

Proposed Revisions

Connecticut's Remediation Standard Regulations Volatilization Criteria

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INTRODUCTION

The volatilization criteria were developed to identify situations where contaminants in groundwater and soil vapor volatilize, travel into an overlying building and result in the potential risk to human health from the inhalation of the contaminants by occupants of the building. Since the development and adoption of the volatilization criteria in the Remediation Standard Regulations (RSRs) in 1996, the Department of Environmental Protection (DEP), the Department of Public Health (DPH), the U.S. Environmental Protection Agency (USEPA), other state agencies and researchers across the country have collected additional laboratory and field information regarding the volatilization of contaminants. This work has resulted in a better understanding of the vapor migration pathway and the associated risk to public health posed by volatile organic compounds present in the subsurface. Consequently, DEP, with the assistance and input of DPH, is proposing revisions to the volatilization criteria. This document describes the basis for the proposed criteria, as well as the basis for the original criteria issued in 1996 for comparison.

The proposed revisions reflect new toxicological information, a revised transport model and additional information and understanding of this potential pathway of exposure that have all become available since the RSRs were formally adopted in 1996. The proposed revised target indoor air concentrations, groundwater volatilization criteria and soil vapor volatilization criteria are presented in Tables 1, 2 and 3, respectively.

The CTDEP is proposing revisions to the volatilization criteria at this time as part of the Department's application to the USEPA for authorization of the RCRA Corrective Action Program. These proposed changes make Connecticut's criteria more consistent with the EPA Draft Guidance "Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soil" that was issued in November 2002.

BASIS FOR DEVELOPMENT OF ORIGINAL VOLATILIZATION CRITERIA

The numerical volatilization criteria adopted in 1996 are listed in Appendices E and F of the RSRs and also in Tables C1, C2 and C3 in Appendix C of this document. These numerical criteria were developed using the transport model presented in ASTM ES 38-94 "Emergency Standard Guide for Risk Based Corrective Action Applied at Petroleum Release Sites" and toxicity information that was available in 1995.

Original Transport Model

The original transport model presented in the ASTM ES 38-94 was based on a model developed by Johnson and Ettinger and utilized a simplified approach for simulating the transport of volatiles from groundwater, through the soil media and building foundations, and into building structures as airborne contaminants. That model was based on the assumption that diffusion is the sole method of transport from subsurface contamination into the indoor air environment. Diffusion is the process resulting from random motion of molecules by which there is a net flow of matter from a region of high concentration to a region of low concentration. Equations used to develop the original volatilization criteria are shown in Appendix G of the RSRs and in Tables X2.1, X2.2, and X2.3 of ASTM ES 38-94.

The original transport model required the input of a variety of parameters to define the subsurface conditions, the building foundation and the interior environment of the building. Since these parameters are widely variable depending on site-specific conditions, default values were developed. Default values for the various parameters used in the model are presented in Appendix G of the RSRs and are the default values recommended in Tables X2.4 and X2.5 of ASTM ES 38-94. In general, these input parameters describe a conservative scenario in an effort to best protect human health and the environment in the generic or broad application of these criteria.

Original Target Indoor Air Concentrations

The volatilization criteria were developed by calculating a target indoor air concentration (TAC) for each chemical using risk assessment algorithms and toxicity values recommended by USEPA in 1995 and exposure assumptions recommended in ASTM ES 39-94. Background concentrations for certain chemicals were also taken into consideration when establishing the TACs. The background concentrations were described in Table 4 of ASTM ES 38-94 and in Table 3-1 of Massachusetts DEP's "Background Documentation for the Development of the MCP Numerical Standards". For some chemicals, the background concentrations were greater than the calculated risk-based concentrations. For these chemicals, the TACs were set at the background concentrations.

Ceiling Value for Groundwater Volatilization Criteria

A ceiling value of 50,000 micrograms per liter ("µg/L") was applied to all of the groundwater volatilization criteria for which the risk-based criteria were greater than 50,000 µg/L. The purpose of the ceiling value was to prevent gross contamination from being overlooked and to ensure that remediation in accordance with these criteria would address potential odor problems.

Quantification Limits

In general, if the risk-based criteria for a contaminant in soil, groundwater or soil vapor was a concentration lower than that which could be reasonably quantified, the RSR criteria was adjusted upward to a level that could be quantified by laboratories in Connecticut. In 1996, the soil vapor volatilization criteria were adjusted such that any risk-based soil vapor volatilization criteria that was determined to be less than one part per million ("ppm") was adjusted up to 1 ppm.

PROPOSED REVISIONS TO THE VOLATILIZATION CRITERIA

The proposed volatilization criteria are based on:

- 1) The Johnson and Ettinger (1991) model, incorporating its extensions developed in 1998 and 1999 (Johnson et al. 1998 and Johnson et al. 1999),
- 2) New toxicity information,
- 3) New exposure assumptions,
- 4) Ceiling values for target indoor air concentrations, and
- 5) Updated quantification limits.

Proposed revised target indoor air concentrations, groundwater volatilization criteria and soil vapor volatilization criteria are shown in Tables 1, 2 and 3 of this document.

Revised Transport Model

The revised Johnson and Ettinger model incorporates both diffusion and advection as the mechanisms of transport of subsurface contamination into the indoor air environment. While diffusion is a passive process, advection is an active process brought about by pressure gradients. Gases will move from areas of high pressure to areas of low pressure. Buildings, particularly under wintertime conditions, are depressurized due to warmed air constantly rising towards the roof. This allows influx of air from the soil gas, which follows the pressure gradient from soil gas into the basement. The greater the depressurization of the building, the greater the zone of influence will be. The zone of influence is the depth from which soil gas can be drawn into the building.

Since the revised model incorporates both diffusion and advection as transport mechanisms, the total amount of transport is greater than that calculated using the original model. Sampling at sites in Connecticut show that the original model under-predicted indoor air concentrations based on groundwater and soil vapor sample results. Therefore, the revised model provides a more accurate and realistic representation of volatile transport. USEPA is also currently using the revised Johnson and Ettinger model to develop their "Guidance for Evaluating the Vapor Intrusion into Indoor Air". In addition, many states including Massachusetts, Michigan, Pennsylvania, Virginia, West Virginia and California are also using this model to develop criteria for this exposure pathway. Appendix A describes the revised model in detail.

The default input values used in the revised model are the same as those used in the 1996 model with one exception, Q_{soil}/Q_B . Q_{soil}/Q_B is the ratio of soil gas intrusion rate to building ventilation rate and was not part of the original model. The default input value used for Q_{soil}/Q_B is taken from USEPA's "Guidance for Evaluating the Vapor Intrusion into Indoor Air". All variables used in the revised model are listed and defined in Tables A1 and A2. Table A3 shows the typical values or range of values for these parameters as well as the default values used to calculate the proposed volatilization criteria.

Revised and Updated Target Indoor Air Concentrations

The target indoor air concentrations (TACs) were again derived by CT DPH for each chemical using risk-based calculations recommended by USEPA, the chemical-specific reference concentrations (RfCs) and cancer unit risks currently available. Appendix B presents these risk-based equations. The following issues were addressed in the TAC revisions:

- 1) Updated toxicity values,
- 2) Revised exposure assumptions for industrial/commercial settings,
- 3) Increased exposure and susceptibility for children for residential settings,
- 4) Updated background concentrations, and
- 5) Ceiling value for TACs.

Toxicity Values

All of the toxicity values have been reviewed and revised to reflect up-to-date toxicity values. The most significant changes are the toxicity values for several chlorinated hydrocarbons including 1,1-dichloroethylene (“DCE”), trichloroethylene (“TCE”), and vinyl chloride. 1,1-Dichloroethylene is no longer regulated as a low dose linear carcinogen; although, there remains considerable uncertainty regarding its potential carcinogenicity, which is reflected in the new TAC. The net result of this is an increase in the 1,1-DCE TAC by 200 fold over the former value. The evidence for the carcinogenicity of trichloroethylene in humans has become strengthened with an associated increase in USEPA’s estimate of its cancer potency (Cogliano, et al., 2001). This change would have led to a considerable lowering of the TCE TAC, if not for the fact that TCE is a background indoor air contaminant. Setting the TAC for TCE at its background concentration leads to a 5 fold lowering of the TAC, relative to the 1996 value. USEPA’s carcinogenicity reassessment of vinyl chloride has led to a decrease in its potency estimate by 10 fold, leading to a commensurate increase in the TAC for vinyl chloride.

While USEPA’s Integrated Risk Information System (IRIS) database was relied upon as the primary source of toxicity values, other federal and state risk assessment databases (USEPA’s Health Effects Assessment Summary Tables – HEAST, ATSDR’s Chronic Minimum Risk Levels – MRLs, California EPA’s Chronic RELs) were reviewed to determine the consistency of toxicity values across agencies. These other data sources were used in derivation of TACs in cases where USEPA did not have a value listed on IRIS. Appendix B presents all of the new toxicity values and how they were used in deriving TACs for both residential and industrial/commercial scenarios.

Exposure Assumptions

Exposure assumptions for the residential scenario have not changed: 30 year residence at the affected location, daily exposure for 350 days/year, with an inhalation rate of 20 m³/day for a 70 kg adult. The exposure assumptions for the industrial/commercial scenario are revised to better reflect likely workplace exposures. The inhalation rate per day has been reduced by one half to 10 m³/day to reflect a shorter exposure time in the industrial/commercial exposure scenario. The other exposure assumptions for this scenario have not changed (25 years exposure, 250 days/year, 70 kg body weight).

Increased Exposure and Susceptibility of Children to Carcinogens

Increased exposure and susceptibility of children in a residential scenario to carcinogens was taken into consideration during these revisions. The residential scenario involves young children, which is a receptor group that is likely to be at elevated risk relative to adults due to several factors: 1) their greater respiratory rate per body weight and lung surface area (Child-Specific Exposure Factors Handbook, USEPA, 2000; Thurlbeck, 1982); and 2) due to the likelihood that they have increased sensitivity to carcinogens (Ginsberg, 2003; USEPA, 2003; USEPA, 2000). TACs based on adult exposure parameters and sensitivity may not be adequately protective of children.

The first factor, children's increased inhalation rate, is the basis for a 2-fold adjustment of the TAC to ensure protection of children.

The second factor, increased sensitivity to carcinogens, was the rationale for an additional 2-fold adjustment factor, but in this case it is applied only for genotoxic carcinogens. Juvenile animal studies indicate that even very brief exposures in early life can lead to substantial cancer risk (Vessinovitch, 1979; Toth, 1968). However, the standard rodent cancer bioassay upon which unit risks are derived starts dosing after this period of development. For these reasons, the development of TACs for the residential scenario incorporates a children's carcinogen sensitivity factor. This factor is applied to genotoxicants, a type of carcinogen whose effects in early life are most clearly documented at the present time. The adjustment factor is 2 fold based upon the vinyl chloride example on IRIS (USEPA, 2000). The underlying principle is that the risk from short-term early life exposure can be equal to the risk stemming from much longer exposure beginning later in life, and that risks must be additive across these age groups (Ginsberg, 2003). This approach is consistent with USEPA's IRIS file for vinyl chloride and draft Cancer Risk Assessment Guidelines (USEPA, 2000; USEPA, 2003).

Background Concentrations in Indoor Air

Since 1996, there has been an increased focus around the United States on measuring indoor air quality in impacted and non-impacted (or "background") homes, offices, schools and other environments. This had led to an enhanced database for background indoor air data (Foster, et al., 2002; Kurtz and Folkes, 2002; NYSDOH, 1997; Clayton, et al., 1999; Shields, et al., 1996; USEPA/BASE Study, 1999). These datasets, along with the pre-existing indoor air datasets (Stolwick, 1990; Vermont DOH, 1992; Brown, et al., 1994; Daisey, et al., 1994; Sheldon, et al., 1992; Shah and Singh, 1988) have been reviewed while giving particular attention to those volatile organic compounds (VOCs) (typically carcinogens) with risk-based TACs that approach or are below what can be considered background. VOC indoor air measurements are typically lognormally distributed; therefore, the central tendency background concentration (the median) was chosen to represent background. While higher concentrations may be found in certain background locations, the central tendency was used because of the way it would be applied: 1) to replace a risk-based TAC such that the background concentration would already be above a risk target; and 2) to back-calculate the allowable contribution from subsurface VOC contamination, such that the amount that is from background sources plus the amount allowed from subsurface sources would still be within the range of the background data distribution.

VOC background concentrations and how they are used in the derivation of TACs are shown chemical-by-chemical in Appendix B.

TAC Ceiling Value

A ceiling value of 500 ug/m³ was applied to both the residential and industrial/commercial scenarios for those VOCs with risk-based TACs exceeding

this ceiling value. This ceiling value was derived as an upper bound concentration that signals the presence of an unusual indoor air source for an individual VOC. It is prudent to keep the concentration of individual VOCs below this level to avoid odor complaints, degraded air quality, or non-specific health complaints. VOC odor thresholds were separately considered but only in isolated cases where the odor threshold is the key factor in setting a TAC. Appendix B provides a detailed discussion of this topic.

Current Quantification Limits

Based on the use of current analytical methods, concentrations in soil vapor can be reliably quantified at a level significantly lower than 1ppm. Therefore, the soil vapor volatilization criteria were adjusted such that any risk-based soil vapor volatilization criteria that are determined to be less than 0.5 ppb, are adjusted up to 0.5 ppb. The only criteria adjusted up to 0.5 ppb, is the residential soil vapor volatilization criteria for ethylene dibromide (EDB).

Criteria for New Chemicals

Since 1996, the DEP has approved volatilization criteria for a number of compounds for which criteria had not been established in the original regulations. Based on all of the requests for additional criteria for additional chemicals submitted since 1996, the following compounds have been added to the list of volatilization criteria: trichlorofluoromethane, chloroethane, chloromethane, dichlorodifluoromethane, isopropylbenzene (cumene), cis-1,2-dichloroethene, trans-1,2-dichloroethene, bromodichloromethane, n-butylbenzene, sec-butylbenzene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene and 4-isopropyltoluene (4-cymene).

APPLICATION OF THE VOLATILIZATION CRITERIA

Under the current regulations, the groundwater volatilization criteria are applicable to “all ground water polluted with a volatile organic substance within 15 feet of the ground surface or a building”. However, research since 1996 has demonstrated that volatiles in groundwater at depths much deeper than 15 feet have been the source of vapor intrusion into overlying structures at concentrations that pose a risk to public health. The USEPA in their “Guidance for Evaluating the Vapor Intrusion into Indoor Air” is recommending applying criteria up to buildings up to 100 feet from the contamination source. Other states including Michigan and Pennsylvania require that volatilization issues be addressed when polluted ground water is within 30 feet of the surface. After evaluating geology and hydrogeology in Connecticut, DEP is proposing that the volatilization criteria should be applied to groundwater within 30 feet of the ground surface or a building.

The RSRs adopted in 1996 provide baseline numeric criteria that can be used to demonstrate compliance or that can be used as a screening level. The regulations also provide the option of developing a site-specific criteria by calculating an attenuation factor using input parameters that are appropriate for the circumstances at a specific site. The site-specific option will also be retained in the proposed revisions to the regulations. However, the revised Johnson and Ettinger model should be used for such calculations. Further, the option to take measures that would prevent the migration of volatiles into indoor air rather than remediate the ground water

and the option to record a land use restriction that would prohibit the construction of a building over ground water polluted by VOCs will be retained in the revised regulations.

SUMMARY

DEP is proposing to revise the volatilization criteria to better protect human health and to remain consistent with federal programs. The revisions proposed in this document are in keeping with the following objectives:

- The proposed revised volatilization criteria are similar to those used by USEPA and other states.
- The revised transport model more accurately predicts indoor air concentrations.
- The toxicity information has been updated to current toxicity values.
- The exposure assumptions have been refined to be both protective and realistic.
- The depth to groundwater to which these criteria should be applied has been increased to 30 feet based on new research that demonstrates indoor exposures resulting from the migration of volatiles from a ground water source significantly deeper than 15 feet.

A comparison of 1996 TACs and volatilization criteria to proposed revised TACs and volatilization criteria is presented in the three tables in Appendix C.

DEP is seeking comments from the public on these revisions before proposing revised regulations in July 2003. Please send you comments to:

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Table 1
Proposed Target Indoor Air Concentrations

Compound	CAS Number	Residential TAC (ug/m ³)	Industrial/Commercial TAC (ug/m ³)
Acetone	67641	180	500 ⁽¹⁾
Acrylonitrile	107131	NA	NA
Benzene	71432	3.3 ⁽²⁾	3.3 ⁽²⁾
Bromoform	75252	0.55	7.3
2-Butanone (MEK)	78933	500 ⁽¹⁾	500 ⁽¹⁾
Carbon tetrachloride	56235	0.5 ⁽²⁾	0.54 ⁽²⁾
Chlorobenzene	108907	37	200
Chloroform	67663	0.5 ⁽²⁾	0.5 ⁽²⁾
Dibromochloromethane	124481	NA	NA
1,2-Dichlorobenzene	95501	73	410
1,3-Dichlorobenzene	541731	73	410
1,4-Dichlorobenzene	106467	24	24
1,1-Dichloroethane	75343	77	430
1,2-Dichloroethane	107062	0.07	0.31
1,1-Dichloroethylene	75354	10	20
cis-1,2-Dichloroethylene	156592	See New Criteria below	See New Criteria below
trans-1,2-Dichloroethylene	156605	See New Criteria below	See New Criteria below
1,2-Dichloropropane	78875	0.13	0.42
1,3-Dichloropropene	542756	0.21	2.9
Ethyl benzene	100414	53	290
Ethylene dibromide (EDB)	106934	0.0028	0.038
Methyl-tert-butyl-ether	1634044	160	190 ⁽³⁾
Methyl isobutyl ketone	108101	37	200
Methylene chloride	75092	3 ⁽²⁾	17
Styrene	100425	52	290

Table 1
(Continued)

Proposed Target Indoor Air Concentrations

Compound	CAS Number	Residential TAC (ug/m³)	Industrial/Commercial TAC (ug/m³)
1,1,1,2-Tetrachloroethane	630206	0.082	1.1
1,1,2,2-Tetrachloroethane	79345	0.011	0.14
Tetrachloroethylene	127184	5 ⁽²⁾	5 ⁽²⁾
Toluene	108883	210	500 ⁽¹⁾
1,1,1 Trichloroethane	71556	500	500 ⁽¹⁾
1,1,2-Trichloroethane	79005	2.2	12
Trichloroethylene	79016	1 ⁽²⁾	1 ⁽²⁾
Vinyl chloride	75014	0.14	1.9
Xylenes	1330207	220	500 ⁽¹⁾
New Criteria			
Trichlorofluoromethane	75694	370	500 ⁽¹⁾
Chloroethane	75003	500 ⁽¹⁾	500 ⁽¹⁾
Chloromethane	74873	14	80
Dichlorodifluoromethane	75718	91	500 ⁽¹⁾
Isopropylbenzene (Cumene)	98828	120 ⁽³⁾	120 ⁽³⁾
cis-1,2-dichloroethene	156592	18	100
trans-1,2-dichloroethene	156605	37	200
Bromodichloromethane	75274	0.034	0.46
N-butylbenzene	104518	73	410
Sec-butylbenzene	135988	73	410
1,2,4-trimethylbenzene	95636	9.3	52
1,3,5-trimethylbenzene	108678	9.3	52
4-isopropyltoluene (4-cymene)	99876	67	370

⁽¹⁾ Based on a ceiling value. ⁽²⁾ Based on a background concentration.

⁽³⁾ Based on an odor threshold concentration.

Table 2**Proposed Ground Water Volatilization Criteria**

Compound	CAS Number	Residential GWVC (ug/L)	Industrial/Commercial GWVC (ug/L)
Acetone	67641	50000	50000
Acrylonitrile	107131	NA	NA
Benzene	71432	130	310
Bromoform	75252	75	2300
2-Butanone (MEK)	78933	50000	50000
Carbon tetrachloride	56235	5.3	14
Chlorobenzene	108907	1800	23000
Chloroform	67663	26	62
Dibromochloromethane	124481	NA	NA
1,2-Dichlorobenzene	95501	5100	50000
1,3-Dichlorobenzene	541731	4300	50000
1,4-Dichlorobenzene	106467	1400	3400
1,1-Dichloroethane	75343	3000	41000
1,2-Dichloroethane	107062	6.5	68
1,1-Dichloroethylene	75354	190	920
cis-1,2-Dichloroethylene	156592	See New Criteria below	See New Criteria below
trans-1,2-Dichloroethylene	156605	See New Criteria below	See New Criteria below
1,2-Dichloropropane	78875	7.4	58
1,3-Dichloropropene	542756	11	360
Ethyl benzene	100414	2700	36000
Ethylene dibromide (EDB)	106934	0.3	11
Methyl-tert-butyl-ether	1634044	21000	50000
Methyl isobutyl ketone	108101	13000	50000
Methylene chloride	75092	160	2200
Styrene	100425	3100	42000

Table 2
(Continued)

Proposed Ground Water Volatilization Criteria

Compound	CAS Number	Residential GWVC (ug/L)	Industrial/Commercial GWVC (ug/L)
1,1,1,2-Tetrachloroethane	630206	2	64
1,1,2,2-Tetrachloroethane	79345	1.8	54
Tetrachloroethylene	127184	340	810
Toluene	108883	7100	41000
1,1,1 Trichloroethane	71556	6500	16000
1,1,2-Trichloroethane	79005	220	2900
Trichloroethylene	79016	27	67
Vinyl chloride	75014	1.6	52
Xylenes	1330207	8700	48000
New Criteria			
Trichlorofluoromethane	75694	1300	4200
Chloroethane	75003	12000	29000
Chloromethane	74873	390	5500
Dichlorodiflouromethane	75718	93	1200
Isopropylbenzene (Cumene)	98828	2800	6800
Cis-1,2-dichloroethene	156592	830	11000
trans-1,2-dichloroethene	156605	1000	13000
Bromodichloromethane	75274	2.3	73
N-butylbenzene	104518	1500	21000
Sec-butylbenzene	135988	1500	20000
1,2,4-trimethylbenzene	95636	360	4800
1,3,5-trimethylbenzene	108678	280	3900
4-isopropyltoluene (4-cymene)	99876	1600	22000

Table 3**Proposed Soil Vapor Volatilization Criteria**

Compound	CAS Number	Residential SVVC (ppm)	Industrial/Commercial SVVC (ppm)
Acetone	67641	57	290
Acrylonitrile	107131	NA	NA
Benzene	71432	0.78	1.4
Bromoform	75252	0.04	0.98
2-Butanone (MEK)	78933	130	230
Carbon tetrachloride	56235	0.06	0.12
Chlorobenzene	108907	6.1	60
Chloroform	67663	0.078	0.14
Dibromochloromethane	124481	NA	NA
1,2-Dichlorobenzene	95501	9.2	95
1,3-Dichlorobenzene	541731	9.2	95
1,4-Dichlorobenzene	106467	3	5.5
1,1-Dichloroethane	75343	14	150
1,2-Dichloroethane	107062	0.013	0.11
1,1-Dichloroethylene	75354	1.9	7
cis-1,2-Dichloroethylene	156592	See New Criteria below	See New Criteria below
trans-1,2-Dichloroethylene	156605	See New Criteria below	See New Criteria below
1,2-Dichloropropane	78875	0.021	0.13
1,3-Dichloropropene	542756	0.035	0.89
Ethyl benzene	100414	9.3	93
Ethylene dibromide (EDB)	106934	0.0005	0.007
Methyl-tert-butyl-ether	1634044	34	73
Methyl isobutyl ketone	108101	6.8	68
Methylene chloride	75092	0.65	6.8
Styrene	100425	9.3	95

Table 3
(Continued)

Proposed Soil Vapor Volatilization Criteria

Compound	CAS Number	Residential SVVC (ppm)	Industrial/Commercial SVVC (ppm)
1,1,1,2-Tetrachloroethane	630206	0.009	0.22
1,1,2,2-Tetrachloroethane	79345	0.0012	0.028
Tetrachloroethylene	127184	0.56	1
Toluene	108883	42	180
1,1,1 Trichloroethane	71556	70	130
1,1,2-Trichloroethane	79005	0.31	3.1
Trichloroethylene	79016	0.14	0.26
Vinyl chloride	75014	0.041	1
Xylenes	1330207	38	160
New Criteria			
Trichlorofluoromethane	75694	50	120
Chloroethane	75003	140	260
Chloromethane	74873	5.1	53
Dichlorodifluoromethane	75718	14	140
Isopropylbenzene (Cumene)	98828	19	34
Cis-1,2-dichloroethene	156592	3.4	35
trans-1,2-dichloroethene	156605	7.1	70
Bromodichloromethane	75274	0.0038	0.095
N-butylbenzene	104518	10	100
Sec-butylbenzene	135988	10	100
1,2,4-trimethylbenzene	95636	1.4	15
1,3,5-trimethylbenzene	108678	1.4	15
4-isopropyltoluene (4-cymene)	99876	9.3	94

Appendix A

Johnson and Ettinger Model

APPENDIX A

JOHNSON AND ETTINGER MODEL

The revised Johnson and Ettinger model incorporates both diffusion and advection as mechanisms of transport of subsurface contamination into indoor air environment. Diffusion is the mechanism by which vapor moves from a region of higher concentration to a region of lower concentration. Diffusion is typically the vertical component of transport in this model. Advection is the transport mechanism by which vapor moves to a region where there is a difference in pressure, temperature or other factor. This Johnson and Ettinger model is the most widely used vapor transport model across the United States.

The Johnson and Ettinger model uses the conservation of mass principle and makes the following assumptions:

- Steady state conditions exist
- An infinite source of contamination exists
- The subsurface is homogeneous
- Air mixing in the building is uniform
- Preferential pathways do not exist
- Biodegradation (or any other transformation process) does not occur
- Contaminants are homogeneously distributed
- Contaminant vapors enter a building primarily through cracks and other openings in the foundation and walls
- Ventilation rates and pressure differences are assumed to remain constant

The output of the Johnson and Ettinger model is the dimensionless attenuation factor (α) that represents the ratio of the indoor air concentration to the vapor concentration at a subsurface source. Using the attenuation factor and the recommended target indoor air concentrations, allowable soil vapor and ground water concentrations were back calculated. These concentrations are the recommended volatilization criteria. The Connecticut Department of Public Health recommended appropriate target indoor air concentrations for residential and industrial/commercial scenarios.

- For ground water volatilization criteria:

$$\text{GWVC (ug/L)} = \text{Target Indoor Air Concentration (}\mu\text{g/m}^3\text{)} / (1000 \text{ L/m}^3 \times \alpha \times H)$$

where H = Henry's Law Constant (unitless)

- For soil vapor volatilization criteria:

$$\text{SVVC (mg/m}^3\text{)} = \text{Target Indoor Air Concentration (}\mu\text{g/m}^3\text{)} / (1000 \mu\text{g/mg} \times \alpha)$$

$$\text{SVVC (ppm)} = \text{SVVC (mg/m}^3\text{)} \times 24.45 / \text{Molecular Weight}$$

where 24.45 = molar volume in liters at 760 torr barometric pressure at 25 ° C

The Johnson and Ettinger model calculates the attenuation factor as follows:

Attenuation Factor for Diffusion and Advection –

$$\alpha = (A \times e^B) / [e^B + A + (A/C)(e^B - 1)]$$

where:

$$A = (D_{T}^{eff} A_B) / (Q_B L_T) \text{ or } (D_{T}^{eff}) / (E_B (V_B/A_B) L_T)$$

$$B = (Q_{soil} L_{crack}) / (D_{crack}^{eff} \eta A_B) \text{ or } [(Q_{soil}/Q_b) E_B (V_B/A_B) L_{crack}] / [D_{crack}^{eff} \eta]$$

$$C = Q_{soil}/Q_B$$

where:

$$D_{T}^{eff} = L_T / [(L_{vadose}/D_{vadose}^{eff}) + (L_{cap}/D_{cap}^{eff})]$$

$$D_{crack}^{eff} = D^{air} (\theta_{V-crack}^{3.33}/\theta_{T-crack}^2) + (D^{water}/H) (\theta_{m-crack}^{3.33}/\theta_{T-crack}^2)$$

where:

$$D_{vadose}^{eff} = D^{air} (\theta_{V-vadose}^{3.33}/\theta_{T-vadose}^2) + (D^{water}/H) (\theta_{m-vadose}^{3.33}/\theta_{T-vadose}^2)$$

$$D_{cap}^{eff} = D^{air} (\theta_{V-cap}^{3.33}/\theta_{T-cap}^2) + (D^{water}/H) (\theta_{m-cap}^{3.33}/\theta_{T-cap}^2)$$

The input values for these equations are defined in Tables A1 and A2 of this Appendix. Conservative default values for each input variable were used to calculate the generic volatilization criteria listed in Tables 2 and 3. The acceptable ranges for these default values are presented in Table A3 along with the default input values used by CTDEP to calculate the generic criteria. In addition, Table A4 presents molecular weights and Henry's Law Constants (H) used by CTDEP.

Basically the input values describe the vapor transport pathway including the

- subsurface soils and stratigraphy;
- foundation of the structure;
- interior environment of the structure; and
- transport properties of the contaminants.

The subsurface soils are assumed to be sand and the stratigraphy is assumed to be homogeneous. The default input values for the moisture content (θ_m) and vapor content (θ_v) of the soils in both the vadose zone and the capillary fringe were chosen to represent sandy soils in the subsurface. The thickness of the capillary fringe (L_{cap}) is also based on an estimated thickness of capillary fringe for a typical sand. The default input values used for the total depth (L_T) to groundwater and the total depth to a soil vapor sample are 3 meters and 1 meter, respectively.

The default values used to describe the foundation of the building are the thickness of the foundation (L_{crack}) assumed at 0.15 meters and the areal fraction of cracks in foundation (η) assumed at 0.01 (worst case value). Also, the soil properties of the soil in the cracks (θ_m and θ_v) are estimated based on a sand soil type. The default values used to describe the indoor

environment are the enclosed space air exchange rate (E_B), the volume of the building divided by the area of the building (or just the height of the building) (V_B/A_B) and the ratio of soil gas intrusion rate to the building ventilation rate (Q_{soil}/Q_B). These values differ for the residential scenario and the industrial commercial scenario.

The default values used describe the transport properties of the contaminants are Henry's Law Constants (H) listed for specific chemical on Table A4, and the diffusion in water (D^{water}) and the diffusion in air (D^{air}). Though the diffusion rates can be chemical-specific, a general diffusion rates in air ($8.64 \times 10^{-5} \text{ M}^2/\text{d}$) and in water ($7.26 \times 10^{-1} \text{ M}^2/\text{d}$) were used for all of the chemicals.

All of the default input values used in this current model were also used in the original model with the exception of the ratio Q_{soil}/Q_B . This ratio was not part of the original model. The default input value used for Q_{soil}/Q_B is also the default value used in USEPA's "Guidance of reevaluating the Vapor Intrusion into Indoor Air" dated November 2002. The default input values used in the original model remain unchanged. The default values are those recommended by ASTM 38-94 in Tables X2.4 and X2.5.

The article written by Johnson titled "Identification of Critical Parameters for the Johnson and Ettinger (1991) Vapor Intrusion Model" dated May 2002 provides additional information regarding the input values and the sensitivity of the final attenuation factor to various input values.

The attenuation factors used to calculate the proposed revised criteria are based on the default input values listed in Table A3 and the revised Johnson and Ettinger model. In general, the attenuation factors used to calculate the proposed revised criteria are greater than the attenuation factors used to calculate the original criteria in 1996. For the ground water scenario, the attenuation factor increased by a multiple of approximately 2.5, from about 8×10^{-5} to 2×10^{-4} for the residential scenario and from 3×10^{-5} to 7×10^{-5} for the industrial/commercial scenario. For the soil vapor scenario, the attenuation factor increased by a multiple of approximately 10, from about 1.5×10^{-4} to 1.3×10^{-3} for residential the scenario and from 6×10^{-5} to 7×10^{-4} for the industrial/commercial scenario. The revised Johnson and Ettinger model produces a more conservative attenuation factor compared to the original model.

Table A1
Definition of Variables

	Definition	Units
H	Chemical Specific Henry's Law constant	$\mu\text{g}/\text{m}^3\text{-vapor} / \mu\text{g}/\text{m}^3\text{-H}_2\text{O}$
$\theta_{\text{m-vadose}}$	Volumetric Moisture Content in Vadose Zone	$\text{m}^3\text{-H}_2\text{O} / \text{m}^3\text{-soil}$
$\theta_{\text{T-vadose}}$	Total Porosity in Vadose Zone	$\text{m}^3\text{-voids} / \text{m}^3\text{-soil}$
$\theta_{\text{m-crack}}$	Volumetric Moisture Content in Cracks	$\text{m}^3\text{-H}_2\text{O} / \text{m}^3\text{-soil}$
$\theta_{\text{T-crack}}$	Total Porosity in Cracks	$\text{m}^3\text{-voids} / \text{m}^3\text{-soil}$
$\theta_{\text{m-cap}}$	Volumetric Moisture Content in Cracks in Capillary Fringe	$\text{m}^3\text{-H}_2\text{O} / \text{m}^3\text{-soil}$
$\theta_{\text{T-cap}}$	Total Porosity in Capillary Fringe	$\text{m}^3\text{-voids} / \text{m}^3\text{-soil}$
D^{air}	Chemical Specific Molecular Diffusion Coefficient in Air	m^2 / d
D^{water}	Chemical Specific Molecular Diffusion Coefficient in Water	m^2 / d
K	Soil Permeability (near foundation) to Air Flow	m^2
ΔP	Indoor-Outdoor Air Pressure Difference	g / ms^2
X_{crack}	Total Length of Cracks through which Soil Gas Vapors are Flowing	m
μ	Viscosity of Air	g / ms
Z_{crack}	Crack Opening Depth Below Grade	m
η	Fraction of Enclosed Space Area Open for Vapor Intrusion	m^2 / m^2
A_{B}	Surface Area of the Enclosed Space in Contact with Soil	m^2
V_{B}	Enclosed Space Volume	m^3
E_{B}	Enclosed Space Air Exchange Rate	1/d
L_{T}	Depth from Foundation to Source	m
L_{cap}	Thickness of Capillary Fringe	m
L_{crack}	Foundation Thickness	m

Table A2

Calculated Variables

	Definition	Calculation	Units
V_B/A_B	Ratio of Enclosed Space Volume to Exposed Surface Area		m
Q_B	Enclosed Space Volumetric Air Flow Rate	$= V_B E_B$	m^3 / d
R_{crack}	Effective Crack Radius or Width	$= \eta A_B / X_{crack}$	m
$\theta_{V-vadose}$	Volumetric Vapor Content in Vadose Zone	$= \theta_{T-vadose} - \theta_{m-vadose}$	$m^3\text{-vapor} / m^3\text{-soil}$
$\theta_{V-crack}$	Volumetric Vapor Content in Cracks	$= \theta_{T-crack} - \theta_{m-crack}$	$m^3\text{-vapor} / m^3\text{-soil}$
θ_{V-cap}	Volumetric Vapor Content in Capillary Fringe	$= \theta_{T-cap} - \theta_{m-cap}$	$m^3\text{-vapor} / m^3\text{-soil}$
Q_{soil}	Pressure Driven Soil Gas Flow Rate from the subsurface into the enclosed space	$= (2\pi k \Delta P X_{crack}) / [\mu \ln(2Z_{crack}/R_{crack})]$	m^3 / d
Q_{soil}/Q_B	Ratio of Soil Gas Intrusion Rate to Building Ventilation Rate		unitless
D^{water}/D^{air}	Ratio of Molecular Diffusion in water to air		unitless
L_{vadose}	Thickness of Vadose Zone	$= L_T - L_{cap}$	m

Table A3

Default Input Values

	Units	Typical Value Range ⁽¹⁾	Notes	Res GWVC	I/C GWVC	Res SVVC	I/C SVVC
H	$\mu\text{g}/\text{m}^3\text{-vapor} / \mu\text{g}/\text{m}^3\text{-H}_2\text{O}$	0.01 - 1.0	For most aromatic & chlorinated solvents	---	---	---	---
$\theta_{\text{m-vadose}}$	$\text{m}^3\text{-H}_2\text{O} / \text{m}^3\text{-soil}$		ASTM default value. Typical for sand.	0.12	0.12	0.12	0.12
$\theta_{\text{T-vadose}}$	$\text{m}^3\text{-voids} / \text{m}^3\text{-soil}$		ASTM default value. Typical for sand.	0.38	0.38	0.38	0.38
$\theta_{\text{m-crack}}$	$\text{m}^3\text{-H}_2\text{O} / \text{m}^3\text{-soil}$		ASTM default value. Typical for sand.	0.12	0.12	0.12	0.12
$\theta_{\text{T-crack}}$	$\text{m}^3\text{-voids} / \text{m}^3\text{-soil}$		ASTM default value. Typical for sand.	0.38	0.38	0.38	0.38
$\theta_{\text{m-cap}}$	$\text{m}^3\text{-H}_2\text{O} / \text{m}^3\text{-soil}$		ASTM default value. Typical for sand.	0.342	0.342	0.342	0.342
$\theta_{\text{T-cap}}$	$\text{m}^3\text{-voids} / \text{m}^3\text{-soil}$		ASTM default value. Typical for sand.	0.38	0.38	0.38	0.38
D^{air}	M^2 / d	0.1 - 1	For most chemicals	7.26E-01	7.26E-01	7.26E-01	7.26E-01
D^{water}	M^2 / d			8.64E-05	8.64E-05	8.64E-05	8.64E-05
k	m^2	1E-6 - 1E-12					
ΔP	g / ms^2	0 - 200	or 0 to 20 Pascals				
X_{crack}	m						
μ	g / ms						
Z_{crack}	m						
η	m^2 / m^2	0.0005 - 0.005	ASTM default value. 0.01 for worst-case scenario.	0.01	0.01	0.01	0.01
A_B	m^2						
V_B	m^3	147 - 672	Range from USDOE (1995)				
E_B	1/d	4.8 - 24	ASTM default values. 12 for Residential scenario and 19.9 for Industrial/Commercial scenario.	12	19.9	12	19.9
L_T	m	0.01 - 50	ASTM default values. 3 for Groundwater criteria and 1 for Soil Vapor criteria.	3	3	1	1
L_{cap}	m		ASTM default values. 0.05 for Groundwater criteria and 0 for Soil Vapor criteria.	0.05	0.05	0	0
L_{crack}	m	0.15 - 0.5	ASTM default value.	0.15	0.15	0.15	0.15

Table A3
(continued)

Default Input Values

	Units	Typical Value Range ⁽¹⁾	Notes	Res GWVC	I/C GWVC	Res SVVC	I/C SVVC
V_B/A_B	m	2 - 3	ASTM default values. 2 for Residential scenario and 3 for Industrial/Commercial scenario.	2	3	2	3
Q_B	m ³ / d						
R_{crack}	m						
$\theta_{V-vadose}$	m ³ -vapor / m ³ -soil		ASTM default value. Typical for sand.	0.26	0.26	0.26	0.26
$\theta_{V-crack}$	m ³ -vapor / m ³ -soil		ASTM default value. Typical for sand.	0.26	0.26	0.26	0.26
θ_{V-cap}	m ³ -vapor / m ³ -soil		ASTM default value. Typical for sand.	0.038	0.038	0.038	0.038
Q_{soil}	m ³ / d						
Q_{soil}/Q_B	unitless	0.0001 – 0.05	EPA Vapor Intrusion Guidance default value.	0.003	0.003	0.003	0.003
D^{water}/D^{air}	unitless	~ 1E-4		1.19E-04	1.19E-04	1.19E-04	1.19E-04
L_{vadose}	m		ASTM default value. 2.95 for Groundwater criteria and 1 for Soil Vapor criteria.	2.95	2.95	1	1

⁽¹⁾ Johnson, (2002), *Identification of Critical Parameters for the Johnson and Ettinger (1991) Vapor Intrusion Model*, API Bulletin #17, May.

Table A4

Henry's Law Constants and Molecular Weights

Compound	CAS Number	Henry's Law Constant (unitless)	Molecular Weight (g/mole)
Acetone	67641	1.75E-03	58
Acrylonitrile	107131		
Benzene	71432	2.26E-01	78
Bromoform	75252	2.18E-02	253
2-Butanone (MEK)	78933	1.12E-03	72
Carbon tetrachloride	56235	1.20E+00	154
Chlorobenzene	108907	1.61E-01	113
Chloroform	67663	1.39E-01	119
Dibromochloromethane	124481		
1,2-Dichlorobenzene	95501	7.95E-02	147
1,3-Dichlorobenzene	541731	1.08E-01	147
1,4-Dichlorobenzene	106467	1.12E-01	147
1,1-Dichloroethane	75343	2.23E-01	99
1,2-Dichloroethane	107062	4.51E-02	99
1,1-Dichloroethylene	75354	6.11E-01	97
cis-1,2-Dichloroethylene	156592	See listing below	See listing below
trans-1,2-Dichloroethylene	156605	See listing below	See listing below
1,2-Dichloropropane	78875	1.16E-01	113
1,3-Dichloropropene	542756	1.44E-01	111
Ethyl benzene	100414	1.41E-01	106
Ethylene dibromide (EDB)	106934	2.76E-02	188
Methyl-tert-butyl-ether	1634044	2.42E-02	88
Methyl isobutyl ketone	108101	5.66E-03	100
Methylene chloride	75092	1.31E-01	85
Styrene	100425	1.07E-01	104

Table A4
(Continued)

Henry's Law Constants and Molecular Weights

Compound	CAS Number	Henry's Law Constant (unitless)	Molecular Weight (g/mole)
1,1,1,2-Tetrachloroethane	630206	4.51E-01	168
1,1,2,2-Tetrachloroethane	79345	1.56E-02	168
Tetrachloroethylene	127184	8.36E-02	166
Toluene	108883	2.74E-01	92
1,1,1 Trichloroethane	71556	9.47E-01	133
1,1,2-Trichloroethane	79005	3.73E-02	133
Trichloroethylene	79016	3.74E-01	131
Vinyl chloride	75014	1.14E+00	63
Xylenes	1330207	2.16E-01	106
New Criteria			
Trichlorofluoromethane	75694	4.00E+00	137
Chloroethane	75003	4.50E-01	65
Chloromethane	74873	3.60E-01	51
Dichlorodifluoromethane	75718	1.40E+01	121
Isopropylbenzene (Cumene)	98828	4.70E-01	120
Cis-1,2-dichloroethene	156592	1.70E-01	97
trans-1,2-dichloroethene	156605	3.80E-01	97
Bromodichloromethane	75274	8.70E-02	164
N-butylbenzene	104518	5.24E-01	134
Sec-butylbenzene	135988	5.68E-01	134
1,2,4-trimethylbenzene	95636	2.30E-01	120
1,3,5-trimethylbenzene	108678	3.20E-01	120
4-isopropyltoluene (4-cymene)	99876	4.51E-01	134

Appendix B

Derivation of Target Indoor Air Concentrations

APPENDIX B

DERIVATION OF TARGET INDOOR AIR CONCENTRATIONS

This Appendix presents the derivation of target indoor air concentrations (TACs) for the volatile organic compounds (VOCs) listed in the existing Remediation Standard Regulations (RSR) volatilization criteria, together with TACs for 13 additional VOCs not previously listed. These additional VOCs though not originally listed, have appeared in groundwater and/or soil gas at sites in Connecticut. This Appendix includes two tables that list the TACs and the underlying toxicity values, modifying factors and background considerations. The following is a brief overview of the risk-based derivation methodology followed by the specific approaches used for the residential and industrial/commercial scenarios.

General TAC Methodology

TACs are air concentrations within homes or workplaces that are not expected to cause adverse health effects from chronic exposure. TACs rely upon chemical-specific toxicity values that describe the VOC's potency in terms of: 1) the reference concentration (RfC) - air concentration which will be free of risk for non-cancer health effects from chronic exposure; or 2) the unit risk factor – potency of VOC to produce carcinogenic effects per microgram per cubic meter ($\mu\text{g}/\text{m}^3$) of air chronically inhaled. These toxicity values are typically derived by USEPA from studies in which laboratory animals were exposed for chronic periods, with the toxic response based upon continuous exposure (24 hours per day (hr/d), every day of the year). Therefore, these targets need modification for exposure scenarios in which less than continuous exposure is likely (e.g., the industrial/commercial scenario). The TACs are set such that the lifetime cancer risk is at the de minimis risk level (one in a million or $1\text{E}-06$) and the hazard index (TAC/RfC_m where RfC_m is the RfC modified for the time-weight averaged amount of exposure in the specific scenario) for non-carcinogens is equal to unity.

While USEPA's Integrated Risk Information System (IRIS) database is the primary source of toxicology information for TAC development, other toxicology databases are also recognized as having well documented and widely used toxicity values. These include the Agency for Toxic Substances and Disease Registry (ATSDR)'s chronic Minimum Risk Levels (MRLs), California EPA's chronic Reference Exposure Levels (RELs) and USEPA's Health Effects Assessment Summary Tables (HEAST). In cases where a toxicity value was not available on IRIS, the value was sought from these other data sources. If still no value could be found, CTDPH conducted its own chemical-specific risk assessment. In certain cases, USEPA has listed provisional toxicity values that rely upon the best available science currently available, but these values may be somewhat more uncertain and are not supported by USEPA to the same extent as those values on IRIS. CTDPH has examined the basis for these particular values closely and, in isolated cases, has made adjustments.

A number of VOCs in the TAC list are possible rather than proven animal carcinogens, or, if proven, their cancer mechanism has uncertain relevance to low dose exposures in humans. These types of carcinogens were labeled as Group C carcinogens in USEPA's former cancer guidelines and are considered as Class 3 agents by IARC. Their carcinogenicity database is either too uncertain or incomplete to allow an extrapolation of risk to low dose human exposures. Rather than applying the classical low dose linear approach on the one hand, or ignoring their carcinogenic potential on the other, this derivation lowers the RfC by an uncertainty factor to account for this potential hazard. This approach is consistent with that developed by USEPA's Office of Drinking Water to establish Maximum Contaminant Levels

(MCLs). The default cancer uncertainty factor is 10 fold, although 3.33 fold (one half log lower) was used in cases where the uncertainty already built into the RfC was large (1000 fold or greater); this reduction in the cancer uncertainty factor was used to keep the overall uncertainty factor to less than 10,000.

In several cases toxicity values were available for the oral but not inhalation dose route. A dose route extrapolation to convert from the reference dose (in mg/kg/d) to RfC ($\mu\text{g}/\text{m}^3$) was used as long as the target site was not local to the site of bodily entry, but rather was at a systemic location (i.e., internal organs or systems).

The following are the general equations for the derivation of TACs. These equations and most of the parameter value inputs have not changed since the setting of the 1996 RSRs

For carcinogenic effects:
$$\text{TAC} = \frac{\text{TR} \times \text{BW} \times \text{AT}_c \times 365 \text{ d/yr} \times 10^3 \mu\text{g}/\text{mg}}{\text{Sf}_i \times \text{IR}_{\text{air}} \times \text{EF} \times \text{ED}}$$

For non-carcinogenic effects:
$$\text{TAC} = \frac{\text{THQ} \times \text{BW} \times \text{RfD}_i \times \text{AT}_n \times 365 \text{ d/yr} \times 10^3 \mu\text{g}/\text{mg}}{\text{IR}_{\text{air}} \times \text{EF} \times \text{ED}}$$

- where:
- AT_c = averaging time for carcinogens, years
Use $\text{AT}_c = 70$ years
 - AT_n = averaging time for non-carcinogens, years
For residential use $\text{AT}_n = 30$ years
For commercial/industrial use $\text{AT}_n = 25$ years
 - BW = adult body weight, kg
Use $\text{BW} = 70$ kg
 - ED = exposure duration, years
For residential use $\text{ED} = 30$ years
For commercial/industrial use $\text{ED} = 25$ years
 - EF = exposure frequency, days/years
For residential use $\text{EF} = 350$ days/year
For commercial/industrial use $\text{EF} = 250$ days/year
 - IR_{air} = daily indoor inhalation rate, m^3/day
For residential use $\text{IR}_{\text{air}} = 20 \text{ m}^3/\text{day}$
For commercial/industrial use $\text{IR}_{\text{air}} = 10 \text{ m}^3/\text{day}$
 - TAC = target indoor air concentration, $\mu\text{g}/\text{m}^3$ -air
 - RfD_i = inhalation chronic reference dose, $\text{mg}/\text{kg}\text{-day}$
Use numbers from IRIS and/or HEAST and/or other sources.
 - SF_i = inhalation cancer slope factor, $\text{kg}\text{-day}/\text{mg}$
Use numbers from IRIS and/or HEAST and/or other sources.
 - THQ = target hazard quotient for individual constituents, dimensionless
Use $\text{THQ} = 1$
 - TR = target excess individual lifetime cancer risk, dimensionless
Use $\text{TR} = 1 \times 10^{-6}$

Modifications to the Residential Scenario

The exposure assumptions shown in the equations above pertain to adults (70 kg body weight, 20 m³/d inhalation rate). However, young children inhale more air per body weight and respiratory surface area than do adults (Child-Specific Exposure Factors Handbook, USEPA, 2000; Thurlbeck, 1982). This is an especially important consideration with regards to VOCs that can cause respiratory irritation and thus have the potential to exacerbate asthma due to the local dose in the lung. However, it also applies to systemic toxicants. The child/adult dose differential from inhalation exposure is approximately 2 fold over the first six years of life (e.g., at 1 year of age: 4.5 m³/d inhalation rate for 7.4 kg body weight for an inhalation rate/body weight ratio that is 2.1 fold larger than the adult assumption). Thus, the systemic and local respiratory tract dose to young children can be assumed to be approximately 2 fold larger than in adults for a significant portion of childhood. Since young children may be more generally sensitive to toxicants (many systems are immature and rapidly developing - Faustman, 2000), the potential importance of this exposure differential is accentuated. Thus, to be protective of children as potentially the most highly exposed and sensitive group, the residential TACs are adjusted by a 2 fold factor that corresponds with the greater inhalation exposure rate in children.

Children's increased vulnerability to toxicants has perhaps been best characterized in the area of carcinogenic risk. Standard cancer bioassays from which most unit risk values are derived, begin chemical administration when rodents are 4-6 weeks of age. At this age the animals are sexually mature and growth is not as rapid as in juvenile animals. Thus, this type of cancer study misses a potentially important vulnerability window. In fact, numerous cancer studies in which rodents were dosed beginning in early life demonstrate considerably greater potency in the neonatal period than at older ages (Vesselinovitch, et al., 1979; Toth, 1968; Maltoni, et al., 1981).

The reason for this greater susceptibility likely stems from the greater time period for expression of cancer when testing begins earlier in life, and because rapidly dividing tissues are more sensitive to genotoxicants (Laib, et al., 1985, Anderson, 2000). These issues have recently been summarized in a publication by CTDPH (Ginsberg, 2003) and by USEPA in their draft revisions to the cancer risk assessment guidelines (USEPA, 2003). The case of vinyl chloride sensitivity in early life stages has been evaluated closely by USEPA to support their recent revision to the vinyl chloride IRIS file (USEPA, 2000). That assessment showed that brief exposures in early life produced a cancer response later in life that was roughly equivalent to what would be seen from an adult-only (lifetime) exposure. On that basis, the IRIS file recommends that the unit risk factor for vinyl chloride derived for adults be doubled if there will be long-term exposure that will include children. Analysis of other juvenile animal bioassays indicates that this also appears to be true for a wide variety of chemicals, particularly those with a genotoxic mode of action (Ginsberg, 2003; USEPA, 2003). For this reason, the revised TACs for genotoxic carcinogens have an adjustment factor (2 fold lowering of TAC) to account for the greater sensitivity of early life stages (Ginsberg, 2003; USEPA, 2003).

In summary, the residential scenario includes a 2 fold adjustment factor for children's increased inhalation exposure rate relative to adults, and a 2 fold adjustment factor for children's increased sensitivity when exposed to genotoxic carcinogens. In this latter case, the combined children's adjustment factor is 4 fold. This approach is consistent with USEPA's IRIS file for vinyl chloride and draft Cancer Risk Assessment Guidelines. The Table B1 shows the use of these factors in deriving TACs.

Industrial/Commercial TAC Calculations

The industrial/commercial scenario is simpler than the residential scenario in that it only involves adults. The exposure parameters shown above for this scenario indicate that relative to the assumptions that go into RfCs and cancer unit risk values, workers will be exposed to less inhaled contaminant due to fewer hours/day of exposure (8 instead of 24 hr), fewer days per year of exposure (250 instead of 365), and fewer total years of exposure (25 instead of 70). The shorter hours per day of worker exposure is partially compensated for by the higher breathing rate workers may have compared to the general public. This leads to the assumption that 50% of the day's inhalation volume occurs while at work. In setting TACs for the workplace it is appropriate to increase the RfC by a factor of 2 for inhalation rate (20m³/d vs. 10 m³/d) and by a factor of 1.46 for exposure days per year (365 vs. 250). This yields a combined workplace adjustment factor for RfCs of 2.92 (i.e., the workplace TAC can be 2.92 fold higher than the RfC). For carcinogens, the cumulative number of years is also part of the exposure calculation and so the 70/25 yr factor (2.8) is multiplied by 2.92 to yield a combined 8.176 adjustment factor. This factor is multiplied by the air concentration associated with de minimis risk for the general public to yield the air concentration corresponding to de minimus risk for workers. These exposure factors are in the Table B2 to show their use in deriving TACs for this scenario.

Ceiling TAC

The Tables B1 and B2 list a number of VOCs whose risk-based TAC is relatively high, a value that would allow gross contamination of indoor air. In these cases a ceiling value of 500 ug/m³ is used. The ceiling value is based upon datasets showing that individual VOC concentrations in buildings tend to average less than 500 ug/m³ across a broad array of building types and indoor air contaminants (Brown, et al., Indoor Air 4: 123-134, 1994). The 98th percentile value for these indoor air contaminants was highly variable but most values were between 50 and 1000 ug/m³, indicating that a level of 500 ug/m³ represents an upper bound concentration that stems from an unusual contamination source. Such high concentrations may contribute to decreases in air quality that are noticeable to building inhabitants (Otto, et al., 1990). Therefore, this ceiling value is a prudent default value that can be replaced when more specific information becomes available (e.g., odor threshold data), as indicated for several VOCs in this derivation.

Indoor Air Background Concentrations

Since 1996, there has been an increased focus around the United States on measuring indoor air quality in impacted and non-impacted (or "background") homes, offices, schools and other environments. This had led to an enhanced database for background indoor air data (Foster, et al., 2002; Kurtz and Folkes, 2002; NYSDOH, 1997; Clayton, et al., 1999; Shields, et al., 1996; Girman, et al. report of USEPA/BASE Study, 1999). These datasets, along with the pre-existing indoor air datasets (Stolwick, 1990; Vermont DOH, 1992; Brown, et al., 1994; Daisey, et al., 1994; Sheldon, et al., 1992; Shah and Singh, 1988) have been reviewed while giving particular attention to those VOCs (typically carcinogens) with risk-based TACs that are in the range where they may approach or are below what can be considered background. VOC indoor air measurements are typically lognormally distributed; therefore, the central tendency background concentration (the median) was chosen to represent background. While higher concentrations may be found in certain background locations, the central tendency was used because of the way it would be applied: 1) to replace a risk-based TAC such that the background concentration would already be above a risk target; and 2) to back-calculate the allowable contribution from subsurface VOC contamination, such that the amount that is from

background sources plus the amount allowed from subsurface sources would still be within the range of the background data distribution.

VOC background concentrations and how they are used in the derivation of TACs are shown chemical-by-chemical in Tables B1 and B2.

Table B1

Target Air Concentrations (TACs) for Residential Scenario (Page 1)

VOC	Toxicity Value ¹	Modifying Factors ²	Risk-Based TAC ⁴	Background	TAC
Acetone	IRIS RfD (0.1mg/kg-d) converted to RfC (350 ug/m ³)	2x CexpF	183 ug/m ³	--- ⁷	180 ug/m ³
Benzene	IRIS unit risk (8.3E-6/ug/m ³)	2x CexpF; 2x CsensF	0.07 ug/m ³	3.25 ug/m ³	3.3 ug/m ³
Bromoform	IRIS unit risk (1.1E-6/ug/m ³)	2x CexpF; 2x CsensF	2.2 ug/m ³	Not available	0.55 ug/m ³
2-Butanone (MEK)	IRIS RfC (1000 ug/m ³)	2x CexpF	520 ug/m ³	--- ⁷	500 ug/m ³ – C ³
Carbon Tetrachloride	IRIS unit risk (1.5E-5/ug/m ³)	2x CexpF; 2x CsensF	0.04 ug/m ³	0.5 ug/m ³	0.5 ug/m ³
Chlorobenzene	IRIS RfD (0.02 mg/kg-d) converted to RfC (70 ug/m ³)	2x CexpF	37 ug/m ³	--- ⁷	37 ug/m ³
Chloroform	IRIS unit risk (2.3E-5/ug/m ³)	2x CexpF	0.05 ug/m ³	0.5 ug/m ³	0.5 ug/m ³
1,2-Dichlorobenzene	HEAST RfC (140 ug/m ³)	2x CexpF	73 ug/m ³	--- ⁷	73 ug/m ³
1,3-Dichlorobenzene	Analogy with 1,2-DCB	2x CexpF	73 ug/m ³	--- ⁷	73 ug/m ³
1,4-Dichlorobenzene	EPA Provisional unit risk (6.3E-06/ug/m ³)	None – since provisional unit risk	0.39 ug/m ³	24 ug/m ³	24 ug/m ³
1,1-Dichloroethane	HEAST (“A”) RfC (490ug/m ³)	3.33x Cancer UF; 2x CexpF	77 ug/m ³	--- ⁷	77 ug/m ³
1,2-Dichloroethane	IRIS unit risk (2.6E-5/ug/m ³)	2x CexpF; 2x CsensF	0.023 ug/m ³	0.07 ug/m ³	0.07 ug/m ³
1,1-Dichloroethylene	CalEPA REL (70 ug/m ³); ATSDR MRL (80 ug/m ³)	10x Cancer UF	7 ug/m ³	<5 ug/m ³	10 ug/m ³
1,2-Dichloropropane	EPA provisional oral slope → unit risk (1.9E-05/ug/m ³)	None – since provisional unit risk	0.13 ug/m ³	Not available	0.13 ug/m ³
1,3-Dichloropropene	IRIS unit risk (2.9E-6/ug/m ³)	2x CexpF; 2x CsensF	0.21 ug/m ³	Not available	0.21 ug/m ³
Ethylbenzene	IRIS RfC (1000 ug/m ³)	10x Cancer UF; 2x CexpF	53 ug/m ³	<10 ug/m ³	53 ug/m ³
Ethylene dibromide	IRIS unit risk (2.2E-04)	2x CexpF; 2x CsensF	0.003 ug/m ³	Not available	0.0028 ug/m ³

Table B1**Target Air Concentrations (TACs) for Residential Scenario (Page 2)**

VOC	Toxicity Value¹	Modifying Factors²	Risk-Based TAC⁴	Background	TAC
Methyl-t-butyl ether	IRIS RfC (3000 ug/m ³)	10x Cancer UF; 2x CexpF	160 ug/m ³	--- ⁷	160 ug/m ³
Methyl isobutyl ketone	HEAST(A") RfC (70 ug/m ³)	2x CexpF	37 ug/m ³	--- ⁷	37 ug/m ³
Methylene chloride	IRIS unit risk (4.7E-07/ug/m ³)	2x CexpF	2.6 ug/m ³	3 ug/m ³	3 ug/m ³
Styrene	IRIS RfC (1000 ug/m ³)	10x Cancer UF; 2x CexpF	52 ug/m ³	--- ⁷	52 ug/m ³
1,1,1,2-Tetrachloroethane	IRIS unit risk (7.43E-06/ug/m ³)	2x CexpF; 2x CsensF	0.082 ug/m ³	Not available	0.082 ug/m ³
1,1,2,2-Tetrachloroethane	IRIS unit risk (5.7E-05/ug-m ³)	2x CexpF; 2x CsensF	0.01 ug/m ³	Not available	0.01 ug/m ³
Tetrachloroethylene (PERC)	CalEPA unit risk (5.9E-06/ug/m ³)	2x CexpF	0.21 ug/m ³	5 ug/m ³	5 ug/m ³
Toluene	IRIS RfC (400 ug/m ³)	2x CexpF	208 ug/m ³	--- ⁷	210 ug/m ³
1,1,1-Trichloroethane	CalEPA REL (1000 ug/m ³)	2x CexpF	520 ug/m ³	--- ⁷	500 ug/m ³ - C ³
1,1,2-Trichloroethane	IRIS RfD converted to RfC (14 ug/m ³)	3.33x Cancer UF; 2x CexpF	2.2 ug/m ³	0.03 ug/m ³	2.2 ug/m ³
Trichloroethylene	IRIS provisional unit risk (1.1E-04/ug/m ³)	2x CexpF; 2x CsensF	0.006 ug/m ³	1 ug/m ³	1 ug/m ³
Vinyl chloride	IRIS unit risk for early life + adult exposure (8.6E-06/ug/m ³)	2x CexpF	0.14 ug/m ³	0.01 ug/m ³	0.14 ug/m ³
Xylenes	ATSDR MRL (430 ug/m ³)	2x CexpF	220 ug/m ³	--- ⁷	220 ug/m ³
Trichlorofluoromethane	HEAST ("A")RfC (700 ug/m ³)	2x CexpF	365 ug/m ³	--- ⁷	370 ug/m ³

Table B1

Target Air Concentrations (TACs) for Residential Scenario (Page 3)

VOC	Toxicity Value¹	Modifying Factors²	Risk-Based TAC⁴	Background	TAC
Chloroethane	IRIS RfC (10,000 ug/m ³)	10x Cancer UF; 2x CexpF	520 ug/m ³	--- ⁷	500 ug/m ³ - C ³
Chloromethane	IRIS RfC (90 ug/m ³)	3.33x Cancer UF; 2x CexpF	14 ug/m ³	Not available	14 ug/m ³
Dichlorodifluoromethane	HEAST ("A")RfC (175 ug/m ³)	2x CexpF	91 ug/m ³	--- ⁷	91 ug/m ³
Isopropylbenzene (cumene)	IRIS RfC (385 ug/m ³)	2x CexpF	200 ug/m ³	--- ⁷	120 ug/m ³ (odor threshold)
cis-1,2-Dichloroethene	HEAST RfD → RfC (35 ug/m ³)	2x CexpF	18 ug/m ³	Not available	18 ug/m ³
trans-1,2-Dichloroethane	IRIS RfD → RfC (70 ug/m ³)	2x CexpF	37 ug/m ³	--- ⁷	37 ug/m ³
Bromodichloromethane	IRIS oral slope factor → unit risk (1.8E-05/ug/m ³)	2x CexpF; 2x CsensF	0.034 ug/m ³	Not available	0.034 ug/m ³
n-Butylbenzene	EPA provisional RfD → RfC (140 ug/m ³)	2x CexpF	73 ug/m ³	--- ⁷	73 ug/m ³
sec-Butylbenzene	EPA provisional RfD → RfC (140 ug/m ³)	2x CexpF	73 ug/m ³	--- ⁷	73 ug/m ³
1,2,4-Trimethylbenzene	EPA Provisional RfC (6 ug/m ³)	RfC ↑ed 3x ⁵ 2x CexpF	9 ug/m ³	Not available	9.3 ug/m ³
1,3,5Trimethylbenzene	EPA Provisional RfC (6 ug/m ³)	RfC ↑ed 3x ⁵ 2x CexpF	9 ug/m ³	Not available	9.3 ug/m ³
4-Isopropyltoluene	DPH risk assessment ⁶ yields RfC of 133 ug/m ³	2x CexpF	67 ug/m ³	--- ⁷	67 ug/m ³

Footnotes for Residential TAC Table B1

¹ Tox Value Notes: Values from IRIS, HEAST, CalEPA chronic RELs or ATSDR chronic MRLs; EPA provisional values have been derived by the agency but not fully documented or supported; HEAST "A" refers to values from Alternative Table within HEAST. Dose route extrapolation conducted when no inhalation tox value available and oral toxicity is to systemic sites.

² Modifying Factors: CexpF = children's exposure factor for increased respiratory rate per body wt and respiratory surface area;
CsensF = children's sensitivity factor for genotoxic carcinogens
Cancer UF = uncertainty factor for evidence of carcinogenicity but extrapolation to low dose uncertain.

³ "C" designation indicates ceiling value of 500 ug/m³.

⁴ TACs based upon de minimis (1 in a million) cancer risk or a hazard index of 1 for non-cancer effects.

⁵ EPA provisional RfC for 1,2,4- and 1,3,5-TMB have unnecessarily large uncertainty factors which drive very low RfC.

⁶ 4-Isopropyltoluene risk assessment based upon analogy with isopropylbenzene with evidence neurotoxicity as key endpoint (4-IPT 3x > potency than IPB).

⁷ Background concentration not sought since risk-based TAC is relatively high and unlikely to be in range of background.

Table B2

Target Air Concentrations (TACs) for Industrial/Commercial Scenario (Page 1)

VOC	Toxicity Value ¹	Modifying Factors ²	Risk-Based TAC ⁴	Background	TAC
Acetone	IRIS RfD (0.1mg-kg-d) converted to RfC (350 ug/m ³)	2.92 less worker exp.	1022 ug/m ³	--- ⁷	500 ug/m ³ – C ³
Benzene	IRIS unit risk (8.3E-6/ug/m ³)	8.176 less worker exp.	0.99 ug/m ³	3.25 ug/m ³	3.3 ug/m ³
Bromoform	IRIS unit risk (1.1E-6/ug/m ³)	8.176 less worker exp.	7.34 ug/m ³	Not available	7.3 ug/m ³
2-Butanone (MEK)	IRIS RfC (1000 ug/m ³)	2.92 less worker exp.	2900 ug/m ³	--- ⁷	500 ug/m ³ – C ³
Carbon Tetrachloride	IRIS unit risk (1.5E-5/ug/m ³)	8.176 less worker exp.	0.54 ug/m ³	0.5 ug/m ³	0.54 ug/m ³
Chlorobenzene	IRIS RfD (0.02 mg-kg-d) converted to RfC (70 ug/m ³)	2.92 less worker exp.	200 ug/m ³	--- ⁷	200 ug/m ³
Chloroform	IRIS unit risk (2.3E-5/ug/m ³)	8.176 less worker exp.	0.36 ug/m ³	0.5 ug/m ³	0.5 ug/m ³
1,2-Dichlorobenzene	HEAST RfC (140 ug/m ³)	2.92 less worker exp.	410 ug/m ³	--- ⁷	410 ug/m ³
1,3-Dichlorobenzene	Analogy with 1,2-DCB	2.92 less worker exp.	410 ug/m ³	--- ⁷	410 ug/m ³
1,4-Dichlorobenzene	EPA Provisional unit risk (6.3E-06/ug/m ³)	8.176 less worker exp.	1.3 ug/m ³	24 ug/m ³	24 ug/m ³
1,1-Dichloroethane	HEAST (“A”) RfC (490 ug/m ³)	3.33x Cancer UF; 2.92 less worker exp.	430 ug/m ³	--- ⁷	430 ug/m ³
1,2-Dichloroethane	IRIS unit risk (2.6E-5/ug/m ³)	8.176 less worker exp.	0.31 ug/m ³	0.07 ug/m ³	0.31 ug/m ³
1,1-Dichloroethylene	CalEPA REL (70 ug/m ³); ATSDR MRL (80 ug/m ³)	10x Cancer UF	20 ug/m ³	<5 ug/m ³	20 ug/m ³
1,2-Dichloropropane	EPA provisional oral slope → unit risk (1.9E-05/ug/m ³)	8.176 less worker exp.	0.42 ug/m ³	Not available	0.42 ug/m ³
1,3-Dichloropropene	IRIS unit risk (2.9E-6/ug/m ³)	8.176 less worker exp.	2.9 ug/m ³	Not available	2.9 ug/m ³
Ethylbenzene	IRIS RfC (1000 ug/m ³)	10x Cancer UF; 2.92 less worker exp.	290 ug/m ³	<10 ug/m ³	290 ug/m ³
Ethylene dibromide	IRIS unit risk (2.2E-04)	8.176 less worker exp.	0.038 ug/m ³	Not available	0.038 ug/m ³

Table B2

Target Air Concentrations (TACs) for Industrial/Commercial Scenario (Page 2)

VOC	Toxicity Value ¹	Modifying Factors ²	Risk-Based TAC ⁴	Background	TAC
Methyl-t-butyl ether	IRIS RfC (3000 ug/m ³)	10x Cancer UF; 2.92 less worker exp.	876 ug/m ³	--- ⁷	190 ug/m ³ (odor threshold)
Methyl isobutyl ketone	HEAST(A") RfC (70 ug/m ³)	2.92 less worker exp.	200 ug/m ³	--- ⁷	200 ug/m ³
Methylene chloride	IRIS unit risk (4.7E-07/ug/m ³)	8.176 less worker exp.	17 ug/m ³	3 ug/m ³	17 ug/m ³
Styrene	IRIS RfC (1000 ug/m ³)	10x Cancer UF; 2.92 less worker exp.	290 ug/m ³	--- ⁷	290 ug/m ³
1,1,1,2-Tetrachloroethane	IRIS unit risk (7.43E-06/ug-3)	8.176 less worker exp.	1.1 ug/m ³	Not available	1.1 ug/m ³
1,1,2,2-Tetrachloroethane	IRIS unit risk (5.7E-05/ug-m3)	8.176 less worker exp.	0.14 ug/m ³	Not available	0.14 ug/m ³
Tetrachloroethylene (PERC)	CalEPA unit risk (5.9E-06/ug/m ³)	8.176 less worker exp.	1.4 ug/m ³	5 ug/m ³	5 ug/m ³
Toluene	IRIS RfC (400 ug/m ³)	2.92 less worker exp.	1165 ug/m ³	--- ⁷	500 ug/m ³ - C ³
1,1,1-Trichloroethane	CalEPA REL (1000 ug/m ³)	2.92 less worker exp.	2900 ug/m ³	--- ⁷	500 ug/m ³ - C ³
1,1,2-Trichloroethane	IRIS RfD converted to RfC (14 ug/m ³)	3.33x Cancer UF; 2.92 less worker exp.	12.3 ug/m ³	0.03 ug/m ³	12 ug/m ³
Trichloroethylene	IRIS provisional unit risk (1.1E-04/ug/m ³)	8.176 less worker exp.	0.074 ug/m ³	1 ug/m ³	1 ug/m ³
Vinyl chloride	IRIS unit risk for adult exposure (4.3E-6/ug/m ³)	8.176 less worker exp.	1.9 ug/m ³	0.01 ug/m ³	1.9 ug/m ³
Xylenes	ATSDR MRL (430 ug/m ³)	2.92 less worker exp.	1256 ug/m ³	--- ⁷	500 ug/m ³ - C ³
Trichlorofluoromethane	HEAST ("A")RfC (700 ug/m ³)	2.92 less worker exp.	2044 ug/m ³	--- ⁷	500 ug/m ³ - C ³

Table B2

Target Air Concentrations (TACs) for Industrial/Commercial Scenario (Page 3)

VOC	Toxicity Value ¹	Modifying Factors ²	Risk-Based TAC ⁴	Background	TAC
Chloroethane	IRIS RfC (10,000 ug/m ³)	10x Cancer UF; 2.92 less worker exp.	2920 ug/m ³	--- ⁷	500 ug/m ³ - C ³
Chloromethane	IRIS RfC (90 ug/m ³)	3.33x Cancer UF; 2.92 less worker exp.	80 ug/m ³	Not available	80 ug/m ³
Dichlorodifluoromethane	HEAST ("A")RfC (175 ug/m ³)	2.92 less worker exp.	511 ug/m ³	--- ⁷	500 ug/m ³ - C ³
Isopropylbenzene (cumene)	IRIS RfC (385 ug/m ³)	2.92 less worker exp.	1168 ug/m ³	--- ⁷	120 ug/m ³ (odor threshold)
cis-1,2-Dichloroethene	HEAST RfD → RfC (35 ug/m ³)	2.92 less worker exp.	102 ug/m ³	Not available	100 ug/m ³
trans-1,2-Dichloroethane	IRIS RfD → RfC (70 ug/m ³)	2.92 less worker exp.	204 ug/m ³	--- ⁷	200 ug/m ³
Bromodichloromethane	IRIS oral slope factor → unit risk (1.8E-05/ug/m ³)	8.176 fold less exp.	0.46 ug/m ³	Not available	0.46 ug/m ³
n-Butylbenzene	EPA provisional RfD → RfC (140 ug/m ³)	2.92 less worker exp.	410 ug/m ³	--- ⁷	410 ug/m ³
sec-Butylbenzene	EPA provisional RfD → RfC (140 ug/m ³)	2.92 less worker exp.	410 ug/m ³	--- ⁷	410 ug/m ³
1,2,4-Trimethylbenzene	EPA Provisional RfC (6 ug/m ³)	RfC ↑ed 3x ⁵ 2.92 less worker exp.	52 ug/m ³	Not available	52 ug/m ³
1,3,5-Trimethylbenzene	EPA Provisional RfC (6 ug/m ³)	RfC ↑ed 3x ⁵ 2.92 less worker exp.	52 ug/m ³	Not available	52 ug/m ³
4-Isopropyltoluene	DPH risk assessment ⁶ yields RfC of 133 ug/m ³	2.92 less worker exp.	370 ug/m ³	--- ⁷	370 ug/m ³

Footnotes for Industrial/Commercial TAC Table

¹ Tox Value Notes: Values from IRIS, HEAST, CalEPA chronic RELs or ATSDR chronic MRLs; EPA provisional values have been derived by the agency but not fully documented or supported; HEAST "A" refers to values from Alternative Table within HEAST. Dose route extrapolation conducted when no inhalation tox value available and oral toxicity is to systemic sites.

² Modifying Factors: Worker exposure assumptions for non-cancer effects: 250d/year and 10m³ inhaled per day leads to 2.92 fold less cumulative exposure than assumed for RfC – general public. For carcinogenic effects, this factor is increased 2.8 fold because workers exposed 25 yr instead of 70 yr leading to an overall 8.176 fold lower cumulative exposure than general public.

³ "C" designation indicates ceiling value of 500 ug/m³.

⁴ TACs based upon de minimis (1 in a million) cancer risk or a hazard index of 1 for non-cancer effects.

⁵ EPA provisional RfCs for 1,2,4- and 1,3,5-TMB have unnecessarily large uncertainty factors which drive very low RfC.

⁶ 4-Isopropyltoluene risk assessment based upon analogy with isopropylbenzene with neurotoxicity as key endpoint (4-IPT 3x > potency than IPB).

⁷ Background concentration not sought since risk-based TAC is relatively high and unlikely to be in range of background.

Appendix C

Comparison to 1996 Volatilization Criteria

Table C1

Comparison of Target Indoor Air Concentrations

Compound	CAS Number	Residential TAC (ug/m³)	1995 Residential TAC (ug/m³)	Ind/Com TAC (ug/m³)	1995 Ind/Com TAC (ug/m³)
Acetone	67641	▼180	834	▼500 ⁽¹⁾	1170
Acrylonitrile	107131	NA	NA	NA	NA
Benzene	71432	►3.3 ⁽²⁾	3.25 ⁽²⁾	▼3.3 ⁽²⁾	21.5 ⁽²⁾
Bromoform	75252	▼0.55	2.21	▲7.3	3.72
2-Butanone (MEK)	78933	▼500 ⁽¹⁾	1040	▼500 ⁽¹⁾	1460
Carbon tetrachloride	56235	▼0.5 ⁽²⁾	1 ⁽²⁾	▼0.54	1 ⁽²⁾
Chlorobenzene	108907	▲37	20.9	▲200	29.2
Chloroform	67663	▼0.5 ⁽²⁾	3 ⁽²⁾	▼0.5 ⁽²⁾	3 ⁽²⁾
Dibromochloromethane	124481	NA	NA	NA	NA
1,2-Dichlorobenzene	95501	▼73	209	▲410	292
1,3-Dichlorobenzene	541731	▼73	209	▲410	292
1,4-Dichlorobenzene	106467	▼24 ⁽²⁾	834	▼24 ⁽²⁾	1170
1,1-Dichloroethane	75343	▼77	521	▼430	730
1,2-Dichloroethane	107062	▼0.07	0.0936	▲0.31	0.157
1,1-Dichloroethylene	75354	▲10	0.0487	▲20	0.0818
cis-1,2-Dichloroethylene	156592	See New Criteria below	NA	See New Criteria below	NA
trans-1,2-Dichloroethylene	156605	See New Criteria below	NA	See New Criteria below	NA
1,2-Dichloropropane	78875	►0.13	0.128	▲0.42	0.215
1,3-Dichloropropene	542756	▲0.21	0.0658	▲2.9	0.11
Ethyl benzene	100414	▼53	1040	▼290	1460
Ethylene dibromide (EDB)	106934	▼0.0028	0.0111	▲0.038	0.0186
Methyl-tert-butyl-ether	1634044	▼160	521	▼190 ⁽³⁾	730
Methyl isobutyl ketone	108101	▼37	83.4	▲200	117
Methylene chloride	75092	▼3 ⁽²⁾	45 ⁽²⁾	▼17	45 ⁽²⁾
Styrene	100425	▲52	5 ⁽²⁾	▲290	7.17

Table C1
(Continued)

Comparison of Target Indoor Air Concentrations

Compound	CAS Number	Residential TAC (ug/m ³)	1996 Residential TAC (ug/m ³)	Ind/Com TAC (ug/m ³)	1996 Ind/Com TAC (ug/m ³)
1,1,1,2-Tetrachloroethane	630206	▼0.082	0.329	▲1.1	0.552
1,1,2,2-Tetrachloroethane	79345	▼0.011	0.042	▲0.14	0.0705
Tetrachloroethylene	127184	▼5 ⁽²⁾	11 ⁽²⁾	▼5 ⁽²⁾	11 ⁽²⁾
Toluene	108883	▼210	417	▼500 ⁽¹⁾	584
1,1,1 Trichloroethane	71556	▼500	1040	▼500 ⁽¹⁾	1460
1,1,2-Trichloroethane	79005	▼2.2	30 ⁽²⁾	▼12	30 ⁽²⁾
Trichloroethylene	79016	▼1 ⁽²⁾	5 ⁽²⁾	▼1 ⁽²⁾	5 ⁽²⁾
Vinyl chloride	75014	▲0.14	0.029	▲1.9	0.0487
Xylenes	1330207	▼220	313	▲500 ⁽¹⁾	438
New Criteria					
Trichlorofluoromethane	75694	370	NA	500 ⁽¹⁾	NA
Chloroethane	75003	500 ⁽¹⁾	NA	500 ⁽¹⁾	NA
Chloromethane	74873	14	NA	80	NA
Dichlorodifluoromethane	75718	91	NA	500 ⁽¹⁾	NA
Isopropylbenzene (Cumene)	98828	120 ⁽³⁾	NA	120 ⁽³⁾	NA
cis-1,2-dichloroethene	156592	18	NA	100	NA
trans-1,2-dichloroethene	156605	37	NA	200	NA
Bromodichloromethane	75274	0.034	NA	0.46	NA
N-butylbenzene	104518	73	NA	410	NA
Sec-butylbenzene	135988	73	NA	410	NA
1,2,4-trimethylbenzene	95636	9.3	NA	52	NA
1,3,5-trimethylbenzene	108678	9.3	NA	52	NA
4-isopropyltoluene (4-cymene)	99876	67	NA	370	NA

⁽¹⁾ Based on a ceiling value. ⁽²⁾ Based on a background concentration. ⁽³⁾ Based on an odor threshold concentration. ▲ TAC increased. ▼ TAC decreased. ► TAC stayed the same.

Table C2

Comparison of Ground Water Volatilization Criteria

Compound	CAS Number	Residential GWVC (ug/L)	1996 Residential GWVC (ug/L)	Ind/Com GWVC (ug/L)	1996 Ind/Com GWVC (ug/L)
Acetone	67641	▶ 50000	50000	▶ 50000	50000
Acrylonitrile	107131	NA	NA	NA	NA
Benzene	71432	▼ 130	215	▼ 310	3491
Bromoform	75252	▼ 75	920	▼ 2300	3800
2-Butanone (MEK)	78933	▶ 50000	50000	▶ 50000	50000
Carbon tetrachloride	56235	▼ 5.3	16	▼ 14	40
Chlorobenzene	108907	▶ 1800	1800	▲ 23000	6150
Chloroform	67663	▼ 26	287	▼ 62	710
Dibromochloromethane	124481	NA	NA	NA	NA
1,2-Dichlorobenzene	95501	▼ 5100	30500	▶ 50000	50000
1,3-Dichlorobenzene	541731	▼ 4300	24200	▶ 50000	50000
1,4-Dichlorobenzene	106467	▼ 1400	50000	▼ 3400	50000
1,1-Dichloroethane	75343	▼ 3000	34600	▼ 41000	50000
1,2-Dichloroethane	107062	▼ 6.5	21	▼ 68	90
1,1-Dichloroethylene	75354	▲ 190	1	▲ 920	6
cis-1,2-Dichloroethylene	156592	See New Criteria below	NA	See New Criteria below	NA
trans-1,2-Dichloroethylene	156605	See New Criteria below	NA	See New Criteria below	NA
1,2-Dichloropropane	78875	▼ 7.4	14	▶ 58	60
1,3-Dichloropropene	542756	▲ 11	6	▲ 360	25
Ethyl benzene	100414	▼ 2700	50000	▼ 36000	50000
Ethylene dibromide (EDB)	106934	▼ 0.3	4	▼ 11	16
Methyl-tert-butyl-ether	1634044	▼ 21000	50000	▶ 50000	50000
Methyl isobutyl ketone	108101	▼ 13000	50000	▶ 50000	50000
Methylene chloride	75092	▼ 160	4512	▼ 2200	11117
Styrene	100425	▲ 3100	580	▲ 42000	2065

Table C2
(Continued)

Comparison of Ground Water Volatilization Criteria

Compound	CAS Number	Residential GWVC (ug/L)	1996 Residential GWVC (ug/L)	Ind/Com GWVC (ug/L)	1996 Ind/Com GWVC (ug/L)
1,1,1,2-Tetrachloroethane	630206	▼2	12	▲64	50
1,1,2,2-Tetrachloroethane	79345	▼1.8	23	▼54	100
Tetrachloroethylene	127184	▼340	1500	▼810	3820
Toluene	108883	▼7100	23500	▼41000	50000
1,1,1-Trichloroethane	71556	▼6500	20400	▼16000	50000
1,1,2-Trichloroethane	79005	▼220	8000	▼2900	19600
Trichloroethylene	79016	▼27	219	▼67	540
Vinyl chloride	75014	►1.6	2	▲52	2
Xylenes	1330207	▼8700	21300	▼48000	50000
New Criteria					
Trichlorofluoromethane	75694	1300	NA	4200	NA
Chloroethane	75003	12000	NA	29000	NA
Chloromethane	74873	390	NA	5500	NA
Dichlorodifluoromethane	75718	93	NA	1200	NA
Isopropylbenzene (Cumene)	98828	2800	NA	6800	NA
Cis-1,2-dichloroethene	156592	830	NA	11000	NA
trans-1,2-dichloroethene	156605	1000	NA	13000	NA
Bromodichloromethane	75274	2.3	NA	73	NA
N-butylbenzene	104518	1500	NA	21000	NA
Sec-butylbenzene	135988	1500	NA	20000	NA
1,2,4-trimethylbenzene	95636	360	NA	4800	NA
1,3,5-trimethylbenzene	108678	280	NA	3900	NA
4-isopropyltoluene (4-cymene)	99876	1600	NA	22000	NA
▲ GWVC increased. ▼ GWVC decreased. ► GWVC stayed the same.					

Table C3

Comparison of Soil Vapor Volatilization Criteria

Compound	CAS Number	Residential SVVC (ppm)	1996 Residential SVVC (ppm)	Ind/Com SVVC (ppm)	1996 Ind/Com SVVC (ppm)
Acetone	67641	▼57	2400	▼290	8250
Acrylonitrile	107131	NA	NA	NA	NA
Benzene	71432	▼0.78	1	▼1.4	113
Bromoform	75252	▼0.04	1.5	▼0.98	6
2-Butanone (MEK)	78933	▼130	2400	▼230	8285
Carbon tetrachloride	56235	▼0.06	1	▼0.12	2.7
Chlorobenzene	108907	▼6.1	31	▼60	106
Chloroform	67663	▼0.078	4.5	▼0.14	10.4
Dibromochloromethane	124481	NA	NA	NA	NA
1,2-Dichlorobenzene	95501	▼9.2	240	▼95	818
1,3-Dichlorobenzene	541731	▼9.2	240	▼95	818
1,4-Dichlorobenzene	106467	▼3	950	▼5.5	3270
1,1-Dichloroethane	75343	▼14	850	▼150	3037
1,2-Dichloroethane	107062	▼0.013	1	▼0.11	1
1,1-Dichloroethylene	75354	▲1.9	1	▲7	1
cis-1,2-Dichloroethylene	156592	See New Criteria below	NA	See New Criteria below	NA
trans-1,2-Dichloroethylene	156605	See New Criteria below	NA	See New Criteria below	NA
1,2-Dichloropropane	78875	▼0.021	1	▼0.13	1
1,3-Dichloropropene	542756	▼0.035	1	▼0.89	1
Ethyl benzene	100414	▼9.3	1650	▼93	5672
Ethylene dibromide (EDB)	106934	▼0.0005	1	▼0.007	1
Methyl-tert-butyl-ether	1634044	▼34	1000	▼73	3415
Methyl isobutyl ketone	108101	▼6.8	140	▼68	480
Methylene chloride	75092	▼0.65	89	▼6.8	218
Styrene	100425	▲9.3	8	▲95	28

Table C3
(Continued)

Comparison of Soil Vapor Volatilization Criteria

Compound	CAS Number	Residential SVVC (ppm)	1996 Residential SVVC (ppm)	Ind/Com SVVC (ppm)	1996 Ind/Com SVVC (ppm)
1,1,1,2-Tetrachloroethane	630206	▼0.009	1	▼0.22	1.5
1,1,2,2-Tetrachloroethane	79345	▼0.0012	1	▼0.028	1
Tetrachloroethylene	127184	▼0.56	11	▼1	27
Toluene	108883	▼42	760	▼180	2615
1,1,1 Trichloroethane	71556	▼70	1310	▼130	4520
1,1,2-Trichloroethane	79005	▼0.31	40	▼3.1	93
Trichloroethylene	79016	▼0.14	7	▼0.26	16
Vinyl chloride	75014	▼0.041	1	►1	1
Xylenes	1330207	▼38	500	▼160	1702
New Criteria					
Trichlorofluoromethane	75694	50	NA	120	NA
Chloroethane	75003	140	NA	260	NA
Chloromethane	74873	5.1	NA	53	NA
Dichlorodifluoromethane	75718	14	NA	140	NA
Isopropylbenzene (Cumene)	98828	19	NA	34	NA
Cis-1,2-dichloroethene	156592	3.4	NA	35	NA
trans-1,2-dichloroethene	156605	7.1	NA	70	NA
Bromodichloromethane	75274	0.0038	NA	0.095	NA
N-butylbenzene	104518	10	NA	100	NA
Sec-butylbenzene	135988	10	NA	100	NA
1,2,4-trimethylbenzene	95636	1.4	NA	15	NA
1,3,5-trimethylbenzene	108678	1.4	NA	15	NA
4-isopropyltoluene (4-cymene)	99876	9.3	NA	94	NA
▲ SVVC increased. ▼ SVVC decreased. ► SVVC stayed the same.					