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Appendix D

APPENDIX D

RE-RUN OF QRA FOR LANDFILL GAS : JOHNSON ETTIGER APPROACH

An Assessment of the Impacts of Outdoor Air Emission and the Lateral Migration of Landfill Gases From the Area 6 Waste Mass

Release of gases from the site surface and their impacts on outdoor air have been undertaken based on the Johnson and Ettinger models. In the following equations the volatilisation factor (VF_{ss}) is predicted using the approach of Johnson *et al* (1990), whilst the effective diffusion coefficient (D_{eff}) is estimated by the method proposed by Johnson and Ettinger (1991).

$$C_{outdoor\ air} = C_{soil} \times VF_{ss}$$

As we have already measured the gas concentrations in the ground within the waste mass at Area 6, we already have a range of values for C_{soil}.

The value of V_{ss} has been calculated thus:

$$VF_{ss} = \frac{2W\rho_s d}{U_{air}\delta_{air}\tau}$$

Where: **W** is the length of the source zone parallel to the wind direction, ρ_s is the soil bulk density, **d** is the thickness of the gas contaminated zone, U_{air} is the wind speed, δ_{air} is the mixing zone or breathing zone height and τ is the exposure duration.

Table 1. Parameters Used In Calculating The Soil Surface Volatilisation Factor - VF_{ss}

Parameter	Symbol	Value	Units	Source/Justification
Length of Source Zone parallel to wind direction	W	1000	cm	Longest estimated length of AREA 6 from housing
Soil bulk density	ρ_s	1.7	g/cm^3	Site Data
Wind speed	U_{air}	800	cm/s	CLR 10
Mixing Zone Height	δ_{air}	120	cm	Breathing Zone height (Professional judgement)
Thickness of affected zone	d	8000	cm	Waste thickness in AREA 6
Averaging time/exposure duration	τ	189216000	S	CLR 10 (6 year old child)
VF_{ss} (calculated)		**0.0014974**		

Hence any gas concentration observed at the site will result in outdoor concentrations which are less than the 1%v/v and 1.5%v/v limits for methane and carbon dioxide respectively. There for 100%v/v methane would result in an outdoor air concentration of 0.15%v/v. Hence there is no risk to local residents from exposure to outdoor air.

We have also modelled the potential for gasses to migrate through the unsaturated zone towards the local residences using solutions to the advection/diffusion equations based on the findings of van Genuchten et al. See Tables 3 and 4 below.

Under both diffusive and advective conditions no gasses will be present in measurable concentrations beyond 10m of the waste mass boundary. This has been modelled under the worst case condition which assumes that the highest methane concentration ever observed in the waste in Area 6 i.e. 30.3%v/v in BH 6/10 on 12th March 2003. It should also be noted that

the highest concentrations of methane and carbon dioxide in the boundary vent monitoring wells were 6.7%v/v and 9.9%v/v respectively. Both monitored on 5th November 2004 in J11. In the venting trench monitoring wells (C1-C8) which represents the boundary between the waste mass and the properties gasses have been detected at or below the limit of detection (0.1%v/v).

Hence we determine that there is a negligible risk to local residents from emissions of methane and carbon dioxide to outdoor air. Similarly there is a negligible risk to local residents from methane and carbon dioxide migrating through the ground between the Area 6 waste mass to local domestic dwellings.

Table 2
Calculation of Lateral Gas Migration by Diffusion

Parameter	Notation	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Units	Reference/justification
Distance from source	x_s	*6.5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*50*	*75*	*100*	*125*	*150*	*175*	*200*	m	
Diffusion coefficient in air	D_a	1.70E-05	1.70E-05	1.70E-05	1.70E-05	1.70E-05	1.70E-05	1.70E-05	1.70E-05	1.70E-05	1.70E-05	1.70E-05	1.70E-05	1.70E-05	1.70E-05	1.70E-05	1.70E-05	m^2/s	Diffusivity for a 50:50 mixture of methane and carbon dioxide - Reference 7
Air filled porosity	θ_a	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	dimensionless	Site Data
Water filled porosity	θ_w	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	dimensionless	Site Data
Elapsed time since gas release	t	*0.08*	*0.08*	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	years	*Estimated time since landfill gas production commenced.*
Elapsed time since gas release	t	2628000	2628000	2628000	2628000	2628000	2628000	2628000	2628000	2628000	2628000	2628000	2628000	2628000	2628000	2628000	2628000	s	
Total porosity	θ	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	m^3/m^3	Sum of water and air filled porosity
Effective diffusion coefficient	D^{eff}	2.63E-06	2.63E-06	2.63E-06	2.63E-06	2.63E-06	2.63E-06	2.63E-06	2.63E-06	2.63E-06	2.63E-06	2.63E-06	2.63E-06	2.63E-06	2.63E-06	2.63E-06	2.63E-06	m^2/s	After van Genuchten
Ratio of concnetration at x to the source concentra	C_x/C_o	0.08	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	dimensionless	
SOURCE CONC (%v/v) =		30.3	2.441968	0.217745	0.001675	2.31E-06	5.5E-10	2.23E-14	1.53E-19	1.75E-25	3.34E-32	1.06E-39	6.58E-89	1.1E-157	4.9E-246	0	0	0		

Table 3
Calculation of Lateral Gas Migration by Advection and Diffusion

Parameter	Notation	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Units	Reference/justification
Distance from source	x_s	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*50*	*75*	*100*	*125*	*150*	*175*	*200*	m	
Intrinsic permeability	k	1.08E-11	1.081E-11	1.081E-11	1.081E-11	1.081E-11	1.081E-11	1.081E-11	1.081E-11	1.081E-11	1.081E-11	1.081E-11	1.081E-11	1.081E-11	1.081E-11	1.081E-11	1.081E-11	m^2	Calculated Intrinsic Permeability
Viscosity of air	μ	1.71E-05	0.0000171	0.0000171	0.0000171	0.0000171	0.0000171	0.0000171	0.0000171	0.0000171	0.0000171	0.0000171	0.0000171	0.0000171	0.0000171	0.0000171	0.0000171	Pa.s	
Pressure at x=0	P1	*1001*	1001	1001	1001	1001	1001	1001	1001	1001	1001	1001	1001	1001	1001	1001	1001	mbar	*Estimated driving pressure at the landfill*
Pressure at x=>0	P2	*1000*	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	mbar	*Soil gas pressure at the receptor*
Degradation rate	λ	*0.00E+00*	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	s^{-1}	*Assumed no degradation*
Diffusion coefficient in air	D_a	1.70E-05	1.70E-05	1.70E-05	1.70E-05	1.70E-05	1.70E-05	1.70E-05	1.70E-05	1.70E-05	1.70E-05	1.70E-05	1.70E-05	1.70E-05	1.70E-05	1.70E-05	1.70E-05	m^2/s	Diffusivity for a 50:50 mixture of methane and carbon dioxide
Air filled porosity	θ_a	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	dimensionless	Site Data
Water filled porosity	θ_w	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	dimensionless	Site Data
Retardation coefficient	R	*1*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	dimensionless	It is assumed that there is no sorption of gas to the soil matrix
Elapsed time since gas release	t	*0.08*	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	years	Estimated time since landfill gas production commenced.
Pressure difference	ΔP	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	Pa	Calculated from P1-P2
Total porosity	θ_T	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	dimensionless	Sum of water and air filled porosity
Gas velocity	v	3.16E-07	3.16E-07	3.16E-07	3.16E-07	3.16E-07	3.16E-07	3.16E-07	3.16E-07	3.16E-07	3.16E-07	3.16E-07	3.16E-07	3.16E-07	3.16E-07	3.16E-07	3.16E-07	m/s	van Genuchten
Effective diffusion coefficient	D^{eff}	2.63E-06	2.63E-06	2.63E-06	2.63E-06	2.63E-06	2.63E-06	2.63E-06	2.63E-06	2.63E-06	2.63E-06	2.63E-06	2.63E-06	2.63E-06	2.63E-06	2.63E-06	2.63E-06	m^2/s	van Genuchten
Retarded gas flow velocity	u	3.16E-07	3.16E-07	3.16E-07	3.16E-07	3.16E-07	3.16E-07	3.16E-07	3.16E-07	3.16E-07	3.16E-07	3.16E-07	3.16E-07	3.16E-07	3.16E-07	3.16E-07	3.16E-07	m/s	van Genuchten
Ratio of concentration at x (Cxt) to the source conce	C_{xt}/C_o	0.23785	0.01283	0.00013	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	dimensionless	van Genuchten
SOURCE CONC (%v/v) =		30.3	7.2067854	0.38877276	0.00402893	7.4802E-06	2.4072E-09	1.3192E-13	1.2185E-18	1.8846E-24	4.86E-31	2.083E-38	5.785E-87	4.39E-155	8.67E-243	0	0	0	