♺EPA Ground Water Issue

Nonaqueous Phase Liquids Compatibility with Materials Used in Well Construction, Sampling, and Remediation

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Background

The EPA Regional Ground Water Forum is a group of EPA professionals representing Regional Superfund and Resource Conservation and Recovery Act Offices (RCRA), committed to the identification and resolution of ground-water issues impacting the remediation of Superfund and RCRA sites. The Forum is supported by and advises the Superfund Technical Support Project. The compatibility of remediation, well construction, and sampling materials with nonaqueous phase liquids (NAPLs) is an issue that is a concern of Superfund decision-makers.

This issue paper provides a comprehensive literature review regarding the compatibility of NAPLs with a wide variety of materials used at hazardous waste sites. A condensed reference table of compatibility data for 207 chemicals and 28 commonly used well construction and sampling equipment materials is provided. Field experiences illustrating incompatibility problems of common wastes are also included. This will assist monitoring and recovery system design personnel with the decision making process concerning the most effective materials to be used in heavily contaminated subsurface environments.

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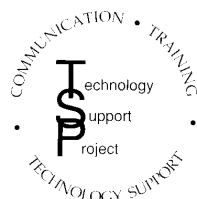
Introduction

NAPLs typically have been divided into two general categories, dense and light. Dense nonaqueous phase liquids (DNAPLs) have a specific gravity greater than water, and light nonaqueous phase liquids (LNAPLs) have a specific

gravity less than water [*Huling and Weaver, 1991*]. Both of these liquids are of major environmental concern because they are commonly found in the subsurface at Superfund sites as well as other hazardous waste sites.

A national Superfund DNAPL site assessment study concluded that approximately 60% of the National Priorities List sites are expected to have a medium to high potential of having DNAPL present [*Hubbard et al., 1993*]. It is also known that LNAPLs affect ground-water quality at thousands of sites across the country [*Newell et al., 1995*]. DNAPLs [*Mercer and Cohen, 1990; Huling and Weaver, 1991; Cohen and Mercer, 1993*] and LNAPLs [*Newell et al., 1995*] present significant technical challenges to remediation efforts and their transport and fate are often complex.

DNAPLs commonly found at Superfund sites include halogenated solvents (e.g., tetrachloroethylene (PCE), trichloroethylene (TCE), dichloroethane (DCA) and carbon tetrachloride); polychlorinated biphenyls (PCBs); pesticides; chlorinated benzenes and phenols; and polycyclic aromatic hydrocarbons (PAHs). Common LNAPLs include fuels and oils. Constituents of NAPLs include volatile aromatics (benzene, toluene, styrene and xylenes); halogenated volatiles (vinyl chloride and chloroethane); and volatile ketones and furans. Due to the diverse characteristics of these chemicals in conjunction with the broad range of

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materials available, it is apparent that the incompatibility issue is complex and broad in scope.

Contaminants may be introduced into the subsurface as a LNAPL or DNAPL, but may partition into the soil pore water and ground water; volatilize into the gaseous phase; and partition onto soil and aquifer material. The two phases of contamination that will be the focus of this issue paper are the nonaqueous phase and the soluble phase. NAPLs may be held relatively immobile by capillary forces as small discontinuous blobs or isolated droplets, generally referred to as residual saturation. As the NAPL saturation increases, the NAPL phase becomes continuous and the mobility of the NAPL increases. NAPLs at residual saturation may affect equipment and materials similar to continuous phase NAPLs. Lastly, the soluble constituents of mixed NAPLs differentially dissolve into the ground water as a function of their mole fraction and solubility. Although these dissolved compounds are no longer NAPLs, near-solubility concentrations of some organic compounds may adversely affect the structural integrity of some materials.

All ground-water sampling, well construction, and remediation materials are subject to degradation or corrosion in the natural environment. For example, metal components may corrode when:
- $pH < 7.0$,
- dissolved oxygen > 2 ppm,
- $H_2S > 1$ ppm,
- total dissolved solids > 1000 ppm,
- $CO_2 > 50$ ppm, or
- chloride > 5000 ppm [*Aller et al., 1989*].

Materials exposed to NAPLs may also be degraded or corroded, which may lead to structural failure. This vulnerability applies to materials exposed to these chemicals in both the subsurface and above ground. A design consideration during any NAPL recovery program should include a material compatibility review to minimize failures [*Huling and Weaver, 1991*]. Additionally, at sites where the presence of NAPLs is suspected, a materials compatibility review should be conducted. Since the time requirements for subsurface remediation systems (product recovery, ground-water remediation) at most RCRA and CERCLA sites are usually long-term, it is economically and technically important that these systems be constructed of materials with known chemical resistance qualities to provide reliable service over many years.

Compatibility

There are two types of effects that NAPLs have on materials used in well construction, sampling, and remediation. First, the structural integrity of a material may be compromised by corrosion or solvation. Secondly, dissolved ground-water contaminants from NAPLs can sorb to or leach from monitoring materials which affect ground-water quality measurements. Another way of viewing these two effects is from a concentration perspective. Sorption to monitoring surfaces may have the greatest effect on water quality measurements when contaminants are present at low dissolved concentrations. Conversely, sorption of contaminants present as NAPLs or in high dissolved concentrations, may have a minimal effect on water quality measurements, while the effects on the structural integrity of the materials may be at a maximum. Compatibility in the Chemical Compatibility Table of this issue paper is defined as a material's ability to withstand corrosion or degradation under specific experimental conditions. This refers to the effects that NAPLs and high concentrations of dissolved organic compounds have on the structural integrity of materials. While the focus of this issue paper is the structural integrity issue, a short discussion on incompatibility issues from a water quality measurement point of view is included for clarification.

Water Quality Measurement Incompatibility

Incompatibility caused by contaminants sorbing to or leaching from monitoring well materials and sampling devices yielding misleading information on the quality of ground water has been demonstrated repeatedly [*Llopis, 1992; Gillham and O'Hannesin, 1990; Barcelona et al., 1988; Jones and Miller, 1988; Sykes et al., 1986*]. This type of incompatibility is greatest with low dissolved concentrations of heavy metals and organic compounds. Presently, the high degree of accuracy (parts per billion) required of some chemical analyses dictates that all potential sources of error of a ground-water sampling program be identified and minimized [*Llopis, 1992*]. Correspondingly, a properly installed ground-water monitoring well should be constructed so that well materials do not influence the ground-water sample for at least 30 years [*Morrison, 1986*].

The composition of contaminated ground water and sediment (pH, Eh, conductivity, temperature, specific organic compound species, and co-solvent effects) in contact with well construction and sampling materials influences sorption and leaching processes. In addition, the complex and varied nature of site-specific ground-water contamination in conjunction with numerous material types makes it challenging to predict the sorption and leaching potential of various sampling materials. However, recent studies show a general agreement on which well casing materials are the best to use to reduce measurement anomalies.

Rigid polyvinylchloride (PVC), polytetrafluoroethylene (PTFE), and fiberglass reinforced epoxy (FRE) had relatively low sorption rates when exposed to trichloroethane, tetrachloroethane, trichloroethylene, tetrachloroethylene, hexachloroethane, and bromoform compared to flexible polymers [*Reynolds et al., 1990*]. Stainless steel, rigid PVC, and fluoropolymer well casings generally adsorb minor amounts of trace-level organic compounds once equilibrated with the subsurface environment and none of the casings leached organic compounds when solvent cements were not used to connect the casings [*Gillham and O'Hannesin, 1990; Parker et al., 1990: Parker and Ranney, 1994*]. Some iron-based casing materials may influence abiotic degradation of halogenated aliphatics [*Reynolds et al., 1990; Gillham and O'Hannesin, 1994*].

Studies indicate that stainless steel can leach dissolved metals under anoxic conditions [*Hewitt, 1989; 1992; 1993; Parker et al., 1990*].

Structural Integrity Incompatibility

Structural integrity of materials can be affected by both pure-phase NAPLs and dissolved organic compounds in ground water. In the following discussion, corrosion of metals and the types of polymer degradation are presented with a review of concentration-related effects of dissolved organic compounds with monitoring materials. The Chemical Compatibility Table in this issue paper was prepared to evaluate the effects of pure-phase or 100% concentrations of compounds, except where noted.

Corrosion: Chemical corrosion results from chemical reactions with metals and soil or water [*U.S. Dept. of Interior, 1981*]. The corroded metal usually goes into solution and is carried away from the point of attack [*Moehrl, 1961*]. Galvanic corrosion occurs when two or more dissimilar metals are in contact and an electrolyte is present [Schweitzer, 1991]. Accordingly, corrosion in this issue paper applies to the breakdown of a metal surface attacked by chemicals, resulting in a measurable reduction of metal thickness over time.

Degradation: Plastics do not exhibit a corrosion rate, but undergo degradation by various mechanisms. Types of plastic degradation in a ground-water environment are oxidative, mechanical, microbial, and chemical attack. Oxidative degradation of polymers is catalyzed by heavy metals, such as copper, in a redox reaction in which peroxide groups are decomposed, accelerating the degradation reaction [*Al-Malaika, 1987*]. However, many polymeric formulations include antioxidants which inhibit oxidation reactions. Bond cleavage may result in mechanical degradation when stress is imposed on polymer chains through grinding, milling, or stretching [*Dole, 1983; Agarwal and Porter, 1988*]. Mechanical degradation is a term that describes changes in a material when applied stresses from manufacturing, machining, handling, and installation techniques cause chips, fractures, and other deformations. It has been observed that enzymes attack noncrystalline regions preferentially; therefore, the resistance of susceptible polymers to microbial degradation is related directly to the degree of crystallinity of the polymer [*Bradley et al., 1973*]. Chemical resistance of a polymer is its ability to withstand attack by chemicals over a period of time without excessive changes in dimensions, weight, or mechanical properties [*Seymour, 1989*]. Plastic materials are primarily degraded by solvation, which is the penetration of the plastic by an organic solvent that causes softening, swelling, and ultimate failure [*Schweitzer, 1991*]. At a given chemical concentration, diffusion of a chemical into the polymer will proceed until equilibrium conditions are attained. Due to the inter-polymer diffusion of these chemicals, polymers may dissolve, swell due to absorption and diffusion, or they may stress crack by selectively absorbing solvents [*Seymour, 1989*]. The Chemical Compatibility Table in this issue paper does not differentiate between types of degradation.

Concentration-Related Effects: Ambiguity exists on the subject of structural compatibility. This is partially attributed to studies being conducted at different aqueous concentrations, from NAPLs to below solubility concentrations. For example, a lack of agreement exists concerning the use of PVC well casing in the presence of gasoline [U.S.EPA, 1986]. EPA has concluded that PVC is not an acceptable material for monitoring well construction because the PVC casing may swell and deteriorate in the presence of the aromatic hydrocarbon fraction of gasoline. This finding is consistent with the Chemical Compatibility Table in this report where pure-phase aromatic compounds (e.g., benzene, toluene, and xylenes), which are a few of the numerous components of gasoline, will degrade Type I PVC. However, Schmidt [*1987*] published an opposing report concerning PVC and gasoline compatibility that included both laboratory immersion tests and field observations. Schmidt's conclusion was that "Schedule 40, rigid, Type I PVC casing and screen could be used with confidence when monitoring for the occurrence of gasolines on the ground water table." The literature review conducted for this issue paper found that all chemical resistance test data recommend Type I PVC for use in gasoline, diesel, and jet fuels. The conflicting recommendations of these reports may be related to the different concentrations of aromatic compounds tested.

Recent work with methylene chloride, an excellent solvent of PVC, softened PVC at activities as low as 0.1 (10% of the solubility limit)[*Parker and Ranney, 1994*]. Activity of a compound was estimated by dividing the aqueous concentration by its solubility. Experiments with TCE, which is not as good a solvent of PVC as methylene chloride, suggest that softening of PVC did not occur at activities below 0.6. A mixed-organic-solvent study indicated that when dealing with an aqueous mixture of organic solvents there is some type of cumulative or interactive effect resulting in softening of PVC at activities above 0.3 [*Parker and Ranney, 1994*]. Acetone, miscible in water and a good solvent of PVC, caused rapid softening at 50% concentrations (0.5 g/ml) [*Parker and Ranney, 1994*].

Another example illustrating the lack of agreement involves structural degradation effects under high concentrations. Barcelona et al., [*1988*], suggested that significant losses of strength and durability of rigid PVC may be expected under conditions where organic contaminants are present in high concentrations. However, Taylor and Parker [*1990*] reported that PVC, PTFE, and stainless steel (304, 316) casing material did not change surface structure (using scanning electron microscopy) when exposed to dichlorobenzenes, toluene, and PCE at activities of 0.25 after 6 months. This discrepancy may be partly due to the different compatibility testing protocols; strength and durability versus visual effects.

Annular Sealants and Barrier Wall Materials

Compatibility of annular sealant materials, cements, and grouts with NAPLs has not been comprehensively studied. However, the permeability of clay and other materials in landfill liners and barrier walls has been measured to study the deterioration effect of various leachates and select soluble organic liquids.

Abdul et al., [*1990*], found that organic solvents (benzene, toluene, *p*-xylene, nitrobenzene, TCE, PCE, ethyl acetate, 2-butanone, and phenol) at 0.1 to 0.5 activities in water solutions did not significantly increase the permeability of bentonite or kaolin clays that were first stabilized with 0.005 N $CaSO_4$. The hydraulic conductivity of bentonite in all of the 0.1 solutions was lower than with water, while kaolin was slightly more permeable with these solutions. However, it was determined that neat (100%) solutions increased the

measured hydraulic conductivity of the clay materials by up to two orders of magnitude. Phenol, ethyl acetate, and *p*-xylene neat solutions increased the permeability of bentonite. Benzene, phenol, and toluene neat solutions increased the permeability of kaolin. In general, hydrophobic solvents caused clays to shrink, producing distinct large vertical cracks. The hydrophillic solvents typically caused the clays to aggregate and fracture, forming a network of cracks [*Abdul et al.*, 1990].

In another study, cement-asphalt (Aspemix), bentonite-sand, and organophilic clay-cement mixtures were found to have increased hydraulic conductivities above $1x10^{-7}$ cm/s when contacted with pure methylene chloride [*Sai and Anderson, 1992*]. In the same study, attapulgite clay-cement (Impermix) mixture maintained hydraulic conductivities below $1x10^{-7}$ cm/s in the presence of pure methylene chloride.

DNAPL composed of dichloromethane, xylene, halogenated semi-volatiles and a mixture of other solvents (density 1.1 g/cm^3) was used to evaluate the effects of DNAPL on the integrity of cement and a 3% bentonite-cement grout [*Cassil and Barton, 1994*]. In column studies where cement was added to tubes containing varying amounts of DNAPL, the DNAPL amended columns were discolored, pitted, and had channels where the DNAPL had moved along the interface of the tube wall and the grout. This was not observed in the control where water was initially present. In a column study where a 3% bentonite-cement grout was added to the same DNAPL in a column, the permeability was significantly greater than in the control where an equal volume of water was added. The grout was mottled, irregular, and had the presence of voids, cavities, and channels. The control column which initially contained water did not exhibit these characteristics. Therefore, both the cement and cement-bentonite mixture were more permeable when set in a DNAPL environment.

In light of these few studies, NAPLs may act to promote vertical migration of contaminants along a well casing or breach containment systems designed to separate contaminated zones from cleaner zones. However, this issue has not been fully investigated. The compatibility of NAPLs with annular sealants, well packing, and barrier wall materials should be determined on a site-specific basis by testing the proposed materials and chemicals that are likely to be in contact with those materials.

Annular sealants, well packing, and barrier wall materials are not included in the Chemical Compatibility Table because of the limited information available.

Field Experience and Practical Considerations

Relatively little field experience is reported in the literature regarding remediation, well construction, and sampling materials compatibility with contaminants. This may be due to several reasons. The environmental field is relatively young and many materials may not have had sufficient contact time for significant failures to be observed. Lack of reporting may also be due to the inherent hidden effects of subsurface chemical incompatibility with materials. For example, extraction and monitoring well structural failures are seldom observed from the surface. Wells that do appear to be

malfunctioning are usually sealed or grouted without knowing the real cause of the problem. Additionally, silting-in of a well is routinely diagnoised as a screen size design problem, but may acutally be the result of screen deterioration from chemical incompatibilty.

Field experience with various types of wastes and materials commonly found at hazardous waste sites provides useful information. While the information is qualitative, it illustrates a few guidelines regarding chemical compatibility.

Creosote Wastes: Creosote manufacturers generally recommend against the use of PVC and recommend the use of steel materials when creosote is pumped under pressure. In the field, the PVC will become "gummy", (i.e., altered physical integrity) and will definitely fail under pressure [*Sale, 1993*]. However, PVC has been used with creosote fairly reliably as a product thickness well, or gravity drainline, where it is not under pressure. Polyethylene was used successfully as creosote drainline material (i.e., DNAPL recovery). These drainlines have been jet-routed to remove solids which have accumulated in the pipe and continue to operate successfully.

Most of the components used in pumps are made of steel. However, there are some butyl rubber or plastic washers and seals which will fail in the presence of creosote [*Sale, 1993*]. Therefore, it is recommended to examine the various pumping parts that come in contact with creosote and ascertain that they are not butyl rubber or plastic. Specifications for pump parts can be provided by pump manufacturers. Typically, incompatible washers, seals, and bushings may be replaced with more chemically resistant Kel-F® or Viton-A®.

Coal Tars: There are several distinct types of coal tars from manufactured gas plant processes, hereinafter all types are inclusive to the term coal tar. There are similarities between coal tar and creosote; they are both a by-product from the production of coke from coal and when coal tar is distilled, the 200° to 400° C fractions are creosote [*McGinnis et al., 1988*]. Many of the same PAHs in creosote are also found in coal tar [*Ripp et al., 1993*]. Taylor [*1993*] and Unites [*1993*] report that PVC material used in heavily contaminated coal tar sediments under non-pressurized conditions appears to function properly. However, PVC wells placed in coal tar sediments did appear swollen after prolonged exposure and the screened interval may have been compromised [*Villaume, 1993*]. Others have observed that screened intervals become clogged with coal tar, presumably due to the viscous nature of coal tar [*Murarka, 1993*]. Based on the chemical similarities between creosote and coal tar, it is reasonable to assume that PVC is suitable for product thickness wells, or gravity drainlines, under non-pressurized conditions, but it may fail under pressurized conditions.

Mixed NAPL (Solvents) Wastes: Hazardous waste sites usually involve the co-disposal of various chemicals which collectively float or sink as a NAPL. For example, a mixed DNAPL composed primarily of bis, 2-chloro-ethyl ether (38%), DCA (2.5%), styrene, TCE, and an oil carrier was found at a Superfund site in Texas. At this site, a dedicated PVC bailer in a PVC cased well underwent partial solvation due to the incompatibility between the dedicated PVC material and the NAPL. The remaining PVC bailer and well casing were

sufficiently degraded so that both materials became fused together as a single unit. This resulted in a permanent "cementation" of the bailer to the casing requiring abandonment of the well and construction of a new well with compatible materials [*Newell, 1993*]. This field observation is consistent with information in the Chemical Compatibility Table. For example, PVC is reported as unacceptable material to use with ethers (general), dichloroethane, styrene, and trichloroethylene.

At the same site, a paddle-wheel flowmeter was used to evaluate flow of a water-DNAPL mixture. The flowmeter had a rubber seal component that lasted approximately 48 hours before failure. A Viton® covered rubber (inflatable) packer and a pump with Viton® seals were unaffected after 30 days by the same DNAPL. The Chemical Compatibility Table does not include butyl rubber. However, butyl rubber is known to be vulnerable to degradation in the presence of some organic solvents. In this particular case, there is a conflict in the literature regarding the compatibility of Viton® with ethers (general) and trichloroethylene. Therefore, the potential for failure exists in this situation.

Material incompatibility with chemical wastes generally requires the use of a more resistant, and usually more costly material. One approach to minimize cost is to use PVC casing that is not in contact with the incompatible chemical, with a resistant (stainless steel) screen which is in more immediate contact with the chemical. This must be evaluated and designed on a site specific basis [*Newell, 1993*]. Additionally, the use of PVC material on the periphery of the source area where NAPL is not present may also minimize construction costs.

While very little information regarding fiberglass reinforced epoxy (FRE) exists and is not included in the Chemical Compatibility Table, field information from a DNAPL Superfund site in Texas was obtained with respect to FRE compatibility with chlorinated solvents. An interception well field with five extraction wells was installed to collect DNAPL and prevent it from discharging to a stream. The DNAPL primarily consisted of 1,1,2-trichloroethane, vinyl chloride, and 1,2-DCA with a smaller amount of methylene chloride. Previous experience at this site indicated that PVC material was clearly incompatible due to its almost instantaneous deformation upon installation [*Meyer, 1993*]. The potentially responsible party selected FRE casing and screens due to its predicted superior performance. Approximately one month after installation of the FRE wells, the pumps in two wells with DNAPL failed due to clogging with pieces of fiberglass. Subsequently, complete deterioration of the screen and/or the casing occurred as evidenced by the silting up of the pumps. The pumps were cleaned and the wells were retrofitted with smaller diameter stainless steel insert wells which presently are functioning appropriately [*Meyer, 1993*].

Surfactants: There is a significant amount of surfactant research presently being conducted for its potential use in the field. Since there is very little information on the compatibility of surfactants with remediation materials, specific compatibility testing should be conducted. One case study involves the use of an alkaline polymer surfactant (APS) in a pilot treatability study at a creosote waste site in Laramie, Wyoming. The APS completely destroyed PVC material under non-pressure conditions presenting significant

incompatibility problems [*Sale, 1993*]. Ultimately, steel piping was necessary to minimize incompatibility failures.

General DNAPL Consideration: Due to the known heterogeneous nature of stratigraphy at any site, it is likely for DNAPLs to be present at numerous vertical locations. Therefore, compatibility evaluations need to be made for each contaminated zone along the complete length of a well casing. It is possible that subsequent degradation or corrosion of well casing material or annular sealants may create a vertical pathway where DNAPLs can migrate through previously uncontaminated hydrostratigraphic units. Therefore, it is reasonable to assume that a compromised well, through improper construction or deterioration, may facilitate the transport of DNAPLs.

Remediation, Well Construction, and Sampling Material

Well casing and screening, plumbing appurtenances, bailers, sampling tubes, sample bottles, pumps, water-level indicators, interface probes and a variety of water chemistry probes all may be exposed to corrosive and degrading compounds in heavily contaminated subsurface environments. The information available from equipment manufacturers for each of these products currently on the market either does not exist or is too voluminous to assimilate into a single compatibility table. These products do have a common ground, namely the materials from which they are constructed. Therefore, the materials provide the basis for the Chemical Compatibility Table. Many manufacturers use similar chemical resistance data for their materials to specify acceptable applications for their products.

Quite often, equipment manufacturers recommend that compatibility experiments be constructed by the user prior to use. This practice has the added benefit of providing specific information regarding the specific composition and concentration of the chemicals involved. One problem with this approach is the uncertainty associated with the duration of the experiment. For example, compatibility testing is typically conducted for a short duration. Since the selection of proper materials is partially dependent on long-term performance, data from the short-term tests do not necessarily represent long-term performance.

Manufacturers of polymer resins, metals, and metal alloys provide chemical resistance test data for a variety of chemicals. These data have been incorporated into the Chemical Compatibility Table. Since there is no comprehensive compatibility guide available for subsurface contaminants with specific ground-water sampling and well construction products, it is necessary to determine what materials (e.g., wetted parts) will be exposed to which contaminant.

The following materials (and their acronyms) were included in the compilation of the Chemical Compatibility Table: acrylonitrile butadiene styrene (ABS), acetal / Delrin®, chlorinated polyvinyl chloride (CPVC), fluorinated ethylene propylene(FEP), nylon 6 and 66, high density polypropylene (HDPE), polytetrafluoroethylene / Teflon® (PTFE), polyvinyl chloride (PVC), polyvinylidene fluoride / Kynar® (PVDF), ethylenepropylenediene (EPDM), perfluoroelastomer(Kel-F®), neoprene, Nitrile Buna-N, polyurethane, silicone, Tygon®,

Viton-A®, ceramic, silica, 304 and 316 stainless steel, carbon steel, aluminum, brass, copper, and nickel-alloy steel (Hastelloy-C®). Rigid PVC is listed in two columns, medium-impact Type I, and high-impact Type II [*Harper, 1975*].

In the table, well construction and sampling materials listed are referenced by these materials and not the many available configurations (e.g., schedule 40 vs. schedule 80 PVC pipe). Bailers, well casing, and drain materials generally are constructed from PVC Types I and II, CPVC, nylon, HDPE, PTFE, FEP, 304 and 316 stainless steel, carbon steel, Hastelloy-C®, or aluminum. Fittings and tubing are made of brass, copper, stainless steel, aluminum, nylon, Tygon®, PTFE, or silicone. Pump diaphragms, gaskets, and o-rings are made of PTFE, EPDM, Kel-F®, Neoprene, Nitrile Buna-N, polyurethane, silicone, or Viton-A®. Other wetted pump parts are made of various metals and plastics. Silica was included to represent sand packing material. Ceramics represent lysimeter material. There was very little compatibility information published on fiberglass reinforced epoxy (FRE); therefore, FRE was not included in the Chemical Compatibility Table.

Compilation of Contaminants

The Chemical Compatibility Table contains 207 organic compounds which are primarily NAPLs or contaminants associated with EPA's list of 129 priority pollutants [*Viessman and Hammer, 1985*]. Metals from the EPA's priority pollutant list were not included in the Chemical Compatibility Table. The compatibility table does not differentiate between isomers of a single compound (e.g., 2-nitrophenol and 4-nitrophenol) or variations of trade name chemicals (e.g., the 7 different Aroclors). In addition to the EPA's priority pollutant list, the table includes several common mixtures (e.g., gasoline, white liquor) and other organic compounds that may be problematic if present in pure phase. Although the data presented were compiled primarily for NAPLs, there are numerous exceptions. For example, there are several entries for compounds which are miscible with water (e.g., acetone, ethyl alcohol, methyl alcohol). Some entries are reported as percent (%) mixtures of organic compounds which represent the aqueous phase concentration in water (i.e., Aldrin, Chlorodane, DDT). Additionally, there are several inorganic chemicals (e.g., carbonic acid, H_2O_2).

There are 47 environmentally important chemicals listed at the end of the Chemical Compatibility Table for which no data were found. Thirteen (13) of these compounds are polycyclic aromatic hydrocarbons (PAHs) which are commonly found in creosote and coal tar type wastes [*McGinnis et al., 1988; Ripp et al., 1993*]. Creosote and coal tar are mixtures of hundreds of compounds which these PAHs represent only a fraction. At room temperature (and below), these compounds are solids in pure form. As such, no compatibility data for these compounds were available.

References and data tables listing the resistance properties of common well construction and sampling equipment materials to hundreds of additional chemicals (i.e., calcium hydroxide, nickel nitrate, butylbromide, etc.) can be found among the published literature *[Cole-Parmer Instrument Co. Catalog, 1995-1996; Schweitzer, 1991; Craig, 1989; De Renzo, 1985; Harper, 1975; Rabald, 1968]*. These additional chemicals, however, have not been included in the Chemical

Compatibility Table because of their limited occurrence as environmental contaminants.

Several references were used to compile the Chemical Compatibility Table. The two major references were the 1995-1996 Cole-Parmer Instrument Co. Catalog, Chemical Resistance Charts, and the Corrosion Resistance Tables presented in Schweitzer, 1991. Other references were used for cross-checking data and for less common chemicals *[Craig, 1989; De Renzo, 1985; Harper, 1975; Rabald, 1968]*.

Chemical Compatibility Table

The Chemical Compatibility Table has been compiled to assist remediation design personnel with selecting the most appropriate remediation, well construction, and sampling materials for specific waste conditions. This table should only be used as a guide since it is extremely difficult to universally represent actual conditions in the testing procedure. It may be necessary to perform additional, site-specific testing under actual operating conditions to obtain compatibility information regarding the suitability of a particular material. This is especially true considering the number of possible combinations of chemical and physical conditions which occur at any given hazardous waste site.

At a minimum, the references used in compiling the Chemical Compatibility Table generally reported findings from 48-hour immersion tests with 100% or neat solutions, unless otherwise noted.

Remediation, well construction, and sampling materials have been divided into four categories: plastics, elastopolymers, earth-materials, and metals. The compatibility classification for the corrosion of metals is:

Excellent (E)   = less than 2 mils per year
Satisfactory (S)   = less than 20 mils per year
Good (G)   = less than 50 mils per year
Unsatisfactory (U) = greater than 50 mils per year

(note: 1 mil equals one one-thousandth of an inch)

The corrosion rate data may be used with material thickness data to estimate the lifetime of the materials. There are several other variables and parameters which will influence actual corrosion rates and, therefore, this approach should only be considered a rough estimate.

Two classification schemes were used to represent degradation data for the plastics, elastopolymers, and earth-materials categories:

applicable to at least 22°C	*applicable to at least 15°C*
A = Excellent - No Effect	
B = Good - Minor Effect	R = Resistant
C = Fair - Moderate Effect	
U = Poor - Severe Effect	U = Unsatisfactory

The A, B, and C classifications are roughly equivalent to the R "resistant" classification. In order to provide a reliable compatibility table, data for each chemical were cross-

checked between references whenever possible. The notation " X = Conflicting Data" refers to the situation when a chemical and a corresponding material had two or more references that did not agree on the compatibility classification, and at least one of the references reported the compatibility as unsatisfactory. For example, a conflict was noted when the compatibility of a chemical with a given material was reported as "U" and "A"," B" or "C"; or if the compatibility was reported as "U" and "R". The notation " - " refers to no data available when none of the references had compatibility data for a chemical and material.

Example

Remediation, well construction, and sampling materials comprise the columns of the Chemical Compatibility Table, while the chemicals are listed alphabetically by row. The compatibility classification may be read from the chemical (row) and material (column) intersection. For example, if trichloroethylene (TCE) was the chemical of concern and compatible well construction and sampling materials needed to be identified, then TCE could be located by row and compatible materials could be determined.

Materials in the metals group are compatible with pure-phase TCE, but many plastics and elastopolymers are not. If a recovery well was being designed, then 304 or 316 stainless steel would be a compatible choice. PVC, however, is incompatible with pure-phase TCE and is not suggested for a recovery system.

In designing a sampling system, compatibility of materials for pumps and sampling lines can be evaluated. Specifically, all components of the system should be evaluated, including well casing and screen, sampling lines, bailers, pumps and their component parts, above ground piping, etc. For example, wetted parts of a pump such as seals and bushings constructed of Kel-F® and Teflon® are compatible with TCE, but products containing neoprene and silicone are not recommended. It should be noted that no compatibility data were reported for TCE and Tygon® and that conflicting data were reported for TCE and Viton-A®.

In general, most metal and plastic materials may be adequate for use in low dissolved concentrations of NAPLs, from a structural integrity point of view. However, some elastopolymers may not provide adequate service because these materials seem to be the most susceptible to degradation. The Chemical Compatibility Table provides a comprehensive list of published information for pure-phase compounds. Data on various concentrations of compounds in water are not included in the table.

Summary

NAPLs are common contaminants at hazardous waste sites and are present in the subsurface in continuous and residual phases. Their soluble constituents dissolve into the surrounding ground water. High aqueous concentrations of organic compounds and NAPLs can be detrimental to long-term subsurface monitoring and recovery systems by degrading well construction, sampling, and remediation materials.

This issue paper provides a guide on the compatibility of NAPLs and other environmentally important contaminants with materials used in well construction, subsurface sampling, and other various remediation activities. A Chemical Compatibility Table is presented which identifies the compatibility of 207 contaminants with materials such as metals (stainless steel, nickel steel, aluminum, etc.), plastics (PVC, PTFE, polypropylene, etc.), earth materials (ceramic, silica) and elastopolymers (Tygon®, silicone, Viton-A®, etc.). This information can assist scientists and engineers with the decision-making process when designing monitoring and recovery systems for heavily contaminated subsurface environments.

The Chemical Compatibility Table was compiled from numerous sources which employed various testing protocols. The conditions and duration under which the information was generated are not universal. As such, the compatibility information should only be used as a guideline. Site-specific compatibility tests would provide more reliable information.

The field experiences reported in this issue paper serve to illustrate the compatibility problems of a few of the common wastes and materials found at hazardous waste sites. These experiences also emphasize the need to report material failures to minimize similar occurrences in future remediation work.

References

Abdul A. S., T. L. Gibson and D. N. Rai, 1990, Laboratory studies of the flow of some organic solvents and their aqueous solutions through Bentonite and Kaolin Clays, Ground Water, Vol. 28, No.4, pp. 524-533.

Agarwal S. H., and R. S. Porter, 1988, J. Appl. Polym. Sci., Vol. 25, pp. 173.

Aller, L., T. W. Bennett, G. Hackett, R. J. Petty, J. H. Lehr, H. Sedoris, D. M. Nielsen, and J. E. Denne, 1989, Handbook of Practices for the Design and Installation of Ground-Water Monitoring Wells. EPA/600/4-89/034.

Al-Malaika, S., 1987, History of polymeric composites, R. B. Seymour and R. D. Deanin, Eds., VNU Science Press, Chapter 13.

Barcelona, M. J., J. A. Helfrich, and E. E. Garske, 1988, Verification of sampling methods and selection of materials for ground water contamination studies, Ground-Water Contamination: Field Methods, ASTM STP 963, A. G. Collins and A. I. Johnson, Eds., American Society for Testing and Materials, Philadelphia, PA, pp. 221-231.

Bradley, S. A., P. Engler, and S. H. Carr, 1973, Microbial degradation of polymer solids, Appl. Polym. Sym., Vol. 22, pp. 269.

Cassil, J.K., and T. S. Barton, 1994, Effect of dense nonaqueous phase liquids on neat cement and bentonite-cement grout intregrity, Syntex Agribusiness, Inc., Environmental Projects Department, Springfield, MO, DRAFT Report.

Cohen, R.M. and J.W. Mercer, 1993, <u>DNAPL Site Evaluation</u>, EPA/600/R-93/022.

<u>Cole-Parmer Instrument Company Catalog 1995-1996</u>, Chemical resistance charts, pp.1463-1471.

Craig, B. D., 1989, <u>Handbook of Corrosion Data</u>, ASM International, Metals Park, OH.

De Renzo, D. J., 1985, <u>Corrosion Resistant Materials Handbook</u>, 4th Ed., Noyes Data Corp.

Dole M., 1983, The effects of hostile environments on coating and plastics, D. P. Garner and G. A. Stahl, Eds., <u>ACS Symposium Series No. 229</u>, American Chemical Society.

Gillham, R. W., and S. F. O'Hannesin, 1990, Sorption of aromatic hydrocarbons by material used in construction of ground water sampling wells, <u>Ground Water and Vadose Zone Monitoring</u>, ASTM STP 1053, D. M. Nielsen and A. I. Johnson, Eds., American Society for Testing and Materials, Philadelphia, PA, pp. 108-122.

Gillham, R. W., and S. F. O'Hannesin, 1994, Enhanced degradation of halogenated aliphatics by zero-valent iron, <u>Ground Water</u>, Vol. 32, No. 6, pp. 958-967.

Harper, C. A., 1975, <u>Handbook of Plastics and Elastomers</u>, McGraw-Hill, Inc., New York, NY, Chapter 4, pp. 32-33.

Hewitt, A. D., 1989, Leaching of metal pollutants from four well casings used for ground-water monitoring. <u>Special Report 89-32, USA Cold Regions Research and Engineering Laboratory</u>, Hanover, NH.

Hewitt, A. D., 1992, Potential of common well casing materials to influence aqueous metal concentrations, <u>Ground Water Monitoring Review</u>, Vol. 12, No. 2, pp. 131-135.

Hewitt, A. D., 1993, Dynamic study of common well screen materials, <u>Ground Water Monitoring Review</u>, Vol. 13, No. 1, pp. 87-94.

Hubbard, T., S. Wilhelm, and R. Breeden, 1993, <u>Superfund DNAPL Site Assessment Study, National Results</u>, Draft Final Report.

Huling, S. G., and J. W. Weaver, 1991, <u>Dense Nonaqueous Phase Liquids,</u> EPA/540/4-91/002.

Jones, J. N., and G. D. Miller, 1988, Adsorption of selected organic contaminants onto possible well casing materials, <u>Ground-Water Contamination: Field Methods</u>, ASTM STP 963, A. G. Collins and A. I. Johnson, Eds., American Society for Testing and Materials, Philadelphia, PA, pp. 185-198.

Llopis, J. L., EPA, 1992, <u>Survey of Laboratory Studies Relating to the Sorption/Desorption of Contaminants on Selected Well Casing Material,</u> EPA/540/4-91/005, Revised August 1992.

McGinnis G. D., H. Borazjani, L. MacFarland, D. Pope, and D. Strobel, 1988, <u>Characterization and Laboratory Soil Treatability Studies for Creosote and Pentachlorophenol Sludges and Contaminated Soil</u>, EPA/600/2-88/055.

Meyer, J., Personal Communication, EPA Region 6 Remedial Project Manager, Dallas, TX, September, 1993.

Mercer, J. W. and R. M. Cohen, 1990. A Review of Immiscible Fluids in the Subsurface: Properties, Models, Characterization, and Remediation, <u>J. of Contam. Hydrol</u>., Vol. 6, pp. 107-163.

Moehrl, K. E., 1961, Corrosion attack in water wells, <u>Corrosion</u>, Vol. 17, No. 2, pp. 26-27.

Morrison, R. D., 1986, The new monitoring well, <u>Ground Water Age</u>, April, pp. 19-21.

Murarka, I. P., Personal Communication, Electric Power Research Institute, Palo Alto, CA, September 1993.

Newell, C., Personal communication, Ground Water Services, Houston, TX, August 1993.

Newell, C., S. D. Acree, R. R. Ross, and S. G. Huling, 1995, <u>Light Nonaqueous Phase Liquids,</u> EPA/540/S-95/500.

Parker, L. V., A. D. Hewitt, and T. F. Jenkins, 1990, Influence of casing materials on trace-level chemicals in well water, <u>Ground Water Monitoring Review</u>, Vol. 10, No. 2, pp. 146-156.

Parker, L. V., and T. A. Ranney, 1994, Softening of rigid polyvinyl chloride by high concentrations of aqueous solutions of methylene chloride, <u>Special Report 94-27, USA Cold Regions Research and Engineering Laboratory</u>, Hanover, NH.

Rabald, E., 1968, <u>Corrosion Guide</u>, 2nd Ed., Elsevier Science, Inc., Publishing Co., New York, NY, 900 pp.

Reynolds, C. W., J. T. Hoff, R. W. Gillham, 1990, Sampling bias caused by materials used to monitor halocarbons in ground water, <u>Environmental Science and Technology</u>, Vol. 24, No. 1, pp. 135-142.

Ripp, J., B. Taylor, D. Mauro, and M. Young, 1993, <u>Chemical and physical characteristics of tar samples from selected manufactured gas plant (MGP) sites</u>, prepared for Electric Power Research Institute, Palo Alto, CA, TR-102184, Research Project 2879-12.

Sai J. O., D. C. Anderson, 1992, Barrier Wall Materials for Containment of Dense Nonaqueous Phase Liquid (DNAPL), <u>Hazardous Waste & Hazardous Materials</u>, Vol. 9, No. 4, pp. 317-330.

Sale, T., Personal Communication, CH$_2$M Hill, Denver, CO, August 1993.

Schmidt, G.W., 1987, The use of PVC casing and screen in the presence of gasolines on the ground water table, <u>Ground Water Monitoring Review</u>, Vol. 7, No. 2, pp. 94.

Schweitzer, Philip A., 1991, <u>Corrosion Resistance Tables</u>, 3rd Ed., Parts A and B, Mercel Dekker, Inc., New York, NY.

Seymour, R. B., 1989, Influence of long-term environmental factors on properties, <u>Engineered Materials Handbook</u>, Vol.

2, Engineering Plastics, ASM International, Metals Park, OH, pp. 423-432.

Sykes, A. L., R. A. McAllister, and J. B. Homolya, 1986, Sorption of organics by monitoring well construction materials, Ground Water Monitoring Review, Vol. 6, No. 4, pp. 44-47.

Taylor B., Personal Communication, META Environmental, Inc., Watertown, MA, September 1993.

Taylor, S., and L. Parker, 1990, Surface changes in well casing pipe exposed to high concentrations of organics in aqueous solution, Special Report 90-7, USA Cold Regions Research and Engineering Laboratory, Hanover, NH.

Unites, D., Personal Communication, Atlantic Environmental Services, Inc., Colchester, CT, September 1993.

U.S.EPA 1986, RCRA Ground Water Monitoring Technical Enforcement Guidance Document, Washington D.C. OSWER-9950.1 pp. 78-79.

U.S. Dept. of Interior, 1981, A guide for the investigation, development, and management of ground-water resources, Ground Water Manual, 371 pp.

Viessman, W. Jr., and M. J. Hammer, 1985, Water Supply and Pollution Control, 4th ed., Harper & Row, New York, NY, pp. 232-234.

Villaume, J., Personal Communication, Pennsylvania Power and Light Company, Allentown, PA, September 1993.

CHEMICAL COMPATIBILITY TABLE

For All Non-Metals

R = Resistant
A = Excellent - No effect
B = Good - Minor effect
C = Fair - Moderate effect
U = Unsatisfactory
X = Conflicting Data
- = No Data Available

For Metals

E < 2 mils Penetration/Year
G < 20 mils Penetration/Year
S < 50 mils Penetration/Year
U > 50 mils Penetration/Year
(1 mil = .001 inch)
A = Excellent - No effect*
B = Good - Minor effect*
C = Fair - Moderate effect*
* No corrision rate reported

	Plastics											Elastopolymers										Metals						
	ABS	Acetal (Delrin)	CPVC	FEP	Nylon 6, 66	HDPE	Polypropylene	PTFE (Teflon)	PVC Type I	PVC Type II	PVDF (Kynar)	EPDM	Kel-F	Neoprene	Nitrile Buna-N	Polyurethane	Silicone	Tygon	Viton-A	Ceramic	Silica	304 Stainless	316 Stainless	Carbon Steel	Hastelloy-C	Aluminum	Brass	Copper
Acetaldehyde	U	A	U	R	U	U	A	A	U	U	X	A	A	C	U	U	A	U	U	-	R	E	E	G	E	G	U	U
Acetamide	-	A	-	R	R	R	A	A	U	-	C	A	A	B	A	U	B	U	B	-	-	G	G	-	-	G	-	-
Acetate Solvent	U	-	U	R	R	R	B	A	U	U	A	A	A	C	U	-	A	U	U	-	-	E	E	G	E	E	S	G
Acetic Acid 10%	X	X	C	R	U	R	B	A	U	-	C	A	A	C	C	-	C	U	R	A	R	E	E	U	E	G	U	G
Acetic Acid, Glacial	U	U	U	R	U	R	A	A	U	U	B	U	A	X	X	U	B	U	U	A	R	E	E	U	E	E	U	U
Acetone	U	A	U	R	R	R	A	A	U	U	U	A	A	U	U	U	B	U	U	A	R	E	E	G	E	E	G	E
Acetonitrile	U	-	-	R	R	-	R	R	-	-	R	R	-	-	-	-	-	-	-	-	-	G	G	G	-	E	G	G
Acetophenone	U	-	-	R	R	U	R	R	U	U	R	R	-	U	U	-	-	-	U	-	-	G	G	G	G	G	G	G
Acetyl Chloride	U	-	U	R	U	U	U	A	U	U	R	U	-	U	U	U	-	-	R	-	R	G	G	G	-	U	U	U
Acetylene	R	-	R	R	R	-	R	R	R	R	R	R	-	R	R	-	-	-	R	-	-	E	E	G	E	U	U	U
Acrylonitrile	U	-	X	R	R	R	A	A	X	U	A	X	-	C	U	-	U	-	U	-	-	G	G	G	E	G	G	G
Adipic Acid	R	-	A	R	-	R	B	A	R	R	A	A	A	B	X	-	U	-	X	-	-	G	G	G	E	G	-	G
Aldrin (1 oz/gal)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	E	E	G	-	E	-	U
Allyl Alcohol	U	-	R	R	R	R	R	R	R	R	R	R	-	R	R	-	-	-	R	-	-	E	E	G	G	G	G	E
Allyl Chloride	U	-	U	R	-	R	R	R	U	U	R	U	-	U	U	-	-	-	-	-	R	G	E	U	-	U	-	-
Ammonium Acetate	-	-	A	R	A	-	A	A	R	R	R	A	-	A	B	-	-	A	A	-	-	G	G	-	-	G	U	U
Ammonium Oxalate 10%	-	-	-	R	-	-	R	R	R	-	-	R	-	-	-	-	-	-	-	-	-	G	G	U	E	E	-	U
Amyl Acetate	U	B	U	R	R	R	X	A	U	U	A	A	A	U	U	U	U	U	U	A	R	E	E	G	E	E	E	G
Amyl Alcohol	R	A	A	R	A	R	B	A	R	U	A	A	A	A	B	U	U	A	B	A	R	G	G	G	G	G	G	G
Amyl Chloride	U	-	U	R	U	U	U	R	U	U	U	R	-	U	U	-	-	-	R	-	-	G	G	U	E	U	G	G
Aniline	U	A	X	R	X	R	X	A	U	U	A	X	A	U	U	U	U	C	B	A	R	E	E	G	G	G	U	U
Aniline Hydrochloride	U	-	U	R	U	U	X	A	X	U	A	B	-	U	U	-	U	U	A	-	R	U	U	U	U	U	U	G
Antifreeze	B	U	A	-	U	-	U	-	A	-	-	A	-	C	A	-	C	B	A	-	-	-	A	-	-	A	-	-
Aroclor 1248	-	-	-	R	A	U	U	A	-	-	-	B	A	U	X	-	B	-	A	-	-	G	G	G	E	E	E	E
Asphalt	-	B	X	R	A	R	B	A	A	-	A	U	A	U	X	-	U	-	A	-	-	G	G	G	-	E	E	E
Benzaldehyde	X	A	U	R	A	U	X	A	U	U	A	A	A	U	U	U	U	U	U	A	R	G	G	U	G	G	G	G
Benzene	U	A	U	R	A	U	X	A	U	U	A	U	B	U	U	U	U	C	A	A	R	G	G	G	G	E	G	G
Benzo Sulfonic Acid 10%	R	-	R	R	U	R	R	R	R	R	R	U	-	R	U	U	-	-	R	-	R	G	G	U	G	U	G	-
Benzyl Alcohol	U	A	X	R	B	U	A	A	U	U	A	B	A	X	X	U	-	U	A	A	R	E	E	G	G	G	G	E
Benzoic Acid	R	B	A	R	X	B	R	A	R	R	A	U	A	B	U	U	B	A	A	A	R	G	G	U	E	G	G	G
Benzol	U	A	U	R	X	U	U	A	U	U	A	U	A	U	U	U	U	C	A	A	R	G	G	G	G	E	G	G
Benzonitrile	-	-	-	R	R	A	A	-	A	-	-	-	A	-	-	-	A	-	-	-	-	U	U	-	C	-	-	-
Benzyl Chloride	U	A	U	R	R	-	C	R	R	-	R	U	-	U	U	-	U	-	A	-	-	G	G	U	-	U	U	U
Bromobenzene	-	-	-	R	-	-	U	R	-	-	R	U	-	U	U	-	-	-	R	-	-	-	-	-	-	-	-	-
Butadiene	U	A	A	R	R	U	U	A	R	U	A	X	A	B	X	U	U	-	B	-	-	G	G	G	G	G	G	G
Butane	B	A	C	R	R	U	U	A	R	R	A	U	A	A	A	R	U	C	A	-	-	G	G	E	G	G	G	G
Butyl Alcohol	U	A	A	R	B	B	R	A	R	U	A	A	A	A	X	-	B	B	A	-	R	E	E	G	G	E	G	G
n-Butyl Amine	-	X	U	R	R	U	U	A	U	U	X	-	U	U	R	-	B	U	U	-	-	-	G	G	G	G	-	-
Butyl Ether	-	U	U	R	A	-	-	A	R	-	A	U	A	U	B	-	U	A	U	-	-	E	E	-	E	-	-	-
Butyl Phenol	U	-	U	R	-	-	U	R	U	U	R	-	-	U	-	-	-	-	U	-	-	G	E	-	G	G	-	-
Butyl Phthalate	-	-	U	R	R	-	R	R	R	-	R	B	A	D	U	-	A	-	C	-	-	G	G	-	G	U	G	G

	Plastics											Elastopolymers										Metals						
	ABS	Acetal (Delrin)	CPVC	FEP	Nylon 6, 66	HDPE	Polypropylene	PTFE (Teflon)	PVC Type I	PVC Type II	PVDF (Kynar)	EPDM	Kel-F	Neoprene	Nitrile Buna-N	Polyurethane	Silicone	Tygon	Viton-A	Ceramic	Silica	304 Stainless	316 Stainless	Carbon Steel	Hastelloy-C	Aluminum	Brass	Copper
Butylacetate	U	A	X	R	A	R	X	A	U	U	B	B	A	X	U	-	U	U	U	-	R	G	G	G	G	E	G	G
Butyric Acid	U	A	U	R	U	U	R	R	U	U	A	B	A	U	U	-	U	U	B	-	R	G	G	U	E	G	G	G
Carbon Tetrachloride	U	B	U	R	X	U	U	R	U	U	R	U	A	U	U	U	U	B	A	A	R	E	E	G	E	U	G	E
Carbonic Acid	R	B	A	R	R	R	A	A	R	R	A	B	A	X	X	R	A	-	A	A	-	G	G	G	E	E	G	G
Chloroacetic Acid	U	U	U	R	U	U	C	A	R	R	A	B	A	U	U	U	U	A	U	-	-	U	U	U	E	U	U	U
Chlorobenzene	U	X	U	R	R	U	U	B	U	U	A	U	A	U	U	-	U	A	A	A	R	G	G	G	E	G	G	G
Chlorobromomethane	-	-	-	-	C	-	A	A	U	-	-	B	-	U	U	-	U	-	A	A	-	-	-	-	-	-	B	-
Chlordane (1/4 lb/gal)	U	-	-	-	-	-	-	R	-	-	-	U	-	C	B	-	U	-	A	-	-	G	G	G	-	-	-	-
Chloroethane	U	A	U	R	R	R	X	A	U	U	A	X	A	U	U	-	U	-	B	-	-	G	G	G	-	-	-	G
Chloroform	U	A	U	R	R	U	X	A	U	U	A	U	B	U	U	U	U	B	A	A	R	E	E	U	G	G	G	G
Chloronaphthalene	U	-	-	-	-	-	-	-	R	-	-	-	-	U	U	-	-	-	-	-	-	-	G	-	E	U	-	-
Chlorophenol 5% (aq.)	-	R	U	R	U	-	-	R	U	U	R	-	-	-	-	-	-	-	-	-	-	G	G	S	E	-	-	-
Citric Acid	U	B	B	R	R	A	A	A	R	-	A	A	A	A	A	-	A	-	A	A	R	E	E	U	E	E	-	E
Cresol	U	U	U	R	U	U	U	R	X	U	R	U	A	U	U	U	U	U	X	-	R	E	G	G	G	G	-	-
Cresylic Acid 50%	U	U	U	R	U	R	X	R	R	R	R	X	-	U	U	U	U	-	A	-	-	G	G	G	G	G	-	-
Crude Oil	R	R	R	R	R	U	R	U	U	U	U	U	-	U	R	R	-	-	R	-	-	E	E	G	E	E	G	G
Cyclohexane	R	A	U	R	R	R	U	A	X	-	R	U	A	U	B	R	U	U	A	-	-	G	G	G	G	G	G	G
Cyclohexanone	U	A	U	R	R	U	U	A	U	U	R	B	U	U	U	-	U	U	U	A	-	G	G	U	G	G	G	G
DDT 5%	-	-	U	-	-	-	-	-	U	U	-	-	-	-	-	-	-	-	-	-	-	E	E	G	-	E	-	-
Detergents (general)	B	A	A	R	R	R	A	A	R	R	A	A	A	B	A	-	A	A	A	A	-	E	G	G	E	G	G	E
Diacetone Alcohol	-	A	U	R	R	R	R	A	R	-	A	A	B	U	U	-	U	B	U	-	-	G	G	G	E	E	E	E
Dibutyl Phthalate	U	-	U	R	R	U	R	R	U	U	U	R	-	U	U	U	-	-	U	-	-	G	G	G	G	G	G	G
Dichlorobenzene	U	-	U	R	X	U	C	A	U	U	A	U	-	U	U	-	U	-	C	-	-	-	G	-	E	G	-	-
Dichloroethane	U	A	U	R	R	R	X	A	U	U	A	U	A	U	U	-	-	U	C	A	R	G	G	G	G	G	G	-
Dichloroethylene	U	-	-	R	R	-	R	R	U	U	R	U	-	U	U	-	-	-	R	-	-	G	G	-	G	G	-	-
Dichlorofluoromethane	-	-	-	R	-	-	-	R	U	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diesel Fuel	-	A	A	R	R	R	A	A	R	-	A	U	A	B	A	-	U	-	A	-	-	E	E	G	G	E	E	-
Diethanolamine	-	-	-	R	R	-	R	R	U	U	U	-	-	R	-	-	-	-	-	-	-	E	E	E	E	E	-	G
Diethyl Amine	U	B	U	R	R	U	A	X	U	-	X	B	A	A	C	-	B	C	A	-	-	G	G	U	-	G	-	-
Diethyl Ether	U	R	U	R	R	U	R	A	U	U	R	U	C	U	U	-	U	-	U	-	-	G	G	G	G	G	G	G
Diethyl Phthalate	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diethylene Glycol	B	A	A	R	R	R	A	A	X	-	A	A	-	A	A	-	B	C	A	-	-	E	E	E	G	G	-	G
Dimethyl Aniline	U	U	U	R	R	-	X	A	U	U	A	B	A	U	U	-	U	U	U	-	-	B	B	-	B	A	-	-
Dimethyl Ether	-	-	-	R	-	-	-	R	-	-	-	-	-	U	R	-	-	-	-	-	-	G	G	-	G	-	G	G
Dimethyl Formamide	U	X	U	R	R	R	A	X	U	U	U	X	A	X	U	-	C	U	X	-	-	-	G	U	-	E	-	-
Dimethyl Phthalate	U	-	-	R	R	-	R	R	U	U	R	-	-	U	U	-	-	-	R	-	-	E	E	E	-	E	-	-
Dimethyl Sulfoxide	-	R	U	R	R	R	R	R	U	-	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dinitrotoluene	-	-	-	-	-	-	-	R	-	-	-	U	-	U	U	-	U	-	X	-	-	G	G	-	-	-	-	-
Dioctyl Phthalate	U	-	U	R	R	U	U	R	U	U	R	R	-	U	U	U	-	-	R	-	-	G	G	G	-	E	-	-
Dioxane	U	R	-	R	R	U	R	R	U	-	U	U	-	U	U	-	-	-	U	-	-	G	G	G	G	G	G	G
Diphenyl	-	-	-	R	R	-	U	A	U	-	-	U	-	B	U	R	U	-	A	-	-	G	G	G	G	G	G	G
Diphenyl Oxide	-	U	-	-	-	-	U	A	U	-	B	U	-	U	A	-	C	U	A	-	-	B	A	-	B	B	-	A
Esters (general)	-	-	U	R	R	-	-	R	U	U	R	-	-	-	-	-	-	-	-	-	-	-	G	-	-	-	-	-
Ethane	-	A	A	-	U	-	U	A	A	-	A	U	-	B	A	-	U	A	A	-	-	A	A	-	-	-	-	A
Ethanolamine	-	U	U	R	R	-	X	A	U	-	X	B	U	B	B	-	B	-	U	A	-	E	E	G	G	G	-	-
Ethers (general)	U	A	U	-	R	U	U	A	U	U	R	C	B	U	X	-	U	C	X	-	R	E	E	G	G	G	G	G
Ethyl Acetate	U	A	U	R	R	R	A	A	U	U	X	B	A	U	U	U	B	U	U	A	R	G	G	G	-	G	G	G
Ethyl Alcohol	B	A	B	R	R	R	A	A	R	R	R	A	B	A	C	U	B	C	A	A	R	G	G	E	E	G	G	G
Ethyl Benzene	-	R	-	R	-	U	U	R	U	U	R	U	-	U	U	-	-	-	R	-	-	S	G	U	E	G	-	-
Ethyl Benzoate	U	-	U	-	-	U	B	A	U	-	U	-	-	U	U	-	U	U	A	-	-	-	-	-	-	-	-	-
Ethyl Chloride	U	R	U	R	R	U	U	R	U	U	R	R	-	U	R	U	-	-	B	-	R	E	E	G	G	-	-	G
Ethyl Ether	U	A	U	R	R	U	U	A	U	U	R	U	A	U	X	U	U	-	U	-	R	G	G	G	G	G	G	G

	Plastics											Elastopolymers								Ceramic		Metals						
	ABS	Acetal (Delrin)	CPVC	FEP	Nylon 6, 66	HDPE	Polypropylene	PTFE (Teflon)	PVC Type I	PVC Type II	PVDF (Kynar)	EPDM	Kel-F	Neoprene	Nitrile Buna-N	Polyurethane	Silicone	Tygon	Viton-A	Ceramic	Silica	304 Stainless	316 Stainless	Carbon Steel	Hastelloy-C	Aluminum	Brass	Copper
Ethyl Sulfate	-	-	-	-	-	-	-	A	-	-	-	-	A	-	A	-	-	-	A	-	-	U	U	-	-	-	-	B
Ethylene Bromide	U	-	U	R	R	U	U	A	U	U	A	X	B	X	U	-	U	U	A	-	-	E	E	-	E	-	-	-
Ethylene Chloride	U	A	U	R	R	R	X	A	U	U	A	X	A	U	U	-	U	-	B	-	-	G	G	G	-	-	-	G
Ethylene Chlorohydrin	U	U	U	R	U	U	X	A	U	U	A	B	-	X	U	U	C	U	A	-	-	G	G	G	G	G	G	G
Ethylene Diamine	U	X	U	R	U	-	R	A	U	U	B	A	U	X	A	-	A	-	B	-	-	G	G	G	U	G	U	U
Ethylene Dibromide	-	-	-	R	-	-	R	R	-	-	R	-	-	-	-	-	-	-	-	-	-	-	G	-	G	-	G	-
Ethylene Glycol	A	B	A	R	R	R	A	A	R	R	A	A	A	A	A	R	A	B	R	A	-	G	G	G	E	E	G	G
Ethylene Oxide	U	U	X	R	R	R	U	A	U	U	A	X	C	U	U	U	U	-	U	-	R	G	G	G	E	E	U	-
Formaldehyde 100%	B	A	A	-	U	-	C	A	A	-	A	A	A	C	C	-	B	B	U	-	-	C	A	-	A	A	-	A
Formaldehyde 37%	A	A	A	R	R	R	A	A	R	R	A	A	A	B	X	U	-	-	R	-	R	E	E	U	G	G	E	G
Formic Acid 5%	-	U	R	R	U	R	R	R	R	-	R	R	-	R	U	-	-	-	R	-	-	G	E	-	E	U	S	E
Fuel oils	U	A	-	R	R	R	A	B	R	R	B	U	A	B	X	R	U	A	A	-	-	G	G	G	G	G	G	G
Gasoline (high-aromatic)	U	B	A	-	-	-	A	B	A	-	A	U	A	A	A	-	U	A	A	A	-	A	A	-	A	U	-	-
Gasoline (leaded)	U	A	U	R	R	U	X	A	R	-	A	U	A	B	A	R	U	C	A	A	-	G	G	G	E	G	G	G
Gasoline (unleaded)	U	A	X	R	R	U	X	A	R	-	A	U	A	B	A	R	U	C	A	-	-	G	G	G	E	G	G	G
Glycolic Acid	B	A	A	R	-	R	A	A	R	R	B	A	B	A	A	-	A	A	A	-	-	G	G	U	G	G	-	-
Heptane	X	A	A	R	R	R	C	A	R	R	A	U	A	B	A	U	U	B	A	-	-	G	G	G	E	G	G	G
Hexachloroethane	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	G	G	-	G	G	S	G
Hexamine	-	-	-	R	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	E	E	-	E	E	G	-
Hexane	U	A	B	R	R	U	B	A	R	R	A	U	A	B	A	R	U	U	A	-	-	E	E	G	E	G	G	-
Hexyl Alcohol	-	A	-	-	A	-	-	A	A	-	-	C	-	A	A	-	B	A	C	-	-	A	A	-	A	A	-	-
Hydraulic Oil (petro.)	-	B	-	-	A	-	U	A	A	-	A	U	-	A	A	-	B	A	A	-	-	A	A	-	A	A	A	A
Hydraulic Oil (synthetic)	-	-	-	-	A	-	U	A	A	-	A	A	-	A	U	-	B	A	A	-	-	A	A	-	A	A	A	A
Hydrazine	-	B	U	-	-	U	C	C	-	-	A	A	-	B	B	-	B	-	A	-	-	A	A	-	-	-	-	A
Hydrogen Peroxide (dilute)	R	R	U	R	R	R	R	R	R	-	R	R	-	U	R	-	-	-	R	-	-	G	G	U	E	E	U	U
Hydroquinone	X	A	A	R	U	-	A	A	A	R	R	U	-	A	X	-	-	-	B	-	-	G	G	G	G	G	G	-
Hydroxyacetic Acid 70%	-	A	A	-	-	-	-	A	U	-	A	A	-	A	A	-	-	-	A	-	-	-	-	-	-	-	-	-
Iodoform	-	-	-	R	-	-	R	C	-	-	C	A	-	A	U	-	-	C	R	-	R	E	E	U	U	G	-	G
Isobutyl Alcohol	B	A	-	-	A	-	A	A	A	-	-	A	-	A	B	-	A	A	A	-	-	-	-	-	-	-	-	-
Isooctane	-	-	-	-	A	B	A	A	A	-	A	U	A	B	A	-	U	A	A	-	-	A	A	-	-	A	A	-
Isopropyl Acetate	U	U	U	R	R	R	B	A	U	U	X	B	-	U	U	-	U	-	U	-	-	E	G	E	G	G	-	-
Isopropyl Alcohol	R	A	C	R	U	R	A	A	R	R	R	A	-	B	B	U	A	A	A	A	-	G	G	G	G	G	G	G
Isopropyl Ether	-	U	R	R	R	-	X	A	R	R	X	U	A	U	B	R	U	A	U	-	-	E	G	-	-	-	G	G
Isotane	-	-	-	-	U	-	U	-	A	-	A	-	-	U	A	-	-	-	-	A	-	-	-	-	-	U	-	-
Jet Fuel JP-4, JP-5	-	A	R	R	R	-	A	A	R	R	A	U	A	U	A	U	U	A	A	-	-	G	G	G	E	G	E	-
Kerosene	X	A	R	R	R	R	R	A	R	R	A	U	A	A	U	U	U	U	A	A	-	G	G	G	G	G	G	G
Lacquer thinners	A	U	-	-	A	-	U	A	U	-	-	U	-	U	U	-	U	U	U	-	-	-	G	-	-	G	-	-
Lacquers	A	U	-	-	A	-	U	A	U	-	U	U	-	U	U	-	U	A	U	-	-	E	E	-	-	-	-	-
Lactic Acid	U	B	A	R	R	-	B	A	R	R	B	A	A	A	X	-	A	A	A	A	-	G	G	U	G	G	G	G
Lead Acetate	B	B	A	R	R	R	A	A	R	R	A	A	A	A	B	-	A	B	U	A	-	G	G	U	G	U	U	G
Linoleic Acid	A	B	A	R	U	U	B	A	R	R	A	U	-	U	B	-	B	A	B	-	-	G	G	U	G	G	U	U
Maleic Acid	R	A	A	R	X	R	R	A	R	R	A	X	-	U	U	-	-	C	A	-	R	G	G	U	G	-	G	-
Malic Acid	R	A	R	R	X	R	A	A	R	R	A	U	-	X	A	-	B	A	A	-	-	E	E	U	G	G	-	U
Melamine	-	A	A	-	A	-	A	A	U	-	-	A	-	U	C	-	C	U	A	-	-	-	U	-	-	-	-	-
Methane	-	A	-	R	R	-	A	A	R	R	A	X	-	B	A	-	U	-	A	-	-	E	E	G	E	E	E	G
Methyl Acetate	U	X	U	R	R	R	X	A	U	U	B	X	A	X	U	-	U	A	U	-	-	G	G	S	E	G	-	-
Methyl Acetone	-	U	-	-	A	-	-	A	U	-	U	A	-	U	U	-	A	U	U	-	-	A	A	-	-	A	A	-
Methyl Acylate	-	B	-	-	-	U	-	-	-	-	B	B	-	B	U	-	U	-	U	-	-	A	-	-	-	-	-	-
Methyl Alcohol	U	A	A	R	R	R	A	A	R	R	A	A	A	A	A	U	A	A	U	A	R	G	G	G	E	G	G	G
Methyl Alcohol 10%	U	A	A	-	B	B	A	A	A	-	A	A	A	A	A	-	A	A	A	A	-	-	-	-	-	-	-	-
Methyl Amide	U	U	-	-	-	-	-	A	A	U	-	C	A	A	-	B	-	-	U	U	-	-	A	A	-	-	A	U*
Methyl Bromide	U	U	U	R	U	R	X	A	U	U	A	U	-	U	B	-	-	-	A	-	-	G	G	G	-	U	-	-
Methyl Butyl Ketone	-	U	-	-	U	U	U	-	-	-	U	A	-	U	U	-	U	-	U	-	-	A	A	-	-	-	-	-

	Plastics											Elastopolymers								Ceramic		Metals						
	ABS	Acetal (Delrin)	CPVC	FEP	Nylon 6, 66	HDPE	Polypropylene	PTFE (Teflon)	PVC Type I	PVC Type II	PVDF (Kynar)	EPDM	Kel-F	Neoprene	Nitrile Buna-N	Polyurethane	Silicone	Tygon	Viton-A	Ceramic	Silica	304 Stainless	316 Stainless	Carbon Steel	Hastelloy-C	Aluminum	Brass	Copper
Methyl Chloride	U	B	U	R	R	U	U	A	U	U	A	U	A	U	U	U	U	U	A	-	-	E	E	U	G	U	E	G
Methyl Chloroform	U	-	U	R	-	-	U	R	U	U	R	U	-	U	U	-	-	-	R	-	-	-	-	-	-	-	-	-
Methyl Dichloride	-	U	-	-	C	-	U	-	-	-	U	U	-	-	U	-	-	-	A	-	-	-	-	-	-	-	-	-
Methyl Ethyl Ketone	U	U	U	R	R	U	B	A	U	U	U	A	A	U	U	U	U	U	U	A	-	G	G	G	G	G	G	G
Methyl Isopropyl Ketone	-	-	-	-	A	-	-	A	U	-	-	C	-	U	U	-	C	-	U	-	-	A	A	-	-	A	-	A
Methyl Methacrylate	-	U	R	R	-	-	X	R	R	U	B	U	-	U	U	-	C	-	U	-	-	G	G	U	-	G	-	-
Methyl Pentanone	U	-	U	R	R	R	R	A	U	U	X	B	A	U	U	-	U	-	U	-	-	G	G	G	G	G	G	G
Methylene Chloride	U	B	U	R	U	U	B	A	U	U	B	X	A	U	U	U	-	U	B	-	R	G	G	G	E	E	G	G
Monochloroacetic acid U*	-	U	-	-	U	U	-	A	-	-	B	C	B	A	U	-	-	-	C	-	-	A	A	-	A	U*	B	
Monoethanolamine	-	U	-	R	R	-	B	A	U	U	U	B	-	X	B	-	B	-	X	-	-	E	E	G	G	G	G	G
Motor Oil	C	B	A	R	R	U	U	A	R	R	B	U	A	B	A	-	-	A	R	A	-	G	G	G	-	-	G	G
Napthalene	U	X	U	R	R	U	R	A	U	U	A	U	A	U	U	R	U	C	A	A	-	E	E	G	G	G	G	G
Nitrobenzene	U	X	U	R	R	U	B	A	U	U	A	U	A	U	U	U	U	U	B	-	R	G	G	G	G	E	G	G
Nitromethane	U	A	U	R	U	-	R	A	R	R	A	B	A	U	U	-	U	B	U	-	-	G	G	G	-	G	-	-
Nitrophenol	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	G	G	-	G	-	G
Octane	-	-	-	R	-	R	R	R	U	U	R	U	-	R	R	-	-	-	R	-	-	-	G	G	-	G	G	G
Octyl Alcohol	A	A	B	-	A	-	-	-	-	-	-	B	-	B	B	-	B	-	B	-	-	A	A	-	C	A	-	A
Oleic Acid	X	A	A	R	R	U	B	A	R	R	A	B	B	X	B	R	U	C	B	A	-	E	E	G	G	G	S	G
Oxalic Acid 5%	R	U	R	R	U	R	R	R	R	R	R	R	-	R	U	-	-	-	R	-	-	U	G	U	G	G	S	G
Palmitic Acid 10%	A	A	A	R	R	R	B	A	R	R	A	B	-	U	A	R	U	B	A	-	-	-	G	-	-	G	G	G
Pentachlorophenol	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	R	-	-	-	-	E	-	-	-	-
Pentane	-	B	-	-	A	-	U	A	A	-	A	U	-	B	A	-	U	A	A	-	-	C	C	-	A	B	-	-
Petroleum	B	B	A	R	-	U	B	A	R	-	A	U	-	B	A	-	U	-	A	-	-	G	G	-	-	G	G	G
Phenol 10%	U	X	A	R	U	R	B	A	U	U	A	B	B	U	U	U	U	C	A	A	-	G	G	G	G	E	G	G
Phthalic Acid	B	C	X	R	R	-	A	A	U	U	A	A	-	A	U	-	B	-	A	-	-	G	E	S	G	G	G	G
Phthalic Anhydride	B	C	U	R	-	-	U	A	U	-	A	A	-	A	U	-	-	B	A	-	-	E	E	G	E	E	G	-
Picric Acid	X	A	U	R	U	U	A	A	U	U	A	A	-	A	X	-	B	-	A	-	R	G	G	U	G	E	U	U
Propyl Alcohol	X	A	A	R	U	R	A	A	R	R	A	A	A	A	A	-	A	A	A	A	-	E	E	G	E	G	G	G
Propylene	B	-	-	-	-	-	-	A	B	-	-	U	-	U	U	-	U	B	A	-	-	B	A	-	-	A	-	A
Propylene Glycol	B	B	X	R	R	R	A	A	U	U	A	A	-	C	A	-	A	-	A	A	-	G	G	G	G	G	G	G
Propylene Oxide	-	-	-	R	-	R	R	R	U	U	U	R	-	U	U	-	-	-	U	-	-	E	E	-	-	-	-	-
Pyridine	-	B	U	R	R	R	A	A	U	U	U	X	A	U	U	-	U	U	U	A	-	G	G	G	E	G	G	G
Sodium Acetate	B	B	A	R	R	R	A	A	R	R	A	A	A	B	B	-	U	-	U	A	-	G	G	U	G	E	G	G
Sodium Benzoate	A	-	A	R	R	R	A	A	R	R	A	A	-	A	B	-	-	B	A	-	-	-	-	-	G	G	-	E
Sodium Hypochlorite 20%	R	U	R	R	U	R	R	R	R	R	R	R	A	U	U	-	B	C	A	-	U	U	U	U	U	G	S	S
Stearic Acid	U	A	B	R	R	R	A	A	R	R	A	X	-	B	B	R	B	B	A	-	R	G	E	S	E	G	S	G
Styrene	-	A	U	-	A	U	-	A	U	-	-	U	-	U	U	-	U	-	B	-	-	A	A	-	U*	A	A	B
Tartaric Acid	-	B	A	-	B	-	A	A	A	-	B	B	A	A	A	-	A	B	A	A	-	C	C	-	B	B	U*	A
Tetrachloroacetic Acid	R	-	R	R	R	R	R	R	R	R	R	U	-	R	R	R	-	-	R	-	-	E	E	-	G	G	S	U
Tetrachloroethane	-	A	X	R	R	-	C	A	U	U	A	U	A	U	U	-	U	-	A	-	R	E	E	E	E	G	-	S
Tetrachloroethylene	U	A	U	R	R	U	U	A	U	U	R	U	A	U	U	U	U	-	A	-	-	E	E	G	G	G	G	G
Tetrachlorophenol	-	-	-	-	-	-	R	R	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tetraethyl Lead	U	-	R	R	-	U	R	R	R	R	R	U	-	-	U	-	-	-	R	-	-	G	G	G	-	G	G	-
Tetrahydrofuran	U	A	U	R	R	U	C	A	U	U	B	U	A	U	U	-	U	-	X	A	-	E	G	E	E	U	-	-
Toluene	U	X	U	R	R	U	C	A	U	U	A	U	B	U	X	U	U	U	C	A	-	E	E	E	E	E	E	E
Toxaphene-Xylene 10-90%	-	-	U	R	-	-	R	R	U	-	-	-	-	-	-	-	-	-	-	-	-	G	G	S	-	S	-	-
Trichloroacetic Acid	-	-	R	R	U	R	A	A	R	-	B	B	A	U	R	-	U	C	C	A	-	U	U	U	G	U	G	G
Trichlorobenzene	-	-	-	-	-	-	R	U	-	-	-	-	-	U	U	U	-	-	R	-	-	-	-	E	-	-	-	-
Trichloroethane	-	A	-	-	-	-	C	A	C	-	A	U	A	U	U	-	U	-	A	-	-	-	-	-	-	-	-	-
Trichloroethylene	U	U	U	R	R	U	C	A	U	U	B	U	A	U	U	U	U	-	X	A	-	G	G	G	E	E	G	G
Trichlorofluoromethane	-	-	-	-	-	-	-	U	-	-	-	-	U	U	-	-	-	-	-	-	-	-	G	-	-	G	-	-
Trichloropropane	U	A	-	-	-	-	-	A	-	-	-	-	A	A	U	-	-	U	A	-	-	A	A	-	A	U*	-	A

	Plastics											Elastopolymers										Metals						
	ABS	Acetal (Delrin)	CPVC	FEP	Nylon 6, 66	HDPE	Polypropylene	PTFE (Teflon)	PVC Type I	PVC Type II	PVDF (Kynar)	EPDM	Kel-F	Neoprene	Nitrile Buna-N	Polyurethane	Silicone	Tygon	Viton-A	Ceramic	Silica	304 Stainless	316 Stainless	Carbon Steel	Hastelloy-C	Aluminum	Brass	Copper
Triethanolamine	R	U	R	R	R	U	R	R	U	U	R	R	-	R	U	U	-	-	R	-	-	G	G	G	G	G	U	E
Triethylamine	U	U	A	R	R	-	U	A	R	R	A	A	A	A	C	-	-	A	X	B	-	G	G	-	-	-	-	-
Trimethylpropane	U	-	R	R	-	-	U	R	R	R	R	-	-	-	R	R	-	-	-	-	-	-	-	-	-	-	-	-
Turpentine	U	A	A	R	R	U	X	A	X	U	A	U	A	U	R	U	U	B	A	A	-	E	E	G	G	G	S	G
Vinyl Acetate	U	-	U	R	-	U	B	A	U	U	A	B	-	X	X	-	U	U	A	B	-	E	E	G	E	E	G	-
Vinyl Chloride	U	-	U	-	A	-	-	A	U	-	B	C	-	U	U	-	-	U	A	A	-	B	A	-	A	B	-	B
White liquor (Pulp mill)	X	U	R	R	R	-	R	R	R	R	R	R	-	R	R	-	-	-	R	-	-	G	G	S	G	G	-	-
White Water (Paper mill)	R	B	-	-	R	-	R	-	R	-	-	-	-	A	-	-	-	-	A	-	-	A	A	-	-	-	-	-
Xylene	U	A	U	R	R	U	B	A	U	U	A	U	A	U	U	U	U	U	X	A	-	G	G	G	E	G	G	G

This table should only be used as a guide since it is difficult to duplicate operating conditions. To fully guarantee the suitability of a particular material, chemical resistance tests should be conducted under actual operating conditions.

No data was found on the following environmentally important chemicals:

Acenaphthene [1]
Acenapthalene [1]
Acrolein
Anthracene [1]
Benzidine
Benzo(a)athracene [1]
Benzo(b)fluoranthene [1]
Benzo(g,h,i)perylene [1]
Benzo(a)pyrene [1]
Bromophenylphenylether
Butylbenzylphthalate
Chlorodibromomethane
Chloroethoxymethane
Chloroethylether
Chloroethylvinylether
Chloroisopropylether

Chloromethylether
Chlorophenylphenylether
Chrysene [1]
DDD [2]
DDE [2]
Dichlorobenzidine
Dichlorobromomethane
Dichlorophenol
Dichlorophenoxyacetic acid
Dichloropropane
Dichloropropylene
Dieldrin [2]
Dinitrophenol
Diphenylhydrazine
Endosulfan
Endrin [2]

Fluoranthene [1]
Fluorene [1]
Heptachlor [2]
Hexachlorobenzene
Hexachlorobutadiene
Hexachlorocyclohexane
Indeno(1,2,3-c,d)pyrene [1]
Isophorone
2-Methylnapthalene
Parachlorometa cresol
Phenanthrene [1]
Phenylenepyrene
Pyrene [1]
Trichlorophenol
Trichlorophenoxyacetic acid

[1] *Component of cresotoe and coal tar. At room temperature and below, these compounds are solid in pure form.*
[2] *Pesticides*