Case Studies of Possible Chlordane Vapor Intrusion into School Buildings

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Abstract-

Chlordane, an organochlorine pesticide, was phased out in the United States from use on crops and landscaping in 1978 and as a termiticide for use in soil in 1988. Chlordane is persistent and highly toxic, having been measured in outdoor air, indoor air, and indoor dust decades after discontinuation of use. Vapor intrusion of chlordane is a likely source of higher indoor versus outdoor air concentrations. Remedial investigations of school sites undergoing renovation in California were performed. Chlordane (as technical chlordane) was found adjacent to the foundation of some school buildings as part of standard site characterization in soil concentrations as high as 0.14%. Step out sampling below the foundation of school buildings was performed where physically possible, usually associated with demolition or significant structural renovation to the buildings. Chlordane was, in individual cases found below a significant portion of some buildings and not just along the footings, suggesting application prior to construction. Concentrations in soil were highly variable but in individual samples were as high as 0.24%. Two buildings have been sampled thus far for chlordane in indoor air when removal of the impacted soils from below the foundation was not the first choice for remediation. Concentrations of chlordane (reported as technical chlordane) in indoor air have been measured as high as 0.14 ug/m3 which is greater than the USEPA residential risk based screening levels (cancer endpoint) but similar to the commercial industrial screening levels (0.12 ug/m3). The site characterization for chlordane and the investigation of vapor intrusion will be presented as well as recent updates on risk assessment for chlordane in California.

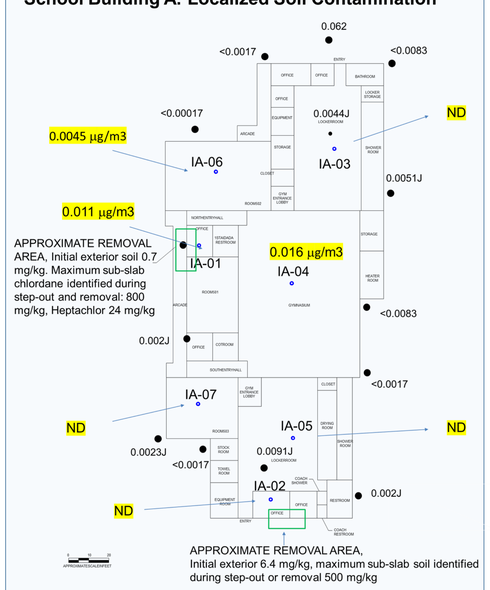
Background and Methodology-

- Under the State of California's education code, school districts planning to utilize state bond funds for school property acquisition or construction are required to conduct environmental reviews for hazardous materials for kindergarten through grade 12 school facilities. The investigation of pesticide contamination follows DTSC's 2006 guidance: "INTERIM GUIDANCE EVALUATION OF SCHOOL SITES WITH POTENTIAL SOIL CONTAMINATION AS A RESULT OF LEAD FROM LEAD-BASED PAINT, ORGANOCHLORINE PESTICIDES FROM TERMITICIDES, AND POLYCHLORINATED BIPHENYLS FROM ELECTRICAL TRANSFORMERS". The guidance provides recommendations on sampling of buildings where chlordane or other organochlorine pesticides were applied, focusing on structures to be demolished or already demolished and replaced with school buildings.

- In two recent examples of school modernizations, elevated chlordane was identified adjacent to and below concrete slab foundation buildings which were not planned for demolition. Indoor air was sampled and analyzed using USEPA method TO-10a to evaluate the risk from vapor intrusion. Samples were taken for 20-24 hrs with no mechanical ventilation operating. Indoor air levels were compared to risk based screening levels. As an exploratory method to account for exposure to chlordane in indoor dust, ingestion exposure was estimated using the air to dust partitioning equations in *Weschler and Nazaroff (2010) SVOC partitioning between the gas phase and settled dust. Atmospheric Environment. 44(30) 3609-3620* and an adult indoor dust ingestion factor from the USEPA Exposure Factors Handbook .

- To gain additional understanding on whether vapor intrusion of organochlorine pesticides may currently still be an issue and the possible need for additions to DTSCs guidance, the literature on indoor levels of chlordane was examined to understand the ranges of concentrations which may be observed. An effort was begun to examine DTSC's Envirostor database for chlordane pesticide application sites which have been high enough to undergo cleanup to gain an understanding of how frequently highly elevated soil concentrations may be present for comparison with the levels found in the two school buildings described.

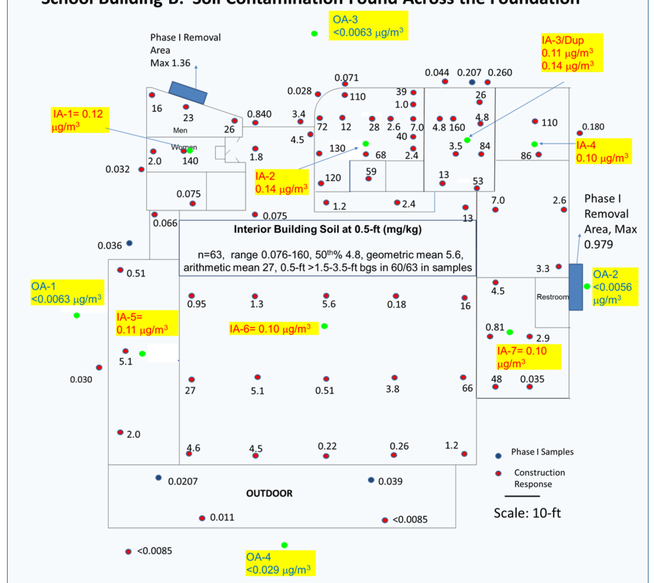
School Building A: Localized Soil Contamination



Bldg A	Technical Chlordane	α-Chlordane	γ-Chlordane	Heptachlor	β-HCH
	µg/m³				
IA-01	**0.011**	<0.00083	**0.001**	**0.00086**	**0.001**
IA-02	<0.0042	<0.00083	<0.00083	<0.00083	<0.00083
IA-03	<0.0042	<0.00083	<0.00083	<0.00083	<0.00083
IA-04	**0.016**	**0.0015**	**0.002**	<0.00082	<0.00082
IA-05	<0.0041	<0.00083	<0.00083	<0.00083	<0.00083
IA-06	**0.0045**	<0.00082	<0.00082	<0.00082	<0.00082
IA-07	<0.0041	<0.00082	<0.00082	<0.00082	<0.00082
[1] C/I SL (Teacher)	0.12			0.0094	0.023
Cumulative Inhalation risk using maximum=					**2.7E-07**

[1] C/I SL=Commercial/Industrial Screeening Level

School Building B: Soil Contamination Found Across the Foundation



Bldg B	Chlordane (Technical)	Alachlor	Hexachloro-benzene
	µg/m3		
IA-1	**0.12**	<0.0056	<0.0014
IA-2	**0.14**	**0.013**	**0.0017**
IA-3	**0.11**	**0.01**	<0.0014
IA-3D	**0.14**	<0.023	<0.0058
IA-4	**0.10**	**0.073**	**0.0016**
IA-5	**0.11**	**0.011**	**0.0018**
IA-6	**0.10**	**0.028**	<0.0014
IA-7	**0.10**	**0.018**	<0.0014
OA-1 to 4	**<0.0063-<0.029**	<0.0063-<0.029	<0.0016-<0.0072
C/I SL (Teacher)	0.12	None	0.024
Cumulative Inhalation risk using maximum=			**1.2E-06**

Volatility of Organichlorine Pesticides and the Potential for VI

	VP	HLC	Considered Volatile	Melting Point	C sautration, sand, foc=0.006	[1] Predicted Vapor Phase at Csat	[2] Predicted Indoor Air	Residential IA SL
	mm(Hg)	(atm-m³/mol)	HLC >1E-05	°C	mg/kg	ug/m³	ug/m3	ug/m³
Organochlorine Pesticides								
Aldrin	1.20E-04	4.50E-05	V	100	8.36	34	0.102	5.70E-04
[3] Chlordane (Technical)	1.00E-05	4.90E-05	V	110	22.80	112	0.336	2.80E-02
DDD	1.40E-06	6.60E-06						
[3] p,p-DDE	6.00E-06	4.20E-05	V	89	28.8	80	0.24	2.90E-02
[3] DDT	1.60E-07	8.30E-06		110	40.8	80	0.24	2.90E-02
[3] Dieldrin	5.90E-06	1.00E-05		180	23	390	1.17	6.10E-04
Endrin	3.00E-06	6.40E-06						
Endosulfan	1.70E-07	6.50E-05	V	110	13.5	660	1.98	2.50E+01
Heptachlor	4.00E-04	2.90E-04	V	96	44.3	195	0.585	2.00E-03
Heptachlor Epoxide (metabolite)	2.00E-05	2.10E-05	V	160	12	400	1.2	1.00E-03
Hexachlorobenzene	1.80E-05	1.70E-03	V	230	0.231	12.4	0.0372	5.30E-03
Toxaphene	6.70E-06	6.00E-06						
α-HCH	3.50E-05	6.70E-06						
β-HCH	3.60E-07	4.40E-07						
γ-HCH (Lindane)	4.20E-05	5.10E-06						
In use herbicide, reported in School B indoor air								
Alachlor	*2.00E-05*	*8.32E-09*						

[1] Modeled using three-phase equillibrium, Johnson (1990).

[2] Indoor air levels predicted using the median EPA subslab to indoor air attenuation factor of 0.003

[3] Chlordane, DDT, DDE, and Dieldrin were the most frequently detected OCPs in soil at single and mutlifamily homes, with frequencies of 98, 95, 91 and 71%, respectively (DTSC, 2006, Residential Pesticide Study).

Survey of Chlordane Levels in Soil at DTSC Cleanup of Chlordane Application Sites

Soil Screening Levels	Chlordane (mg/kg)	[1] All Structures at School B	[2] Survey of DTSC Envrostor Remediation Sites with chlordane >DTSC SL
100x C/I EPA RSL	>770	(3/17)	(3/70)
10x C/I EPA RSL	>77 to 770	(3/17)	(7/70)
EPA Commercial/Industrial	>7.7-77	(3/17)	(33/70)
EPA Residential	>1.7-7.7	(2/17)	(23/70)
[3] DTSC Residential	>0.44-1.7	(1/17)	(4/70)
	<0.44	(5/17)	

[1] 12 of the 17 buildings have completed remediation or demolition, a least 2 more planned with additional data to be collected

[2] School modernizations, future schools and future residential sites with removals for chlordane with detections >DTSC SLs including two schools presented here. Sites with pesticde related businesses excluded as they may not result from pesticde applications. Some sites are limited to only several structures while others incldue over 50 seperate structures.

[3] As of September 2018, per the Toxicity Criteria Rule the OEHHA toxicity factors for chlordane are no longer used for risk assessments in California.

Indoor Air Studies With Chlordane Concnetrations (ng/m³)

Study	Date	Location	N	[1] Analytes	Length	Frequency	Median	Mean	GeoMean	Max
Studies in the 1970s and 80s freqently found chlordane in indoor air in treated homes >1000 ng/m3 , sometimes at very high levels										
Highest levels were assoiated with misapplication, as well as the presence of below or within foundation vents or crawl spaces										
USEPA (1990)	1986-1988	FL	62-72 Homes	Technical	24-Hr	3 seasons	51-84	220.3-324		2050-4380
		MA	49-51 Homes	Technical	24-Hr	2 seasons	29	199.34		1700
			OA Combined				<4-20	2.02-38.43		75-628
Chlordane use was limited in 1976 and below-ground use for termite treatment was ended in 1988										
Jantunen (2000)	1996-1997	AL	5 home	TC	24-hr	11 months	30 (+/- 28)			
				CC		(1-7/month)	18 (+/-19)			
				TN			9 (+/-10)			
				CN			3.1(+/-2.9)			
			Outdoor Air	TC (Highest Congener)			0.047 (+/-33)			
Clayton (2003)	1997	MN	98 homes	CC/TC	6-days	Single	0.2/0.6			
			52 Outdoor Air	CC/TC			0.2/0.4			
Morgan (2014)	2000-2001	NC	129 homes	CC/TC	48-Hr	Single	0.89/1.51			54.7/92.1
			Outdoor Air	CC/TC			0.08/.12			3.74/9.3
		NC	13 day care	CC/TC			0.51/0.79			17.7
			Outdoor Air	CC/TC			0.15/0.28			108/115
		OH	93 Homes	CC/TC			0.26/0.36			
			Outdoor Air	CC/TC			.1/.11			
		OH	Day Care	CC/TC			0.18/0.26			
			Outdoor Air	CC/TC			0.064/0.07			
Offenberg (2004)	1999-2001	CA (L.A.)	61 homes	Sum of CC, TC, CN and TN	24-hr	2 seasons (subset)	[2] 2.1		1.98	115.5
			61 Outdoor Air						0.58	4.27
		NJ	45 homes				[2] 1.2		1.3	31.8
			45 Outdoor Air						0.17	11
		TX	51 homes				[2] 2.3		4.18	38.91
			51 Outdoor Air						0.28	1.77
Rudel (2003)	1999-2001	MA	120	CC/TC	24-hr	Single	0.1/0.22	3.7/5		61/83
Rudel (2010)	2009	CA (North)	50 homes	CC/TC	24-hr	Single	<0.3/<0.3			3.5/4.8
			43 Outdoor Air				<0.3/<0.3			0.81/1.1

[1] Technical Chlordane may contain over 140 different components, with more than 30 chlordane, chlordene and nonachlor isomers. Later formulations were more pure cis and trans chlordane. ATSDR (2018) references values of Cis and Trans chlordane as 60-85% of the

[1] CC= cis-chlordane (*a.k.a* α-chlordane), TC- trans-chlordane (*a.k.a*. γ-chlordnae), CN= cis-nanachlor, TN= trans-nonachlor

[1] Heptachlor was also produced and used as a separate compound. Heptachlor and the epoxide metabolite are separate analytes in EPA methods.

[2] Median value estimated from figure.

Additional Buildings Extensively Sampled Below the Foundation From School B

	Year constructed	Maximum Exterior Concentration	Maximum Concentration Below Foundation
		(mg/kg)	(mg/kg)
School A Building	*1959*	*160*	*800*
School B Building	*1977, Replaced 1935 Classrooms*	*3.4*	*160*
School B	1950	1024	0.05
School B	1950	1,200	1,400
School B	1963	83	610
School B	1963	646	140
School B	1951	9.16	2,400
School B	1951 and 1976	0.122	62

Risk Based Screening Levels for Pesticides in Air (µg/m3)

		Chlordane	Heptachlor	(β-HCH)	[2] Alachlor	Hexachlorobenzene
US EPA RSL	Cancer					
Residential		**0.028**	**0.002**	**0.005**	None	*0.006*
Commercial/Industrial		**0.12**	**0.0094**	**0.023**	None	*0.027*
DTSC (HHRA Note 3)				[3] HCH (mixed-isomers)		
Resdiential		[1] *0.0083*	EPA RSL	**0.0026**	None	**0.0053**
Commercial/Industrial		[1] *0.036*	EPA RSL	**0.011**	None	**0.024**
US EPA RSL	Non-cancer					
Residential		**0.73**	None	None	None	None
Commercial/Industrial		***3.1***	None	None	None	None
DTSC (HHRA Note 3)						
Residential		EPA RSL	**2.1**	None	None	**3.3**
Commercial/Industrial		EPARSL	**8.8**	None	None	**14**
Other						
Residential		[4] *0.021*			None	
Commercial/Industrial		[4] *0.123*			None	

[1] As of September 2018 under the California Toxicity Criteria Rule, the screening levels shown in bold are required for use in risk assessments in California. The DTSC screening levels calculated using the OEHHA toxicity factors for chlordane will no longer be used.

[2] Alachlor is a current use herbicide and is not classified as volatile (Henry's Law <1E-5 atm-m3/mol)

Alachlor also has no published inhalation cancer or non-cancer toxity factors or risk based screning levels

[3] Hexachlorocyclohexane reported as mixed isomers

[4] Calculated using 2018 ATSDR MRL chronic.

Chlordane is semi-volatile and unlike VOCs may be present in dust and on surfaces. In order to estimate the additional exposure from dust ingestion, the following calculations were made:

$$Cg = \frac{Ct}{1 + \frac{TSP}{\rho_{part}} \times f_{om\_part} \times Koa}$$

where Cg= gas phase concentration

Ct=total concentration (maximum measured 0.14)

TSP=total suspended particles (average indoor air concentration), 30 ug/m³ assumed

ρ_{part} =airborne particle density (g/m³), assumed to be 2 x 10^{-6}

f_{om_part} = fraction organic matter in particles (assumed 0.4)

Koa= octanol-air partition coefficient

$$Xdust = \frac{Cg \times f_{om\_dust} \times Koa}{\rho_{dust}}$$

- where $Xdust$ is the derived concertation in dust
- f_{om_dust}= fraction organic matter settled dust (assumed to be 0.4)
- ρ_{dust} = density of dust (g/m³), assumed to be 2 x 10^{-6}

***Xdust* =11.5 mg/kg**

Screening Level for indoor dust ingestion for a worker (60 mg/day) =15.5 mg/kg

Additional ingestion risk= 0.74 E-06.

Conclusions:

- Indoor air studies of homes suggest a limited number of structures in California are likely to be at risk of vapor intrusion of chlordane (and other OCPs) above screening levels.
- Presumably buildings with the highest potential for indoor levels exceeding screening criteria are associated with application of chlordane extensively below the foundation. Crawl spaces with bare soil or ventilation ducts in the foundation are known risk factors.
- Identification of buildings with extensive chlordane concentrations in soil below the foundation cannot definitively be made solely based upon a small sample of external soil samples.

The exterior of school buildings are routinely sampled for organochlorine pesticides during school modernizations. Structures which will be left in place may warrant additional sampling.

- Additional exterior samples based upon building size. Current guidance recommends only limited samples based upon building type (single family, multi-family, commercial).
- Sampling below the foundation of existing structures when exterior contamination is identified.
- Requiring additional samples upon demolition/or renovation of the structure where sub-foundation samples were not collected in the first phase of sampling.
- Supplementing soil sampling with indoor air sampling where sufficient below foundation samples are not possible, or widespread and highly elevated concentrations are observed.
- Exposure through ingestion and possibly dermal pathways may contribute to the VI risks for SVOCs. Wipe samples of commonly-contacted surfaces can be taken to refine the risks estimates using the DTSC recommended exposure parameters for PCB wipes samples in Human Health Risk Assessment Note 8.