPENDIX III.

Chemical compositions of hazardous waste streams injected into noncommercial class I industrial waste disposal wells in Texas.

Company: Amoco
Plant: Texas City
UIC No.: WDW- 80

DRAFT

Waste: organic, brine, caustic
Process: refinery operation

Gallons of waste injected in 1985: 13540330
1986: 33790
Injection temperature (centigrade):
Specific gravity: 1.00-1.14

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	7.6	7.6
total dissolved solids	1820	16619
Na	520	520
K	0.20	0.20
Mg	0.01	0.01
Cl	760	1843
HC03	12070.00	12070.00
sulfide	0.10	1117.00
sulfate	78.00	78.00
sulfite	6000.00	6000.00
F	1.20	1.20
ammonia	0.10	985.00
nitrate	36.00	36.00
nitrogen (kjeldahl)	12000.00	12000.00
Zn	0.11	0.11
As	0.160	0.160
Cu	600.00	600.00
Cr	0.080	0.080
Se	0.010	0.010
Pb	96.000	96.000
Cd	6.000	6.000
Ba	0.000	0.800
Ag	0.02	0.02
CN (cyanide)	0.01	0.01

ORGANIC COMPOUNDS	MINIMUM (mg/l)	MAXIMUM (mg/l)
Total Organic Carbon	16.00	13650.00
Chemical Oxygen Demand	31	74130
Biochemical Oxygen Demand	64	21116
Oil and Grease	4.00	4.00
phenols (group)	420.00	872.00
cresol (cresylic acid)	0.00	4200.00
mercaptans	0.00	4000.00

NOTES:

DRAFT

Type of waste: sour water, ammonia rich water, amine solutions, brines, spent caustic.

The same waste is injected into WDW-80, 127, and 128.

Company: Amoco
Plant: Texas City
UIC No.: WDW- 127

DRAFT

Waste: organic, brine, caustic
Process: refinery operation

Gallons of waste injected in 1985: 148105360
1986: no data
Injection temperature (centigrade):
Specific gravity: 1.00-1.14

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	7.6	7.6
total dissolved solids	1820	16619
Na	520	520
K	0.20	0.20
Mg	0.01	0.01
Cl	760	1843
HCO3	12070.00	12070.00
sulfide	0.10	1117.00
sulfate	78.00	78.00
sulfite	6000.00	6000.00
F	1.20	1.20
ammonia	0.10	985.00
nitrate	36.00	36.00
nitrogen (kjeldahl)	12000.00	12000.00
Zn	0.11	0.11
As	0.160	0.160
Cu	600.00	600.00
Cr	0.080	0.080
Se	0.010	0.010
Pb	96.000	96.000
Cd	6.000	6.000
Ba	0.000	0.800
Ag	0.02	0.02
CN (cyanide)	0.01	0.01

ORGANIC COMPOUNDS

Total Organic Carbon	16.00	13650.00
Chemical Oxygen Demand	31	74130
Biochemical Oxygen Demand	64	21116
Oil and Grease	4.00	4.00
phenols (group)	420.00	872.00
cresol (cresylic acid)	0.00	4200.00
mercaptans	0.00	4000.00

NOTES:

Type of waste: sour water, ammonia rich water, amine solutions, brines, spent caustic.

The same waste is injected into WDW-80, 127, and 128

DRAFT

DRAFT

Company: Amoco
Plant: Texas City
UIC No.: WDW- 128

Waste: organic, brine, caustic
Process: refinery operation

Gallons of waste injected in 1985: 45947780
1986: no data
Injection temperature (centigrade):
Specific gravity: 1.00-1.14

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	7.6	7.6
total dissolved solids	1820	16619
Na	520	520
K	0.20	0.20
Mg	0.01	0.01
Cl	760	1843
HCO3	12070.00	12070.00
sulfide	0.10	1117.00
sulfate	78.00	78.00
sulfite	6000.00	6000.00
F	1.20	1.20
ammonia	0.10	985.00
nitrate	36.00	36.00
nitrogen (kjeldahl)	12000.00	12000.00
Zn	0.11	0.11
As	0.160	0.160
Cu	600.00	600.00
Cr	0.080	0.080
Se	0.010	0.010
Pb	96.000	96.000
Cd	6.000	6.000
Ba	0.000	0.800
Ag	0.02	0.02
CN (cyanide)	0.01	0.01

ORGANIC COMPOUNDS		
Total Organic Carbon	16.00	13650.00
Chemical Oxygen Demand	31	74130
Biochemical Oxygen Demand	64	21116
Oil and Grease	4.00	4.00
phenols (group)	420.00	872.00
cresol (cresylic acid)	0.00	4200.00
mercaptans	0.00	4000.00

NOTES:

Type of waste: sour water, ammonia rich water, amine solutions, brines, spent caustic.

The same waste is injected into WDW-80, 127, and 128.

DRAFT

Company: Arco
Plant: Channelview
UIC No.: WDW- 36

Waste: organic
Process: manufacture of synthetic organic chemicals

Gallons of waste injected in 1985: no data
1986: 24750327
Injection temperature (centigrade): ambient
Specific gravity: 1.03-1.06

WASTE COMPOSITION

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	11.0	13.0
total dissolved solids	60500	86100
Na	11650	25450
CO3	9550.00	13750.0
sulfide	50.00	8550.00
nitrogen (kjeldahl)	5.00	21.00
Hg	0.000	0.020

ORGANIC COMPOUNDS

ORGANIC COMPOUNDS	MINIMUM (mg/l)	MAXIMUM (mg/l)
Total Organic Carbon	22900.00	46000.00
Chemical Oxygen Demand	75000	133000
alpha-methyl benzyl alcohol	2630.00	3620.00
propylene glycol (propanediol)	11010.00	13670.00
benzene	0.00	100.00
ethyl benzene	0.00	100.00
styrene (vinyl benzene)	0.00	40.00
acetophenone (methyl phenyl ketone-benzene deriv)	220.00	620.00
phenol	2100.00	3800.00
allyic alcohol	0.00	100.00

NOTES:

Chemical pretreatment: ph adjusted

Waste produced from manufacture of:
- methyl ethyl ketone by butylene hydrolysis
- isopropyl alcohol by catalytic hydrogenation of acetone
- poly butadiene by polymerization
- ethylene and propylene by pyrolysis of naphthe and/or gas oil
- styrene maleic anhydride by esterification of styrene and maleic anhydride

Type of waste: 4 waste streams
1. caustic waste water
2. oxidation heavies
3. formaldehyde

4. misc. wastewaters

Permit reports suggest that the same waste stream is injected into WDW-36, 148, and 162.

DRAFT

DRAFT

Company: Arco
Plant: Channelview
UIC No.: WDW- 148

Waste: organic
Process: manufacture of synthetic organic chemicals

Gallons of waste injected in 1985: 77240689
1986: no data
Injection temperature (centigrade): ambient
Specific gravity: 1.03-1.06

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	11.0	13.0
total dissolved solids	60500	86100
Na	11650	25450
CO3	9550.00	13750.0
sulfide	50.00	8550.00
nitrogen (kjeldahl)	5.00	21.00
Hg	0.000	0.020

ORGANIC COMPOUNDS

Total Organic Carbon	22900.00	46000.00
Chemical Oxygen Demand	75000	133000
alpha-methyl benzyl alcohol	2630.00	3620.00
propylene glycol (propanediol)	11010.00	13670.00
benzene	0.00	100.00
ethyl benzene	0.00	100.00
styrene (vinyl benzene)	0.00	40.00
acetophenone (methyl phenyl ketone-benzene deriv)	220.00	620.00
phenol	2100.00	3800.00
allyic alcohol	0.00	100.00

NOTES:

Chemical pretreatment: pH adjusted

See memo WDW-36

DRAFT

Company: Arco
Plant: Channelview
UIC No.: WDW- 162

Waste: organic
Process: manufacture of synthetic organic chemicals

Gallons of waste injected in 1985: 44
1986: no data
Injection temperature (centigrade): ambient
Specific gravity: 1.03-1.06

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	11.0	13.0
total dissolved solids	60500	86100
Na	11650	25450
CO3	9550.00	13750.0
sulfide	50.00	8550.00
nitrogen (kjeldahl)	5.00	21.00
Hg	0.000	0.020

ORGANIC COMPOUNDS		
Total Organic Carbon	22900.00	46000.00
Chemical Oxygen Demand	75000	133000
alpha-methyl benzyl alcohol	2630.00	3620.00
propylene glycol (propanediol)	11010.00	13670.00
benzene	0.00	100.00
ethyl benzene	0.00	100.00
styrene (vinyl benzene)	0.00	40.00
acetophenone (methyl phenyl ketone-benzene deriv)	220.00	620.00
phenol	2100.00	3800.00
allyic alcohol	0.00	100.00

NOTES:

Chemical pretreatment: pH adjusted

See memo WDW-36

DRAFT

Company: Asarco
Plant: Amarillo Copper
UIC No.: WDW- 129

Waste: acid, metals
Process: electrolytic refining of Cu

Gallons of waste injected in 1985: 69743814
1986: no data
Injection temperature (centigrade): ambient
Specific gravity: 1.0

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	1.5	1.5
total dissolved solids	13520	13520
Na	1700	1700
Mg	51.00	51.00
Cl	827	827
H2S04$	4900.00	4900.00
nitrate	1700.00	1700.00

ORGANIC COMPOUNDS

NOTES:

Chemical pretreatment: pH neutralized

Other chemicals reported as present without concentrations: SiO2, K, Al, Fe

Also trace metal compounds = 382 mg/l

Company: Badische
Plant: Freeport
UIC No.: WDW- 51

DRAFT

Waste: organic
Process: manufacture of cyclohexanone and caprolactam

Gallons of waste injected in 1985: 33780000
1986: 38287000
Injection temperature (centigrade): ambient
Specific gravity: 1.16

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	6.5	7.5
total dissolved solids	50000	100000
Na	100000	125000
Ca	0.00	1.00
Mg	0.00	1.00
Fe	0.00	2.60
Si	0.00	73.00
Al	0.00	4.50
Cl	0	2500
B	0.00	15.00
sulfate	0.00	30000.00
ammonia	0.00	3000.00
Zn	0.00	5.00
Cu	0.00	0.10
Ni	0.00	1.20
Mn	0.00	0.10
Cr	0.000	0.160
Co	1.70	20.00

ORGANIC COMPOUNDS

cyclohexane	0.00	2000.00
cyclohexanol (cyclohexyl alcohol)	1000.00	3600.00
cyclohexanone	100.00	1000.00
formic acid	500.00	1000.00
acetic acid (ethanoic)	500.00	1000.00
propionic acid (propanoic)	500.00	1000.00
butyric acid (butanoic)	500.00	1000.00
valeric acid (pentanoic)	500.00	94000.00
caproic acid (hexanoic)	500.00	40000.00
hydroxycaproic acid	25000.00	300000.0
malonic acid	10000.00	27000.00
succinic acid	10000.00	27000.00
glutaric acid	10000.00	10000.00
adipic acid	30000.00	40000.00
caprolactam (aminohexanoic acid lactam)	0.00	5000.00
polyesters	0.00	85000.00
polyesters	0.00	85000.00
sulfonated organics	0.00	10000.00

DRAFT

NOTES:
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Generalized description of waste stream: A combination of varying amounts of extraction tower bottoms, caustic water and acid water.

The same was is injected into WDW-51 and 99.

DRAFT

Company: Badische
Plant: Freeport
UIC No.: WDW- 99

Waste: organic
Process: manufacture of cyclohexanone and caprolactam

Gallons of waste injected in 1985: 0
1986: 0
Injection temperature (centigrade): ambient
Specific gravity: 1.16

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	6.5	7.5
total dissolved solids	50000	100000
Na	100000	125000
Ca	0.00	1.00
Mg	0.00	1.00
Fe	0.00	2.60
Si	0.00	73.00
Al	0.00	4.50
Cl	0	2500
B	0.00	15.00
sulfate	0.00	30000.00
ammonia	0.00	3000.00
Zn	0.00	5.00
Cu	0.00	0.10
Ni	0.00	1.20
Mn	0.00	0.10
Cr	0.000	0.160
Co	1.70	20.00

ORGANIC COMPOUNDS

cyclohexane	0.00	2000.00
cyclohexanol (cyclohexyl alcohol)	1000.00	3600.00
cyclohexanone	100.00	1000.00
formic acid	500.00	1000.00
acetic acid (ethanoic)	500.00	1000.00
propionic acid (propanoic)	500.00	1000.00
butyric acid (butanoic)	500.00	1000.00
valeric acid (pentanoic)	500.00	94000.00
caproic acid (hexanoic)	500.00	40000.00
hydroxycaproic acid	25000.00	300000.0
malonic acid	10000.00	27000.00
succinic acid	10000.00	27000.00
glutaric acid	10000.00	10000.00
adipic acid	30000.00	40000.00
caprolactam (aminohexanoic acid lactam)	0.00	5000.00
polyesters	0.00	85000.00
polyesters	0.00	85000.00
sulfonated organics	0.00	10000.00

NOTES:
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See WDW-51

DRAFT

DRAFT

Company: Caithness Mining
Plant: Hebbronville
UIC No.: WDW- 185

Waste: low level radioactive (Ra226-U)
Process: in-situ leach for uranium and aquifer restoration

Gallons of waste injected in 1985: 44302504
1986: no data
Injection temperature (centigrade): ambient
Specific gravity: 1.0-1.1

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	6.5	7.5
total dissolved solids	1000	42000
Na	500	10000
K	0.00	100.00
Ca	100.00	3000.00
Mg	0.00	200.00
Cl	500	10000
C03	100.00	3000.0
HC03	100.00	5000.00
sulfate	100.00	5000.00
Mo	0.00	100.00
U	0.00	100.00
Ra226 (pCi/liter)	200.00	1000.00

ORGANIC COMPOUNDS

NOTES:

Company: Celanese
Plant: Bay City
UIC No.: WDW- 14

DRAFT

Waste: organic
Process: chemical manufacturing (see memo)

Gallons of waste injected in 1985: 57803040
1986: 66307680
Injection temperature (centigrade): 29-35
Specific gravity: 1.002

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	5.9	6.6
total dissolved solids	366	948
ammonia	500.00	500.00
nitrate	0.60	1.50
Zn	0.15	0.42
V	0.001	0.032
As	0.001	0.006
Cu	0.07	0.14
Ni	1.00	3.45
Mn	0.10	0.61
Cr	0.011	0.260
Se	0.001	0.006
Pb	0.001	0.017
Cd	0.001	0.002
Ba	0.002	0.093
Hg	0.300	2.600
CN (cyanide)	0.00	10.00

ORGANIC COMPOUNDS

Total Organic Carbon	1430.00	2591.00
cyclohexane	200.00	300.00
methyl alcohol (methanol)	0.00	300.00
ethy alcohol (ethanol)	0.00	300.00
propyl alcohol (propanol)	0.00	300.00
butyl alcohol (butanol)	0.00	300.00
pentyl alcohol (pentanol)	0.00	300.00
hexanol	0.00	1000.00
amyl alcohol	0.00	600.00
phenols (group)	0.10	0.33
formic acid	0.00	1500.00
acetic acid (ethanoic)	0.00	1500.00
propionic acid (propanoic)	0.00	1500.00
butyric acid (butanoic)	0.00	1500.00
valeric acid (pentanoic)	0.00	1500.00
succinic acid	0.00	500.00
glutaric acid	0.00	500.00
adipic acid	0.00	500.00
hexamethylene imine	1400.00	1400.00

hexamethylene imine	1400.00	1400.00
chlorinated organics	9.00	403.00

NOTES:

Chemical pretreatment: pH adjusted with NH_3 and $NaOH$

Waste from manufacture of:
- acetaldehyde
- vinyl acetate
- n-butyl alcohol
- n-propyl alcohol
- iso-butyl alcohol
- heptanoic acid
- nonanoic acid
- hydrogen
- systhesis gas
- C7 and C9 aldehydes
- propionic acid
- fatty alcohols

The same waste is injected into WDW-14, 32, and 49.

Company: Celanese
Plant: Bay City
UIC No.: WDW- 32

DRAFT

Waste: organic
Process: chemical manufacturing (see WDW-14)

Gallons of waste injected in 1985: 53062560
1986: 37015200
Injection temperature (centigrade): 29-35
Specific gravity: 1.002

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	5.9	6.6
total dissolved solids	366	948
ammonia	500.00	500.00
nitrate	0.60	1.50
Zn	0.15	0.42
V	0.001	0.032
As	0.001	0.006
Cu	0.07	0.14
Ni	1.00	3.45
Mn	0.10	0.61
Cr	0.011	0.260
Se	0.001	0.006
Pb	0.001	0.017
Cd	0.001	0.002
Ba	0.002	0.093
Hg	0.300	2.600
CN (cyanide)	0.00	10.00

ORGANIC COMPOUNDS		
Total Organic Carbon	1430.00	2591.00
cyclohexane	200.00	300.00
methyl alcohol (methanol)	0.00	300.00
ethy alcohol (ethanol)	0.00	300.00
propyl alcohol (propanol)	0.00	300.00
butyl alcohol (butanol)	0.00	300.00
pentyl alcohol (pentanol)	0.00	300.00
hexanol	0.00	1000.00
amyl alcohol	0.00	600.00
phenols (group)	0.10	0.33
formic acid	0.00	1500.00
acetic acid (ethanoic)	0.00	1500.00
propionic acid (propanoic)	0.00	1500.00
butyric acid (butanoic)	0.00	1500.00
valeric acid (pentanoic)	0.00	1500.00
succinic acid	0.00	500.00
glutaric acid	0.00	500.00
adipic acid	0.00	500.00
hexamethylene imine	1400.00	1400.00

hexamethylene imine	1400.00	1400.00
chlorinated organics	9.00	403.00

NOTES:
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Chemical pretreatment: pH adjusted with NH3 and NaOH

See notes WDW 14

Company: Celanese
Plant: Bay City
UIC No.: WDW- 49

DRAFT

Waste: organic
Process: chemical manufacturing (see WDW-14)

Gallons of waste injected in 1985: 5402560
1986: 34165440
Injection temperature (centigrade): 29-35
Specific gravity: 1.002

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	5.9	6.6
total dissolved solids	366	948
ammonia	500.00	500.00
nitrate	0.60	1.50
Zn	0.15	0.42
V	0.001	0.032
As	0.001	0.006
Cu	0.07	0.14
Ni	1.00	3.45
Mn	0.10	0.61
Cr	0.011	0.260
Se	0.001	0.006
Pb	0.001	0.017
Cd	0.001	0.002
Ba	0.002	0.093
Hg	0.300	2.600
CN (cyanide)	0.00	10.00

ORGANIC COMPOUNDS

Total Organic Carbon	1430.00	2591.00
cyclohexane	200.00	300.00
methyl alcohol (methanol)	0.00	300.00
ethy alcohol (ethanol)	0.00	300.00
propyl alcohol (propanol)	0.00	300.00
butyl alcohol (butanol)	0.00	300.00
pentyl alcohol (pentanol)	0.00	300.00
hexanol	0.00	1000.00
amyl alcohol	0.00	600.00
phenols (group)	0.10	0.33
formic acid	0.00	1500.00
acetic acid (ethanoic)	0.00	1500.00
propionic acid (propanoic)	0.00	1500.00
butyric acid (butanoic)	0.00	1500.00
valeric acid (pentanoic)	0.00	1500.00
succinic acid	0.00	500.00
glutaric acid	0.00	500.00
adipic acid	0.00	500.00
hexamethylene imine	1400.00	1400.00

hexamethylene imine	1400.00	1400.00
chlorinated organics	9.00	403.00

NOTES:

Chemical pretreatment: pH adjusted with NH_3 and NaOH

See notes WDW-14

DRAFT

DRAFT

Company: Celanese
Plant: Bay City
UIC No.: WDW- 110

Waste: acid, organic
Process: chemical manufacturing (see memo)

Gallons of waste injected in 1985: 56823840
1986: 89974080
Injection temperature (centigrade): 49-54
Specific gravity: 1.001

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	2.6	2.9
total dissolved solids	380	423
nitrate	1.50	2.50
Zn	0.01	0.04
V	0.004	0.008
As	0.001	0.003
Cu	0.19	0.35
Ni	0.01	0.03
Mn	0.01	0.04
Cr	0.001	0.003
Se	0.002	0.008
Pb	0.000	0.036
Cd	0.000	0.002
Ba	0.042	0.090
Hg	0.300	2.600

ORGANIC COMPOUNDS		
Total Organic Carbon	3697.00	4460.00
Chemical Oxygen Demand	4310	12298
cyclohexane	200.00	300.00
methyl alcohol (methanol)	0.00	300.00
ethy alcohol (ethanol)	0.00	300.00
propyl alcohol (propanol)	0.00	300.00
butyl alcohol (butanol)	0.00	300.00
pentyl alcohol (pentanol)	0.00	300.00
hexanol	0.00	1000.00
amyl alcohol	0.00	600.00
phenols (group)	0.05	0.12
formic acid	0.00	1500.00
acetic acid (ethanoic)	0.00	1500.00
propionic acid (propanoic)	0.00	1500.00
butyric acid (butanoic)	0.00	1500.00
valeric acid (pentanoic)	0.00	1500.00
succinic acid	0.00	500.00
glutaric acid	0.00	500.00
adipic acid	0.00	500.00
hexamethylene imine	1400.00	1400.00
hexamethylene imine	1400.00	1400.00

chlorinated organics	2666.00	7818.00

NOTES:
======

Chemical pretreatment: ph adjusted to 2-4 by adding NH3 and/or NaOH

Waste produced from manufacture of:
    acetaldehyde
    acetic acid
    n-butyl alcohol
    n-propyl alcohol
    isobutyl alcohol
    vinyl acetate

DRAFT

NOTE: An analysis of the organic composition of the WDW-110 waste stream was not porvided. Waste production for WDW 110, however, is the result of processes similar to waste production processes for waste injected into WDW-14, 34, and 49 which are located at the same site as WDW-110. Therefore, the organic waste analysis from WDW-14, 34, and 49 injection stream where included in the composition of WDW-110's waste stream as a best estimate.

Company: Celanese
Plant: Bishop
UIC No.: WDW- 211

DRAFT

Waste: organic
Process: chemical manufacturing (see memo)

Gallons of waste injected in 1985: 93793000
1986: no data
Injection temperature (centigrade): 18-29
Specific gravity: 1.0

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	4.5	5.5
total dissolved solids	500	10000

ORGANIC COMPOUNDS

methyl alcohol (methanol)	331.00	900.00
butyl alcohol (butanol)	65.00	106.00
trimethylol propane	39.00	1527.00
ditrimethylol propane	0.00	4.00
trimethylol propane mono cyclic formal	27.00	1643.00
bis-trimethylol propane mono layer formal	15.00	45.00
pentaerythritol	201.00	2113.00
di pentaerythritol	21.00	21.00
trioxane (metaformaldehyde)	340.00	340.00
tetroxane	75.00	75.00
tetra ethylamine	26.00	26.00
formaldehyde	2500.	2500.
butylene glycol (butanediol)	45.	220.
ethyl propalene glycol (ethyl propanediol)	0.0	484.
neopetyl glycol	130.	130.

NOTES:

Chemical pretreatment: pH adjusted to 5

Waste produced from manufacture of:

- formaldehyde
- methanol oxidation
- methanol synthesis
- paraformaldehyde
- nylon production
- compounding of poly butylene terephthalate
- pentaerythol
- diacetone
- alcohol
- butyraldehyde
- butanol
- methylal

butyl acetate

DRAFT

Company: Celanese
Plant: Bishop
UIC No.: WDW- 212

DRAFT

Waste: organic
Process: chemical manufacturing(see memo)

Gallons of waste injected in 1985: 12355000
1986: no data
Injection temperature (centigrade): 18-25
Specific gravity: 1.0

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	4.5	5.5
total dissolved solids	500	1000

ORGANIC COMPOUNDS

trimethylol propane	39.00	1527.00
ditrimethylol propane	0.00	4.00
trimethylol propane mono cyclic formal	27.00	1643.00
bis-trimethylol propane mono layer formal	15.00	45.00
pentaerythritol	201.00	2113.00
di pentaerythritol	21.00	21.00
trioxane (metaformaldehyde)	340.00	340.00
tetroxane	75.00	75.00
tetra ethylamine	26.00	26.00
formaldehyde	2500.	2500.
butylene glycol (butanediol)	45.	220.
ethyl propalene glycol (ethyl propanediol)	0.0	484.
neopetyl glycol	130.	130.

NOTES:

Chemical pretreatment: pH adjusted to 5

Waste produced from the manufacture of the same group of chemicals as WDW-211 in addition to:

- propyl acetate
- 1,3,butylene glycol
- trimethylol propane
- trioxane
- polyacetal copolymer

Despite the addition chemicals manufactured in production of the waste injected into WDW-212, the organic compositions of the WDW-211 and WDW-212 waste streams are the same.

Company: Celanese
Plant: Clear Lake
UIC No.: WDW- 33

DRAFT

Waste: organic
Process: chemical manufacture (see memo)

Gallons of waste injected in 1985: 120029200
1986: 123720240
Injection temperature (centigrade): ambient
Specific gravity: 1.002

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	3.0	5.0
total dissolved solids	1901	2629
Na	200	1000
K	5.00	20.00
Cl	1000	5000
PO4	500.00	5000.00
B	1.00	20.00
CO3	250.00	2500.0
HCO3	250.00	2500.00
sulfate	500.00	5000.00
F	1000.00	5000.00
ammonia	0.00	5000.00
nitrate	50.00	5000.00
I	1.00	14.60
Zn	1.00	3.00
Cu	1.00	10.00
Mn	1.00	10.00
Cr	1.000	5.000
CN (cyanide)	0.08	0.20

ORGANIC COMPOUNDS

Total Organic Carbon	5000.00	25000.00
methyl alcohol (methanol)	500.00	10000.00
butyl alcohol (butanol)	500.00	50000.00
ethylene glycol (ethanediol)	1000.00	10000.00
diethylene glycol	100.00	50000.00
triethylene glycol	100.00	50000.00
butylene glycol (butanediol)	500.00	5000.00
polyglycols	1000.00	5000.00
butanone (methyl ethyl ketone)	1000.00	5000.00
acetaldehyde (ethanal)	1000.00	5000.00
chloroaldehyde	1000.00	10000.00
dichloroaldehyde	1000.00	10000.00
trichloroaldehyde	1000.00	5000.00
acetic acid (ethanoic)	5000.00	30000.00
acrylic acid (2-propenoic acid)	1000.00	5000.00
citric acid (2-hydroxy 1,2,3 propanetircarboxylic acid)	1000.00	5000.00

oxalic acid (ethanedioic)	1000.00	5000.00
acetic anhydride (ethanoic anhydride)	1000.00	5000.00
ethyl acetate (ethyl ethanoate)	500.00	5000.00
butyl acetate (butyl ethanoate)	500.00	5000.00
propyl acetate (propyl ethanoate)	1000.00	5000.00
vinyl acetate (vinyl ethanoate)	50.00	5000.00
acrylate esters	1000.00	5000.00
sodium acetate	1000.00	4000.00
sulfamic acid (amidosulfonic acid)	1000.00	5000.00
butyl formcel	1000.00	5000.00

NOTES:

Chemical pretreatment: pH adjusted to about 5 by addition of caustic

Waste produced from manufacture of:
- acetaldehyde
- acetic acid
- vinyl acetate
- methyl alcohol
- carbon monoxide
- acrylic acid
- acrylic esters
- ethylene oxide
- ethylene glycol
- diethylene glycol
- triethylene glycol

The same waste is injected into WDW-33 and 45.

Company: Celanese
Plant: Clear Lake
UIC No.: WDW- 45

DRAFT

Waste: organic
Process: chemical manufacture (see memo WDW 33)

Gallons of waste injected in 1985: 0
1986: 319800
Injection temperature (centigrade): ambient
Specific gravity: 1.002

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	3.0	5.0
total dissolved solids	1901	2629
Na	200	1000
K	5.00	20.00
Cl	1000	5000
PO4	500.00	5000.00
B	1.00	20.00
CO3	250.00	2500.0
HCO3	250.00	2500.00
sulfate	500.00	5000.00
F	1000.00	5000.00
ammonia	0.00	5000.00
nitrate	50.00	5000.00
I	1.00	14.60
Zn	1.00	3.00
Cu	1.00	10.00
Mn	1.00	10.00
Cr	1.000	5.000
CN (cyanide)	0.08	0.20

ORGANIC COMPOUNDS

Total Organic Carbon	5000.00	25000.00
methyl alcohol (methanol)	500.00	10000.00
butyl alcohol (butanol)	500.00	50000.00
ethylene glycol (ethanediol)	1000.00	10000.00
diethylene glycol	100.00	50000.00
triethylene glycol	100.00	50000.00
butylene glycol (butanediol)	500.00	5000.00
polyglycols	1000.00	5000.00
butanone (methyl ethyl ketone)	1000.00	5000.00
acetaldehyde (ethanal)	1000.00	5000.00
chloroaldehyde	1000.00	10000.00
dichloroaldehyde	1000.00	10000.00
trichloroaldehyde	1000.00	5000.00
acetic acid (ethanoic)	5000.00	30000.00
acrylic acid (2-propenoic acid)	1000.00	5000.00
citric acid (2-hydroxy 1,2,3 propanetircarboxylic acid)	1000.00	5000.00

oxalic acid (ethanedioic)	1000.00	5000.00
acetic anhydride (ethanoic anhydride)	1000.00	5000.00
ethyl acetate (ethyl ethanoate)	500.00	5000.00
butyl acetate (butyl ethanoate)	500.00	5000.00
propyl acetate (propyl ethanoate)	1000.00	5000.00
vinyl acetate (vinyl ethanoate)	50.00	5000.00
acrylate esters	1000.00	5000.00
sodium acetate	1000.00	4000.00
sulfamic acid (amidosulfonic acid)	1000.00	5000.00
butyl formcel	1000.00	5000.00

NOTES:

Chemical pretreatment: pH adjusted to about 5 by addition of caustic

WDW-33 and 45 have the same waste stream composition

Company: Chevron
Plant: Palangana Dome
UIC No.: WDW- 134

DRAFT

Waste: Ra226
Process: in-situ leach mining for U

Gallons of waste injected in 1985: 15046100
1986: no data
Injection temperature (centigrade): 16-27
Specific gravity: 1.003

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	6.5	7.96
total dissolved solids	6299	233204
Na	160	82361
Ca	20.00	6800.00
Mg	47.70	1215.00
Fe	22.00	22.00
Cl	732	141830
HCO3	273.00	1674.00
sulfate	839.00	1870.00
ammonia	449.00	2969.00
Mo	18.30	292.00
Ba	0.106	29.600
Ra226 (pCi/liter)	122.00	1168.00

ORGANIC COMPOUNDS

NOTES:

Chemical pretreatment: pH to 6.5 with HCl

Company: Cominco Chem
Plant: Burger
UIC No.: WDW- 115

DRAFT

Waste: alkaline ammonia-sulfate
Process: manfacture of anhydrous ammonia and urea

Gallons of waste injected in 1985: 148765918
1986: 182640372
Injection temperature (centigrade): 16
Specific gravity: 1.00-1.02

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	7.0	8.5
total dissolved solids	1653	3960
Na	740	740
Ca	112.00	160.00
Mg	61.00	61.00
Si	8.00	8.00
Al	0.50	0.50
Cl	314	559
HCO3	1220.00	2190.00
sulfate	612.00	1080.00
ammonia	323.00	600.00

ORGANIC COMPOUNDS

Chemical Oxygen Demand	292	687
Biochemical Oxygen Demand	186	186

NOTES:

Company: Conoco
Plant: Trevino Mine
UIC No.: WDW- 189

DRAFT

Waste: Ra226
Process: in-situ leach mining for U (see memo)

Gallons of waste injected in 1985: 63084765
1986: no data
Injection temperature (centigrade): 16
Specific gravity: 1.007

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	4	5
total dissolved solids	5840	9670
Na	790	2610
K	31.00	36.00
Ca	267.00	1025.00
Mg	113.00	247.00
Fe	0.04	0.09
Si	33.00	37.00
Cl	1349	3200
B	2.40	2.40
HCO3	34.00	332.00
sulfate	2004.00	3177.00
F	0.39	1.00
ammonia	0.10	0.24
nitrate	0.16	0.16
Mo	0.16	1.30
Zn	0.04	0.04
V	0.000	0.020
As	0.012	0.074
Cu	0.00	0.02
Ni	0.00	0.02
Mn	0.26	0.29
Cr	0.000	0.006
Se	0.060	0.175
Pb	0.001	0.001
Ba	0.000	0.140
Hg	0.000	0.001
U	5.09	12.70
Ra226 (pCi/liter)	27.00	140.00

ORGANIC COMPOUNDS

NOTES:

Chemical pretreatment: pH to 4-5 with HCl

Lixiviant is either Na-HCO3- or NH4-based

Company: Corpus Christi Petro
Plant: Olefins
UIC No.: WDW- 152

DRAFT

Waste: sulfide contaminated wastewater from refinery
Process: manufacture of olefinic hydrocarbons

Gallons of waste injected in 1985: 18017580
1986: no data
Injection temperature (centigrade): 32
Specific gravity: 1.01-1.14

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	12.8	13.5
total dissolved solids	22000	173000
Na	25000	44240
K	64.70	75.00
Ca	13.20	196.00
Mg	0.10	2.20
Fe	0.00	7.10
Cl	4	456
CO3	20000.00	20981.0
sulfide	3700.00	35000.00
sulfate	100.00	135.00
sulfite	0.00	69500.00
Ba	0.000	0.100

ORGANIC COMPOUNDS

Total Organic Carbon	1080.00	35000.00
Oil and Grease	11.00	126.00
phenols (group)	0.03	15.00

NOTES:

The same waste is injected into WDW-152 and 153.

Company: Corpus Christi Petro
Plant: Olefins
UIC No.: WDW- 153

DRAFT

Waste: sulfide contaminated wastewater from refinery
Process: manufacture of olefinic hydrocarbons

Gallons of waste injected in 1985: 121680
1986: no data
Injection temperature (centigrade): 32
Specific gravity: 1.01-1.14

WASTE COMPOSITION

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	12.8	13.5
total dissolved solids	22000	173000
Na	25000	44240
K	64.70	75.00
Ca	13.20	196.00
Mg	0.10	2.20
Fe	0.00	7.10
Cl	4	456
CO3	20000.00	20981.0
sulfide	3700.00	35000.00
sulfate	100.00	135.00
sulfite	0.00	69500.00

ORGANIC COMPOUNDS

ORGANIC COMPOUNDS	MINIMUM (mg/l)	MAXIMUM (mg/l)
Total Organic Carbon	1080.00	35000.00
Oil and Grease	11.00	126.00
phenols (group)	0.03	15.00

NOTES:

Company: Diamond Shamrock
Plant: McKee
UIC No.: WDW- 20

DRAFT

Waste:
Process: petroleum refinery, natural gas processing, NH3 plant

Gallons of waste injected in 1985: 82549300
1986: no data
Injection temperature (centigrade): 38
Specific gravity: 1.01

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	8.5	8.5
total dissolved solids	4339	4339
Na	880	880
K	50.00	50.00
Ca	106.00	106.00
Mg	56.00	56.00
Fe	1.70	1.70
Cl	875	875
PO4	0.30	0.30
HCO3	230.00	230.00
sulfide	0.12	0.12
sulfate	1150.00	1150.00
ammonia	53.00	53.00
nitrate	0.12	0.12
nitrogen (kjeldahl)	86.00	86.00
Zn	0.23	0.23
As	0.000	0.010
Cu	0.12	0.12
Ni	0.16	0.16
Mn	0.12	0.12
Cr	0.080	0.080
Se	0.000	0.010
Pb	0.000	0.010
Cd	0.010	0.010
Ba	16.500	16.500
Hg	0.000	0.005

ORGANIC COMPOUNDS

Total Organic Carbon	74.00	74.00
Chemical Oxygen Demand	326	326
Biochemical Oxygen Demand	192	192
Oil and Grease	30.00	30.00
phenol	10.25	10.25

NOTES:

Chemical pretreatment: pH adjusted

The same waste is injected into WDW-20, 102, and 192.

DRAFT

Company: Diamond Shamrock
Plant: McKee
UIC No.: WDW- 102

DRAFT

Waste:
Process: petroleum refinery, natural gas processing, NH3 plant

Gallons of waste injected in 1985: 11973690
1986: 11721940
Injection temperature (centigrade): 38
Specific gravity: 1.01

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	8.5	8.5
total dissolved solids	4339	4339
Na	880	880
K	50.00	50.00
Ca	106.00	106.00
Mg	56.00	56.00
Fe	1.70	1.70
Cl	875	875
PO4	0.30	0.30
HCO3	230.00	230.00
sulfide	0.12	0.12
sulfate	1150.00	1150.00
ammonia	53.00	53.00
nitrate	0.12	0.12
nitrogen (kjeldahl)	86.00	86.00
Zn	0.23	0.23
As	0.000	0.010
Cu	0.12	0.12
Ni	0.16	0.16
Mn	0.12	0.12
Cr	0.080	0.080
Se	0.000	0.010
Pb	0.000	0.010
Cd	0.010	0.010
Ba	16.500	16.500
Hg	0.000	0.005

ORGANIC COMPOUNDS		
Total Organic Carbon	74.00	74.00
Chemical Oxygen Demand	326	326
Biochemical Oxygen Demand	192	192
Oil and Grease	30.00	30.00
phenol	10.25	10.25

NOTES:

Chemical pretreatment: pH adjusted

Company: Diamond Shamrock
Plant: McKee
UIC No.: WDW- 192

DRAFT

Waste:
Process: petroleum refinery, natural gas processing, NH3 plant

Gallons of waste injected in 1985: 78110500
1986: no data
Injection temperature (centigrade): 38
Specific gravity: 1.01

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	8.5	8.5
total dissolved solids	4339	4339
Na	880	880
K	50.00	50.00
Ca	106.00	106.00
Mg	56.00	56.00
Fe	1.70	1.70
Cl	875	875
PO4	0.30	0.30
HCO3	230.00	230.00
sulfide	0.12	0.12
sulfate	1150.00	1150.00
ammonia	53.00	53.00
nitrate	0.12	0.12
nitrogen (kjeldahl)	86.00	86.00
Zn	0.23	0.23
As	0.000	0.010
Cu	0.12	0.12
Ni	0.16	0.16
Mn	0.12	0.12
Cr	0.080	0.080
Se	0.000	0.010
Pb	0.000	0.010
Cd	0.010	0.010
Ba	16.500	16.500
Hg	0.000	0.005

ORGANIC COMPOUNDS

Total Organic Carbon	74.00	74.00
Chemical Oxygen Demand	326	326
Biochemical Oxygen Demand	192	192
Oil and Grease	30.00	30.00
phenol	10.25	10.25

NOTES:

Chemical pretreatment: pH adjusted

Company: Dupont
Plant: Beaumont
UIC No.: WDW- 100

DRAFT

Waste: organic, ammonium sulfate
Process: chemical manufacture (see memo)

Gallons of waste injected in 1985: 80600000
1986: 80800000
Injection temperature (centigrade): 45
Specific gravity: 1.02-1.06

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	6.5	8.1
total dissolved solids	41045	68836
Na	0	5329
Fe	2.27	5.90
PO4	1.80	3.00
sulfate	12070.00	43510.00
ammonia	1615.00	4965.00
nitrogen (kjeldahl)	8459.00	15729.00
Mo	4.70	40.10
Zn	0.06	0.28
As	0.007	0.017
Cu	0.02	0.03
Ni	3.20	3.54
Cr	0.040	0.240
CN (cyanide)	174.00	547.00

ORGANIC COMPOUNDS		
Total Organic Carbon	13763.00	16543.00
Chemical Oxygen Demand	17827	29691
Biochemical Oxygen Demand	6353	9517
acetaldehyde (ethanal)	0.00	14.00
acrolein (propenal)	33.00	33.00
phenol	1.63	6.18
pyridine	0.00	14.00
methyl pyridine	0.00	14.00
acetonitrile (ethanenitrile)	192.00	658.00
acrylonitrile	177.00	459.00
fumaronitrile	1780.00	1780.00
nicotinonitrile	410.00	410.00
succinonitrile	2100.00	2100.00
phthalonitrile	64.00	64.00
maleonitrile	1511.00	1511.00
acrylamide	0.00	14.00
HCN	2000.00	3000.00

NOTES:

Chemical pretreatment: ph adjusted

DRAFT

Waste produced from manufacture of:
- animal feed supplement
- chlorsulfonated synthetic rubber
- hydrocarbon synthetic rubber
- ammonia
- amethonal
- acrylonitrile
- blending of tetraethyl lead

The same waste is injected into WDW-100, 101, and ultimately into WDW-188 which is not yet in service.

Company: Dupont
Plant: Beaumont
UIC No.: WDW- 101

DRAFT

Waste: organic, ammonium sulfate
Process: chemical manufacture (see memo WDW-100)

Gallons of waste injected in 1985: 145900000
1986: 143900000
Injection temperature (centigrade): 45
Specific gravity: 1.02-1.06

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	6.5	8.1
total dissolved solids	41045	68836
Na	0	5329
Fe	2.27	5.90
PO4	1.80	3.00
sulfate	12070.00	43510.00
ammonia	1615.00	4965.00
nitrogen (kjeldahl)	8459.00	15729.00
Mo	4.70	40.10
Zn	0.06	0.28
As	0.007	0.017
Cu	0.02	0.03
Ni	3.20	3.54
Cr	0.040	0.240
CN (cyanide)	174.00	547.00

ORGANIC COMPOUNDS

Total Organic Carbon	13763.00	16543.00
Chemical Oxygen Demand	17827	29691
Biochemical Oxygen Demand	6353	9517
acetaldehyde (ethanal)	0.00	14.00
acrolein (propenal)	33.00	33.00
phenol	1.63	6.18
pyridine	0.00	14.00
methyl pyridine	0.00	14.00
acetonitrile (ethanenitrile)	192.00	658.00
acrylonitrile	177.00	459.00
fumaronitrile	1780.00	1780.00
nicotinonitrile	410.00	410.00
succinonitrile	2100.00	2100.00
phthalonitrile	64.00	64.00
maleonitrile	1511.00	1511.00
acrylamide	0.00	14.00
HCN	2000.00	3000.00

NOTES:

Chemical pretreatment: ph adjusted

DRAFT

Company: Dupont
Plant: Ingleside
UIC No.: WDW- 109

DRAFT

Waste: freon* alkaline waste
Process: manufacture of chlorocarbons and freon*

Gallons of waste injected in 1985: 0
1986: 154490
Injection temperature (centigrade): ambient
Specific gravity: 1.07-1.09

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	10	13.8
total dissolved solids	70000	100000
Na	500	75000
K	50.00	60.00
Ca	10.00	20.00
Mg	6.00	7.00
Fe	1.50	3.00
Cl	250	50000
HCO3	11000.00	18000.00
sulfate	80.00	200.00
sulfite	0.00	100.00
F	800.00	10000.00
As	1.000	2500.000
Cu	0.15	0.20
CCl4 (carbon tetrachloride)	0.00	20.00

ORGANIC COMPOUNDS

polychlorinated biphenyl (PCB)	0.00	2.00
tetrachloroethylene	0.00	2.00
freon 113* (a fluorinated haloalkane)	0.00	100.00

NOTES:

Chemical pretreatment: sodium sulfite or H2O2 added to destroy sodium hypochlorite
The same waste is injected into WDW-109 and 121.

DRAFT

Company: Dupont
Plant: Ingleside
UIC No.: WDW- 121

Waste: freon* alkaline waste
Process: manufacture of chlorocarbons and freon*

Gallons of waste injected in 1985: 7881120
1986: 6830820
Injection temperature (centigrade): ambient
Specific gravity: 1.07-1.09

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	10	13.8
total dissolved solids	70000	100000
Na	500	75000
K	50.00	60.00
Ca	10.00	20.00
Mg	6.00	7.00
Fe	1.50	3.00
Cl	250	50000
HCO3	11000.00	18000.00
sulfate	80.00	200.00
sulfite	0.00	100.00
F	800.00	10000.00
As	1.000	2500.000
Cu	0.15	0.20
CCl4 (carbon tetrachloride)	0.00	20.00

ORGANIC COMPOUNDS

polychlorinated biphenyl (PCB)	0.00	2.00
tetrachloroethylene	0.00	2.00
freon 113* (a fluorinated haloalkane)	0.00	100.00

NOTES:

Chemical pretreatment: sodium sulfite and H2O2 added to destroy sodium hypochlorite

Company: Dupont
Plant: LaPorte
UIC No.: WDW- 82

DRAFT

Waste: acid, organic
Process: manufacture of polyvinyl alcohol and vinyl acetate

Gallons of waste injected in 1985: 48667900
1986: 64076118
Injection temperature (centigrade): 50
Specific gravity: .9-1.0

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	2	7
total dissolved solids	1000	5000
K	0.00	200.00
CO3	0.00	200.0

ORGANIC COMPOUNDS		
methyl alcohol (methanol)	1000.00	4000.00
acetaldehyde (ethanal)	100.00	600.00
hydroquinone (1,4 benzenediol)	0.00	200.00
acetic acid (ethanoic)	1000.00	5000.00
methyl acetate (methyl ethanoate)	300.00	2000.00
ethyl acetate (ethyl ethanoate)	0.00	100.00
butyl acetate (butyl ethanoate)	0.00	100.00
vinyl acetate (vinyl ethanoate)	500.00	3000.00
sodium acetate	1000.00	4000.00
potassium acetate	0.00	60.00
polyvinyl alcohol (PVA)	10.00	300.00
H 10 Defoamer	0.00	50.00
Versenex 80	0.00	50.00

NOTES:

The same waste is injected into WDW-82, 83, and 149.

DRAFT

Company: Dupont
Plant: LaPorte
UIC No.: WDW- 83

Waste: acid, organic
Process: manufacture of polyvinyl alcohol and vinyl acetate

Gallons of waste injected in 1985: 51258300
1986: 62969487
Injection temperature (centigrade): 50
Specific gravity: .9-1.0

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	2	7
total dissolved solids	1000	5000
K	0.00	200.00
CO3	0.00	200.0

ORGANIC COMPOUNDS		
methyl alcohol (methanol)	1000.00	4000.00
acetaldehyde (ethanal)	100.00	600.00
hydroquinone (1,4 benzenediol)	0.00	200.00
acetic acid (ethanoic)	1000.00	5000.00
methyl acetate (methyl ethanoate)	300.00	2000.00
ethyl acetate (ethyl ethanoate)	0.00	100.00
butyl acetate (butyl ethanoate)	0.00	100.00
vinyl acetate (vinyl ethanoate)	500.00	3000.00
sodium acetate	1000.00	4000.00
potassium acetate	0.00	60.00
polyvinyl alcohol (PVA)	10.00	300.00
H 10 Defoamer	0.00	50.00
Versenex 80	0.00	50.00

NOTES:

Company: Dupont
Plant: LaPorte
UIC No.: WDW- 149

DRAFT

Waste: acid, organic
Process: manufacture of polyvinyl alcohol and vinyl acetate

Gallons of waste injected in 1985: 50861400
1986: no data
Injection temperature (centigrade): 50
Specific gravity: .9-1.0

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	2	7
total dissolved solids	1000	5000
K	0.00	200.00
CO3	0.00	200.0

ORGANIC COMPOUNDS

methyl alcohol (methanol)	1000.00	4000.00
aldehydes	100.00	600.00
hydroquinone (1,4 benzenediol)	0.00	200.00
acetic acid (ethanoic)	1000.00	5000.00
methyl acetate (methyl ethanoate)	300.00	2000.00
ethyl acetate (ethyl ethanoate)	0.00	100.00
butyl acetate (butyl ethanoate)	0.00	100.00
vinyl acetate (vinyl ethanoate)	500.00	3000.00
sodium acetate	1000.00	4000.00
potassium acetate	0.00	60.00
polyvinyl alcohol (PVA)	10.00	300.00
H 10 Defoamer	0.00	50.00
Versenex 80	0.00	50.00

NOTES:

Company: Dupont
Plant: Sabine River
UIC No.: WDW- 54

DRAFT

Waste: organic
Process: manufacture of adiponitrile

Gallons of waste injected in 1985: 147576000
1986: 134877000
Injection temperature (centigrade):
Specific gravity: 1.00-1.04

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	1	3
Fe	0.00	5.00
Cl	50	300
PO4	15.00	25.00
B	0.00	50.00
H2SO4$	1000.00	5000.00
ammonia	10.00	500.00
Zn	0.00	5.00
Cu	0.00	5.00
Ni	0.00	4000.00
CN (cyanide)	50.00	1000.00

ORGANIC COMPOUNDS		
organic nitrile compounds	500.00	20000.00

NOTES:

The same waste is injected into WDW-54, 55, and 191.

Company: Dupont
Plant: Sabine River
UIC No.: WDW- 55

DRAFT

Waste: organic
Process: manufacture of adiponitrile

Gallons of waste injected in 1985: 0
1986: no data
Injection temperature (centigrade):
Specific gravity: 1.00-1.04

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	1	3
Fe	0.00	5.00
Cl	50	300
P04	15.00	25.00
B	0.00	50.00
H2S04$	1000.00	5000.00
ammonia	10.00	500.00
Zn	0.00	5.00
Cu	0.00	5.00
Ni	0.00	4000.00
CN (cyanide)	50.00	1000.00

ORGANIC COMPOUNDS

organic nitrile compounds	500.00	20000.00

NOTES:

The same waste is injected into WDW-54, 55, and 191.

Company: Dupont
Plant: Sabine River
UIC No.: WDW- 56

DRAFT

Waste: organic
Process: manufacture of adiponitrile

Gallons of waste injected in 1985: 16137000
1986: 28086000
Injection temperature (centigrade):
Specific gravity: .95-1.15

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	7	14
Na	15000	125000
Cl	16000	60000
P04	0.00	25000.00
B	0.00	11.50
Zn	0.00	10000.00
Ni	500.00	35000.00

ORGANIC COMPOUNDS		
benzene	0.00	5000.00
phenol	0.00	20000.00
cresol (cresylic acid)	0.00	50000.00
dinitrile	0.0	970000.0
organic phosphorous compounds	0.0	100000.0

NOTES:

The same waste is injected into WDW-56 and 57.

Two waste stream compositions were reported, but not mixing ratio was given. The range in waste stream composition listed here was determined assuming that 100% of either stream could be injected at any time.

Company: Dupont
Plant: Sabine River
UIC No.: WDW- 57

DRAFT

Waste: organic
Process: manufacture of adiponitrile

Gallons of waste injected in 1985: 1955000
1986: 3473000
Injection temperature (centigrade):
Specific gravity: .95-1.15

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	7	14
Na	15000	125000
Cl	16000	60000
P04	0.00	25000.00
B	0.00	11.50
Zn	0.00	10000.00
Ni	500.00	35000.00

ORGANIC COMPOUNDS

benzene	0.00	5000.00
phenol	0.00	20000.00
cresol (cresylic acid)	0.00	50000.00
dinitrile	0.0	970000.0
organic phosphorous compounds	0.0	100000.0

NOTES:

The same waste is injected into WDW-56 and 57. See memo WDW-56.

DRAFT

Company: Dupont
Plant: Sabine River
UIC No.: WDW- 132

Waste: organic acid
Process: manufacture of adipic acid

Gallons of waste injected in 1985: no data
1986: no data
Injection temperature (centigrade): 25-35
Specific gravity: 1.02

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	.3	3.0
nitrate	9000.00	9000.00
V	25.000	25.000
Cu	74.00	74.00

ORGANIC COMPOUNDS

butyl alcohol (butanol)	300.00	300.00
aldehydes	400.00	400.00
acetic acid (ethanoic)	2200.00	2200.00
propionic acid (propanoic)	1500.00	1500.00
butyric acid (butanoic)	3000.00	3000.00
valeric acid (pentanoic)	1700.00	1700.00
caproic acid (hexanoic)	85.00	85.00
succinic acid	3300.00	3300.00
glutaric acid	7100.00	7100.00
adipic acid	3000.00	3000.00
organic acids (monobasic acid, carboxylic acid)	2000.00	5000.00
dicarboxylic acids (dibasic acids)	10000.00	15000.00

NOTES:

The same waste is injected into WDW-132, and 207.

DRAFT

Company: Dupont
Plant: Sabine River
UIC No.: WDW- 191

Waste: organic
Process: manufacture of adiponitrile

Gallons of waste injected in 1985: 26708000
1986: no data
Injection temperature (centigrade):
Specific gravity: 1.00-1.04

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	1	3
Fe	0.00	5.00
Cl	50	300
PO4	15.00	25.00
B	0.00	50.00
H2SO4$	1000.00	5000.00
ammonia	10.00	500.00
Zn	0.00	5.00
Cu	0.00	5.00
Ni	0.00	4000.00
CN (cyanide)	50.00	1000.00

ORGANIC COMPOUNDS

organic nitrile compounds	500.00	20000.00

NOTES:

The same waste is injected into WDW-54, 55, and 191.

DRAFT

Company: Dupont
Plant: Sabine River
UIC No.: WDW- 207

Waste: organic, acid
Process: manufacture of adipic acid

Gallons of waste injected in 1985: 138140000
1986: no data
Injection temperature (centigrade): 25-35
Specific gravity: 1.02

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	.3	3.0
nitrate	9000.00	9000.00
V	25.000	25.000
Cu	74.00	74.00

ORGANIC COMPOUNDS

butyl alcohol (butanol)	300.00	300.00
aldehydes	400.00	400.00
acetic acid (ethanoic)	2200.00	2200.00
propionic acid (propanoic)	1500.00	1500.00
butyric acid (butanoic)	3000.00	3000.00
valeric acid (pentanoic)	1700.00	1700.00
caproic acid (hexanoic)	85.00	85.00
succinic acid	3300.00	3300.00
glutaric acid	7100.00	7100.00
adipic acid	3000.00	3000.00

NOTES:

The same wasete stream is injected into WDW-132, and 207.

Company: Dupont
Plant: Victoria
UIC No.: WDW- 4

DRAFT

Waste: organics, salts, cyanide, metals--alkaline
Process: manufacture of adiponitrile, hexamethylenediamine

Gallons of waste injected in 1985: 26729280
1986: 586704
Injection temperature (centigrade): 40-60
Specific gravity: 1.04

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	8	12
total dissolved solids	40000	60000
Na	18000	22000
Fe	100.00	100.00
Cl	18000	22000
PO4	100.00	100.00
B	100.00	100.00
sulfate	1000.00	1000.00
ammonia	400.00	400.00
Ni	500.00	500.00
CN (cyanide)	2000.00	2000.00

ORGANIC COMPOUNDS

Total Organic Carbon	4000.00	5000.00
Chemical Oxygen Demand	9170	12000
Oil and Grease	300.00	700.00
phenyl borates	6000.00	7000.00

NOTES:

The same waste is injected into WDW-4, 105, 106, 142, and 143.

Additional waste components:
hydroxides = 200 mg/l
miscellaneous trace metals = 200 mg/l

==

Company: Dupont
Plant: Victoria
UIC No.: WDW- 28

DRAFT

Waste: nitric acid, organic acid, organics, metals
Process: manufacture of adipic acid, dodecanedioic acid, nitric acid

Gallons of waste injected in 1985: 138520000
1986: 152447780
Injection temperature (centigrade): 40-60
Specific gravity: 1.0

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	1	3
total dissolved solids	5000	10000
Fe	1.00	3.00
Cl	20	40
ammonia	25.00	75.00
nitrate	5000.00	15000.00
Zn	1.00	1.00
V	10.000	20.000
Cu	20.00	40.00
Cr	1.000	1.000

ORGANIC COMPOUNDS

Total Organic Carbon	5000.00	8000.00
Chemical Oxygen Demand	15000	20000

NOTES:

The same waste is injected into WDW-28, 29, 30, and 145.

Company: Dupont
Plant: Victoria
UIC No.: WDW- 29

DRAFT

Waste: nitric acid, organic acid, organics, metals
Process: manufacture of adipic acid, dodecanedioic acid, nitric acid

Gallons of waste injected in 1985: 131222340
1986: 138422500
Injection temperature (centigrade): 40-60
Specific gravity: 1.0

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	1	3
total dissolved solids	5000	10000
Fe	1.00	3.00
Cl	20	40
ammonia	25.00	75.00
nitrate	5000.00	15000.00
Zn	1.00	1.00
V	10.000	20.000
Cu	20.00	40.00
Cr	1.000	1.000

ORGANIC COMPOUNDS

Total Organic Carbon	5000.00	8000.00
Chemical Oxygen Demand	15000	20000

NOTES:

The same waste is injected into WDW-28, 29, 30, and 145.

DRAFT

Company: Dupont
Plant: Victoria
UIC No.: WDW- 30

Waste: nitric acid, organic acid, organics, metals
Process: manufacture of adipic acid, dodecanedioic acid, nitric acid

Gallons of waste injected in 1985: 132608400
1986: 136931220
Injection temperature (centigrade): 40-60
Specific gravity: 1.0

WASTE COMPOSITION

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	1	3
total dissolved solids	5000	10000
Fe	1.00	3.00
Cl	20	40
ammonia	25.00	75.00
nitrate	5000.00	15000.00
Zn	1.00	1.00
V	10.000	20.000
Cu	20.00	40.00
Cr	1.000	1.000

ORGANIC COMPOUNDS

ORGANIC COMPOUNDS	MINIMUM (mg/l)	MAXIMUM (mg/l)
Total Organic Carbon	5000.00	8000.00
Chemical Oxygen Demand	15000	20000

NOTES:

The same waste is injected into WDW-28, 29, 30, and 145.

==

Company: Dupont
Plant: Victoria
UIC No.: WDW- 105

DRAFT

Waste: organics, salts, cyanide, metals--alkaline
Process: manufacture of adiponitrile, hexamethylenediamine

Gallons of waste injected in 1985: 12722400
1986: 41194080
Injection temperature (centigrade): 40-60
Specific gravity: 1.04

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	8	12
total dissolved solids	40000	60000
Na	18000	22000
Fe	100.00	100.00
Cl	18000	22000
PO4	100.00	100.00
B	100.00	100.00
sulfate	0.00	1000.00
ammonia	400.00	400.00
Ni	500.00	500.00
CN (cyanide)	2000.00	2000.00

ORGANIC COMPOUNDS

ORGANIC COMPOUNDS	MINIMUM (mg/l)	MAXIMUM (mg/l)
Total Organic Carbon	4000.00	5000.00
Chemical Oxygen Demand	9170	12000
Oil and Grease	300.00	700.00
phenyl borates	6000.00	7000.00

NOTES:

The same waste is injected into WDW-4, 105, 106, 142, and 143.

See note WDW-4.

Company: Dupont
Plant: Victoria
UIC No.: WDW- 106

DRAFT

Waste: organics, salts, cyanide, metals--alkaline
Process: manufacture of adiponitrile, hexamethylenediamnie

Gallons of waste injected in 1985: 40907520
1986: 28335600
Injection temperature (centigrade): 40-60
Specific gravity: 1.04

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	8	12
total dissolved solids	40000	60000
Na	18000	22000
Fe	100.00	100.00
Cl	18000	22000
PO4	100.00	100.00
B	100.00	100.00
sulfate	0.00	1000.00
ammonia	400.00	400.00
Ni	500.00	500.00
CN (cyanide)	2000.00	2000.00

ORGANIC COMPOUNDS

Total Organic Carbon	4000.00	5000.00
Chemical Oxygen Demand	9170	12000
Oil and Grease	300.00	700.00
phenyl borates	6000.00	7000.00

NOTES:

The same waste is injected into WDW-4, 105, 106, 142, and 143.

See note WDW-4.

Company: Dupont
Plant: Victoria
UIC No.: WDW- 142

DRAFT

Waste: organics, salts, cyanide, metals--alkaline
Process: manufacture of adiponitrile, hexamethylenediamine

Gallons of waste injected in 1985: 72298080
1986: no data
Injection temperature (centigrade): 40-60
Specific gravity: 1.04

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	8	12
total dissolved solids	40000	60000
Na	18000	22000
Fe	100.00	100.00
Cl	18000	22000
PO4	100.00	100.00
B	100.00	100.00
sulfate	1000.00	1000.00
ammonia	400.00	400.00
Ni	500.00	500.00
CN (cyanide)	2000.00	2000.00

ORGANIC COMPOUNDS		
Total Organic Carbon	4000.00	5000.00
Chemical Oxygen Demand	9170	12000
Oil and Grease	300.00	700.00
phenyl borates	6000.00	7000.00

NOTES:

The same waste is injected into WDW-4, 105, 106, 142, and 143.

See note WDW-4.

DRAFT

Company: Dupont
Plant: Victoria
UIC No.: WDW- 143

Waste: organics, salts, cyanide, metals--alkaline
Process: manufacture of adiponitrile, hexamethylenediamine

Gallons of waste injected in 1985: 85126509
1986: no data
Injection temperature (centigrade): 40-60
Specific gravity: 1.04

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	8	12
total dissolved solids	40000	60000
Na	18000	22000
Fe	100.00	100.00
Cl	18000	22000
PO4	100.00	100.00
B	100.00	100.00
sulfate	1000.00	1000.00
ammonia	400.00	400.00
Ni	500.00	500.00
CN (cyanide)	2000.00	2000.00

ORGANIC COMPOUNDS

Total Organic Carbon	4000.00	5000.00
Chemical Oxygen Demand	9170	12000
Oil and Grease	300.00	700.00
phenyl borates	6000.00	7000.00

NOTES:

The same waste is injected into WDW-4, 105, 106, 142, and 143.

See note WDW-4.

Company: Dupont
Plant: Victoria
UIC No.: WDW- 144

DRAFT

Waste: organics, salts, cyanide, metals--alkaline
Process: manf. adiponitrile,hexamethylenediamine; tritotylphosphite degradation

Gallons of waste injected in 1985: 35848800
1986: no data
Injection temperature (centigrade): 40-60
Specific gravity: 1.04

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	8	12
total dissolved solids	40000	60000
Na	18000	22000
Fe	100.00	100.00
Cl	18000	22000
PO4	100.00	100.00
B	100.00	100.00
sulfate	1000.00	1000.00
ammonia	400.00	400.00
Ni	500.00	500.00
CN (cyanide)	2000.00	2000.00

ORGANIC COMPOUNDS

Total Organic Carbon	4000.00	5000.00
Chemical Oxygen Demand	9170	12000
Oil and Grease	300.00	700.00
phenyl borates	6000.00	7000.00
triphenyl boran	200.00	400.00
organic nitrile compounds	13600.00	27200.00

NOTES:

The waste stream injected into WDW-144 is similar to that injected into WDW-4, 105, 106, 142, and 143 with the addition of tritotylphosphite degradation products equivalent to 6000 - 12000 mg/l.

See note WDW-4.

DRAFT

Company: Dupont
Plant: Victoria
UIC No.: WDW- 145

Waste: nitric acid, organic acid, organics, metals
Process: manufacture of adipic acid, dodecanedioic acid, nitric acid

Gallons of waste injected in 1985: 137275800
1986: no data
Injection temperature (centigrade): 40-60
Specific gravity: 1.0

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	1	3
total dissolved solids	5000	10000
Fe	1.00	3.00
Cl	20	40
ammonia	25.00	75.00
nitrate	5000.00	15000.00
Zn	1.00	1.00
V	10.000	20.000
Cu	20.00	40.00
Cr	1.000	1.000

ORGANIC COMPOUNDS

Total Organic Carbon	5000.00	8000.00
Chemical Oxygen Demand	15000	20000

NOTES:

The same waste is injected into WDW-28, 29, 30, and 145.

Company: El Paso Prod
Plant: Odessa Petro
UIC No.: WDW- 16

DRAFT

Waste: organic
Process: chemical manufacture (see memo)

Gallons of waste injected in 1985: no data
1986: 75300000
Injection temperature (centigrade): 27-38
Specific gravity: 1.01

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	7.5	8.5
total dissolved solids	10500	10500
Na	2700	2700
Ca	418.00	418.00
Mg	17.00	17.00
Cl	5460	5460
HCO3	650.00	650.00
sulfate	690.00	690.00
Zn	0.00	1.00
Cu	0.00	1.00

ORGANIC COMPOUNDS

NOTES:

Chemical pretreatment: pH adjusted to 7.5-8.5 by addition of HCl

Waste produced from manufacture of:
- olefins
- polyolefins
- styrene
- ammonia
- 1,3-butadiene

Same waste injected into WDW-6,88,126,154. (Except 2,4 dintrophenol is only injected nto WDW-16. Amount injected not reported.)

NOTE: THIS SHOULD BE AN ORGANIC WASTE BUT NO ORGANIC ANALYSIS WAS REPORTED.

DRAFT

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============================================================
Company:  El Paso Prod
Plant:    Odessa Petro
UIC No.: WDW-   88

Waste:    organic
Process: chemical manufacture (see WDW-16)

Gallons of waste injected in 1985:    74419000
                             1986:    88509000
Injection temperature (centigrade): 27-38
Specific gravity: 1.01


WASTE COMPOSITION                                    MINIMUM   MAXIMUM
                                                      (mg/l)   (mg/l)
=================                                     =======  =======

pH                                                    7.5       8.5
total dissolved solids                              10500     10500
Na                                                   2700      2700
Ca                                                    418.00       418.00
Mg                                                     17.00        17.00
Cl                                                   5460      5460
HCO3                                                  650.00       650.00
sulfate                                               690.00       690.00
Zn                                                      0.00         1.00
Cu                                                      0.00         1.00

ORGANIC COMPOUNDS
=================


NOTES:
======
Chemical pretreatment: pH adjusted to 7.5-8.5 by addition of HCl

The same waste is injected into WDW-16, 88, 126,
and 154.
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DRAFT

Company: El Paso Prod
Plant: Odessa Petro
UIC No.: WDW- 126

Waste: organic
Process: chemical manufacture (see WDW-16)

Gallons of waste injected in 1985: 99962000
1986: no data
Injection temperature (centigrade): 27-38
Specific gravity: 1.01

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	7.5	8.5
total dissolved solids	10500	10500
Na	2700	2700
Ca	418.00	418.00
Mg	17.00	17.00
Cl	5460	5460
HC03	650.00	650.00
sulfate	690.00	690.00
Zn	0.00	1.00
Cu	0.00	1.00

ORGANIC COMPOUNDS

NOTES:

Chemical pretreatment: pH adjusted to 7.5-8.5 by addition of HCl

The same waste is injected into WDW-16, 88, 126, and 154.

Company: El Paso Prod
Plant: Odessa Petro
UIC No.: WDW- 154

DRAFT

Waste: organic
Process: chemical manufacture (see WDW-16)

Gallons of waste injected in 1985: 37305000
1986: no data
Injection temperature (centigrade): 27-38
Specific gravity: 1.01

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	7.5	8.5
total dissolved solids	10500	10500
Na	2700	2700
Ca	418.00	418.00
Mg	17.00	17.00
Cl	5460	5460
HCO3	650.00	650.00
sulfate	690.00	690.00
Zn	0.00	1.00
Cu	0.00	1.00

ORGANIC COMPOUNDS

NOTES:

Chemical pretreatment: pH adjusted to 7.5-8.5 by addition of HCl

The same waste is injected into WDW-16, 88, 126, and 154.

Company: Everest Mineral
Plant: Hobson Mine
UIC No.: WDW- 168

DRAFT

Waste: Ra226
Process: in-situ leach mining for U and yellow cake extraction

Gallons of waste injected in 1985: 21216830
1986: no data
Injection temperature (centigrade):
Specific gravity:

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	6.59	7.6
total dissolved solids	5840	47100
Na	1210	16660
K	37.00	250.00
Ca	169.00	800.00
Mg	19.00	158.00
Fe	52.00	52.00
Si	46.00	75.00
Cl	1810	27120
B	14.00	14.00
HC03	346.00	615.00
sulfate	23.00	2030.00
F	0.41	0.41
ammonia	29.00	245.00
nitrate	0.00	0.01
Mo	0.02	10.20
Zn	0.06	0.06
V	0.030	0.030
As	0.025	0.680
Cu	0.06	0.06
Ni	0.00	0.01
Mn	0.84	0.84
Cr	0.032	0.032
Se	0.000	0.060
Pb	0.029	0.029
Cd	0.001	0.001
Ba	88.000	88.000
U	0.00	11.00
Ra226 (pCi/liter)	177.00	670.00
Pb210 (pCi/liter)	202.00	254.00

ORGANIC COMPOUNDS

NOTES:

DRAFT

Company: Everest Mineral
Plant: Las Palmas Mine
UIC No.: WDW- 187

Waste: Ra226
Process: in-situ leach mining for U

Gallons of waste injected in 1985: 41380709
1986: no data
Injection temperature (centigrade): ambient
Specific gravity: 1.0-1.1

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	4.5	6.5
total dissolved solids	9500	9500
Na	1200	1200
K	15.00	15.00
Ca	2040.00	2040.00
Mg	50.00	50.00
Fe	5.00	5.00
Si	50.00	50.00
Cl	1800	1800
P04	1.00	1.00
HC03	860.00	860.00
sulfate	2030.00	2030.00
F	1.00	1.00
ammonia	245.00	245.00
nitrate	0.50	0.50
Mo	30.00	30.00
Zn	2.00	2.00
As	0.600	0.600
Cu	0.10	0.10
Ni	0.05	0.05
Se	0.050	0.050
Pb	0.200	0.200
Cd	0.010	0.010
Ba	0.500	0.500
U	12.00	12.00
Ra226 (pCi/liter)	2500.00	2500.00

ORGANIC COMPOUNDS

NOTES:

DRAFT

Company: GAF Corp
Plant: Texas City
UIC No.: WDW- 34

Waste: organic
Process: organic chemical synthesis; aceteline industrial chemicals (see note)

Gallons of waste injected in 1985: 89670000
1986: 75370000
Injection temperature (centigrade): ambient
Specific gravity: 1.05-1.15

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	6.5	8.5
Na	100	1900
Cl	100	1000
sulfate	1620.00	8100.00
ammonia	500.00	5000.00

ORGANIC COMPOUNDS		
methyl alcohol (methanol)	1000.00	4000.00
butyl alcohol (butanol)	50.00	200.00
butylene glycol (butanediol)	400.00	2000.00
tetrahydrofuran	100.00	1000.00
formaldehyde (methanal)	200.00	1000.00
hydroxymethylacetylen (propargyle alcohol)	200.00	1000.00
butynediol	200.00	1000.00
benzene	200.00	1000.00
pyrrolidone (2-pyrrolidone)	200.00	2000.00
N-methyl pyrrolidone	50.00	200.00
vinyl pyrrolidone	200.00	2000.00
butyrolactone (4-hydroxybutanoic acid lactone)	200.00	1000.00

NOTES:

Chemical pretreatment: pH adjusted to 6.5-8.5

Waste produced from manufacture of:
1,4-butynediol
propargyl alcohol
1,4-butenediol
1,4-butanediol
2 butyrolactone
2-pyrrolidone
N-vinyl-2-pyrrolidone
N-methyl-2-pyrrolidone
polyvinylpyrrolidone
polyvinylpyrrolidone/polyvinyl acetate copolymers
amiben

WDW 34 waste is different from WDW 114.
WDW 34 waste is sent to WDW 113 if necessary.

DRAFT

Company: GAF Corp
Plant: Texas City
UIC No.: WDW- 113

Waste: organic
Process: organic chemical synthesis; aceteline industrial chemicals(see WDW-34)

Gallons of waste injected in 1985: no data
1986: 16240000
Injection temperature (centigrade): ambient
Specific gravity: 1.05-1.15

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	6.5	8.5
Na	3800	50000
Cl	10000	50000
sulfate	19620.00	81000.00
Zn	0.13	0.85
Ni	0.29	1.50
Mn	0.10	0.90
Cr	0.290	1.800
Se	0.007	0.008
Pb	0.040	0.200
Hg	0.000	0.002

ORGANIC COMPOUNDS

methyl alcohol (methanol)	3000.00	30000.00
2,5-dichloro benzoic acid	500.00	5000.00
dichloro nitrobenzoic acids	6600.00	95000.00

NOTES:

Chemical pretreatment: pH adjusted to 6.5-8.5

WDW 113 waste is different from WDW 34
WDW 113 waste sent to WDW 114 if necessary

Company: GAF Corp
Plant: Texas City
UIC No.: WDW- 114

DRAFT

Waste: organic
Process: organic chemical synthesis; aceteline industrial chemicals(see WDW-34)

Gallons of waste injected in 1985: 57960000
1986: 30800000
Injection temperature (centigrade): ambient
Specific gravity: 1.00-1.15

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	6.5	8.5
Na	100	50000
Cl	100	50000
sulfate	1620.00	81000.00
ammonia	500.00	5000.00
Zn	0.13	0.85
Ni	0.29	1.50
Mn	0.10	0.90
Cr	0.290	1.800
Se	0.007	0.008
Pb	0.040	0.200
Hg	0.000	0.002

ORGANIC COMPOUNDS

methyl alcohol (methanol)	1000.00	30000.00
butyl alcohol (butanol)	50.00	200.00
butylene glycol (butanediol)	400.00	2000.00
tetrahydrofuran	100.00	1000.00
formaldehyde (methanal)	200.00	1000.00
hydroxymethylacetylen (propargyle alcohol)	200.00	1000.00
butynediol	200.00	1000.00
benzene	200.00	1000.00
pyrrolidone (2-pyrrolidone)	200.00	2000.00
N-methyl pyrrolidone	50.00	200.00
vinyl pyrrolidone	200.00	2000.00
butyrolactone (4-hydroxybutanoic acid lactone)	200.00	1000.00
2,5-dichloro benzoic acid	500.00	5000.00
dichloro nitrobenzoic acids	6600.00	95000.00

NOTES:

Chemical pretreatment: pH adjusted to 6.5-8.5

WDW-114 is use as a standby well for WDW-34 and 113.

See note WDW-34.

DRAFT

Company: IEC
Plant: Three Rivers
UIC No.: WDW- 159

DRAFT

Waste: Ra226
Process: in-situ solution mining for U and aquifer restoration

Gallons of waste injected in 1985: 22383821
1986: no data
Injection temperature (centigrade): 23
Specific gravity: 1.02

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	7	7
total dissolved solids	160	54073
Na	13	8648
K	1.40	132.00
Ca	3.20	245.00
Mg	0.50	173.00
Fe	0.00	2.72
Si	1.80	169.00
Cl	52	12748
B	0.02	3.74
HCO3	60.00	14316.00
sulfate	20.00	15620.00
F	0.16	14.00
ammonia	0.09	9436.00
nitrate	0.70	19.00
Mo	0.00	377.00
Zn	0.01	28.77
V	0.002	0.240
As	0.010	2.250
Cu	0.00	0.44
Ni	0.00	0.25
Mn	0.01	0.21
Cr	0.000	0.220
Se	0.010	65.220
Pb	0.000	0.004
Cd	0.000	0.004
Ba	0.010	0.380
Ag	0.00	0.16
Hg	0.000	0.074
U	1.20	114.00
Ra226 (pCi/liter)	5.50	4096.00

ORGANIC COMPOUNDS

NOTES:

Chemical pretreatment: pH adjust with HCl

DRAFT

Company: Iowa Beef Proc.
Plant: Amarillo Hide
UIC No.: WDW- 120

Waste: NaCl brine
Process: hide processing

Gallons of waste injected in 1985: 4232702
1986: 4281406
Injection temperature (centigrade): 21
Specific gravity: 1.158

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	5.5	5.5
total dissolved solids	249000	249000
Na	77000	77000
Ca	7960.00	7960.00
Mg	1540.00	1540.00
Fe	27.00	27.00
Si	4.00	4.00
Al	0.30	0.30
Cl	143000	143000
HCO3	1340.00	1340.00
sulfate	1600.00	1600.00

ORGANIC COMPOUNDS

NOTES:

DRAFT

Company: Jetco
Plant: Amine
UIC No.: WDW- 117

Waste: ammonia, ammonium chloride
Process: manufacture of nitriles, and quaternary ammonium chloride

Gallons of waste injected in 1985: 26204283
1986: 23076808
Injection temperature (centigrade):
Specific gravity:

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	7.95	10.7
Cl	38	1610
sulfate	58.00	7900.00
As	0.000	0.010
Cr	0.020	0.020
Se	0.000	0.100
Pb	0.060	0.060
Cd	0.000	0.010
Ba	0.000	0.080

ORGANIC COMPOUNDS

Chemical Oxygen Demand	3650	238000
Biochemical Oxygen Demand	300	320
Oil and Grease	0.90	1740.00
quarternary ammonium chloride	0.00	70640.00

NOTES:

DRAFT

Company: Lundberg Ind
Plant: Dumas
UIC No.: WDW- 3

Waste: HCl
Process: potassium sulfate production

Gallons of waste injected in 1985: 74632
1986: 53332
Injection temperature (centigrade): ambient
Specific gravity: 1.13-1.16

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	.02	1
total dissolved solids	815	860
Fe	36.00	44.00
Cl	270000	310000
sulfate	300.00	350.00
sulfite	155.00	325.00
As	0.000	0.100
Cu	0.00	1.00
Pb	0.880	0.880

ORGANIC COMPOUNDS

NOTES:

DRAFT

Company: Merichem
Plant: Houston
UIC No.: WDW- 147

Waste: caustic, organic
Process: hydrocarbon extraction from refinery waste

Gallons of waste injected in 1985: 85910390
1986: no data
Injection temperature (centigrade): ambient
Specific gravity: 1.147

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	12	12
total dissolved solids	80000	80000
Na	20000	80000
C03	0.00	160000.0
sulfide	1000.00	50000.00
ORGANIC COMPOUNDS		
phenols (group)	0.00	10000.00

NOTES:

Company: Mobil
Plant: Corpus Christi
UIC No.: WDW- 150

DRAFT

Waste: Ra226
Process: in-situ solution mining for U

Gallons of waste injected in 1985: 29434896
1986: no data
Injection temperature (centigrade): 7-27
Specific gravity: 1.04

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	4	10
total dissolved solids	3050	22900
Na	942	12950
K	26.00	100.00
Ca	150.00	520.00
Mg	37.00	97.00
Fe	0.19	8.30
Si	21.00	188.00
Cl	804	20720
HCO3	0.00	638.00
sulfate	0.00	2006.00
F	0.43	2.10
ammonia	0.14	11.00
nitrate	0.48	3.70
Mo	0.02	5.20
As	0.001	0.125
Mn	0.14	1.70
Se	0.000	0.045
Pb	0.003	0.041
Cd	0.000	0.005
Hg	0.000	0.001
U	0.00	43.00
Ra226 (pCi/liter)	29.00	311.00

ORGANIC COMPOUNDS

NOTES:

The same waste is injected into WDW-150, 151, and 197.

DRAFT

Company: Mobile
Plant: Corpus Christi
UIC No.: WDW- 151

Waste: Ra226
Process: in-situ solution mining for U

Gallons of waste injected in 1985: 53875008
1986: no data
Injection temperature (centigrade): 7-27
Specific gravity: 1.04

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	4	10
total dissolved solids	3050	22900
Na	942	12950
K	26.00	100.00
Ca	150.00	520.00
Mg	37.00	97.00
Fe	0.19	8.30
Si	21.00	188.00
Cl	804	20720
HCO3	0.00	638.00
sulfate	0.00	2006.00
F	0.43	2.10
ammonia	0.14	11.00
nitrate	0.48	3.70
Mo	0.02	5.20
As	0.001	0.125
Mn	0.14	1.70
Se	0.000	0.045
Pb	0.003	0.041
Cd	0.000	0.005
Hg	0.000	0.001
U	0.00	43.00
Ra226 (pCi/liter)	29.00	311.00

ORGANIC COMPOUNDS

NOTES:

The same waste is injected into WDW-150, 151, and 197.

Company: Mobile
Plant: Corpus Christi
UIC No.: WDW- 197

DRAFT

Waste: Ra226
Process: in-situ solution mining for U

Gallons of waste injected in 1985: 68787648
1986: no data
Injection temperature (centigrade): 7-27
Specific gravity: 1.04

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	4	10
total dissolved solids	3050	22900
Na	942	12950
K	26.00	100.00
Ca	150.00	520.00
Mg	37.00	97.00
Fe	0.19	8.30
Si	21.00	188.00
Cl	804	20720
HC03	0.00	638.00
sulfate	0.00	2006.00
F	0.43	2.10
ammonia	0.14	11.00
nitrate	0.48	3.70
Mo	0.02	5.20
As	0.001	0.125
Mn	0.14	1.70
Se	0.000	0.045
Pb	0.003	0.041
Cd	0.000	0.005
Hg	0.000	0.001
U	0.00	43.00
Ra226 (pCi/liter)	29.00	311.00

ORGANIC COMPOUNDS

NOTES:

The same waste is injected into WDW-150, 151, and 197.

DRAFT

Company: Monsanto
Plant: Chocolate Bayou
UIC No.: WDW- 13

Waste: organic
Process: organic chemical production

Gallons of waste injected in 1985: 362851000
1986: 330004000
Injection temperature (centigrade): 25-60
Specific gravity: 1.00-1.05

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	6.0	9.5
total dissolved solids	25000	200000
Cl	100	35000
sulfate	25000.00	45500.00
ammonia	0.00	85000.00
CN (cyanide)	0.00	300.00

ORGANIC COMPOUNDS

Chemical Oxygen Demand	2500	50000
phenols (group)	0.00	11000.00
organic acids (monobasic acid, carboxylic acid)	0.00	15000.00
volatile sulfur compounds	0.00	10000.00

NOTES:

Waste produced from manufacture of:

- phenol
- diphenyl
- oxide
- acrylonitrile
- solf alkyl benzene
- nitrilotriacetic acid
- methionine hydroxy analog
- sorbic acid
- formalin

DRAFT

Company: Monsanto
Plant: Texas City
UIC No.: WDW- 91

Waste: organic
Process: chemical manufacturing (see note)

Gallons of waste injected in 1985: 74150000
1986: 7247
Injection temperature (centigrade): <71
Specific gravity: 1.05-1.12

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	4.5	7.5
total dissolved solids	104560	104560
Cl	20400	20400
sulfate	41840.00	41840.00
ammonia	1000.00	1000.00
nitrate	0.00	8800.00
nitrogen (kjeldahl)	350.00	350.00

ORGANIC COMPOUNDS

Total Organic Carbon	13500.00	13500.00
Chemical Oxygen Demand	22400	22400
Biochemical Oxygen Demand	8600	8600
methyl alcohol (methanol)	30.00	30.00
formaldehyde (methanal)	200.00	200.00
phenols (group)	30.00	30.00
cyanopyridine	750.00	750.00
acetic acid (ethanoic)	750.00	750.00
acrylic acid (2-propenoic acid)	2750.00	2750.00
acetonitrile (ethanenitrile)	700.00	700.00
acrylonitrile	100.00	100.00
fumaronitrile	850.00	850.00
succinonitrile	900.00	900.00
acrylamide	650.00	650.00
urea	100.00	100.00
tertiary butylamine	100.00	100.00

NOTES:

Chemical pretreatment: pH control

Waste produced from manufacture of:
- acrylonitrile
- HCN
- tert-butylamine
- lactic acid
- acetone cyanohydrin
- iminodiacetic acid

styrene monomer
process wastewaters from other manufacturing areas generally high in organics and inorganics

The same waste is injected into WDW-91 and 196.

DRAFT

Company: Monsanto
Plant: Texas City
UIC No.: WDW- 196

Waste: organic
Process: chemical manufacturing (see WDW-91)

Gallons of waste injected in 1985: 179970000
1986: no data
Injection temperature (centigrade): <71
Specific gravity: 1.05-1.12

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	4.5	7.5
total dissolved solids	104560	104560
Cl	20400	20400
sulfate	41840.00	41840.00
ammonia	1000.00	1000.00
nitrate	0.00	8800.00
nitrogen (kjeldahl)	350.00	350.00

ORGANIC COMPOUNDS

Total Organic Carbon	13500.00	13500.00
Chemical Oxygen Demand	22400	22400
Biochemical Oxygen Demand	8600	8600
methyl alcohol (methanol)	30.00	30.00
formaldehyde (methanal)	200.00	200.00
phenols (group)	30.00	30.00
cyanopyridine	750.00	750.00
acetic acid (ethanoic)	750.00	750.00
acrylic acid (2-propenoic acid)	2750.00	2750.00
acetonitrile (ethanenitrile)	700.00	700.00
acrylonitrile	100.00	100.00
fumaronitrile	850.00	850.00
succinonitrile	900.00	900.00
acrylamide	650.00	650.00
urea	100.00	100.00
tertiary butylamine	100.00	100.00

NOTES:

Chemical pretreatment: pH control

The same waste is injected into WDW-91 and 196.

Company: Penwalt
Plant: Crosby
UIC No.: WDW- 122

DRAFT

Waste: petrochemical waste, organic
Process: organic peroxide, nitrogen compound manf.

Gallons of waste injected in 1985: 32374078
1986: no data
Injection temperature (centigrade):
Specific gravity:

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	7.5	7.5
total dissolved solids	26000	26000
Na	5200	5200
K	3700.00	3700.00
Ca	7.00	7.00
Mg	28.00	28.00
Cl	6000	6000
PO4	150.00	150.00
HCO3	4700.00	4700.00
sulfate	1300.00	1300.00
nitrate	0.10	0.10
nitrogen (kjeldahl)	80.00	80.00
As	0.100	0.100
Cr	0.100	0.100
Pb	0.600	0.600
Cd	0.001	0.001
Ba	0.100	0.100
Ag	0.08	0.08
Hg	0.001	0.001

ORGANIC COMPOUNDS

Chemical Oxygen Demand	2500	2500

NOTES:

Organic composition not listed
although COD up to 250ppm

Company: Phillips
Plant: Borger
UIC No.: WDW- 67

DRAF

Waste: organic
Process: Rubber Chemical Complex

Gallons of waste injected in 1985: 4666500
1986: 1135500
Injection temperature (centigrade): 38-49
Specific gravity: 1.03

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	10.0	11.5
total dissolved solids	0	250000
Na	0	125000
K	0.00	4.00
Ca	0.00	650.00
Mg	0.00	400.00
Fe	0.00	1.40
Si	0.00	14.00
Cl	0	125000
HCO3	0.00	55.00
sulfate	0.00	325.00
ammonia	0.00	1.50
V	0.000	1.000
Cu	0.00	0.07
Mn	0.00	1.40
Sb	0.00	1.00

ORGANIC COMPOUNDS

Total Organic Carbon	0.00	378.00
Chemical Oxygen Demand	0	2440
Biochemical Oxygen Demand	0	330
Oil and Grease	0.00	8.70
tertiary butyl catechol	0.00	50000.00

NOTES:

Report suggests that different waste is injected into WDW 67 and 68. But elsewhere in the report it is suggested that WDW 68 is used as backup. Assumed different waste streams to the two wells.

Company: Phillips
Plant: Borger
UIC No.: WDW- 68

DRAFT

Waste: organic
Process: manufacturing of polyphenylene sulfide (Ryton)

Gallons of waste injected in 1985: 64225000
1986: 62050000
Injection temperature (centigrade): 38-49
Specific gravity: 1.03

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	10.0	11.5
total dissolved solids	33258	42383
Na	10462	13324
K	15.00	18.00
Ca	28.00	30.00
Mg	13.00	17.00
Fe	1.80	2.30
Cl	14861	18962
CO3	217.00	339.0
HCO3	3011.00	3869.00
sulfide	106.00	117.00
sulfate	928.00	1140.00
nitrate	0.19	1.00
Cr	0.040	0.160
Pb	0.230	0.290
Cd	0.160	0.210
Ba	0.004	1.000
Ag	0.01	0.10

ORGANIC COMPOUNDS

Chemical Oxygen Demand	2373	2795
Biochemical Oxygen Demand	550	707
methyl alcohol (methanol)	0.00	1475.00
N-methyl pyrrolidone	3685.00	9880.00
beta mercaptoethanol	0.00	780.00
Sulfolane	0.0	955.
Solfolene	0.04	225.

NOTES:

Company: Sandoz-Velsicol
Plant: Beaumont
UIC No.: WDW- 125

DRAFT

Waste: organic
Process: organic chemical manufacturing (see memo)

Gallons of waste injected in 1985: 64426834
1986: no data
Injection temperature (centigrade): 41
Specific gravity: 1.025

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	2.3	6.5
total dissolved solids	34106	48890
Na	3627	14500
K	3444.00	5350.00
Fe	0.60	1.15
Cl	30000	20815
sulfate	27.00	128.00
Zn	0.10	5.96
Cr	1.000	1.700

ORGANIC COMPOUNDS

Total Organic Carbon	1214.00	2593.00
Oil and Grease	23.00	409.00
methyl alcohol (methanol)	80.00	6145.00
anisole (methoxybenzene)	3.00	3.00
trichlorobenzene	1.00	7.00
dichloroanisoles (dichloromethoxybenzene)	23.00	23.00
dichlorophenol	66.00	390.00
dichlorosalicylic acid (dichlorohydroxybenzoic acid)	7.00	7.00
Banvel (methylated dichlorosalicylic acid)	8.00	150.00
Banvel methyl esters	10.00	10.00
Dicamba (3,6-dichloro-2-methoxybenzoic acid)	9.00	87.00

NOTES:

Process that produces waste:
Conversion of 1,2,4-trichlorobenzene
to 3.6-dichloro-o-anisic acid

Waste for WDW 125 & 155 the same.

Company: Sandoz-Velsicol
Plant: Beaumont
UIC No.: WDW- 155

DRAFT

Waste: organic
Process: organic chemical manufacturing (see memo 155)

Gallons of waste injected in 1985: 63217883
1986: no data
Injection temperature (centigrade): 41
Specific gravity: 1.025

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	2.3	6.5
total dissolved solids	34106	48890
Na	3627	14500
K	3444.00	5350.00
Fe	0.60	1.15
Cl	30000	20815
sulfate	27.00	128.00
Zn	0.10	5.96
Cr	1.000	1.700

ORGANIC COMPOUNDS

Total Organic Carbon	1214.00	2593.00
Oil and Grease	23.00	409.00
methyl alcohol (methanol)	80.00	6145.00
anisole (methoxybenzene)	3.00	3.00
trichlorobenzene	1.00	7.00
dichloroanisoles (dichloromethoxybenzene)	23.00	23.00
dichlorophenol	66.00	390.00
dichlorosalicylic acid (dichlorohydroxybenzoic acid)	7.00	7.00
Banvel (methylated dichlorosalicylic acid)	8.00	150.00
Banvel methyl esters	10.00	10.00
Dicamba (3,6-dichloro-2-methoxybenzoic acid)	9.00	87.00

NOTES:

Waste for WDW 125 & 155 the same

DRAFT

Company: Shell
Plant: Deer Park
UIC No.: WDW- 172

Waste: organic
Process: manufacture of resins, intermediate products, solvents (see note)

Gallons of waste injected in 1985: 45232000
1986: no data
Injection temperature (centigrade): 25-66
Specific gravity: 1.0-1.2

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	4	8
total dissolved solids	56750	172000
Na	40000	60000
K	100.00	200.00
Ca	1.00	3.00
Mg	0.50	1.00
Fe	0.10	5.60
Al	0.00	0.24
Cl	60000	80000
CO3	500.00	1000.0
HCO3	1000.00	8000.00
sulfate	20.00	50.00
Zn	0.20	1.00
As	0.000	0.060
Cu	0.20	1.20
Ni	0.10	0.50
Mn	0.20	2.00
Cr	0.100	0.200
Co	0.00	0.35
Pb	0.040	1.000
Ba	0.060	0.100
Hg	0.001	0.005

ORGANIC COMPOUNDS

propane	0.00	30000.00
Glycerol (glycerine, propane triol)	5400.00	50000.00
polyglycerols	3000.00	3000.00
glycidol	130.00	130.00
bisdioxane	700.00	700.00
acetone (dimethyl ketone)	200.00	2000.00
phenol	2000.00	30000.00
chlorinated hydrocarbons	5000.00	15000.00
chlorohydrin (mono-, di- and epi-)	350.00	350.00

NOTES:

Chemical pretreatment: pH 4 to 8 with HCl

DRAFT

Waste from:

- Epon resin water cuts
- Bisphenol of acetone brine
- epichlorohydrin water cuts
- intermittent miscellaneous aqueous shell manufacturing wastes

The same waste is injected into WDW-172 and 173.

Company: Shell
Plant: Deer Park
UIC No.: WDW- 173

DRAFT

Waste: organic
Process: manufacture of resins, intermediate products, solvents (see WDW-172)

Gallons of waste injected in 1985: 60889822
1986: no data
Injection temperature (centigrade): 25-66
Specific gravity: 1.0-1.2

WASTE COMPOSITION

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	4	8
total dissolved solids	56750	172000
Na	40000	60000
K	100.00	200.00
Ca	1.00	3.00
Mg	0.50	1.00
Fe	0.10	5.60
Al	0.00	0.24
Cl	60000	80000
CO3	500.00	1000.0
HCO3	1000.00	8000.00
sulfate	20.00	50.00
Zn	0.20	1.00
As	0.000	0.060
Cu	0.20	1.20
Ni	0.10	0.50
Mn	0.20	2.00
Cr	0.100	0.200
Co	0.00	0.35
Pb	0.040	1.000
Ba	0.060	0.100
Hg	0.001	0.005

ORGANIC COMPOUNDS

propane	0.00	30000.00
Glycerol (glycerine, propane triol)	5400.00	50000.00
polyglycerols	3000.00	3000.00
glycidol	130.00	130.00
bisdioxane	700.00	700.00
acetone (dimethyl ketone)	200.00	2000.00
phenol	2000.00	30000.00
chlorinated hydrocarbons	5000.00	15000.00
chlorohydrin (mono-, di- and epi-)	350.00	350.00

NOTES:

Chemical pretreatment: pH 4 to 8 with HCl

The same waste is injected into WDW-172 and 173.

DRAFT

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Company: Standard Oil-Vistron
Plant: Port Lavaca
UIC No.: WDW- 163

DRAFT

Waste: organic, cyanide
Process: petrochemical manufacture

Gallons of waste injected in 1985: 45275153
1986: no data
Injection temperature (centigrade):
Specific gravity: 1.042

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	6.2	6.2
total dissolved solids	109000	109000
CN (cyanide)	2038.00	2038.00

ORGANIC COMPOUNDS

acetonitrile (ethanenitrile)	203.00	203.00
acrylonitrile	597.00	597.00

NOTES:

The same waste is injected into WDW-163, 164, and 165.

Company: Standard Oil-Vistron
Plant: Port Lavaca
UIC No.: WDW- 164

DRAFT

Waste: organic, cyanide
Process: petrochemical manufacture

Gallons of waste injected in 1985: 62384101
1986: no data
Injection temperature (centigrade):
Specific gravity: 1.042

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	6.2	6.2
total dissolved solids	109000	109000
CN (cyanide)	2038.00	2038.00

ORGANIC COMPOUNDS

acetonitrile (ethanenitrile)	203.00	203.00
acrylonitrile	597.00	597.00

NOTES:

The same waste is injected into WDW-163, 164, and 165.

Company: Standard Oil-Vistron
Plant: Port Lavaca
UIC No.: WDW- 165

DRAFT

Waste: organic, cyanide
Process: petrochemical manufacture

Gallons of waste injected in 1985: 63412519
1986: no data
Injection temperature (centigrade):
Specific gravity: 1.042

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	6.2	6.2
total dissolved solids	109000	109000
CN (cyanide)	2038.00	2038.00

ORGANIC COMPOUNDS

acetonitrile (ethanenitrile)	203.00	203.00
acrylonitrile	597.00	597.00

NOTES:

The same waste is injected into WDW-163, 164, and 165.

DRAFT

Company: Tenneco Uranium
Plant: Bruni Mine
UIC No.: WDW- 195

Waste: Ra226
Process: in-situ solution mining for U

Gallons of waste injected in 1985: 6290923
1986: no data
Injection temperature (centigrade): ambient
Specific gravity:

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	5.8	9.5
total dissolved solids	22700	22700
Na	5570	5570
K	330.00	330.00
Ca	470.00	470.00
Mg	400.00	400.00
Cl	5800	5800
CO3	880.00	880.0
HCO3	5300.00	5300.00
sulfate	3400.00	3400.00
F	50.00	50.00
nitrate	440.00	440.00
Mo	425.00	425.00
V	10.000	10.000
As	20.000	20.000
U	50.00	50.00
Ra226 (pCi/liter)	1000.00	1000.00

ORGANIC COMPOUNDS

NOTES:

DRAFT

Company: Tex Tin-Gulf
Plant: Texas City
UIC No.: WDW- 237

Waste: acid inorganic
Process: smelting and refining

Gallons of waste injected in 1985: 2312503
1986: no data
Injection temperature (centigrade): 21
Specific gravity: 1.06-1.11

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	0.6	1.0
total dissolved solids	139896	139896
Ca	6078.00	6078.00
Mg	205.00	205.00
Fe	18500.00	35800.00
Al	490.00	497.00
Cl	53100	92631
CO3	0.00	0.5
HCO3	0.00	0.50
sulfate	150.00	150.00
Zn	180.00	180.00
As	46.000	56.000
Cu	87.00	392.00
Ni	46.00	56.00
Mn	164.00	332.00
Cr	54.000	358.000
Co	5.10	9.00
Se	0.020	0.100
Pb	58.000	150.000
Sn	9.20	34.00
Cd	0.500	1.000
Ba	4.200	4.200
Bi	8.80	16.00
Ag	3.20	3.20
Sb	13.00	13.00
Hg	0.007	0.280

ORGANIC COMPOUNDS

Chemical Oxygen Demand	0	1800
Biochemical Oxygen Demand	0	42

NOTES:

DRAFT

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============================================================
Company:  Texaco
Plant:    Amarillo
UIC No.: WDW-  135

Waste:    inorganic sulfate-chloride brine
Process: gasoline, diesel fuel manufacturing

Gallons of waste injected in 1985:    35802890
                             1986:     no data
Injection temperature (centigrade): 38
Specific gravity: 1.006


WASTE COMPOSITION                                         MINIMUM   MAXIMUM
                                                          (mg/l)    (mg/l)
=================                                          =======   =======

pH                                                         7.94      7.94
total dissolved solids                                   11367     11367
Na                                                        3784      3784
Ca                                                         218.00       218.00
Mg                                                          67.50        67.50
Fe                                                           0.00         0.02
Cl                                                        4065      4065
HC03                                                       219.00       219.00
sulfate                                                   3014.00      3014.00

ORGANIC COMPOUNDS
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NOTES:
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The same waste is injected into WDW-135 and 136.
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DRAFT

Company: Texaco
Plant: Amarillo
UIC No.: WDW- 136

Waste: inorganic sulfate-chloride brine
Process: gasoline, diesel fuel manufacturing

Gallons of waste injected in 1985: 54590323
1986: no data
Injection temperature (centigrade): 38
Specific gravity: 1.006

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	7.94	7.94
total dissolved solids	11367	11367
Na	3784	3784
Ca	218.00	218.00
Mg	67.50	67.50
Fe	0.00	0.02
Cl	4065	4065
HC03	219.00	219.00
sulfate	3014.00	3014.00

ORGANIC COMPOUNDS

NOTES:

The same waste is injected into WDW-135 and 136.

DRAFT

Company: US Steel
Plant: George West
UIC No.: WDW- 123

Waste: Ra226
Process: in-situ solution mining for U

Gallons of waste injected in 1985: 12283269
1986: no data
Injection temperature (centigrade): ambient
Specific gravity: 1.00-1.01

WASTE COMPOSITION

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	6.6	7.2
total dissolved solids	3530	9078
Na	392	2130
K	18.00	38.00
Ca	418.00	656.00
Mg	62.00	100.00
Fe	0.24	10.45
Cl	850	1890
HCO3	249.00	910.00
sulfate	1008.00	5250.00
ammonia	0.50	1030.00
Mo	1.00	38.00
V	0.100	0.100
Cu	0.05	2.40
U	4.00	30.00
Ra226 (pCi/liter)	800.00	800.00

ORGANIC COMPOUNDS

NOTES:

Chemical pretreatment: corrosion and scale inhibitor

The same waste is injected into WDW-123, 124, 130, 140, 141, and 174.

DRAFT

Company: US Steel
Plant: George West
UIC No.: WDW- 124

Waste: Ra226
Process: in-situ solution mining for U

Gallons of waste injected in 1985: 66306226
1986: no data
Injection temperature (centigrade): ambient
Specific gravity: 1.00-1.01

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	6.6	7.2
total dissolved solids	3530	9078
Na	392	2130
K	18.00	38.00
Ca	418.00	656.00
Mg	62.00	100.00
Fe	0.24	10.45
Cl	850	1890
HC03	249.00	910.00
sulfate	1008.00	5250.00
ammonia	0.50	1030.00
Mo	1.00	38.00
V	0.100	0.100
Cu	0.05	2.40
U	4.00	30.00
Ra226 (pCi/liter)	800.00	800.00

ORGANIC COMPOUNDS

NOTES:

Chemical pretreatment: corrosion and scale inhibitor

The same waste is injected into WDW-123, 124, 130, 140, 141, and 174.

Company: US Steel
Plant: George West
UIC No.: WDW- 130

DRAFT

Waste: Ra226
Process: in-situ solution mining for U

Gallons of waste injected in 1985: 58606642
1986: no data
Injection temperature (centigrade): ambient
Specific gravity: 1.00-1.01

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	6.6	7.2
total dissolved solids	3530	9078
Na	392	2310
K	18.00	38.00
Ca	418.00	656.00
Mg	62.00	100.00
Fe	0.24	10.45
Cl	850	1890
HCO3	249.00	910.00
sulfate	1008.00	5250.00
ammonia	0.50	1030.00
Mo	1.00	38.00
V	0.100	0.100
Cu	0.05	2.40
U	4.00	30.00
Ra226 (pCi/liter)	800.00	800.00

ORGANIC COMPOUNDS

NOTES:

Chemical pretreatment: corrosion and scale inhibitor

The same waste is injected into WDW-123, 124, 130, 140, 141, and 174.

DRAFT

Company: US Steel
Plant: George West
UIC No.: WDW- 140

Waste: Ra226
Process: in-situ solution mining for U

Gallons of waste injected in 1985: 10328192
1986: no data
Injection temperature (centigrade): ambient
Specific gravity: 1.00-1.01

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	6.6	7.2
total dissolved solids	3530	9078
Na	392	2130
K	18.00	38.00
Ca	418.00	656.00
Mg	62.00	100.00
Fe	0.24	10.45
Cl	850	1890
HC03	249.00	910.00
sulfate	1008.00	5250.00
ammonia	0.50	1030.00
Mo	1.00	38.00
V	0.100	0.100
Cu	0.05	2.40
U	4.00	30.00
Ra226 (pCi/liter)	800.00	800.00

ORGANIC COMPOUNDS

NOTES:

Chemical pretreatment: corrosion and scale inhibitor

The same waste is injected into WDW-123, 124, 130, 140, 141, and 174.

DRAFT

Company: US Steel
Plant: George West
UIC No.: WDW- 141

Waste: Ra226
Process: in-situ solution mining for U

Gallons of waste injected in 1985: 68738708
1986: no data
Injection temperature (centigrade): ambient
Specific gravity: 1.00-1.01

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	6.6	7.2
total dissolved solids	3530	9078
Na	392	2130
K	18.00	38.00
Ca	418.00	656.00
Mg	62.00	100.00
Fe	0.24	10.45
Cl	850	1890
HC03	249.00	910.00
sulfate	1008.00	5250.00
ammonia	0.50	1030.00
Mo	1.00	38.00
V	0.100	0.100
Cu	0.05	2.40
U	4.00	30.00
Ra226 (pCi/liter)	800.00	800.00

ORGANIC COMPOUNDS

NOTES:

Chemical pretreatment: corrosion and scale inhibitor

The same waste is injected into WDW-123, 124, 130, 140, 141, and 174.

DRAFT

Company: US Steel
Plant: George West
UIC No.: WDW- 174

Waste: Ra226
Process: in-situ solution mining for U

Gallons of waste injected in 1985: 87861744
1986: no data
Injection temperature (centigrade): ambient
Specific gravity: 1.00-1.01

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	6.6	7.2
total dissolved solids	3530	9078
Na	392	2130
K	18.00	38.00
Ca	418.00	656.00
Mg	62.00	100.00
Fe	0.24	10.45
Cl	850	1890
HC03	249.00	910.00
sulfate	1008.00	5250.00
ammonia	0.50	1030.00
Mo	1.00	38.00
V	0.100	0.100
Cu	0.05	2.40
U	4.00	30.00
Ra226 (pCi/liter)	800.00	800.00

ORGANIC COMPOUNDS

NOTES:

Chemical pretreatment: corrosion and scale inhibitor

The same waste is injected into WDW-123, 124, 130, 140, 141, and 174.

DRAFT

Company: W R Grace
Plant: Deer Park
UIC No.: WDW- 222

Waste: organic
Process: manufacture of nitroparafins

Gallons of waste injected in 1985: no data
1986: no data
Injection temperature (centigrade): ambient
Specific gravity: 1.0

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	3.0	3.0
total dissolved solids	4424	4424
Na	97	97
Ca	0.80	0.80
Mg	2.10	2.10
Fe	1.90	1.90
Cl	20	20
HC03	0.00	1.00
sulfide	0.25	0.25
sulfate	60.00	60.00
sulfite	0.00	2.00
ammonia	1108.00	1108.00
nitrate	129.00	129.00
Zn	0.12	0.12
CN (cyanide)	31.90	31.90
nitric acid	3740.0	6900.0

ORGANIC COMPOUNDS		
Total Organic Carbon	93020.00	93020.00
formic acid	0.00	15.90
acetic acid (ethanoic)	0.00	220.00
urea	0.00	130.00
carbonyl-bisulfite adduct	0.0	352000.0

NOTES:

Chemical pretreatment: pH adjusted

The same waste is injected into WDW-222 and 223.

Company: W R Grace
Plant: Deer Park
UIC No.: WDW- 223

DRAFT

Waste: organic
Process: manufacture of nitroparafins

Gallons of waste injected in 1985: 11422200
1986: no data
Injection temperature (centigrade): ambient
Specific gravity: 1.0

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	3.0	3.0
total dissolved solids	4424	4424
Na	97	97
Ca	0.80	0.80
Mg	2.10	2.10
Fe	1.90	1.90
Cl	20	20
HCO3	0.00	1.00
sulfide	0.25	0.25
sulfate	60.00	60.00
sulfite	0.00	2.00
ammonia	1108.00	1108.00
nitrate	129.00	129.00
Zn	0.12	0.12
CN (cyanide)	31.90	31.90
nitric acid	3740.0	6900.0

ORGANIC COMPOUNDS		
Total Organic Carbon	93020.00	93020.00
formic acid	0.00	15.90
acetic acid (ethanoic)	0.00	220.00
urea	0.00	130.00
carbonyl-bisulfite adduct	0.0	352000.0

NOTES:

Chemical pretreatment: pH adjusted

The same waste is injected into WDW-222 and 223.

Company: Westinghouse
Plant: Bruni Mine
UIC No.: WDW- 170

DRAFT

Waste: Ra226
Process: in-situ solution mining for U

Gallons of waste injected in 1985: 16463084
1986: no data
Injection temperature (centigrade): ambient
Specific gravity: 1.01

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	4.5	7.5
Ca	460.00	460.00
Cl	4886	4886
HC03	467.00	467.00
sulfate	967.00	967.00
ammonia	943.00	943.00
U	0.50	11.10
Ra226 (pCi/liter)	424.00	777.00

ORGANIC COMPOUNDS

NOTES:

Chemical pretreatment: pH adjust to 5-6

DRAFT

Company: Witco
Plant: Houston
UIC No.: WDW- 111

Waste: organic
Process: chemical manfacturing (see note)

Gallons of waste injected in 1985: 3365900
1986: 14846830
Injection temperature (centigrade): ambient
Specific gravity: 1.005

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	5.5	6.5
total dissolved solids	5690	5690
Na	1700	1700
Ca	108.00	108.00
Mg	7.30	7.30
Fe	35.00	35.00
Cl	109	109
HC03	425.00	425.00
sulfate	3350.00	3350.00

ORGANIC COMPOUNDS

NOTES:

Chemical pretreatment: pH adjusted

The same waste is injected into WDW-111 and 139.

Waste producing processes: Sulfonation, oxylation, neutralization, esterification, amidification, phosphation, phenol-formaldehyde resins, blending and solvents.

Waste is a water solution of sulfonated organics and their salts consisiting of oxylated organic compounds, fatty acid esters and amides, phenol-formaldehyde resins, aromatic and aliphatic solvents.

ORGANICS REPORTED AS % OF TOTAL ORGANIC FRACTION BUT NO TOTAL CONCENTRATION OF ORGANICS IN SOLUTION WAS GIVEN.

ETHOXYLATED C10-C12 ALCOHOLS	22%
PROPAXYLATED DIOLS AND TRIOLS	20%
ETHOXYLATED ALKYL PHENOLS	15%
ETHOXYLATED PHENOLIC RESINS	12%
ESTERS OF POLYOLS AND DIBASIC ACIDS	12%
PHENOLIC RESINS	5%

DRAFT

Ca SALTS OF ALKYL BENZENE SULFONIC ACID	5%
Phosphate esters	2%
Amine salts of alkyl benzene sulfonic acid	1%
Diethanolamides	1%
Alkyl benzene sulfonic acids, alcohol ether sulfates and sodium and __ salts of each	1%
Ethoxylated fatty and resin amines	.5%
Quatanery ammonium compounds	.5%

===
Company: Witco
Plant: Houston
UIC No.: WDW- 139

DRAFT

Waste: organic
Process: chemical manfacturing (see WDW-111)

Gallons of waste injected in 1985:   33442400
1986:   no data
Injection temperature (centigrade): ambient
Specific gravity: 1.005

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	5.5	6.5
total dissolved solids	5690	5690
Na	1700	1700
Ca	108.00	108.00
Mg	7.30	7.30
Fe	35.00	35.00
Cl	109	109
HCO3	425.00	425.00
sulfate	3350.00	3350.00

ORGANIC COMPOUNDS
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NOTES:
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Chemical pretreatment: pH adjusted

The same waste is injected into WDW-111 and 139.

DRAFT

Company: Witco
Plant: Marshall
UIC No.: WDW- 107

Waste: organic
Process: manfacture of organic peroxide materials

Gallons of waste injected in 1985: 92000
1986: no data
Injection temperature (centigrade):
Specific gravity: 1.043

WASTE COMPOSITION

	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	13	13
total dissolved solids	65500	65500
Na	20000	20000
Ca	11.30	11.30
Mg	1.02	1.02
Cl	4400	4400
P04	1285.00	1285.00
C03	16785.00	16785.0
sulfate	600.00	600.00
Cr	25.000	25.000

ORGANIC COMPOUNDS

Total Organic Carbon	7000.00	7000.00
Chemical Oxygen Demand	17000	17000
Oil and Grease	16.00	16.00
butanone (methyl ethyl ketone)	156.00	156.00
dimethyl phthalate (phthalic acid dimethyl ester)	1.10	1.10

NOTES:

WDW 107 and 180 same waste injected.

Waste: A mixture of sodium-chloride and sodium sulfate brines with varying amounts of water soluble organic acids, peroxides and ketones.

Process: The plant produces a variety of organic peroxide materials by semi-continous and batch methods.

Company: Witco
Plant: Marshall
UIC No.: WDW- 180

DRAFT

Waste: organic
Process: manfacture of organic peroxide materials

Gallons of waste injected in 1985: 13856000
1986: no data
Injection temperature (centigrade):
Specific gravity: 1.043

WASTE COMPOSITION	MINIMUM (mg/l)	MAXIMUM (mg/l)
pH	13	13
total dissolved solids	65500	65500
Na	20000	20000
Ca	11.30	11.30
Mg	1.02	1.02
Cl	4400	4400
PO4	1285.00	1285.00
CO3	16785.00	16785.0
sulfate	600.00	600.00
Cr	25.000	25.000

ORGANIC COMPOUNDS		
Total Organic Carbon	7000.00	7000.00
Chemical Oxygen Demand	17000	17000
Oil and Grease	16.00	16.00
butanone (methyl ethyl ketone)	156.00	156.00
dimethyl phthalate (phthalic acid dimethyl ester)	1.10	1.10

NOTES:

The same waste is injected into WDW-107 and 180.

DRAFT

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==============================================================
Company:  Wyoming Minerals
Plant:    Three Rivers
UIC No.: WDW-  156

Waste:    Ra226
Process: in-situ solution mining for U

Gallons of waste injected in 1985:     1075950
                             1986:     no data
Injection temperature (centigrade): ambient
Specific gravity:


WASTE COMPOSITION                                    MINIMUM  MAXIMUM
                                                      (mg/l)   (mg/l)
=================                                     =======  =======

pH                                                     8        8
total dissolved solids                               19700    19700
Na                                                     250      250
Ca                                                   1100.00     1100.00
Mg                                                    310.00      310.00
Cl                                                   12560    12560
HCO3                                                 1720.00     1720.00
sulfate                                              4190.00     4190.00
ammonia                                              6810.00     6810.00
U                                                      29.00       29.00
Ra226 (pCi/liter)                                     671.00      671.00

ORGANIC COMPOUNDS
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NOTES:
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