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Office of Air Quality
Planning and Standards
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Air/Superfund

# AIR / SUPERFUND NATIONAL TECHNICAL GUIDANCE STUDY SERIES

## Estimation of Air Impacts For Air Stripping Of Contaminated Water

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# Estimation of Air Impacts for Air Stripping of Contaminated Water

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## INTRODUCTION

The U.S. Environmental Protection Agency's Office of Air Quality Planning and Standards and the Regional Air Offices have been given the responsibility to evaluate air impacts from Superfund sites. An important part of this program is the analysis of air impacts from various alternatives to cleaning up Superfund sites. Since these analyses are frequently required for planning purposes prior to actual cleanup they depend on estimated emissions and ambient concentrations rather than on field measurements.

This report provides procedures for roughly estimating the ambient air concentrations associated with air stripping. Air stripping is a widely used technique for removing volatile organic compounds (VOC) from contaminated water. Procedures are given to evaluate the effect of the concentration of contaminants in water and the stripping rate on the emission rates and on the ambient air concentrations at selected distances from the air stripper.

Health-based ambient air action levels are also provided for comparison to the estimated ambient concentrations. Many of the health levels have not been verified by EPA or are based on extrapolations of oral exposures or occupational exposures. Their indiscriminate use could either under or over estimate the potential health effects. The statements and conclusions presented in this report are those of the authors and do not reflect U.S. EPA policy.

## ESTIMATION OF AIR EMISSIONS

The primary parameters affecting the emission rate for a given compound from an air stripper are: the concentration of the contaminant in the influent to the stripper, the influent flowrate, the stripping efficiency of the tower, and the effectiveness of any control technologies that are in place. The stripping efficiency will depend on a

number of factors including: the compound's volatility (Henry's Law constant), the type of packing material in the tower, and the gas to liquid contact ratio within the tower.

Equation 1 can be used to estimate the emission rate (ER) from an air stripper in grams/second.

**Uncontrolled Emissions From Air Strippers**

$$ER_i \text{ (g/sec)} = (C_{i,l})(L_R)\left(\frac{SE}{100}\right)(1.67 \times 10^{-5}) \qquad \text{(Eq. 1)}$$

where:

| | | |
|---|---|---|
| $ER_i$ | = | Emission rate of species i (g/sec); |
| $C_{i,l}$ | = | Concentration of species i in influent water (mg/L or ppm); |
| $L_R$ | = | Influent liquid flowrate (L/min); |
| SE | = | Stripping Efficiency (%); and |
| $1.67 \times 10^{-5}$ | = | Constant (g-min/mg-sec). |

Typical water flow rates and other air stripper operating conditions are presented in Table 1 for three different sizes of air strippers. VOC concentrations in ground water typically range from 0.1 to 1 ppmw. A stripping efficiency of 100% for volatile organic compounds is a reasonable, conservative assumption. Alternatively, the stripping efficiency can be determined from Figures 1 and 2, once the G/L ratio and the log of the Henry's Law constant are known. G/L is the gas to liquid ratio within the tower (e.g. $m^3$ air divided by $m^3$ of water treated). A typical G/L is 50. Default values for $L_R$ and SE are 5,700 L/min and 100%, respectively. Henry's Law constants and their logs for frequently encountered organic compounds are given in Appendix A along with other physical properties. A worst-case scenario for cases when the influent contaminant concentrations are not well known is to assume that slightly soluble organic contaminants are present in the water at their maximum water solubility (see Appendix A).

## Table 1.

### Example Scenarios for Air Stripping

| Parameter | Units | Typical Value | | |
|---|---|---|---|---|
| | | Small | Medium | Large |
| Total Influent Liquid Flowrate | L/min | 570 | 2,840 | 5,700 |
| | gpm | 150 | 750 | 1,500 |
| Column Height | m | 7.6 | 9 | 14 |
| Column Diameter | m | 1.2 | 3.6 | 3.6 |
| Exhaust Gas Flowrate | $m^3$/min | 29 | 140 | 285 |
| | cfm | 1,020 | 5,000 | 10,000 |
| Stack Height | m | 8.5 | 10 | 15 |
| Stack Diameter | m | 0.31 | 0.61 | 0.91 |
| Structure Dimensions[a] | m | 7.6 x 1.2 x 1.2 | 9.0 x 3.6 x 3.6 | 13.0 x 3.6 x 3.6 |
| Exit Gas Velocity | m/sec | 6.4 | 8.0 | 7.3 |
| Exit Gas Temperature | C | 20 | 20 | 20 |
| Ambient Temperature | C | 20 | 20 | 20 |
| Air/Liquid Ratio (G/L) | (vol/vol) | 50 | 50 | 50 |
| Stripping Efficiency | % | 99+ | 99+ | 99+ |

[a]For purposes of calculating downwash.

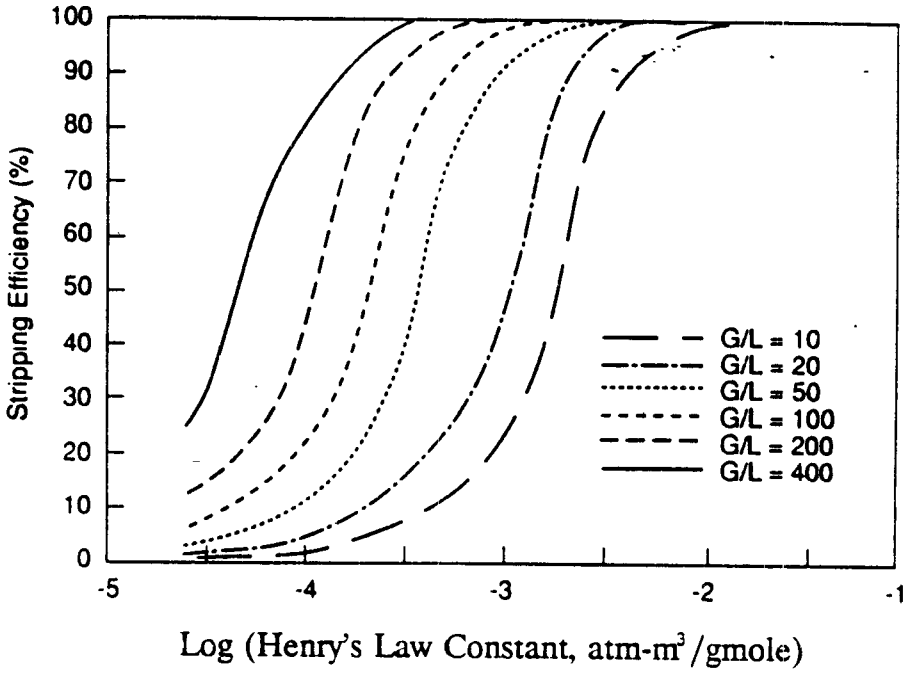


Figure 1. Stripper efficiency vs. Henry's Law constant, parameter = G/L (vol/vol), low efficiency range.

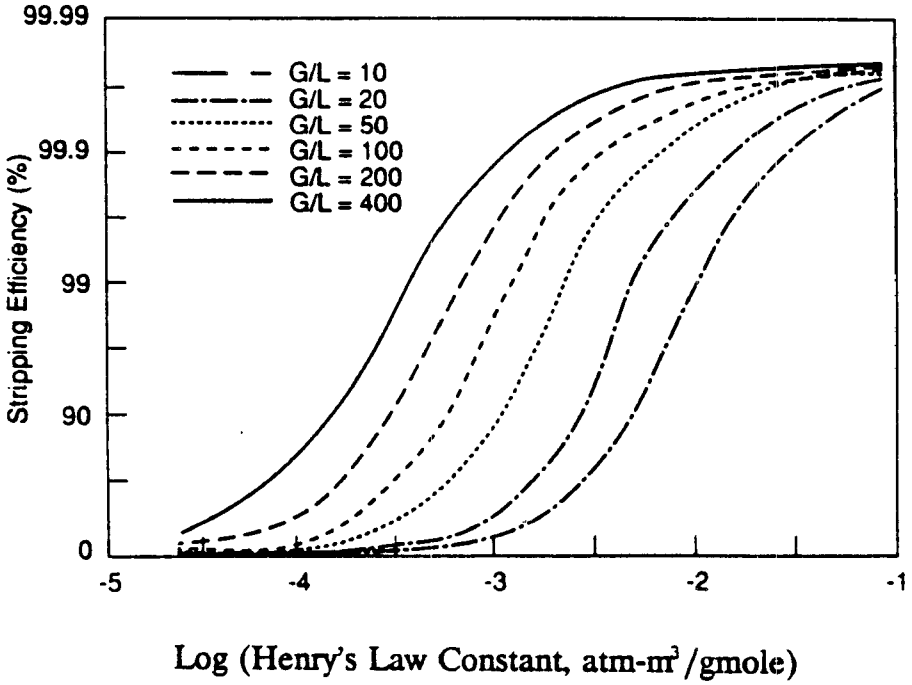


Figure 2. Stripper efficiency vs. Henry's Law constant, parameter = G/L (vol/vol), high efficiency range.

Control technologies for air stripping are not addressed in this document, but can generally be assumed to reduce emissions by one to two orders of magnitude (90 to 99%). The effect on emissions for any control device could be taken into account by adding the following term to Equation 1:

1-(Removal Efficiency (%)/100)

## ESTIMATION OF AMBIENT AIR CONCENTRATIONS

Estimates of short term ambient concentrations should be obtained by using site specific release parameters in the EPA's SCREEN model[2]. Estimates of long term concentrations should be obtained by using EPA's Industrial Source Complex (ISCLT) model. Here, for simplicity, the long term estimates are derived by multiplying the short term estimate obtained from the SCREEN model, by a conversion factor to obtain the annual average estimates. This approach results in a higher estimate of the annual average concentration than if the ISCLT model, with site specific data, is used.

Figure 3 was constructed using release parameters for three sizes of air strippers described in Table 1. In addition to these input parameters, a flat terrain without any structures near the tower was assumed, and downwash was taken into account with the stripper column being the only structure. The fluctuations seen in the dispersion curves are an artifact of the SCREEN model and should be ignored.

Figure 3 can be used to estimate the maximum hourly ambient air concentration for an emission rate of 1 gram per second at selected distances downwind from an air stripper. The dispersion factor, in micrograms/$m^3$ per g/sec, obtained from Figure 3 can be substituted into Equation 2 to estimate the maximum hourly ambient concentration and into Equation 3 to estimate the annual average ambient air concentration for a given downwind distance. Since SCREEN provides maximum short term estimates, the factor of 0.025 in Equation 3 is used to convert the short term

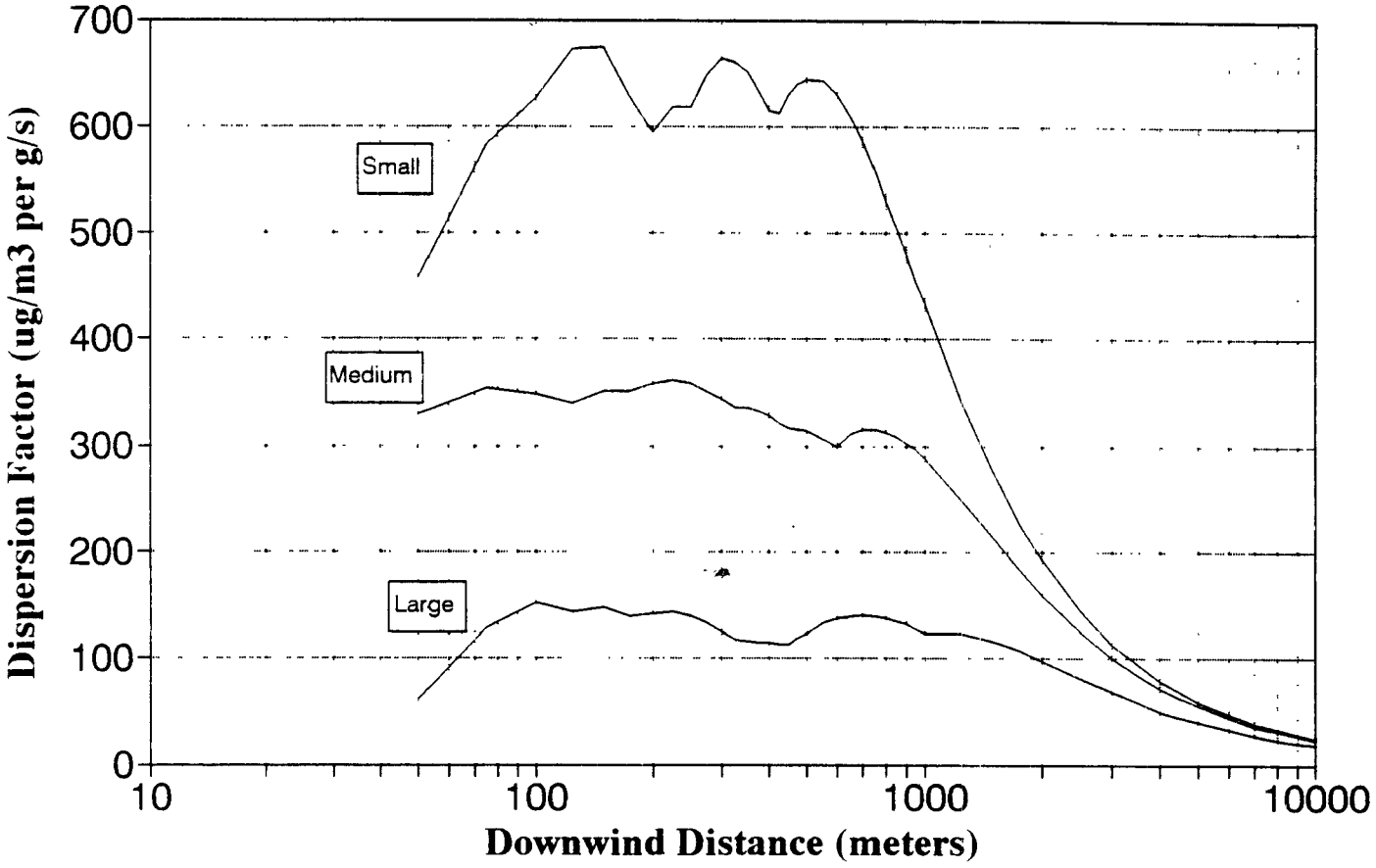


**Figure 3 Dispersion Factor**
**(Maximum Hourly)**

estimate to a maximum annual average estimate. A conservative factor of 0.025 assumes that the wind blows downwind 2.5% of the time over one year and that the terrain is relatively flat.

$$C_m = (ER)(F) \quad \text{(Eq. 2)}$$

$$C_a = (ER)(F)(0.025) \quad \text{(Eq. 3)}$$

where:
- $C_m$ = Maximum hourly ambient air concentration ($\mu g/m^3$);
- $C_a$ = Annual average ambient air concentration ($\mu g/m^3$);
- ER = Emission rate (g/sec); and
- F = Dispersion Factor from Figure 3 ($\mu g/m^3/g/sec$).

## ESTIMATION OF HEALTH EFFECTS

### Cancer Effects Due to Long-Term Exposure

Potential cancer effects resulting from long-term exposure to substances emitted to the air can be evaluated using inhalation unit risk factors. Inhalation unit risk factors are a measure of the cancer risk for each $\mu g/m^3$ of concentration in the ambient air. They are available on EPA's Integrated Risk Information System (IRIS), the Agency's preferred source of toxicity information. User Support can be contacted at (513) 569-7254. Table 2 provides inhalation unit risk factors listed in IRIS as of January 1991 for selected organic compounds.

The next best source of inhalation unit risk factors is EPA's Health Effects Assessment Summary Tables (HEAST) which are updated quarterly.[3]

# Table 2.

## Long-Term and Short-Term Health-Based Action Levels for Ambient Air

| No. | Chemical | CAS Number | Carcinogenicity[a] | Chronic Toxicity[a] | Long-Term Action Levels | | | Short-Term Action Levels[d] |
|---|---|---|---|---|---|---|---|---|
| | | | | | Risk-Specific Concentrations for Carcinogencity | RfC-Based Concentrations for Non-Carcinogenic Effects ($\mu g/m^3$) | Concentrations Based on Occupational Exposure[d] | |
| | | | Inhalation Unit Risk 1/($\mu g/m^3$) | Inhalation RfC ($mg/m^3$) | 10-6 70-year Risk ($\mu g/m^3$) | | Lowest OEL/1000 ($\mu g/m^3$) | Lowest OEL/100 ($\mu g/m^3$) |
| 1 | Acetaldehyde | 75-07-0 | -- | -- | -- | -- | 180 | 1,800 |
| 2 | Acetic Acid | 64-19-7 | -- | -- | -- | -- | 25 | 250 |
| 3 | Acetic anhydride | 108-24-7 | -- | -- | -- | -- | 20 | 200 |
| 4 | Acetone | 67-64-1 | -- | (4e-01)[b] | -- | 400 | 1,780 | 17,800 |
| 5 | Acetonitrile | 75-05-8 | -- | 5e-02 | -- | 50 | 67 | 670 |
| 6 | Acrolein | 107-02-8 | ND[c,e] | 1e-04[c] | -- | 0.1 | 0.23 | 2.30 |
| 7 | Acrylic acid | 79-10-7 | -- | 3e-04 | -- | 0.3 | 5.90 | 59 |
| 8 | Acrylonitrile | 107-13-1 | 6.8e-05 | -- | 1.5e-02[c] | -- | 4.30 | 43 |
| 9 | Allyl alcohol | 107-18-6 | -- | (2e-02)[b] | -- | 20 | 4.80 | 48 |
| 10 | Allyl chloride | 107-05-1 | ND[c,e] | 1e-03 | -- | 7 | 3.00 | 30 |
| 11 | Aniline | 62-53-3 | (1.6e-06)[b] | -- | 6.3e-01 | -- | 7.60 | 76 |
| 12 | Anthracene | 120-12-7 | -- | (1e+00)[b] | -- | 1,000 | 0.20 | 2.00 |
| 13 | Benzaldehyde | 100-52-7 | -- | (4e-01)[b] | -- | 400 | -- | -- |
| 14 | Benzene | 71-43-2 | 8.3e-06 | -- | 1.2e-01[c] | -- | 0.30 | 3.00 |
| 15 | Benzoic acid | 65-85-0 | -- | (1e+01)[b] | -- | 10,000 | -- | -- |
| 16 | Benzyl alcohol | 100-51-6 | -- | (1e+00)[b] | -- | 1,000 | -- | -- |
| 17 | 1,3-Butadiene | 106-99-0 | 2.8e-04 | -- | 3.6e-03 | -- | 22 | 220 |
| 18 | n-Butane | 106-97-8 | -- | -- | -- | -- | 1,900 | 19,000 |
| 19 | 2-Butanol | 15892-23-6 | -- | -- | -- | -- | 303 | 3,030 |
| 20 | n-Butanol | 71-36-3 | -- | (4e-01)[b] | -- | 400 | 152 | 1,520 |
| 21 | n-Butyl-Acetate | 123-86-4 | -- | -- | -- | -- | 710 | 7,100 |
| 22 | Tert-Butyl-Alcohol | 75-65-0 | -- | -- | -- | -- | 300 | 3,000 |
| 23 | Carbon disulfide | 75-15-0 | -- | 1e-02 | -- | 10 | 12 | 120 |
| 24 | Carbon Tetrachloride | 56-23-5 | 1.5e-05 | (2e-03)[b] | 6.7e-02 | 2 | 12.60 | 126 |
| 25 | Chlorobenzene | 108-90-7 | -- | 2e-02 | -- | 20 | 46 | 460 |
| 26 | Chlorodifluoromethane | 75-45-6 | -- | -- | -- | -- | 3,540 | 35,400 |
| 27 | Chloroform | 67-66-3 | 2.3e-05 | (4e-02)[b] | 4.3e-02[c] | 40 | 9.78 | 98 |
| 28 | Chloropentafluoroethane | 76-15-3 | -- | -- | -- | -- | 6,320 | 63,200 |

# Table 2. (Continued)

| No. | Chemical | CAS Number | Carcinogenicity[a] | Chronic Toxicity[a] | Long-Term Action Levels | | | Short-Term Action Levels[d] |
|---|---|---|---|---|---|---|---|---|
| | | | | | Risk-Specific Concentrations for Carcinogencity | RfC-Based Concentrations for Non-Carcinogenic Effects ($\mu g/m^3$) | Concentrations Based on Occupational Exposure[d] | |
| | | | Inhalation Unit Risk 1/($\mu g/m^3$) | Inhalation RfC ($mg/m^3$) | 10-6 70-year Risk ($\mu g/m^3$) | | Lowest OEL/1000 ($\mu g/m^3$) | Lowest OEL/100 ($\mu g/m^3$) |
| 29 | m-Cresol | 108-39-4 | ND[e] | (2e-01)[b] | -- | 200 | 22 | 220 |
| 30 | o-Cresol | 95-48-7 | ND[e] | (2e-01)[b] | -- | 200 | 22 | 220 |
| 31 | p-Cresol | 106-44-5 | ND[e] | (2e-01)[b] | -- | 200 | 22 | 220 |
| 32 | Cyanogen | 460-19-5 | -- | (1e-01)[b] | -- | 100 | 20 | 200 |
| 33 | Cyclohexane | 110-82-7 | -- | -- | -- | -- | 1,030 | 10,300 |
| 34 | Cyclohexanol | 108-93-0 | -- | -- | -- | -- | 200 | 2,000 |
| 35 | Cyclohexanone | 108-94-1 | -- | -- | -- | -- | 100 | 1,000 |
| 36 | Cyclohexene | 110-83-8 | -- | -- | -- | -- | 1,010 | 10,100 |
| 37 | Cyclopentane | 287-92-3 | -- | -- | -- | -- | 1,720 | 17,200 |
| 38 | Dibutyl-O-Phthalate | 84-74-2 | -- | (4e-01)[b] | -- | 400 | 5.00 | 50 |
| 39 | o-Dichlorobenzene | 95-50-1 | -- | 2e-01 | -- | 200 | 300 | 3,000 |
| 40 | p-Dichlorobenzene | 106-46-7 | (6.9e-06)[b] | 7e-01[c] | 1.4e-01 | 700 | 450 | 4,500 |
| 41 | Dichlorodifluoromethane | 75-71-8 | -- | 2e-01 | -- | 200 | 4,950 | 49,500 |
| 42 | 1,1-Dichloroethane | 75-34-3 | ND[e] | 5e-01 | -- | 500 | 400 | 4,000 |
| 43 | 1,2-Dichloroethane | 107-06-2 | 2.6e-05 | -- | 3.8e-02[c] | -- | 4.00 | 40 |
| 44 | 1,1-Dichloroethylene | 75-35-4 | 5e-05 | (3e-02)[b] | 2.0e-02 | 30 | 4.00 | 40 |
| 45 | cis-1,2-dichloroethylene | 156-59-2 | -- | (4e-02)[b] | -- | 40 | 790 | 7,900 |
| 46 | trans-1,2-dichloroethylene | 156-60-5 | -- | (7-02)[b] | -- | 70 | 790 | 7,900 |
| 47 | Dichloromethane | 75-09-2 | 4.7e-07 | 3e+00[c] | 2.1e-00 | 3,000 | 174 | 1,740 |
| 48 | Dichloromonofluoromethane | 75-43-4 | -- | -- | -- | -- | 40 | 400 |
| 49 | 1,2-Dichloropropane | 78-87-5 | (1.9e-05)[b] | -- | 5.3e-02 | -- | 347 | 3,470 |
| 50 | 1,2-Dichloro-1,1,2,2-Tetrafluoroethane | 76-14-2 | -- | -- | -- | -- | 6,990 | 69,900 |
| 51 | Diethyl amine | 109-89-7 | -- | -- | -- | -- | 30 | 300 |
| 52 | Diethyl ether | 60-29-7 | -- | -- | -- | -- | 1,200 | 12,000 |
| 53 | Dimethylamine | 124-40-3 | -- | -- | -- | -- | 18 | 180 |
| 54 | 1,4-Dioxane | 123-91-1 | (3.1e-06)[b] | -- | 3.2e-01 | -- | 90 | 900 |
| 55 | Diphenyl | 92-52-4 | -- | -- | -- | -- | 1.00 | 10 |
| 56 | Ethanol | 64-17-5 | -- | -- | -- | -- | 1,880 | 18,800 |
| 57 | Ethyl acetate | 141-78-6 | -- | (3.0e+00)[b] | -- | 3,000 | 1,400 | 14,000 |
| 58 | Ethyl acrylate | 140-88-5 | (1.4e-05)[b] | -- | 7.1e-02 | -- | 20 | 200 |

# Table 2. (Continued)

| No. | Chemical | CAS Number | Carcinogenicity[a] | Chronic Toxicity[a] | Long-Term Action Levels | | | Short-Term Action Levels[d] |
|---|---|---|---|---|---|---|---|---|
| | | | | | Risk-Specific Concentrations for Carcinogencity | RfC-Based Concentrations for Non-Carcinogenic Effects ($\mu g/m^3$) | Concentrations Based on Occupational Exposure[d] | |
| | | | Inhalation Unit Risk $1/(\mu g/m^3)$ | Inhalation RfC ($mg/m^3$) | 10-6 70-year Risk ($\mu g/m^3$) | | Lowest OEL/1000 ($\mu g/m^3$) | Lowest OEL/100 ($\mu g/m^3$) |
| 59 | Ethyl amine | 75-04-7 | -- | -- | -- | -- | 18 | 180 |
| 60 | Ethylbenzene | 100-41-4 | -- | 1e-00 | -- | 1,000 | 434 | 4,340 |
| 61 | Ethyl bromide | 74-96-4 | -- | -- | -- | -- | 22 | 220 |
| 62 | Ethyl chloride | 75-00-3 | -- | 1e+01 | -- | 10,000 | 2,600 | 26,000 |
| 63 | Ethylenediamine | 107-15-3 | -- | (7.0e-02)[b] | -- | 70 | 25 | 250 |
| 64 | Ethylene glycol | 107-21-1 | -- | (7.0e+00)[b] | -- | 7,000 | 125 | 1,250 |
| 65 | Ethylene imine | 151-56-4 | -- | -- | -- | -- | 0.88 | 8.80 |
| 66 | Ethylene oxide | 75-21-8 | 1.0e-04 | -- | 1.0e-02 | -- | 1.80 | 18 |
| 67 | Formaldehyde | 50-00-0 | 1.3e-05 | -- | 7.7e-02 | -- | 0.37 | 3.70 |
| 68 | Formic Acid | 64-18-6 | -- | (7e+00) | -- | 7,000 | 9.00 | 90 |
| 69 | Furan | 110-00-9 | -- | (4.0e-03)[b] | -- | 4 | -- | -- |
| 70 | Glycerol | 56-81-5 | -- | -- | -- | -- | 5.00 | 50 |
| 71 | n-Heptane | 142-82-5 | -- | -- | -- | -- | 1,600 | 16,000 |
| 72 | n-Hexane | 110-54-3 | -- | 2e-01 | -- | 200 | 176 | 1,760 |
| 73 | Hydrogen cyanide | 74-90-8 | -- | -- | -- | -- | 11 | 110 |
| 74 | Isobutanol | 78-83-1 | -- | 1e+00 | -- | 1,000 | 150 | 1,500 |
| 75 | Isobutyl acetate | 110-19-0 | -- | -- | -- | -- | 700 | 7,000 |
| 76 | Isopropyl alcohol | 67-63-0 | -- | -- | -- | -- | 980 | 9,800 |
| 77 | Isopropyl amine | 75-31-0 | -- | -- | -- | -- | 12 | 120 |
| 78 | Isopropylbenzene | 98-82-8 | -- | 9e-03[c] | -- | 9 | 245 | 2,450 |
| 79 | Methanol | 67-56-1 | -- | (2e+00)[b] | -- | 2,000 | 260 | 2,600 |
| 80 | Methyl acetate | 79-20-9 | -- | (4e+00)[b] | -- | 4,000 | 606 | 6,060 |
| 81 | Methyl acrylate | 96-33-3 | -- | (1e-01)[b] | -- | 100 | 35 | 350 |
| 82 | Methyl amine | 74-89-5 | - | -- | -- | -- | 12 | 120 |
| 83 | Methyl bromide | 74-83-9 | -- | (6e-03)[b] | -- | 6 | 19 | 190 |
| 84 | Methyl-tert-butyl-ether | 1634-04-4 | -- | -- | -- | -- | -- | -- |
| 85 | Methyl chloride | 74-87-3 | 1.8e-06 | -- | 5.5e-01 | -- | 103 | 1,030 |
| 86 | Methylcyclohexane | 108-87-2 | -- | -- | -- | -- | 1,600 | 16,000 |
| 87 | Methyl-ethyl-ketone | 78-93-3 | ND | 3e-01 | -- | 300 | 590 | 5,900 |
| 88 | Methyl formate | 107-31-3 | -- | -- | -- | -- | 246 | 2,460 |

# Table 2. (Continued)

| No. | Chemical | CAS Number | Carcinogenicity[a] | Chronic Toxicity[a] | Long-Term Action Levels | | | Short-Term Action Levels[d] |
|---|---|---|---|---|---|---|---|---|
| | | | | | Risk-Specific Concentrations for Carcinogencity | RfC-Based Concentrations for Non-Carcinogenic Effects ($\mu g/m^3$) | Concentrations Based on Occupational Exposure[d] | |
| | | | Inhalation Unit Risk 1/($\mu g/m^3$) | Inhalation RfC ($mg/m^3$) | 10-6 70-year Risk ($\mu g/m^3$) | | Lowest OEL/1000 ($\mu g/m^3$) | Lowest OEL/100 ($\mu g/m^3$) |
| 89 | Methyl hydrazine | 60-34-4 | (3.1e-04)[b] | -- | 3.2e-03 | -- | 0.019 | 0.19 |
| 90 | Methyl iodide | 74-88-4 | -- | -- | -- | -- | 10 | 100 |
| 91 | Methyl-Isobutyl-Ketone | 108-10-1 | -- | 8e-02 | -- | 80 | 205 | 2,050 |
| 92 | Methyl-Isopropyl-Ketone | 563-80-4 | -- | -- | -- | -- | 705 | 7,050 |
| 93 | Methyl mercaptan | 74-93-1 | -- | -- | -- | -- | 0.98 | 10 |
| 94 | Methyl-n-Propyl-ketone | 107-87-9 | -- | -- | -- | -- | 700 | 7,000 |
| 95 | Alpha-methyl-styrene | 98-83-9 | -- | (2e-01)[b] | -- | 200 | 240 | 2,400 |
| 96 | Monoethanolamine | 141-43-5 | -- | -- | -- | -- | 7.50 | 75 |
| 97 | Morpholine | 110-91-8 | -- | -- | -- | -- | 70 | 700 |
| 98 | Naphthalene | 91-20-3 | -- | (1e-02)[b] | -- | 10 | 50 | 500 |
| 99 | n-Nonane | 111-84-2 | -- | -- | -- | -- | 1,050 | 10,500 |
| 100 | n-Octane | 111-65-9 | -- | -- | -- | -- | 1,400 | 14,000 |
| 101 | n-Pentane | 109-66-0 | -- | -- | -- | -- | 1,770 | 17,700 |
| 102 | Phenanthrene | 85-01-9 | -- | -- | -- | -- | 0.20 | 2 |
| 103 | Phenol | 108-95-2 | -- | (2e+00)[b] | -- | 2,000 | 19 | 190 |
| 104 | Phthalic anhydride | 85-44-9 | -- | (7e+00)[b] | -- | 7,000 | 6.00 | 60 |
| 105 | Propane | 74-98-6 | -- | -- | -- | -- | 1,800 | 18,000 |
| 106 | 1,2-Propanediol | 57-55-6 | -- | 6e+00 | -- | 6,000 | -- | -- |
| 107 | 1-Propanol | 71-23-8 | -- | -- | -- | -- | 492 | 4,920 |
| 108 | Propionic acid | 79-09-4 | -- | -- | -- | -- | 30 | 300 |
| 109 | n-Propyl-Acetate | 109-60-4 | -- | -- | -- | -- | 835 | 8,350 |
| 110 | Propylene oxide | 75-56-9 | 3.7e-06 | 3e-02 | 2.7e-01 | 30 | 48 | 480 |
| 111 | Pyridine | 110-86-1 | -- | 4e-03 | -- | 4 | 15 | 150 |
| 112 | Styrene | 100-42-5 | 5.7e-07 | (7e-01)[b] | 1.8e+00 | 700 | 213 | 2,130 |
| 113 | 1,1,1,2-Tetrachloro-2,2-Difluoroethane | 76-11-9 | -- | -- | -- | -- | 4,170 | 41,700 |
| 114 | 1,1,2,2-Tetrachloroethane | 79-34-5 | 5.8e-05 | -- | 1.7e-02 | -- | 6.90 | 69 |
| 115 | Tetrachloroethylene | 127-18-4 | 5.2e-07 | (4e-02)[b] | 1.9e+00 | 40 | 170 | 1,700 |
| 116 | Tetrahydrofuran | 109-99-9 | -- | -- | -- | -- | 590 | 5,900 |
| 117 | Toluene | 108-88-3 | -- | 2e+00[c] | -- | 2,000 | 375 | 3,750 |
| 118 | p-Toluidine | 106-49-0 | (5.4e-05)[b] | -- | 1.9e-02 | -- | 8.80 | 88 |

# Table 2. (Continued)

| No. | Chemical | CAS Number | Carcinogenicity[a] | Chronic Toxicity[a] | Long-Term Action Levels | | | Short-Term Action Levels[d] |
|---|---|---|---|---|---|---|---|---|
| | | | | | Risk-Specific Concentrations for Carcinogencity | RfC-Based Concentrations for Non-Carcinogenic Effects ($\mu g/m^3$) | Concentrations Based on Occupational Exposure[d] | |
| | | | Inhalation Unit Risk $1/(\mu g/m^3)$ | Inhalation RfC ($mg/m^3$) | 10-6 70-year Risk ($\mu g/m^3$) | | Lowest OEL/1000 ($\mu g/m^3$) | Lowest OEL/100 ($\mu g/m^3$) |
| 119 | 1,1,1-Trichloroethane | 71-55-6 | -- | 1.0e+00 | -- | 1,000 | 1,900 | 19,000 |
| 120 | 1,1,2-Trichloroethane | 79-00-5 | 1.6e-05 | (1.0e-02)[b] | 6.3e-02 | 10 | 45 | 450 |
| 121 | Trichloroethylene | 79-01-6 | 1.7e-6 | -- | 5.9e-01 | -- | 269 | 2,690 |
| 122 | Trichlorofluoromethane | 75-69-4 | -- | 7.0e-01 | -- | 700 | 5,620 | 56,200 |
| 123 | 1,2,3-Trichloropropane | 96-18-4 | -- | (2.0e-02)[b] | -- | 20 | 60 | 600 |
| 124 | 1,1,2-Trichloro-1,2,2-Trifluoroethane | 76-13-1 | -- | (2.7e+01)[b] | -- | 27,000 | 7,600 | 76,000 |
| 125 | Triethylamine | 121-44-8 | -- | -- | -- | -- | 40 | 400 |
| 126 | Trifluorobromomethane | 75-63-8 | -- | -- | -- | -- | 6,090 | 60,900 |
| 127 | 1,2,3-Trimethylbenzene | 526-73-8 | -- | -- | -- | -- | 123 | 1,230 |
| 128 | 1,2,4-Trimethylbenzene | 95-63-6 | -- | -- | -- | -- | 123 | 1,230 |
| 129 | 1,3,5-Trimethylbenzene | 108-67-8 | -- | -- | -- | -- | 123 | 1,230 |
| 130 | Vinyl acetate | 108-05-4 | -- | 2e-01 | -- | 200 | 30 | 300 |
| 131 | Vinyl-chloride | 75-01-4 | 8.4e-05 | -- | 1.2e-02 | -- | 2.60 | 26 |
| 132 | m-Xylene | 108-38-3 | -- | 7.0e-01 | -- | 700 | 434 | 4,340 |
| 133 | o-Xylene | 95-47-6 | -- | 7.0e-01 | -- | 700 | 434 | 4,340 |
| 134 | p-Xylene | 106-42-3 | -- | 3.0e-01 | -- | 300 | 434 | 4,340 |

INSTRUCTIONS ON USE:

Read short-term action level directly from last column. For the three columns of long-term action levels, use the 10-6 risk data, if available, then the RfC data; use the OEL/1000 if no other data exists.

[a] EPA does not necessarily endorse the use of oral slope fators or oral RfDs to derive inhalation values. These are intended to serve as screening levels only and do not represent EPA guidance.

[b] Derived based on oral slope factor (or oral RfD).

[c] Verified, available on IRIS or Workgroup occurrence on final database file, and IRIS input pending.

[d] EPA does not necessarily endorse the use of occupational exposure limits to derive short- and long-term action levels for ambient air. These are intended to serve as screening levels only and do not represent EPA guidance. Intended changes for OEL values are included, where applicable.

[e] EPA Class C or D carcinogen.

Equation 4 can be used to estimate the cancer risk at a specified distance downwind of the air stripper. Cancer risk is a measure of the increased probability of developing cancer in a lifetime as a result of the exposure in question. Equation 4 assumes continuous exposure (24 hours/day, 365 days/year for 70 years) to the estimated annual average concentration in air.

$$R = (C_a)(IUR) \qquad \text{(Eq. 4)}$$

R is the cancer risk from long-term exposure to a specific VOC in air, dimensionless; $C_a$ is the annual average ambient concentration estimated from Equation 3, $\mu g/m^3$; IUR is the inhalation unit risk factor, $(\mu g/m^3)^{-1}$.

If the source operates for less than 70 years, multiply $C_a$ by x/70, where x is the expected operating time of the source in years before using Equation 4. If more than one VOC is present, the cancer risks for each VOC can be summed to derive the total cancer risk at a specified distance downwind of the source.

**Non-Cancer Effects Due to Long-Term Exposure**

Non-cancer effects can be evaluated by using chronic inhalation reference concentrations (RfCs). An inhalation RfC is the an estimate (with uncertainty spanning perhaps an order of magnitude) of continuous exposure to the human population that is likely to be without appreciable risk of deleterious effects during a lifetime. RfCs for a limited number of compounds are available in IRIS and HEAST.

If inhalation RfCs were not available from either IRIS or HEAST, then chronic oral reference dose (RfD) data (in mg/kg/day) were multiplied by 70 kg (average body weight of an adult), then divided by 20 $m^3$/day (average adult inhalation rate), and finally multiplied by 1000 $\mu g/mg$ to derive a value in $\mu g/m^3$.

Ambient air action levels based on extrapolated oral data should be used cautiously. Before extrapolating data an array of factors should be assessed on a compound by compound basis to determine the feasibility of route-to-route extrapolations. Important factors include the absorption, distribution, metabolism and excretion of the compound; portal of entry effects; acute and chronic toxicities; and other information.

For compounds lacking RfC or RfD values, action levels were based on occupational exposure levels recommended by the Occupational Safety and Health Administration (OSHA)[4] and the American Conference of Governmental Industrial Hygienists (ACGIH)[5]. The action levels were estimated by using the lower of the OSHA Permissible Exposure Limit-Time Weighted Average (PEL-TWA) level (or ceiling value) or the ACGIH Threshold Limit Value - Time Weighted Average (TLV-TWA) level (or ceiling value). The lower value was divided by 1000 to compensate for differences between occupational and residential exposures.

Long term non-cancer ambient air action level concentrations based on RfCs, extrapolated RfDs and occupational exposure levels for over 130 compounds are listed in Table 2. The action levels are in units of $\mu g/m^3$ to facilitate comparison to the ambient air concentrations estimated from Equation 3.

**Short-Term Exposure**

The short term (one hour) action levels, in $\mu g/m^3$, are presented in the last column of Table 2. The listed values were obtained by dividing the lowest of (1) the OSHA PEL-TWA or (2) the ACGIH TLV-TWA (or ceiling limits if 8-hour averages are not available) by 100. Division by 100 accounts for variations in human sensitivity (occupational levels are designed to protect healthy adult workers) and for uncertainties in using occupational exposure levels to derive ambient air action levels.

The occupational exposure levels on which the short-term action levels are based are subject to change. To check the values in Table 2 (or to derive values for compounds not listed in Table 3), determine the current OSHA PEL-TWA values by consulting 29 CFR Section 1910 and the most recent edition of the ACGIH publication entitled Threshold Limit Values and Biological Exposure Indices.

The short-term action levels listed in Table 2 can be compared directly with the estimated maximum hourly ambient air concentrations obtained by using Equations 1 and 2 and Figure 3. Use of the short term action levels should consider that no EPA accepted method exists to determine the short-term concentrations of airborne chemicals acceptable for community exposure.

## SIMPLIFIED SCREENING PROCEDURE

Using conservative estimates of emissions and atmospheric dispersion, water concentrations were estimated that correspond to the ambient air action levels listed in Table 2. These water concentrations are listed in Table 3. They represent values that, if exceeded, may result in annual average ambient concentrations that exceed the long term action levels listed in Table 2. Table 3 can be used for quick, but rough determinations of possible adverse health effects from long term exposures to emissions from air strippers.

The water concentrations listed in Table 3 correspond to a cancer risk of $10^{-6}$. If risk values were not available, then the water concentrations were based on the listed RfC-based action levels. If RfCs were not available, then values based on occupational exposure levels were used.

## Table 3.

## Water Concentrations of Concern for Selected Chemicals

| No. | Chemical | "Action Level" | |
|---|---|---|---|
| | | Basis For Health-Based Action Level | Water Conc. (mg/L) |
| 1 | Acetaldehyde | OEL | 500 |
| 2 | Acetic acid | OEL | 70 |
| 3 | Acetic anhydride | OEL | 56 |
| 4 | Acetone | Rfc-Oral | 1100 |
| 5 | Acetonitrile | Rfc | 140 |
| 6 | Acrolein | Rfc | 140 |
| 7 | Acrylic acid | Rfc-Oral | 840 |
| 8 | Acrylonitrile | IUR | 0.042 |
| 9 | Allyl alcohol | Rfc-Oral | 56 |
| 10 | Allyl chloride | Rfc-Oral | 20 |
| 11 | Aniline | IUR-Oral | 1.8 |
| 12 | Anthracene | Rfc-Oral | 2800 |
| 13 | Benzaldehyde | Rfc-Oral | 1100 |
| 14 | Benzene | IUR | 0.34 |
| 15 | Benzoic acid | Rfc-Oral | 28000 |
| 16 | Benzyl alcohol | Rfc-Oral | 2800 |
| 17 | 1,3-Butadiene | IUR | 0.010 |
| 18 | N-Butane | OEL | 5300 |
| 19 | 2-Butanol | OEL | 850 |
| 20 | N-Butanol | OEL | 430 |
| 21 | N-Butyl-Acetate | OEL | 2000 |
| 22 | Tert-Butyl-Alcohol | OEL | 840 |
| 23 | Carbon disulfide | OEL | 34 |
| 24 | Carbon tetrachloride | IUR | 0.19 |
| 25 | Chlorobenzene | Rfc | 56 |

## Table 3-1. (Continued)

| No. | Chemical | "Action Level" | |
|---|---|---|---|
| | | Basis For Health-Based Action Level | Water Conc. (mg/L) |
| 26 | Chlorodifluoromethane | OEL | 9800 |
| 27 | Chloroform | IUR | 0.12 |
| 28 | Chloropentafluoroethane | OEL | 18000 |
| 29 | M-Cresol | Rfc-Oral | 560 |
| 30 | O-Cresol | Rfc-Oral | 560 |
| 31 | P-Cresol | Rfc-Oral | 560 |
| 32 | Cyanogen | OEL | 56 |
| 33 | Cyclohexane | OEL | 2900 |
| 34 | Cyclohexanol | OEL | 560 |
| 35 | Cyclohexanone | OEL | 280 |
| 36 | Cyclohexene | OEL | 2800 |
| 37 | Cyclopentane | OEL | 4800 |
| 38 | Dibutyl-O-Phthalate | Rfc-Oral | 1100 |
| 39 | O-Dichlorobenzene | Rfc | 560 |
| 40 | P-Dichlorobenzene | IUR-Oral | 0.39 |
| 41 | Dichlorodifluoromethane | Rfc | 560 |
| 42 | 1,1-Dichloroethane | IUR-Oral | 0.11 |
| 43 | 1,2-Dichloroethane | IUR | 0.11 |
| 44 | 1,1-Dichloroethylene | IUR | 0.056 |
| 45 | cis-1,2-Dichloroethylene | OEL | 2200 |
| 46 | Trans-1,2-dichloroethylene | Rfc-Oral | 20 |
| 47 | Dichloromethane | IUR | 0.67 |
| 48 | Dichloromonofluoromethane | OEL | 110 |
| 49 | 1,2-Dichloropropane | IUR | 0.15 |
| 50 | 1,2-Dichloro-1,1,2,2-Tetrafluoroethane | OEL | 20000 |

## Table 3-1. (Continued)

| No. | Chemical | "Action Level" | |
|---|---|---|---|
| | | Basis For Health-Based Action Level | Water Conc. (mg/L) |
| 51 | Diethyl amine | OEL | 84 |
| 52 | Diethyl ether | OEL | 3400 |
| 53 | Dimethylamine | OEL | 50 |
| 54 | 1,4-Dioxane | OEL | 250 |
| 55 | Diphenyl | OEL | 2.8 |
| 56 | Ethanol | OEL | 5300 |
| 57 | Ethyl acetate | Rfc-Oral | 8400 |
| 58 | Ethyl acrylate | IUR-Oral | 0.20 |
| 59 | Ethyl amine | OEL | 50 |
| 60 | Ethylbenzene | Rfc-Oral | 1100 |
| 61 | Ethyl bromide | OEL | 2500 |
| 62 | Ethyl chloride | OEL | 7300 |
| 63 | Ethylenediamine | Rfc-Oral | 200 |
| 64 | Ethylene glycol | Rfc-Oral | 20000 |
| 65 | Ethylene imine | OEL | 2.5 |
| 66 | Ethylene oxide | IUR | 4.9 |
| 67 | Formaldehyde | IUR | 1.3 |
| 68 | Formic acid | OEL | 25 |
| 69 | Furan | Rfc-Oral | 11 |
| 70 | Glycerol | OEL | 14 |
| 71 | N-Heptane | OEL | 4500 |
| 72 | N-Hexane | Rfc | 110 |
| 73 | Hydrogen cyanide | OEL | 31 |
| 74 | Isobutanol | Rfc | 2800 |
| 75 | Isobutyl acetate | OEL | 2000 |

## Table 3-1. (Continued)

| No. | Chemical | "Action Level" | |
|---|---|---|---|
| | | Basis For Health-Based Action Level | Water Conc. (mg/L) |
| 76 | Isopropyl alcohol | OEL | 2700 |
| 77 | Isopropyl amine | OEL | 34 |
| 78 | Isopropylbenzene | Rfc | 25 |
| 79 | Methanol | OEL | 730 |
| 80 | Methyl acetate | Rfc-Oral | 11000 |
| 81 | Methyl acrylate | Rfc-Oral | 280 |
| 82 | Methyl amine | OEL | 34 |
| 83 | Methyl bromide | Rfc-Oral | 14 |
| 84 | Methyl t-butyl ether | -- | -- |
| 85 | Methyl chloride | IUR | 0.76 |
| 86 | Methylcyclohexane | OEL | 4500 |
| 87 | Methyl-ethyl-ketone | Rfc | 840 |
| 88 | Methyl formate | OEL | 690 |
| 89 | Methyl hydrazine | IUR | 0.0090 |
| 90 | Methyl iodide | OEL | 28 |
| 91 | Methyl-Isobutyl-Ketone | Rfc | 220 |
| 92 | Methyl-Isopropyl-Ketone | OEL | 2000 |
| 93 | Methyl mercaptan | OEL | 2.7 |
| 94 | Methyl-N-Propyl-Ketone | OEL | 2000 |
| 95 | Alpha-Methyl-Styrene | Rfc-Oral | 560 |
| 96 | Monoethanolamine | OEL | 21 |
| 97 | Morpholine | OEL | 200 |
| 98 | Naphthalene | Rfc-Oral | 28 |
| 99 | N-Nonane | OEL | 2900 |
| 100 | N-Octane | OEL | 3900 |

## Table 3-1. (Continued)

| No. | Chemical | "Action Level" | |
|---|---|---|---|
| | | Basis For Health-Based Action Level | Water Conc. (mg/L) |
| 101 | N-Pentane | OEL | 5000 |
| 102 | Phenanthrene | OEL | 0.56 |
| 103 | Phenol | Rfc-Oral | 5600 |
| 104 | Phthalic anhydride | Rfc-Oral | 20000 |
| 105 | Propane | OEL | 5000 |
| 106 | 1,2-Propanediol | RfC | 17000 |
| 107 | 1-Propanol | OEL | 1400 |
| 108 | Propionic acid | OEL | 84 |
| 109 | N-Propyl-Acetate | OEL | 2300 |
| 110 | Propylene oxide | IUR | 0.76 |
| 111 | Pyridine | Rfc | 11 |
| 112 | Styrene | IUR | 5.0 |
| 113 | 1,1,1,2-Tetrachloro-2,2-Difluoroethane | OEL | 12000 |
| 114 | 1,1,2,2-Tetrachloroethane | IUR | 0.048 |
| 115 | Tetrachloroethylene | IUR | 3.1 |
| 116 | Tetrahydrofuran | OEL | 1700 |
| 117 | Toluene | Rfc | 5600 |
| 118 | P-Toluidine | IUR | 0.053 |
| 119 | 1,1,1-Trichloroethane | Rfc | 2800 |
| 120 | 1,1,2-Trichloroethane | Rfc-Oral | 0.18 |
| 121 | Trichloroethylene | IUR | 1.7 |
| 122 | Trichlorofluoromethane | Rfc | 200 |
| 123 | 1,2,3-Trichloropropane | Rfc-Oral | 56 |
| 124 | 1,1,2-Trichloro-1,2,2-Triflouroethane | Rfc-Oral | 290000 |
| 125 | Triethylamine | OEL | 110 |

## Table 3-1. (Continued)

| No. | Chemical | "Action Level" | |
|---|---|---|---|
| | | Basis For Health-Based Action Level | Water Conc. (mg/L) |
| 126 | Trifluorobromomethane | OEL | 17000 |
| 127 | 1,2,3-Trimethylbenzene | OEL | 340 |
| 128 | 1,2,4-Trimethylbenzene | OEL | 340 |
| 129 | 1,3,5-Trimethylbenzene | OEL | 340 |
| 130 | Vinyl acetate | OEL | 84 |
| 131 | Vinyl-chloride | IUR | 0.067 |
| 132 | M-Xylene | Rfc | 1200 |
| 133 | O-Xylene | Rfc | 1200 |
| 134 | P-Xylene | Rfc | 1200 |

Notes: IUR = Inhalation Unit Risk
IUR-Oral = Derived based on oral slope factor
Rfc = Reference Concentration
Rfc-Oral = Derived based on oral reference concentration
OEL = Occupational Exposure Limit/1000

A number of asumptions were made to generate the values in Table 3. The values in Table 3 assume 100% VOC removal at a stripping rate of 5700 L/minute and an annual average dispersion factor of 3.75 $\mu g/m^3$ per g/s of emissions. Using chloroform as an example, Equation 4 and the inhalation unit risk factor listed in Table 2 were used to estimate the annual average ambient concentration that corresponds to a cancer risk of $10^{-6}$ ($10^{-6}/2.3 \times 10^{-5} = 0.043 \mu g/m^3$). Equation 3 was then used to estimate the emission rate that corresponds to an annual average ambient concentration of 0.043 $\mu g/m^3$ (0.043/3.75 = 0.0115 g/s). Finally, Equation 1 was used to estimate the water concentration that results in an emission rate of 0.011 g/s when 100% of the chloroform is stripped from 5700 L/min of water; $0.0115/(5700 \times 1.67 \times 10^{-5}) =$ 0.12 mg/L.

**EXAMPLE**

The water and air flows to an air stripper are 5040 L/minute and 1060 $m^3$/minute respectively. The contaminants are chloroform, 1,1,1-trichloroethane and trichloroethylene at respective concentrations of 0.01, 0.01 and 0.5 ppmw. Estimate the maximum hourly and annual average ambient air concentrations at 400 meters from the stripper and compare to the action level concentrations listed in Table 2.

First, note that the actual water concentrations for chloroform and trichloroethylene do not exceed those listed in Table 3. This suggests that a more rigorous analysis is not required, though the example is carried through below for illustrative purposes.

The 5040 L/minute water flow to the stripper corresponds to the large facility listed in Table 1. From Figure 3 the maximum hourly ambient air concentration at a distance of 400 meters is approximately 120 $\mu g/m^3$ per g/s emission rate. This corresponds to an annual average dispersion factor of 3 $\mu g/m^3$ per g/s (120 x 0.025 = 3).

The emission rates estimated from Equation 1 and the ambient air concentrations estimated from Equations 2 and 3 are presented in Table 4. The action level water concentrations from Table 3 and the action level ambient air concentrations from Table 2 are presented in Table 5. None of the estimated maximum hourly or annual average ambient concentrations exceed the applicable action levels.

## CONCLUSIONS

The procedures presented here are not intended to negate the need for rigorous analyses that consider site specific meteorological conditions and the health effects of the specific compounds involved. Although the procedures are based on what is typical and reasonable for cleaning up Superfund sites, the underlying assumptions need to be kept in mind. Emission models assume steady-state conditions, dispersion models assume Gaussian distribution of the plume contaminant concentration, and many of the health levels are not endorsed by the Environmental Protection Agency. EPA's Regional Toxicologist should be contacted for general toxicological information and technical guidance on evaluation of chemicals without established toxicity values.

## ACKNOWLEDGEMENTS

Jawad Touma and Norman Huey of EPA contributed to the overall direction of this project. Michael Hunt of the Radian Corporation prepared the sections for estimating the ambient air concentrations. The health effects sections were prepared in consultation with Fred Hauchman of EPA.

## Table 4.

### Estimated Emission Rates and Ambient Air Concentrations

| | Water Concentration (ppmw) | Emission Rate (g/s) | Ambient Concentrations ($\mu g/m^3$) | |
|---|---|---|---|---|
| | | | Maximum Hourly | Annual Average |
| Chloroform | 0.01 | 0.00084 | 0.1 | 0.0025 |
| 1,1,1-Trichloroethane | 0.01 | 0.00084 | 0.1 | 0.0025 |
| Trichloroethylene | 0.5 | 0.042 | 5.1 | 0.13 |

## Table 5.

### Action Level Concentrations

| | Table 3 Water Concentrations (ppmw) | Table 2 Action Levels $\mu g/m^3$ | |
|---|---|---|---|
| | | Long-Term | Short-Term |
| Chloroform | 0.12 | 0.043[1] | 98 |
| 1,1,1-Trichloroethane | 2,800 | 1,000[2] | 19,000 |
| Trichloroethylene | 1.7 | 0.59[1] | 2,690 |

[1]Based on $10^{-6}$, 70-year risk.
[2]Based on reference dose concentrations (RfCs).

## REFERENCES


1. Air/Superfund National Technical Guidance Study Series - Air Stripper Design Manual, EPA-450/1-90-003, U.S. Environmental Protection Agency, Research Triangle Park, NC, May 1990, NTIS PB91-125997, pp 51-52.

2. Screening Procedures for Estimating the Air Quality Impact of Stationary Sources, EPA-450/4-88-010, Research Triangle Park, NC August 1988, NTIS PB89-159396.

3. Health Effects Assessment Summary Tables (HEAST), U.S. Environmental Protection Agency, Wash. D.C., Fourth Quarter, 1990, OERR 9200.6-303(91-1), NTIS No. PB91-92199, January 1991.

4. 29 CFR ch. XVII, Subpart Z, Section 1910.1000, July 1, 1990.

5. 1990-1991 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Indices, American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1990.

# APPENDIX A

# PHYSICAL AND CHEMICAL CONSTANTS FOR SELECTED COMPOUNDS

# APPENDIX A - PHYSICAL PROPERTY DATA

| No. | Chemical | CAS Number | Formula | Henry's Law Constant (atm-m^3/gmol) H | Henry's Law Constant (atm-m^3/gmol) Log H | Maximum Water Solubility (mg/L) |
|---|---|---|---|---|---|---|
| 1 | Acetaldehyde | 75-07-0 | C2H4O | 9.50e-05 | -4.02 | inf |
| 2 | Acetic acid | 64-19-7 | C2H4O2 | 6.27e-02 | -1.20 | inf |
| 3 | Acetic anhydride | 108-24-7 | C4H6O3 | 5.91e-06 | -5.23 | — |
| 4 | Acetone | 67-64-1 | C3H6O | 2.50e-05 | -4.60 | inf |
| 5 | Acetonitrile | 75-05-8 | C2H3N | 5.80e-06 | -5.24 | inf |
| 6 | Acrolein | 107-02-8 | C3H4O | 5.66e-05 | -4.25 | 208000 |
| 7 | Acrylic acid | 79-10-7 | C3H4O2 | 1.00e-07 | -7.00 | inf |
| 8 | Acrylonitrile | 107-13-1 | C3H3N | 8.80e-05 | -4.06 | 73500 |
| 9 | Allyl alcohol | 107-18-6 | C3H6O | 1.80e-05 | -4.74 | inf |
| 10 | Allyl chloride | 107-05-1 | C3H5CL | 3.71e-01 | -0.43 | 3600 |
| 11 | Aniline | 62-53-3 | C6H7N | 2.60e-06 | -5.59 | 35000 |
| 12 | Anthracene | 120-12-7 | C14H10 | 6.75e-02 | -1.17 | 1.3 |
| 13 | Benzaldehyde | 100-52-7 | C7H6O | 4.23e-05 | -4.37 | 3000 |
| 14 | Benzene | 71-43-2 | C6H6 | 5.50e-03 | -2.26 | 1780 |
| 15 | Benzoic acid | 65-85-0 | C7H6O2 | 1.82e-08 | -7.74 | 2900 |
| 16 | Benzyl alcohol | 100-51-6 | C7H8O | 6.10e-07 | -6.21 | 35000 |
| 17 | 1,3-Butadiene | 106-99-0 | C4H6 | 1.42e-01 | -0.85 | 735 |
| 18 | N-Butane | 106-97-8 | C4H10 | 2.91e-01 | -0.54 | 61 |
| 19 | 2-Butanol | 15892-23-6 | C4H10O | 2.20e-06 | -5.66 | 184000 |
| 20 | N-Butanol | 71-36-3 | C4H10O | 2.20e-06 | -5.66 | 77000 |
| 21 | N-Butyl-Acetate | 123-86-4 | C6H12O2 | 1.64e-04 | -3.79 | 14000 |
| 22 | Tert-Butyl-Alcohol | 75-65-0 | C4H10O | 2.20e-06 | -5.66 | inf |
| 23 | Carbon disulfide | 75-15-0 | CS2 | 1.68e-02 | -1.77 | 2900 |
| 24 | Carbon tetrachloride | 56-23-5 | CCL4 | 3.00e-02 | -1.52 | 800 |
| 25 | Chlorobenzene | 108-90-7 | C6H5CL | 3.93e-03 | -2.41 | 488 |
| 26 | Chlorodifluoromethane | 75-45-6 | CHCLF2 | 1.00e-01 | -1.00 | 2 |
| 27 | Chloroform | 67-66-3 | CHCL3 | 3.39e-03 | -2.47 | 9300 |
| 28 | Chloropentafluoroethane | 76-15-3 | C2CLF5 | 2.45e-01 | -0.61 | — |
| 29 | M-Cresol | 108-39-4 | C7H8O | 4.43e-07 | -6.35 | 25000 |
| 30 | O-Cresol | 95-48-7 | C7H8O | 2.60e-06 | -5.59 | 31000 |
| 31 | P-Cresol | 106-44-5 | C7H8O | 4.43e-07 | -6.35 | 24000 |
| 32 | Cyanogen | 460-19-5 | C2N2 | 4.96e-03 | -2.30 | 9300 |
| 33 | Cyclohexane | 110-82-7 | C6H12 | 1.37e-02 | -1.86 | 100 |
| 34 | Cyclohexanol | 108-93-0 | C6H12O | 4.47e-06 | -5.35 | 38200 |
| 35 | Cyclohexanone | 108-94-1 | C6H10O | 4.13e-06 | -5.38 | 23000 |
| 36 | Cyclohexene | 110-83-8 | C6H1O | 1.03e+01 | 1.01 | 213 |
| 37 | Cyclopentane | 287-92-3 | C5H10 | 1.00e-02 | -2.00 | 156 |

## APPENDIX A - PHYSICAL PROPERTY DATA

| No. | Chemical | CAS Number | Formula | Henry's Law Constant (atm-m^3/gmol) H | Log H | Maximum Water Solubility (mg/L) |
|---|---|---|---|---|---|---|
| 38 | Dibutyl-O-Phthalate | 84-74-2 | C16H22O4 | 2.80e-07 | -6.55 | 400 |
| 39 | O-Dichlorobenzene | 95-50-1 | C6H4CL2 | 1.94e-03 | -2.71 | 145 |
| 40 | P-Dichlorobenzene | 106-46-7 | C6H4CL2 | 1.60e-03 | -2.80 | 79 |
| 41 | Dichlorodifluoromethane | 75-71-8 | CCL2F2 | 4.01e-01 | -0.40 | 280 |
| 42 | 1,1-Dichloroethane | 75-34-3 | C2H4CL2 | 1.54e-02 | -1.81 | 5500 |
| 43 | 1,2-Dichloroethane | 107-06-2 | C2H4CL2 | 1.20e-03 | -2.92 | 8690 |
| 44 | 1,1-Dichloroethylene | 75-35-4 | C2H2CL2 | 2.59e-02 | -1.59 | 210 |
| 45 | cis-1,2-Dichloroethylene | 156-59-2 | C2H2CL2 | 4.55e-03 | -2.34 | 800 |
| 46 | trans-1,2-Dichloroethylene | 156-60-5 | C2H2CL2 | 9.46e-03 | -2.02 | 600 |
| 47 | Dichloromethane | 75-09-2 | CH2CL2 | 3.19e-03 | -2.50 | 16700 |
| 48 | Dichloromonofluoromethane | 75-43-4 | CHCL2F | 9.21e+02 | 2.96 | 0.2 |
| 49 | 1,2-Dichloropropane | 78-87-5 | C3H6CL2 | 2.30e-03 | -2.64 | 2700 |
| 50 | 1,2-Dichloro-1,1,2,2-Tetrafluoroethane | 76-14-2 | C2CL2F4 | 2.45e-01 | -0.61 | 137 |
| 51 | Diethyl amine | 109-89-7 | C4H11N | 7.31e-03 | -2.14 | 20000 |
| 52 | Diethyl ether | 60-29-7 | C4H10O | 2.65e-04 | -3.58 | 60400 |
| 53 | Dimethylamine | 124-40-3 | C2H7N | 5.24e-06 | -5.28 | — |
| 54 | 1,4-Dioxane | 123-91-1 | C4H8O2 | 2.31e-05 | -4.64 | inf |
| 55 | Diphenyl | 92-52-4 | C12H10 | 1.01e-01 | -1.00 | 7.5 |
| 56 | Ethanol | 64-17-5 | C2H6O | 3.03e-05 | -4.52 | inf |
| 57 | Ethyl acetate | 141-78-6 | C4H8O2 | 1.28e-04 | -3.89 | 79000 |
| 58 | Ethyl acrylate | 140-88-5 | C5H8O2 | 3.50e-04 | -3.46 | — |
| 59 | Ethyl amine | 75-04-7 | C2H7N | 5.24e-06 | -5.28 | inf |
| 60 | Ethylbenzene | 100-41-4 | C8H10 | 6.44e-03 | -2.19 | 152 |
| 61 | Ethyl bromide | 74-96-4 | C2H5Br | 1.00e-02 | -2.00 | — |
| 62 | Ethyl chloride | 75-00-3 | C2H5Cl | 1.40e-02 | -1.85 | 5740 |
| 63 | Ethylenediamine | 107-15-3 | C2H8N2 | 8.46e-06 | -5.07 | inf |
| 64 | Ethylene glycol | 107-21-1 | C2H6O2 | 1.03e-07 | -6.99 | inf |
| 65 | Ethylene imine | 151-56-4 | C2H5N | 4.54e-04 | -3.34 | inf |
| 66 | Ethylene oxide | 75-21-8 | C2H4O | 1.42e-04 | -3.85 | — |
| 67 | Formaldehyde | 50-00-0 | CH2O | 5.76e-05 | -4.24 | 550000 |
| 68 | Formic acid | 64-18-6 | CH2O2 | 7.00e-07 | -6.15 | inf |
| 69 | Furan | 110-00-9 | C4H4O | 5.34e-03 | -2.27 | 10000 |
| 70 | Glycerol | 56-81-5 | C3H8O3 | 1.30e-08 | -7.89 | 10000 |
| 71 | N-Heptane | 142-82-5 | C7H16 | 2.02e+001.2 | 0.31 | 3 |
| 72 | N-Hexane | 110-54-3 | C6H14 | 2e-01 | -0.91 | 13 |
| 73 | Hydrogen cyanide | 74-90-8 | CHN | 4.65e-07 | -6.33 | inf |
| 74 | Isobutanol | 78-83-1 | C4H10O | 2.20e-06 | -5.66 | 95000 |
| 75 | Isobutyl acetate | 110-19-0 | C6H12O2 | 1.64e-04 | -3.79 | 6300 |
| 76 | Isopropyl alcohol | 67-63-0 | C3H8O | 1.50e-04 | -3.82 | inf |
| 77 | Isopropyl amine | 75-31-0 | C3H9N | 3.58e-04 | -3.45 | 100000 |
| 78 | Isopropylbenzene | 98-82-8 | C9H12 | 6.59e-03 | -2.18 | 50 |

## APPENDIX A - PHYSICAL PROPERTY DATA

| No. | Chemical | CAS Number | Formula | Henry's Law Constant (atm-m^3/gmol) | | Maximum Water Solubility (mg/L) |
|---|---|---|---|---|---|---|
| | | | | H | Log H | |
| 79 | Methanol | 67-56-1 | CH4O | 2.70e-06 | -5.57 | inf |
| 80 | Methyl acetate | 79-20-9 | C3H6O2 | 1.02e-04 | -3.99 | 194000 |
| 81 | Methyl acrylate | 96-33-3 | C4H7O2 | 1.44e-07 | -6.84 | 60000 |
| 82 | Methyl amine | 74-89-5 | CH5N | 5.38e-03 | -2.27 | 11500 |
| 83 | Methyl bromide | 74-83-9 | CH3BR | 2.21e-01 | -0.66 | 17500 |
| 84 | Methyl t-butyl ether | 1634-04-4 | C5H12O | 5.92e-04 | -3.23 | 48,000 |
| 85 | Methyl chloride | 74-87-3 | CH3Cl | 8.14e-03 | -2.09 | 6360 |
| 86 | Methylcyclohexane | 108-87-2 | C7H14 | 9.79e-01 | -0.01 | 14 |
| 87 | Methyl-ethyl-ketone | 78-93-3 | C4H8O | 2.16e-04 | -3.67 | 275000 |
| 88 | Methyl formate | 107-31-3 | C2H4O2 | 1.30e-01 | -0.89 | 304 |
| 89 | Methyl hydrazine | 60-34-4 | CH6N2 | 3.44e-06 | -5.46 | inf |
| 90 | Methyl iodide | 74-88-4 | CH3I | 2.53e-03 | -2.60 | 14000 |
| 91 | Methyl-Isobutyl-Ketone | 108-10-1 | C6H12O | 4.95e-05 | -4.31 | 19000 |
| 92 | Methyl-Isopropyl-Ketone | 563-80-4 | C5H10O | 4.58e-04 | -3.34 | 47000 |
| 93 | Methyl mercaptan | 74-93-1 | CH4S | 4.18e-03 | -2.38 | 23300 |
| 94 | Methyl-N-Propyl-Ketone | 107-87-9 | C5H10O | 4.58e-04 | -3.34 | — |
| 95 | Alpha-Methyl-Styrene | 98-83-9 | C9H10 | 5.91e-03 | -2.23 | 2 |
| 96 | Monoethanolamine | 141-43-5 | C2H7NO | 3.22e-07 | -6.49 | 100000 |
| 97 | Morpholine | 110-91-8 | C4H9NO | 5.73e-05 | -4.24 | inf |
| 98 | Naphthalene | 91-20-3 | C10H8 | 4.80e-04 | -3.32 | 30 |
| 99 | N-Nonane | 111-84-2 | C9H20 | 4.48e-01 | -0.35 | 79 |
| 100 | N-Octane | 111-65-9 | C8H18 | 3.87e+00 | 0.59 | 20 |
| 101 | N-Pentane | 109-66-0 | C5H12 | 1.22e-01 | -0.91 | 360 |
| 102 | Phenanthrene | 85-01-8 | C14H10 | 6.05e-03 | -2.22 | 0.82 |
| 103 | Phenol | 108-95-2 | C6H6O | 4.54e-07 | -6.34 | 80000 |
| 104 | Phthalic anhydride | 85-44-9 | C8H4O3 | 9.00e-07 | -6.05 | 6200 |
| 105 | Propane | 74-98-6 | C3H8 | 2.20e-02 | -1.66 | 62 |
| 106 | 1,2-Propanediol | 57-55-6 | C3H8O2 | 1.50e-06 | -5.82 | 20000 |
| 107 | 1-Propanol | 71-23-8 | C3H8O | 1.50e-04 | -3.82 | inf |
| 108 | Propionic acid | 79-09-4 | C3H6O2 | 4.87e-05 | -4.31 | inf |
| 109 | N-Propyl-Acetate | 109-60-4 | C5H10O2 | 2.94e-04 | -3.53 | 20400 |
| 110 | Propylene oxide | 75-56-9 | C3H6O | 1.34e-03 | -2.87 | 30000 |
| 111 | Pyridine | 110-86-1 | C5H5N | 2.36e-05 | -4.63 | inf |
| 112 | Styrene | 100-42-5 | C8H8 | 2.61e-03 | -2.58 | 300 |
| 113 | 1,1,1,2-Tetrachloro-2,2-Difluoroethane | 76-11-9 | C2CL4F2 | 2.45e-01 | -0.61 | — |
| 114 | 1,1,2,2-Tetrachloroethane | 79-34-5 | C2H2CL4 | 2.50e-04 | -3.60 | 2900 |
| 115 | Tetrachloroethylene | 127-18-4 | C2CL4 | 2.90e-02 | -1.54 | 150 |
| 116 | Tetrahydrofuran | 109-99-9 | C4H8O | 4.90e-05 | -4.31 | inf |
| 117 | Toluene | 108-88-3 | C7H8 | 6.68e-03 | -2.18 | 515 |
| 118 | P-Toluidine | 106-49-0 | C7H9N | 1.91e-05 | -4.72 | 7400 |
| 119 | 1,1,1-Trichloroethane | 71-55-6 | C2H3CL3 | 1.74e-02 | -1.76 | 4400 |
| 120 | 1,1,2-Trichloroethane | 79-00-5 | C2H3CL3 | 7.40e-04 | -3.13 | 4500 |
| 121 | Trichloroethylene | 79-01-6 | C2HCL3 | 9.10e-03 | -2.04 | 1100 |
| 122 | Trichlorofluoromethane | 75-69-4 | CCL3F | 5.83e-02 | -1.23 | 1100 |
| 123 | 1,2,3-Trichloropropane | 96-18-4 | C3H5CL3 | 2.80e-02 | -1.55 | — |
| 124 | 1,1,2-Trichloro-1,2,2-Triflouroethane | 76-13-1 | C2CL3F3 | 2.45e-01 | -0.61 | 170 |
| 125 | Triethylamine | 121-44-8 | C6H15N | 2.66e-03 | -2.58 | 20000 |
| 126 | Trifluorobromomethane | 75-63-8 | CBRF3 | 1.00e-01 | -1.00 | — |
| 127 | 1,2,3-Trimethylbenzene | 526-73-8 | C9H12 | 1.47e-01 | -0.83 | — |
| 128 | 1,2,4-Trimethylbenzene | 95-63-6 | C9H12 | 1.47e-01 | -0.83 | 57 |
| 129 | 1,3,5-Trimethylbenzene | 108-67-8 | C9H12 | 1.47e-01 | -0.83 | 20 |

## APPENDIX A - PHYSICAL PROPERTY DATA

| No. | Chemical | CAS Number | Formula | Henry's Law Constant (atm-m^3/gmol) | | Maximum Water Solubility (mg/L) |
|---|---|---|---|---|---|---|
| | | | | H | Log H | |
| 130 | Vinyl acetate | 108-05-4 | C4H6O2 | 6.20e-04 | -3.21 | 20000 |
| 131 | Vinyl-chloride | 75-01-4 | C2H3CL | 8.60e-02 | -1.07 | 1.1 |
| 132 | M-Xylene | 108-38-3 | C8H10 | 5.20e-03 | -2.28 | 200 |
| 133 | O-Xylene | 95-47-6 | C8H10 | 5.27e-03 | -2.28 | 175 |
| 134 | P-Xylene | 106-42-3 | C8H10 | 5.27e-03 | -2.28 | 198 |