

Appendix 4K

Soil acceptance criteria for excavation workers

1.1 Overview

Excavation workers may be exposed to higher concentrations of volatile contaminants than many other site users, albeit generally for a shorter period of time. The volatilisation of contaminants from soil may impact on the health of the workers involved in subsurface works. Exposure via dermal contact and ingestion of soil was addressed previously as part of the derivation of acceptance criteria for maintenance workers.

The primary concern associated with the exposure of maintenance and construction workers involved in excavation works is the accumulation of volatiles within the excavation. The New Zealand Workplace Exposure Standards (WES) have been used as the basis for derivation of soil acceptance criteria protective of excavation workers. Volatilisation modelling is used to relate the WES to acceptable concentrations in soil.

Assuming air within the excavation is fully mixed, the estimated contaminant concentration in air within the excavation is expected to approach an effective steady state within a period of 1-2 hours. Within this period the diffusion path length is not expected to increase rapidly compared to the initial assumption of 10 cm.

1.2 Air standards

The New Zealand Workplace Exposure Standards (WES) 1994 developed by OSH and the Department of Labour have been used as target air concentrations within the excavation. The WES have been used as the basis for determining a tolerable level of exposure, rather than the risk-based limits used for other receptors, due to the occupational context and the intermittent exposure associated with excavation works.

The WESs are expressed as time-weighted average (TWA) concentrations, based on exposure over an eight-hour working day, for a five day working week. While exposure to volatiles within the excavation is unlikely to occur eight hours/day, five days/week, limits are usually nominated for short term exposures in order to avoid acute health effects. Therefore, the eight hour TWA WESs have been adopted as the basis for exposure to contaminants in the air.

1.3 Volatilisation models

1.3.1 Summary

Volatile contaminants may be expected to accumulate within excavations when the excavation intersects contaminated soil. Workers may be exposed when working in or near the excavation. The use of the WES as a target air concentration within the pit is expected to be conservative as workers are extremely unlikely to spend eight hours/day within the pit. Workers near the pit may be exposed

to contaminants emanating from the pit and stockpiled material although this is expected to be at a lower level than would occur within the excavation.

1.3.2 Assumptions

A simple non-depleting source model was used to estimate the concentration of volatile contaminants in air within the excavation resulting from excavation into contaminated soil not previously exposed to the atmosphere. The soil on the base and the walls of the pit is assumed to be uniformly contaminated. The volatilisation model uses the following assumptions:

- The pit is 10 m x 10 m x 4 m deep
- The diffusion path for contaminants in the soil is 10 cm
- The air exchange rate for pit is 2 hr⁻¹ (selected on the basis of professional judgement given, 2 hr⁻¹ is adopted as a conservative air exchange rate for residential buildings).

1.3.3 Equations

The equation used is a modified form of the Johnson-Ettinger equation. Source depletion is neglected, as is the resistance associated with a concrete slab foundation included in the indoor air vapour intrusion model. The model resembles that of volatiles to indoor air in a basement, with the exception of the concrete wall. The calculation is given as:

$$VF \left[\frac{mg / m^3 - air}{mg / kg - soil} \right] = \frac{H\rho_s}{(\theta_w + k_s\rho_s + H\theta_a) \left(1 + \frac{L_s ER \cdot L_B}{D_s} \right)} \times 10^3 \frac{g}{kg} \quad (K1)$$

where:

- VF = Volatilisation Factor for soil to pit air
 D_s^{eff} = Effective diffusivity (cm²/s)
 L_s = Contaminant diffusion path length (10 cm)
 ER = Air Exchange Rate (s⁻¹)
 L_B = Ratio of Pit Volume to Infiltration Area (cm)
 H = Henry Coefficients (cm/cm)
 r_s = Bulk Density (t/m³)
 q_w = Water fraction in soil
 q_a = Air fraction in soil
 k_s = Soil-water sorption coefficient (foc x Koc)

foc = Fraction of Organic Carbon

Koc = Carbon-water Sorption Coefficient

Diffusion coefficients and other parameters are defined in Appendix 4D.

The estimated acceptance criteria based on protection of excavation workers are presented in Table 4K1b.

To calculate the maximum soil concentration for unprotected excavation workers, the following relationship was used:

$$C_{soil} = \frac{WES}{VF} \quad (K2)$$

where:

C_{soil} = Maximum Soil Concentration (mg/kg)

WES = Workplace Exposure Standard (TWA)

VF = Volatilisation Factor (from eq. K1)

Table 4K1a Workplace exposure standards

Contaminant	Workplace Exposure Standard ¹ (mg/m ³)
C ₇ - C ₉	1640
C ₁₀ - C ₁₄	1050
C ₁₅ - C ₃₆	-
Benzene	16
Toluene	188
Ethylbenzene	434
Xylene	350
Naphthalene	52
Pyrene	-
Benzo(a)pyrene	-

Source: Workplace Exposure Standards 1994. OSH, Department of Labour, Wellington, NZ

Table 4K1b Soil Acceptance Criteria for the Protection of Excavation Workers

Contaminant	Soil Acceptance Criteria (mg/kg)					
	Sand	Silt	Silty Clay	Clay	Pumice	Peats
C ₇ - C ₉	120	500	20,000	-	810	6,700
C ₁₀ - C ₁₄	6,500	31,000	-	-	-	-
C ₁₅ - C ₃₆	-	-	-	-	-	-
Benzene	3.0	17	700	1,800	28	190
Toluene	94	480	-	-	820	7,500
Ethylbenzene	670	3,200	-	-	5,600	-
Xylene	150	780	-	-	1,300	-
Naphthalene	640	3,100	-	-	5,300	-
Pyrene	-	-	-	-	-	-
Benzo(a)pyrene	-	-	-	-	-	-

NOTES:

1. Concentrations based on TWA (Time Weighted Average) for Workers
2. Values not presented
3. " - " Denotes high concentrations not viable.

Table 4K2a Volatilisation from surface soils to excavation pits SAND Soil Type = LH₂O/Lair

Chemical	Dair cm ² /s	Dwat cm ² /s	H @ 20°C L-H ₂ O/L-air	Koc	Deff cm ² /s	ks cm ³ H ₂ O/g-soil
C ₇ - C ₉	0.06	7.10E-06	1.2E+02	10000	4.7E-03	30
C ₁₀ - C ₁₄	0.042	4.80E-06	1.6E+02	1258925	3.3E-03	3776.775
C ₁₅ - C ₃₆	0.033	3.80E-06	1.4E+02	501187233	2.6E-03	1503561.699
Benzene	0.093	1.1E-05	2.2E-01	83	7.3E-03	0.249
Toluene	0.085	9.40E-06	2.6E-01	302	6.6E-03	0.906
Ethylbenzene	0.076	8.50E-06	3.2E-01	1096	5.9E-03	3.288
Xylene	0.072	8.50E-06	2.9E-01	240	5.6E-03	0.72
Naphthalene	0.072	9.40E-06	4.9E-02	1288	5.6E-03	3.864
Pyrene	0.048	7.24E-06	2.2E-04	38019	3.9E-03	114.057
Benzo(a)pyrene	0.05	5.80E-06	2.0E-05	389045	5.6E-03	1167.135

Chemical	Air Standard mg/m ³	VF (mg/m ³)/(mg/kg)	Soil Criteria mg/kg
C ₇ - C ₉	1640	1.41E+01	1.17E+02
C ₁₀ - C ₁₄	1050	1.61E-01	6.53E+03
C ₁₅ - C ₃₆		2.69E-04	
Benzene	16.0	5.41E+00	2.96E+00
Toluene	188	1.99E+00	9.44E+01
Ethylbenzene	434	6.49E-01	6.69E+02
Xylene	350	2.30E+00	1.52E+02
Naphthalene	52	8.13E-02	6.40E+02
Pyrene		8.84E-06	
Benzo(a)pyrene		1.12E-07	

Table 4K2b Volatilisation from surface soils to excavation pits SILT Soil Type

Chemical	Dair cm ² /s	Dwat cm ² /s	H @ 20°C L-H ₂ O/L-air	Koc	Deff cm ² /s	ks cm ³ H ₂ O/g-soil
C ₇ - C ₉	0.06	7.10E-06	1.2E+02	10000	9.8E-04	30
C ₁₀ - C ₁₄	0.042	4.80E-06	1.6E+02	1258925	6.9E-04	3776.775
C ₁₅ - C ₃₆	0.033	3.80E-06	1.4E+02	501187233	5.4E-04	1503561.699
Benzene	0.093	1.1E-05	2.2E-01	83	1.5E-03	0.249
Toluene	0.085	9.40E-06	2.6E-01	302	1.4E-03	0.906
Ethylbenzene	0.076	8.50E-06	3.2E-01	1096	1.2E-03	3.288
Xylene	0.072	8.50E-06	2.9E-01	240	1.2E-03	0.72
Naphthalene	0.072	9.40E-06	4.9E-02	1288	1.2E-03	3.864
Pyrene	0.048	7.24E-06	2.2E-04	38019	2.9E-03	114.057
Benzo(a)pyrene	0.05	5.80E-06	2.0E-05	389045	1.9E-02	1167.135

Chemical	Air Standard mg/m ³	VF (mg/m ³)/(mg/kg)	Soil Criteria mg/kg
C ₇ - C ₉	1640	3.31E+00	4.95E+02
C ₁₀ - C ₁₄	1050	3.38E-02	3.10E+04
C ₁₅ - C ₃₆		5.66E-05	
Benzene	16.0	9.50E-01	1.68E+01
Toluene	188	3.94E-01	4.77E+02
Ethylbenzene	434	1.34E-01	3.23E+03
Xylene	350	4.49E-01	7.80E+02
Naphthalene	52	1.70E-02	3.07E+03
Pyrene		6.42E-06	
Benzo(a)pyrene		3.74E-07	

Table 4K2c Volatilisation from surface soils to excavation pits Silty Clay Soil Type

Chemical	Dair cm ² /s	Dwat cm ² /s	H @ 20°C L-H ₂ O/L-air	Koc	Deff cm ² /s	ks cm ³ H ₂ O/g soil
C ₇ - C ₉	0.06	7.10E-06	1.2E+02	10000	2.1E-05	30
C ₁₀ - C ₁₄	0.042	4.80E-06	1.6E+02	1258925	1.4E-05	3776.775
C ₁₅ - C ₃₆	0.033	3.80E-06	1.4E+02	501187233	1.1E-05	1503561.699
Benzene	0.093	1.1E-05	2.2E-01	83	4.5E-05	0.249
Toluene	0.085	9.40E-06	2.6E-01	302	3.8E-05	0.906
Ethylbenzene	0.076	8.50E-06	3.2E-01	1096	3.3E-05	3.288
Xylene	0.072	8.50E-06	2.9E-01	240	3.2E-05	0.72
Naphthalene	0.072	9.40E-06	4.9E-02	1288	7.4E-05	3.864
Pyrene	0.048	7.24E-06	2.2E-04	38019	8.6E-03	114.057
Benzo(a)pyrene	0.05	5.80E-06	2.0E-05	389045	7.5E-02	1167.135

Chemical	Air Standard mg/m ³	VF (mg/m ³)/(mg/kg)	Soil Criteria mg/kg
C ₇ - C ₉	1640	8.40E-02	1.95E+04
C ₁₀ - C ₁₄	1050	7.09E-04	1.48E+06
C ₁₅ - C ₃₆		1.18E-06	
Benzene	16.0	2.30E-02	6.96E+02
Toluene	188	1.01E-02	1.87E+04
Ethylbenzene	434	3.47E-03	1.25E+05
Xylene	350	1.12E-02	3.12E+04
Naphthalene	52	1.04E-03	5.01E+04
Pyrene		1.91E-05	
Benzo(a)pyrene		1.39E-06	

Table 4K2d Volatilisation from surface soils to excavation pits Clay Soil Type

Chemical	Dair cm ² /s	Dwat cm ² /s	H @ 20°C L-H ₂ O/L-air	Koc	Deff cm ² /s	ks cm ³ H ₂ O/g soil
C ₇ - C ₉	0.06	7.10E-06	1.2E+02	10000	5.5E-07	30
C ₁₀ - C ₁₄	0.042	4.80E-06	1.6E+02	1258925	3.8E-07	3776.775
C ₁₅ - C ₃₆	0.033	3.80E-06	1.4E+02	501187233	3.0E-07	1503561.699
Benzene	0.093	1.1E-05	2.2E-01	83	1.8E-05	0.249
Toluene	0.085	9.40E-06	2.6E-01	302	1.3E-05	0.906
Ethylbenzene	0.076	8.50E-06	3.2E-01	1096	9.9E-06	3.288
Xylene	0.072	8.50E-06	2.9E-01	240	1.1E-05	0.72
Naphthalene	0.072	9.40E-06	4.9E-02	1288	6.7E-05	3.864
Pyrene	0.048	7.24E-06	2.2E-04	38019	1.1E-02	114.057
Benzo(a)pyrene	0.05	5.80E-06	2.0E-05	389045	1.0E-01	1167.135

Chemical	Air Standard mg/m ³	VF (mg/m ³)/(mg/kg)	Soil Criteria mg/kg
C ₇ - C ₉	1640	2.43E-03	6.74E+05
C ₁₀ - C ₁₄	1050	1.88E-05	5.58E+07
C ₁₅ - C ₃₆		3.16E-08	
Benzene	16.0	9.02E-03	1.77E+03
Toluene	188	3.44E-03	5.47E+04
Ethylbenzene	434	1.04E-03	4.17E+05
Xylene	350	3.70E-03	9.46E+04
Naphthalene	52	9.32E-04	5.58E+04
Pyrene		2.54E-05	
Benzo(a)pyrene		1.80E-06	

Table 4K2e Volatilisation from surface soils to excavation pits Pumice Soil Type

Chemical	Dair cm ² /s	Dwat cm ² /s	H @ 20°C L-H ₂ O/L-air	Koc	Deff cm ² /s	ks cm ³ H ₂ O/g-soil
C ₇ - C ₉	0.06	7.10E-06	1.2E+02	10000	9.3E-04	50
C ₁₀ - C ₁₄	0.042	4.80E-06	1.6E+02	1258925	6.5E-04	6294.625
C ₁₅ - C ₃₆	0.033	3.80E-06	1.4E+02	501187233	5.1E-04	2505936.165
Benzene	0.093	1.1E-05	2.2E-01	83	1.5E-03	0.415
Toluene	0.085	9.40E-06	2.6E-01	302	1.3E-03	1.51
Ethylbenzene	0.076	8.50E-06	3.2E-01	1096	1.2E-03	5.48
Xylene	0.072	8.50E-06	2.9E-01	240	1.1E-03	1.2
Naphthalene	0.072	9.40E-06	4.9E-02	1288	1.1E-03	6.44
Pyrene	0.048	7.24E-06	2.2E-04	38019	4.0E-03	190.095
Benzo(a)pyrene	0.05	5.80E-06	2.0E-05	389045	3.0E-02	1945.225

Chemical	Air Standard mg/m ³	VF (mg/m ³)/(mg/kg)	Soil Criteria mg/kg
C ₇ - C ₉	1640	2.03E+00	8.07E+02
C ₁₀ - C ₁₄	1050	1.93E-02	5.43E+04
C ₁₅ - C ₃₆		3.23E-05	
Benzene	16.0	5.76E-01	2.78E+01
Toluene	188	2.30E-01	8.16E+02
Ethylbenzene	434	7.73E-02	5.62E+03
Xylene	350	2.64E-01	1.33E+03
Naphthalene	52	9.79E-03	5.31E+03
Pyrene		5.44E-06	
Benzo(a)pyrene		3.47E-07	

Table 4K2f Volatilisation from surface soils to excavation pits PEATS AND HIGH ORGANIC Soil Type

Chemical	Dair cm ² /s	Dwat cm ² /s	H @ 20°C L-H ₂ O/L-air	Koc	Deff cm ² /s	ks cm ³ H ₂ O/g-soil
C ₇ - C ₉	0.06	7.10E-06	1.2E+02	10000	2.1E-03	1200
C ₁₀ - C ₁₄	0.042	4.80E-06	1.6E+02	1258925	1.5E-03	151071
C ₁₅ - C ₃₆	0.033	3.80E-06	1.4E+02	501187233	1.2E-03	60142467.96
Benzene	0.093	1.1E-05	2.2E-01	83	3.3E-03	9.96
Toluene	0.085	9.40E-06	2.6E-01	302	3.0E-03	36.24
Ethylbenzene	0.076	8.50E-06	3.2E-01	1096	2.7E-03	131.52
Xylene	0.072	8.50E-06	2.9E-01	240	2.6E-03	28.8
Naphthalene	0.072	9.40E-06	4.9E-02	1288	2.6E-03	154.56
Pyrene	0.048	7.24E-06	2.2E-04	38019	2.9E-03	4562.28
Benzo(a)pyrene	0.05	5.80E-06	2.0E-05	389045	1.2E-02	46685.4

Chemical	Air Standard mg/m ³	VF (mg/m ³)/(mg/kg)	Soil Criteria mg/kg
C ₇ - C ₉	1640	2.44E-01	6.72E+03
C ₁₀ - C ₁₄	1050	1.84E-03	5.72E+05
C ₁₅ - C ₃₆		3.06E-06	
Benzene	16.0	8.33E-02	1.92E+02
Toluene	188	2.50E-02	7.51E+03
Ethylbenzene	434	7.62E-03	5.70E+04
Xylene	350	2.97E-02	1.18E+04
Naphthalene	52	9.43E-04	5.51E+04
Pyrene		1.61E-07	
Benzo(a)pyrene		5.94E-09	