

# BACKGROUND INDOOR AIR RISKS AT SELECTED RESIDENCES IN DENVER COLORADO

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## ABSTRACT

Groundwater contaminated with 1,1-dichloroethene (1,1-DCE), trichloroethene and 1,1,1-trichloroethane was the source of chemicals migrating into indoor air in an area of Denver Colorado. The affected dwellings were successfully remediated by sub-slab depressurization, using 1,1-DCE as an indicator. Indoor air from 427 samples were analyzed using EPA Method TO14/15 in Selective Ion Monitoring mode for 1,1,1-trichloroethene, 1,2-dichloroethane, dichloromethane, trichloroethene, vinyl chloride, benzene, chloroform and tetrachloroethane. The data were used to determine background indoor air risks assuming residential exposure (for 30 years). Background single compound and summed cancer and noncancer risks were estimated. The maximum single compound risks were highest for chloroform and benzene both at risks of two in ten thousand ( $2 \times 10^{-4}$ ). The maximum summed risk was  $2.4 \times 10^{-4}$ . The data for all eight compounds were log normally distributed. Also included are summary statistics applicable for risk assessments using *Monte Carlo* analysis where background indoor air risk subtraction is required.

## INDEX TERMS

Background indoor air, Air and pollutant measurement, VOC, Risk assessment, *Monte Carlo*.

## INTRODUCTION

Indoor air quality is of high concern because of the hours individuals spend indoors. A number of studies have documented background levels of volatile organic compounds (VOC) in indoor air (USEPA, 1987, Stolwijk, 1990). Sampling methods were often inconsistent between studies and the detection limits for the studies were not always adequate to evaluate background indoor air risks at a one in one million risk level.

In the process of a multiyear characterization of a site in the Denver area, which has indoor air contaminated by chlorinated VOCs derived from a groundwater plume, an opportunity arose to characterize background VOCs in a large number of residences using modern, low detection limit methods and 24-hour SUMMA canister sampling. This paper presents the results of that background characterization, in a risk assessment that utilizes both a point estimate and probabilistic approach.

The Site data were collected from 59 apartment buildings and over 100 single-family homes from May 1996 to June 2001. This dataset includes over 1,000 samples from 21 single-family homes with radon-type remediation systems as well as 8 town homes and 12 apartment buildings with sub-slab depressurization systems (SSDS) installed to reduce levels of 1,1-dichloroethene (1,1-DCE) due to vapor intrusion.

At the initiation of the project 50 VOC were analyzed by EPA Method TO-15, but the risk assessment (RA) for the Site determined that only four VOC were groundwater-derived,

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indoor air Chemicals of Concern (COCs) at the Site. Therefore, the remaining 46 compounds are representative of typical background levels of these compounds in urban residential indoor air resulting from indoor sources and/or ambient air concentrations. Since many of the samples were collected from locations either outside the area of influence of the groundwater plumes or after SSDS were installed, background data on three of the four indoor air COCs were obtained: 1,1,1-trichloroethane (1,1,1-TCA), 1,1-dichloroethane (1,1-DCA), and trichloroethene (TCE). The following compounds were also included in this study: benzene, chloroform, 1,1-dichloroethene (1,1-DCE), 1,2-dichloroethane (1,2-DCA), 1,1,2-trichloroethane (1,1,2-TCA), dichloromethane (DCM) and tetrachloroethene (PCE). The 1,1-DCE concentrations measured were assumed to originate from groundwater-derived vapor intrusion. Therefore, the database was screened for only those samples with 1,1-DCE below the reporting limit.

### SITE DESCRIPTION

The Site is situated on a local topographic high in a mixed commercial and residential neighborhood. A chlorinated groundwater plume has migrated away from the source and passes beneath an area with numerous multi-story apartment buildings, single-family homes and a few town houses. The apartment buildings and town homes are slab on grade construction. The majority of the single-family homes have basements and many have attached garages. The depth to groundwater ranges from approximately 10 feet near the source to 30 feet at the distal end of the groundwater plume. The indoor air contamination was remediated by SSDS to achieve risk-based regulatory goals established by the Colorado Department of Public Health and Environment (CDPHE).

### SAMPLING AND ANALYTICAL METHODS

All indoor samples were collected over a 24-hour time period with passivated 6-liter SUMMA canisters. Samples were collected on the first occupied floor of a residence or apartment building on a quarterly basis. Where possible within residences, the windows were closed for 24 to 48 hours before sampling. All samples were analyzed at the solvent-free laboratory of Quanterra Air Toxics Laboratory (Severn Trent), City of Industry, CA, by EPA Methods TO14 & TO15 (GC/MS-SIM and SCAN). For all samples, eleven compounds were routinely determined in Selective Ion Monitoring (SIM) mode with the remaining compounds determined in SCAN mode on about 25% of the samples.

Method detection limits (MDLs) were determined according to EPA protocols. The laboratory selected the reporting limits for the 11 SIM compounds based on MDLs, laboratory blank levels and project-specific requirements. The EPA methods were modified for this study to dramatically lower the reporting limits compared to normal EPA TO-15 requirements (Table 1).

**Table 1.** Compound Method Detection Limits (MDLs) (Units are  $\mu\text{g}/\text{m}^3$ )

<i>Compound</i>	<i>MDL</i>	<i>Compound</i>	<i>MDL</i>	<i>Compound</i>	<i>MDL</i>
1,1-DCA	0.013	1,1,2-TCA	0.032	TCE	0.015
1,2-DCA	0.02	Benzene	0.2	PCE	0.1
1,1-DCE	0.011	Chloroform	0.07	Vinyl chloride	0.010
1,1,1-TCA	0.022	Dichloromethane	0.2		

Since October 10, 1998, the project has utilized special GC/MS high-resolution tuning procedures, specified by CDPHE, for all SIM analyses. SIM data gathered after this date are

reported down to the respective MDLs and are considered to provide a more accurate measure of the lowest end of the concentration range for these compounds.

In addition, the project uses SUMMA canisters which are now dedicated to the project and which are subject to cleaning procedures and cleaning verification down to their respective SIM reporting limits. This requirement was instituted after the discovery of carryover contamination in SUMMA canisters in the earliest phase of the project. Data collected prior to the use of dedicated canisters at the Site are not used in this paper.

## **STATISTICAL METHODS**

### **Treatment of data below Reporting Limits**

For all of the historic SIM data collected prior to October 1998, non-detects at the reporting limit were assigned a value equal to one half the reporting limit. This is the standard method of data treatment recommended by EPA guidance (USEPA, 1991). SIM data collected since October 1998 at the Site have been reported down to the MDL with qualifiers added to the data below the laboratory reporting limit but above the MDL. Non-detect results at the MDL are assigned values equal to the MDL.

### **Screening of SIM data to exclude site-impacted results**

The groundwater and indoor air COCs at the site are 1,1,1-TCA, 1,1-DCE, 1,1-DCA and TCE. Post-remediation SIM results with 1,1-DCE greater than the MDL ( $0.011 \mu\text{g}/\text{m}^3$ ) were screened out of the data to be further processed. This was done to exclude any data that may have been impacted by site-related contaminants. 1,1-DCE was chosen for the screening because it has the lowest detection limit of the four COCs, the highest volatility (Henry's Law Constant), the highest relative concentration in groundwater (five times more abundant than TCE and two times more abundant than 1,1,1-TCA), and the highest relative concentration in contaminated indoor air at the Site (ten times more abundant than TCE and 1.5 times more abundant than TCA) (Johnson et al, 2001). 1,1-DCE is also the compound most likely to have the lowest background of the COCs because it is unavailable commercially. Based on all of the above factors, 1,1-DCE is therefore the most sensitive indicator of potential site-related contamination in indoor air. Due to the relative detection limits and volatilities of the COCs and their relative abundances at this site, if 1,1-DCE is below detection, none of the other three COCs could be present in measurable concentrations derived from vapor intrusion.

The resulting post-remediation "background" data set contains 427 analyses of indoor air from 19 single-family homes, 6 town homes and 12 apartment buildings at the Site.

### **Identification and Treatment of Outliers**

After determination of the population distribution, all data were log normalized. Dixon's Test (Dixon, 1953) was used to screen the log normalized indoor air data for individual outliers. Data determined to be outliers at the 95% confidence level were excluded from further analysis. Only two indoor air outliers were removed from the background data set comprised of over 400 samples. The complete analysis for an outlier sample was removed. Outliers, or extreme values, are noted for DCM, PCE and 1,1,1-TCA.

### **Nature of the Population Distributions**

The remaining data, after the above processing, were analyzed by probability plotting methods to determine the most appropriate type of population distribution. The majority of the chemicals correspond to log normal population distributions. DCM shows anomalous behavior with several apparent populations indicated by the segments on the log probability

plot with different slopes. This multiple population character is consistent with, and could be attributed to, the prevalence of DCM in numerous consumer products. Summary statistics for the VOC in indoor air at the Site are shown in Table 2.

**Table 2.** VOC Distribution and Summary Statistics (Units are  $\mu\text{g}/\text{m}^3$ )

<i>Compound</i>	<i>Distribution</i>	<i># of Samples</i>	<i>Max. Conc. (Actual)</i>	<i>Log Arith. Mean</i>	<i>Log Arith Std. Dev</i>	<i>95% UCL</i>
1,1-DCA <sup>1</sup>	Lognormal	427	NA	0.04	--	--
1,2-DCA	Lognormal	427	0.43	0.07	0.042	0.08
1,1,1-TCA	Lognormal	427	14.00	0.70	0.647	0.95
1,1,2-TCA <sup>1</sup>	Lognormal	427	NA	0.032	--	--
Benzene	Lognormal	427	64.00	4.08	2.657	4.64
Chloroform	Lognormal	427	21.00	2.10	3.113	2.3
DCM	Multimodal					
	Lognormal	427	12.00	0.98	0.872	1.17
TCE	Lognormal	427	3.10	0.15	0.148	0.21
PCE	Lognormal	427	42.00	1.62	2.103	2.22
VC	Lognormal	427	0.34	0.01	0.004	0.01

<sup>1</sup> 1,1-DCA and 1,1,2-TCA values were all non-detects at reporting limits of 0.08 and 0.064  $\mu\text{g}/\text{m}^3$  respectively. A value of one half the reporting limit was used for each compound.

### RISK ASSESSMENT METHODS

Inhalation risk estimates (point estimates) were calculated using methods described by the USEPA (USEPA, 1989). The algorithm for the estimation of point excess lifetime cancer risks is shown in Table 3. Risk distributions were estimated using the same algorithm and the assumptions and distributions shown below.

$$\text{Cancer Risk} = \frac{[Air] * IR * EF * ED * SF_i}{AT * BW * RfD_i} \quad \text{Noncancer Risk} = \frac{[Air] * IR * EF * ED}{AT * BW}$$

Where  $[Air]$  is the indoor air concentration,  $IR$  is the inhalation rate,  $EF$  and  $ED$  are the exposure frequency and duration respectively,  $AT$  is the averaging time and  $BW$  is the body weight.  $SF_i$  is the inhalation Slope Factor and  $RfD_i$  is the Inhalation Reference Dose. Cancer risks were estimated using  $SF_i$ , converted from Unit Risk Factors provided on the EPA's Integrated Risk Information System (IRIS, USEPA, 2002) and noncancer risks used Inhalation Reference Dose, (not provided here).

**Table 3.** Risk Assessment Assumptions for Point Estimates

<i>Parameter</i>	<i>Value</i>	<i>Units</i>	<i>Source</i>
Inhalation Rate	15	$\text{m}^3/\text{day}$	USEPA 1997
Body weight	70	kg	USEPA 1989
Exposure Frequency	350	days/year	USEPA 1997
Exposure Duration	30	years	USEPA 1997
Averaging Time: Cancer	25,550	days	USEPA 1989
Noncancer	10,950		USEPA 1997

Monte Carlo simulations for quantitative risk estimates were calculated using @RISK<sup>®</sup> software (version 3.5.2). Input distributions were selected for inhalation rate and body weight (Binkowitz and Wartenberg 2001), and exposure duration, the latter of which was

developed from site-specific residence time, and has a mean of 11.5 years, as compared to the value of 30 years used in the point estimates. Input parameters for the *Monte Carlo* simulations are shown in Table 4.

**Table 4.** Input Distributions for *Monte Carlo* Risk Assessment Simulations

<i>Parameter</i>	<i>Distribution Type</i>	<i>Distribution Input</i>
Inhalation Rate (m <sup>3</sup> /day) (Adult, male + female)	Triangular	8, 15.1, 23.2 (min, most likely, max)
Body weight (kg) (Adult male + female)	Lognormal	70.8, 14.3 (mean, std dev)
Exposure Duration (years)	Truncated Normal	11.5, 12.2, 0, 45 (mean, std dev, min, max)

The calculations were set up to run to convergence (approximately 6,400 iterations), rather than specifying a required number of iterations; the results are provided below.

## RESULTS AND DISCUSSION

### Excess Lifetime Cancer Risks

Point estimate cancer risks, based on the maximum concentration, were highest for chloroform and benzene (both 1.5E-04) (Table 5). The summed point estimate cancer risk, based on the maximum concentrations was 3.2E-04, which is just above the USEPA target risk range of one in one hundred thousand (10<sup>-4</sup> or 1E-04) to one in one million (10<sup>-6</sup> or 1E-06). However, some State agencies require compliance with a 10<sup>-6</sup> risk-based goal and the potential highest background summed risk is 320 times higher than this goal.

### Noncancer Risks

For compounds with noncancer effects, the point risk estimates calculated on the maximum concentration are highest for benzene with a Hazard Quotient (HQ) of 7.7. All other noncancer risk estimates are less than the USEPA target risk range of an HQ less than one. Noncancer risk estimates calculated by *Monte Carlo* methods were always lower than the point estimate for the same VOC and were all less than one, with the exception of benzene, which had an HQ of 3.1, based upon the maximum concentration (results not shown).

**Table 5.** Cancer Risk Estimates

<i>Compound</i>	<i>Point Estimates</i>			<i>Monte Carlo Simulation</i>		
	<i>Maximum Risk</i>	<i>Mean Risk</i>	<i>95% UCL Risk</i>	<i>Maximum Risk</i>	<i>Mean Risk</i>	<i>95<sup>th</sup> Percentile Risk</i>
1,2-DCA	3.45E-06	5.65E-07	6.09E-07	4.94E-06	3.04E-07	8.90E-07
Benzene	1.52E-04	1.01E-05	1.10E-05	8.19E-05	5.28E-06	1.54E-05
Chloroform	1.49E-04	1.45E-05	1.62E-05	1.29E-04	7.49E-06	2.81E-05
DCM	1.74E-06	1.52E-07	1.70E-07	1.44E-06	7.92E-08	2.58E-07
TCE	1.64E-06	9.36E-08	1.10E-07	1.25E-06	4.30E-08	1.43E-07
PCE	7.51E-06	3.37E-07	3.97E-07	4.03E-06	1.56E-07	5.64E-07
VC	9.22E-07	3.30E-08	3.75E-08	1.57E-07	1.95E-08	4.88E-08
Summed Risk	3.17E-04	2.62E-05	2.90E-05	1.57E-04	1.35E-05	4.10E-05

## CONCLUSION

The findings show that background indoor air risks from benzene, chloroform and other VOC are significant in urban residential locations, even in areas where groundwater contamination is absent. For states where risk-based indoor air remediation goals are set at 10<sup>-6</sup> this study

shows that background indoor air contamination for 1,2-DCA, benzene, chloroform, DCM, TCE and PCE are contributing to indoor air risks above the regulatory goal (maximum point estimate). Using average VOC concentrations, point estimates of risk due to benzene and chloroform exceed the  $10^{-6}$  risk goal by an order of magnitude. Consistent with the concept of soil remediation, indoor air remediation should incorporate background into remediation goals to avoid establishing goals that are unattainable because they are below background. The 95<sup>th</sup> percentile risk from the *Monte Carlo* simulations for benzene and chloroform (1.54E-05 and 2.81E-05 respectively) would exceed a state standard of  $10^{-6}$  by an order of magnitude. *Monte Carlo* generated mean and maximum risk estimates were lower than point estimates, due to shorter average exposure duration, with the exception of 1,2-DCA, which had a higher maximum risk estimate under *Monte Carlo* methods.

If *Monte Carlo* simulations are used to develop background risks that are subsequently subtracted from indoor air data to determine compliance with a regulatory standard, the range of background risks presented here would appear to be a reasonable data set for indoor air VOC in an urban area. The present background results are comparable to literature data for benzene, chloroform and PCE (Stolwijk, 1990). The background values for the remaining VOCs are either the only values known (1,2-DCA and Vinyl chloride) or are lower than previously published background values (USEPA, 1987; Stolwijk, 1990). The background data set presented here may actually be biased low due to the extensive public information regarding VOCs in indoor air distributed to the residents at this site over the last five years.

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