APPENDIX S

Assessment of Smoke Ingress

ASSESSMENT OF SMOKE INGRESS

Based on a study "Analyzing Smoke and Toxic Gas Hazards" (Hewitt I. and A.Z. Reza, 1992), the composition of smoke plume of heavy fuel oil fire at 1000^{0}C is as follows:

- CO_2 11.8%
- CO 800ppm

Other components of smoke include NO_X, SO_X and hydrocarbons.

For most practical situations, the composition of fire atmospheres will be such that for narcotic effects CO will be the most important toxic product, and that the most important interaction will be an increased rate of CO uptake due to hyperventiliation caused by CO_2.

On this basis the fractional dose equation for narcosis (in the absence of HCN) would be (SFPE Handbook of Fire Protection Engineering, 1995):

$$\textbf{Total } F_{IN} = F_{ICO}\ VCO_2 + F_{ICO2}$$

where F_{IN} = fraction of an incapacitating dose of all narcotic gases
F_{ICO} = fraction of an incapacitating dose of CO
VCO_2 = multiplication factor for CO_2 - induced hyperventilation
F_{ICO2} = fraction of an incapacitating dose of CO_2

$$F_{ICO} = 2.7642 \times 10^{-5}\ [CO]^{1.036}\ t$$

where [CO] = concentration of CO in ppm
t = exposure time, min

$$F_{ICO2} = t / \exp(6.1623 - 0.5189 \times \%CO_2)$$

$$VCO_2 = \exp(0.1903 \times \%CO_2 + 2.004) / 7.1$$

Table T.1a Incapacitation in Smoke Atmospheres

CASE	CO,PPM	CO_2,%	T, MIN	F_{ICO}	VCO_2	F_{ICO2}	F_{IN}
1	800	11.8	0.8	0.023	9.869	0.769	0.991
2	300	4.4	20	0.204	2.425	0.419	0.914
3	200	3	40	0.268	1.849	0.4	0.895
4	80	1.2	120	0.311	1.308	0.467	0.873
5	14	0.2	120	0.005	1.049	0.281	0.336
6	1.2	0.02	120	0.004	1.049	0.256	0.260

At an indoor smoke concentration of Case 2, the incapacitation dose is almost reached for an exposure time of 20 min. Therefore, when the CO concentration is 300 ppm or lower, the occupants of building have more than 20 minutes to escape before being incapacitated by the narcostic gas. For Case 1 (outdoor concentration), the incapacitation time is 48 seconds. For situation where CO and CO_2 are lower than that shown in Case 4 (e.g. Case 5), the occupants have more than two hours to escape before being incapacitated.

Further calculation is needed to check the variation of indoor concentration (C_i) with time for different outdoor concentrations (C_o) and various air exchange rate (λ). The typical building air exchange rate varies from 0.7 to 3 per hour. A higher exchange rate of 5 per hour is assumed for workshops.

$$\mathbf{C_i = C_o\ [1\text{-}exp(-\lambda t)]}$$

Table T.1b Indoor concentration of CO

C_O,PPM	λ	T,MIN	C_i, PPM
800	3	9.4	300
800	3	28	600
800	5	5	300
800	5	17	600
14	3	30	10.9
14	5	30	8.8
1.2	3	30	0.9
1.2	5	30	1.1

Table T.1c Indoor concentration of CO_2

C_O,%	λ	T,MIN	C_i, %
11.8	3	9.4	4.425
11.8	3	28	8.891
11.8	5	5	4.021
11.8	5	17	8.938
0.2	3	30	0.155
0.2	5	30	0.184
0.02	3	30	0.016
0.02	5	30	0.018