$\boxed{2-1}$ To convert mg/m^3 to ppm:

$$\frac{m^3 \text{ species}}{m^3 \text{ total}} = \left(\frac{mg \text{ species}}{m^3 \text{ total}}\right)\left(\frac{gm}{1000\,mg}\right)\left(\frac{mole}{gm}\right)\left(\frac{m^3}{mole}\right)$$

$$= \left(\frac{mg}{m^3}\right)\left(\frac{1}{1000M}\right)\left(\frac{m^3}{mole}\right)$$

For an ideal gas:

$$\frac{m^3}{mole} = \left(\frac{22.4\,\ell}{mole} \text{ @ STP}\right)\left(\frac{1\,m^3}{1000\,\ell}\right)\left(\frac{T}{273}\right)\left(\frac{1}{P}\right)$$

$$PPM = \frac{m^3 \text{ species} \times 10^6}{m^3 \text{ Total}}$$

$$= \left(\frac{mg}{m^3}\right)\left(\frac{1}{1000\,M}\right)(22.4)\left(\frac{1}{1000}\right)\left(\frac{T}{273}\right)\left(\frac{1}{P}\right) \times 10^6$$

$$= \left(\frac{22.4}{273}\right)\left(\frac{T}{PM}\right)\left(\frac{mg}{m^3}\right)$$

$$\underline{PPM = 0.0825\left(\frac{T}{PM}\right)\left(\frac{mg}{m^3}\right)}$$

$\boxed{2\text{-}2}$

Dose (mg/ℓ)	Log (Dose)	No. of Insects	No. Affected	%	Probit
10.2	1.01	50	44	88.0	6.18
7.7	0.886	49	42	85.7	6.07
5.1	0.708	46	24	52.2	5.06
3.8	0.580	48	16	33.3	4.57
2.6	0.415	50	6	12.0	3.82
0	—	49	0	0	—

The probit variables were read from Table 2-3.
Plots are given on the next page.
The straight line on the probit plot was "eyeball" best fit.

Slope of the probit curve is $\frac{1.2}{0.30} = 4.0$

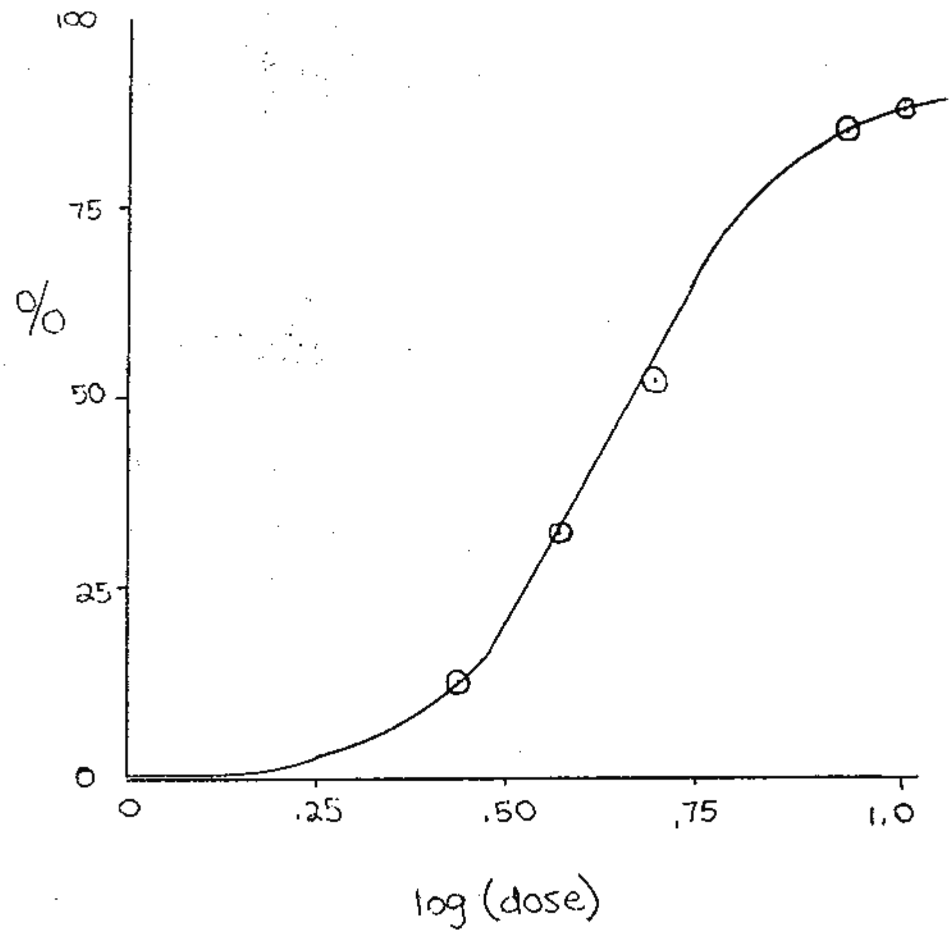
Then $y = 4 \log(\text{dose}) + \text{intercept}$

@ $Y = 5.2$, $\log(\text{dose}) = 0.75$, so

$\text{intercept} = 5.2 - 4(0.75) = 2.2$

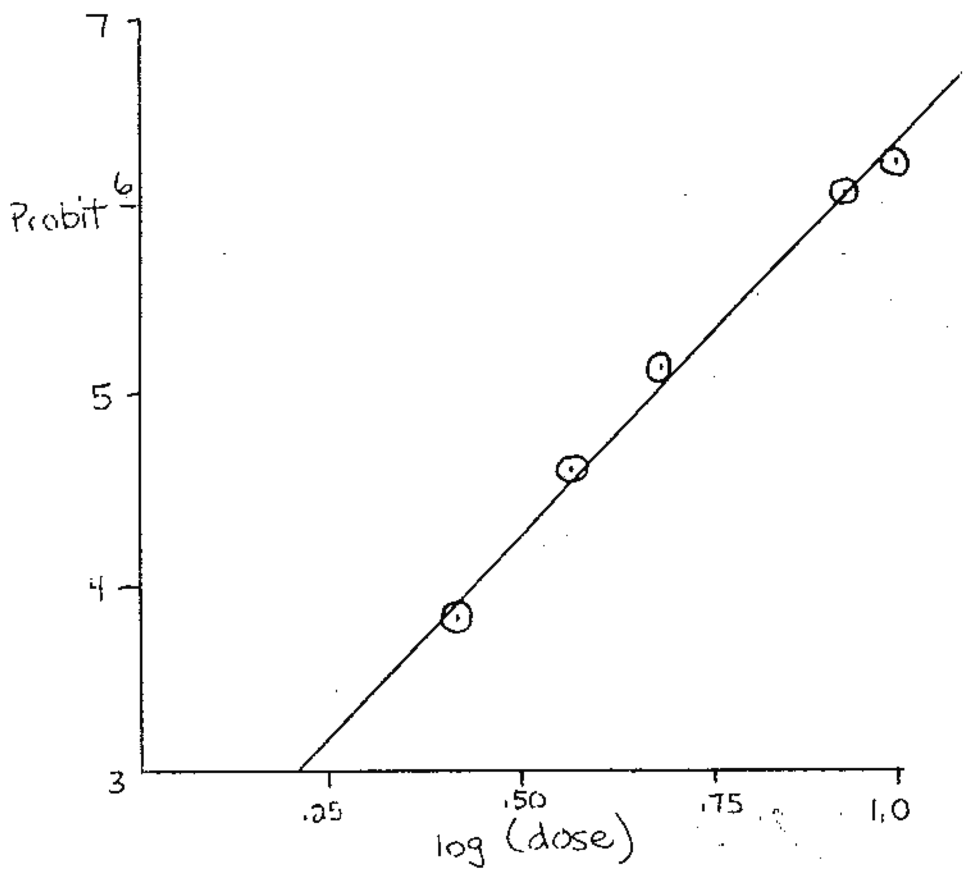
$$\boxed{Y = 4 \log\left(\frac{mg}{\ell}\right) + 2.2}$$ <u>OR</u>

$$Y = 1.74 \ln\left(\frac{mg}{\ell}\right) + 2.2 \quad (\text{since } \ln = 2.3 \log)$$



100
75
%
50
25
0
0
.25
.50
.75
1.0
log (dose)

(a)



7
Probit 6
5
4
3
.25
.50
.75
1.0
log (dose)

(b)

Comparison

			←	Predicted	→
Dose (mg/l)	Probit	No. Affected	Probit	%	No. Affected
10.2	6.18	44	6.23	89	44.5
7.7	6.07	42	5.74	77	37.7
5.1	5.06	24	5.03	51	23.5
3.8	4.57	16	4.52	31.5	15.1
2.6	3.82	6	3.86	12.8	6.4

$\boxed{2\text{-}3}$ Overpressure = 47,000 N/m^2

From Table 2-4:

Structural damage: $Y = -23.8 + 2.92 \ln p^o$

Deaths from lung hemorrhage: $Y = -77.1 + 6.91 \ln p^o$

Eardrums: $Y = -15.6 + 1.93 \ln p^o$

For $p^o = 47{,}000\ N/m^2$

Structural damage: $Y = 7.61$

Deaths (lung hem): $Y = -2.76$

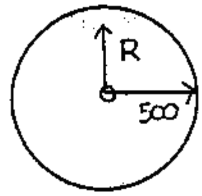
Eardrums: $Y = 5.163$

From Table 2-~~4~~

	Percent Affected
Structural damage:	99.6
Deaths (lung hem):	0 (Y is negative)
Eardrums	56

The blast is not serious enough to expect fatalities, but is serious enough to cause extensive damage to surrounding structures and to rupture the eardrums of more than half of the people exposed. Additional injuries from debris might be expected.

$\boxed{2\text{-}4}$



Explosion at center

500 people in area from 10 to 500 feet away

Explosion overpressure given by: $\log P = 4.2 - 1.8 \log r$

P = psia
r = feet

Assume 500 people are evenly distributed throughout the area.

Compute population density:

Total area $= \pi\left[(500)^2 - (10)^2\right] = 7.85 \times 10^5\ ft^2$

Population density $= \dfrac{500 \text{ people}}{7.85 \times 10^5\ ft^2} = 6.37 \times 10^{-4}$ people$/ft^2$

Procedure: Divide area into shells. Determine overpressure at each shell, number of people in each shell, and number of people affected. The smaller the size of the shell, the more accurate the result.

Determine maximum distances where people are affected. From Table 2-4:

Deaths due to lung hemorrhage: $Y = -77.1 + 6.91 \ln P$

Eardrum rupture: $Y = -15.6 + 1.93 \ln P$

Where P is in N/m^2

The probability is zero when $Y = 0$, so

Deaths (L.H.): $P = \exp\left[\frac{77.1}{6.91}\right] = 7.01 \times 10^4 \ N/m^2$

$= 10.17$ psia

Eardrum rupture: $P = \exp\left[\frac{15.6}{1.93}\right] = 3.24 \times 10^3 \ N/m^2$

$= .470$ psia

This will occur at the following distances

Deaths (L.H): $\log r = \frac{4.2 - \log P}{1.8} = \frac{4.2 - \log(10.17)}{1.8}$

$r = 59.4$ ft.

Eardrum rupture: $\log r = \frac{4.2 - \log(0.470)}{1.8}$

$r = 328$ ft

The death calculation can be performed using a single shell, 59.4 ft in radius.

$A = \pi\left[(59.4)^2 - (10)^2\right] = 10{,}771 \ ft^2$

Total people in shell

$= (10771)(6.37 \times 10^{-4} \ people/ft^2)$

$= 6.86$ people

Average radius $= \frac{10 + 59.4}{2} = 34.7$ ft.

Average overpressure = 28.1 psia
$= 1.94 \times 10^5$ N/m²

Probit Variable $Y = -77.1 + 6.91 \ln(1.94 \times 10^5 \text{ N/m}^2)$
$= 7.033$

Which is a 97% result. It looks like 6 people will be killed by lung hemorrhage. Results show that people should not be allowed within at least 50 feet of the source, instead of 10 feet.

The eardrum rupture is a bit more complicated:

Total people in 328 ft radius:

$$A = \pi\left[(328)^2 - (10)^2\right] = 3.37 \times 10^5 \text{ ft}^2$$

$$\text{People} = (3.37 \times 10^5 \text{ ft}^2)(6.37 \times 10^{-4} \text{ people/ft}^2) = 215$$

0% affected radius is too far out. Compute 1% affected radius:

@ 1% $\quad Y = 2.67$

$$2.67 = -15.6 + 1.93 \ln P$$

$$\ln P = 9.47$$

$$P = (1.292 \times 10^4 \text{ N/m}^2)\left(\frac{1 \text{ psia}}{6890 \text{ N/m}^2}\right) = 1.87 \text{ psia}$$

$$\log(1.87) = 4.2 - 1.8 \log r$$
$$\log r = 2.18$$
$$r = 152 \text{ ft}$$

Total area:

$$A = \pi\left[(1522)^2 - (10)^2\right] = 7.24 \times 10^4 \text{ ft}^2$$

Total people:

$$\text{People} = (7.24 \times 10^4 \text{ ft}^2)(6.37 \times 10^{-4} \text{ people/ft}^2)$$
$$= 46.1 \text{ people}$$

Several ways to divide total area:

1) Fixed number of people per shell
2) Fixed, equal radius increments

Procedure #1 is more accurate.

Divide into 5 shells with $\frac{46.1}{5} = 9.22$ people per shell. Each shell has an area of $\frac{7.24 \times 10^4 \text{ ft}^2}{5} = 1.45 \times 10^4 \text{ ft}^2$. To compute radius:

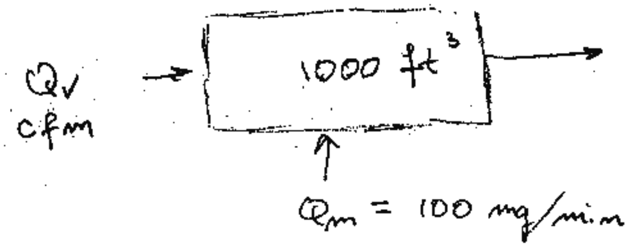
$$R_2 = \sqrt{\frac{A}{\pi} + R_1^2} = \sqrt{4.62 \times 10^3 + R_1^2}$$

Shell Number	R_1	R_2	$\bar{R}$	$\bar{P}$ (psia)	P(N/m²)
1	10	68.7	39.3	21.4	1.47×10^5
2	68.7	96.6	82.6	5.62	3.87×10^4
3	96.6	118.2	107.4	3.50	2.41×10^4
4	118.2	136.3	127.3	2.58	1.78×10^4
5	136.3	152.3	144.3	2.06	1.42×10^4

Shell Number	P(N/m²)	Y	%	No. People
1	1.41×10^5	7.36	99.1	9.1
2	3.87×10^4	4.79	42	3.9
3	2.41×10^4	3.87	13	1.2
4	1.78×10^4	3.29	4.2	0.4
5	1.42×10^4	2.85	1.7	0.2
				14.8 ≈
				15 people

Better estimates can be made with more shells.

2-5.



1 atm

77 °F = 537 °R = 298 °K

TLV-TWA = 100 ppm

Assuming well-mixed

$$\frac{d(VC)}{dt} = Q_m - Q_v C$$

At steady state $\frac{d(VC)}{dt} = 0$

Units:

Q_m = mg/min

Q_v = ft³/min

C = mg/ft³

Using Eq. 2-6

$$C_{ppm} = 0.08205 \frac{T}{PM}\left(\frac{mg}{m^3}\right)$$

$$\therefore \quad mg/m^3 = C_{ppm} \frac{PM}{T} \frac{1}{0.08205}$$

$$= (100)\frac{(1)(100)}{298}\frac{1}{0.08205} = 409 \ mg/m^3$$

$$mg/ft^3 = \left(\frac{mg}{m^3}\right)\left(\frac{m}{3.28\ ft}\right)^3 = \frac{409}{35.3} = 11.6 \ mg/ft^3$$

$$\therefore \quad Q_v = \frac{Q_m}{C} = \frac{100 \ mg/min}{11.6 \ mg/ft^3} = 8.63 \ ft^3/min$$

$\boxed{2\text{-}6}$ Distribution $f(x) = 0.178\, e^{-0.100\,(x-4.51)^2}$

where $f(x)$ is the fraction affected. Thus,

$$\text{Fraction affected} = \int_{2.5}^{7.5} f(x)\,dx$$

$$= 0.178 \int_{2.5}^{7.5} e^{-0.100\,(x-4.51)^2}\,dx$$

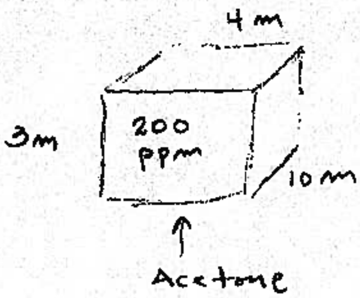
which can be approximated by: $\sum_{i=1}^{x} \left(\frac{f(i) + f(i+1)}{2}\right)\Delta i$

x	$f(x)$	$\frac{f(i) + f(i+1)}{2}\,\Delta i$
2.5	0.676	
3.5	0.903	0.395
4.5	1.000	0.476
5.5	0.907	0.477
6.5	0.673	0.395
7.5	0.409	0.270

$\Sigma = 2.01$

$2.01 \times 0.178 = \underline{0.358} =$ fraction affected

2-7.



The total volume of the room is

$$V = lwh = (3\ \mathrm{m})(4\ \mathrm{m})(10\ \mathrm{m}) = 120\ \mathrm{m}^3$$

The volume occupied by the acetone vapor is

$$\left(\frac{200}{10^6}\right)(120\ \mathrm{m}^3) = 0.024\ \mathrm{m}^3$$

From the ideal gas law,

$$n = \frac{PV}{R_g T} = \frac{(101.3\ \mathrm{kPa})(0.024\ \mathrm{m}^3)}{(8.314\ \mathrm{kPa\ m^3/kg\text{-}mole\ K})(298\ \mathrm{K})} = 0.000981\ \mathrm{kg\text{-}mole}$$

The total mass is

$$(0.000981\ \mathrm{kg\text{-}mol})\left(58.1\ \frac{\mathrm{Kg}}{\mathrm{Kg\text{-}Mol}}\right) = 0.057\ \mathrm{Kg}$$

$$= 57\ \mathrm{gm}$$

The volume in ml's is $= \dfrac{57\ \mathrm{g}}{0.7899\ \mathrm{g/ml}} = 72.2\ \mathrm{ml}$

SOLUTION - Problem 2-8

2-8: There are two ways to interpret this problem

I: Assume that the <u>same</u> workers are exposed to ~~these~~ ammonia concentrations consecutively during the same 8-hour shift. Then

Conc (ppm):	1000	2000	300	150
Minutes:	60	120	180	120
$C^{2.0}$:	10^6	4×10^6	9×10^4	2.2×10^4
$C^{2.0}T$:	60×10^6	480×10^6	16×10^6	2.6×10^6

Since the exposures are consecutive <u>and</u> the same worker, we can sum the causative variables.

$$\sum C^{2.0} T = 559 \times 10^6$$

From Table 2-5

$$Y = -35.9 + 1.85 \ln(559 \times 10^6)$$

$$= -35.9 + 37.3$$

$$= 1.36$$

From Table 2-4, this is less than 1%

Use Equation 2-6 to get a more precise value.

$$\operatorname{erf}\left(\frac{|14-5|}{\sqrt{2}}\right) = \operatorname{erf}\left(\frac{|1.36-5|}{1.414}\right) = \operatorname{erf}(2.57)$$

From Excel, $\operatorname{erf}(0, 2.57) \simeq 1.0$

Then

$$p = 50\left[1 + \frac{1.36-5}{|1.36-5|}(1.0)\right]$$

$$= 50\left[1 + \frac{-3.64}{3.64}(1.0)\right]$$

$= 0 =$ percentage of workers affected

$\therefore$ No workers are affected.

II. This approach assumes that the exposures are separate with different workers. Look at each case individually.

a) $Y = -35.9 + 1.85 \ln(60 \times 10^6) = -2.8$

$\therefore$ 0% workers are affected

b) $Y = -35.9 + 1.85 \ln(480 \times 10^6) = 1.08$

$\therefore$ 0% workers are affected

c) $Y = -35.9 + 1.85 \ln(16 \times 10^6) = -5.21$

$\therefore$ 0% workers are affected

d) $Y \simeq -35.9 + 1.85 \ln(2.6 \times 10^{6}) \simeq -8.57$
$\therefore$ 0% workers are affected

In both cases no workers are affected.
However, all of the exposures exceed
OSHA PEL for ammonia of 50 ppm
and the TLV-TWA of 25 ppm.
Even though there will be no fatalities,
the workers will be overexposed and will
have health effects.

SOLUTION PROBLEM 2-9

A search on the NIOSH web site will yield a number of sources for the definition of the IDLH. The most useful document is *Documentation for Immediately Dangerous to Life and Health Concentrations.* This is NTIS publication PB-94-195047 publish in May, 1994.

This document has the following content in the Background section:

The Occupational Safety and Health Administration (OSHA) defines an IDLH value in their hazardous waste operations and emergency response regulation as follows:

> An atmospheric concentration of any toxic, corrosive or asphyxiant substance that poses an immediate threat to life or would cause irreversible or delayed adverse health effects or would interfere with an individual's ability to escape from a dangerous atmosphere. [29 CFR* 1910.120]

In the OSHA regulation on permit-required confined spaces, an IDLH condition is defined as follows:

> Any condition that poses an immediate or delayed threat to life or that would cause irreversible adverse health effects or that would interfere with an individual's ability to escape unaided from a permit space. Note: Some materials--hydrogen fluoride gas and cadmium vapor, for example--may produce immediate transient effects that, even if severe, may pass without medical attention, but are followed by sudden, possibly fatal collapse 12-72 hours after exposure. The victim "feels normal" from recovery from transient effects until collapse. Such materials in hazardous quantities are considered to be "immediately dangerous to life or health." [29 CFR 1910.146]

SOLUTION PROBLEM 2-10

From the same document used in Problem 2-9:

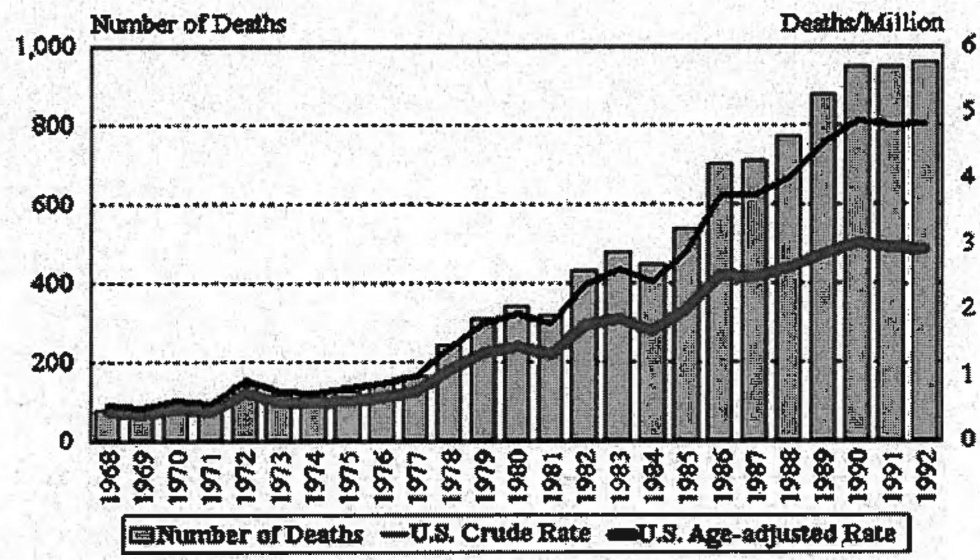
The purpose for establishing this IDLH value was to determine a concentration from which a worker could escape without injury or without irreversible health effects in the event of respiratory protection equipment failure (e.g., contaminant breakthrough in a cartridge respirator or stoppage of air flow in a supplied-air respirator) and a concentration above which only "highly reliable" respirators would be required. In determining IDLH values, the ability of a worker to escape without loss of life or irreversible health effects was considered along with severe eye or respiratory irritation and other deleterious effects (e.g., disorientation or incoordination) that could prevent escape. Although in most cases, egress from a particular worksite could occur in much less than 30 minutes, as a safety margin, IDLH values were based on the effects that might occur as a consequence of a 30-minute exposure. However, the 30-minute period was NOT meant to imply that workers should stay in the work environment any longer than necessary following the failure of respiratory protection equipment; in fact, **EVERY EFFORT SHOULD BE MADE TO EXIT IMMEDIATELY!**

The answer is 30 minutes.

SOLUTION PROBLEM 2-11

A search of the NIOSH web site yields the following document at:
http://www.cdc.gov/niosh/docs/96-134/pdfs/96-134c.pdf

Figure 1-1. Asbestosis: Number of deaths, crude and age-adjusted mortality rates, U.S. residents age 15 and over, 1968-1992



In 1991 there were 946 asbestosis related deaths and in 1992 there were 959 deaths.

The answer is 959 for 1992. Unfortunately, more recent data are not available.

SOLUTION PROBLEM 2-12

The list of IDLH values is provided here: http://www.cdc.gov/niosh/idlh/intridl4.html

The IDLH values are: ethanol – 3,300 PPM; ethylene oxide – 800 ppm

The PEL value for ethanol is provided in Appendix G, and has a value of 1000 ppm.

Ethylene oxide is a regulated chemical and its exposure is described in OSHA standard 1910.1047, which is available on the www. osha.gov web site. This standard states the following:

"8-hour time-weighted average (TWA)." The employer shall ensure that no employee is exposed to an airborne concentration of EtO in excess of one (1) part EtO per million parts of air (1 ppm) as an (8)-hour time-weighted average (8-hour TWA).

"Excursion limit." The employer shall ensure that no employee is exposed to an airborne concentration of EtO in excess of 5 parts of EtO per million parts of air (5 ppm) as averaged over a sampling period of fifteen (15) minutes.

Thus, the PEL (which is an 8 hour exposure limit) is 1 ppm.

SOLUTION PROBLEM 2-13

The TLVs can be found in Appendix G, or on the OSHA (www.osha.gov) or NIOSH web site (www.cdc.gov/niosh). Additional information can be found using the NIOSH Pocket Guide found on-line at www.cdc.gov/niosh/npg.

Ethylene trichloride is listed in Appendix G as trichloroethylene. This chemical synonym can be found in the NIOSH pocket guide and elsewhere.

Ethylene oxide and benzene are regulated chemicals with a specific OSHA regulation. The regulation for ethylene oxide is 1910.1047 and for benzene 1910.1028. These regulations can be found on the www.osha.gov web site. These regulations show an 8-hour exposure limit, which is equivalent to the OSHA PEL value.

The IDLH values are found on the NIOSH web site.

The results are as follows;

	TLV (ppm)	IDLH (ppm)	PEL (ppm)
Ethanol:	1000 – STEL	3,300	1000
Ethylene oxide:	1	800	1 (1910.1047)
Benzene:	0.5	500	1 (1910.1028)
Trichloroethylene:	25	1,000	2 mg/m^3
Fluorine:	1	25	0.1
Hydrogen chloride:	2 – Ceiling	50	5 - Ceiling

SOLUTION PROBLEM 2-14

The LC_{50} data might be difficult to find. It also has wide variability in the literature.
The IDLH data can be found on the NIOSH web site http://www.cdc.gov/niosh/idlh/intridl4.html
The PELs can be found in Appendix G.

	LC_{50} (ppm)	IDLH (ppm)	PEL (ppm)
Ammonia:	2,000	300	50
Carbon monoxide:	1,800 (4 hours)	1,200	50
Ethylene oxide:	800 (4 hours)	800	1 (1910.1047)

(2-15) NIOSH states Death occurs at result of ammonia exposures between 5000 and 10,000 ppm over 30 min period

From Table 2-5

Toxic release – Ammonia Deaths $\Sigma C^{2.0}T$

$k_1 = -35.9$ $\quad k_2 = 1.85$

For Exposures at 5000 ppm for 30 min.

$$Y = k_1 + k_2 \ln C^2 T$$

$$= -35.9 + 1.85 \ln (5000)^2(30)$$

$$= 1.9058 \quad \text{(probits)}$$

$$\frac{0 - 2.67}{0 - 1\%} = \frac{1.9058 - 2.67}{x - 1\%}$$

$$x = 0.71\ \%$$

which is Equivalent to 0.71% of exposed people will death

For Exposures at 10,000 ppm for 30 min

$$Y = -35.9 + 1.85 \ln(10,000)^2(30)$$

$$= 4.47$$

which Equivalent to 39.67% of Exposed people will death

⇒ Based On the NIOSH data and Calculation, deaths will occured at result of ammonia Exposures between 5000 and 10000 ppm over 30 min period, which is consistent with the results from probit equation.

$\boxed{2\text{-}16}$ From the website
www.cdc.gov/niosh

The IDLHs are

ammonia: 300 PPM
Chlorine: 10 PPM
Ethylene oxide: 800 ppm
Hydrogen chloride 50 ppm

Use probit equations from Table 2-5

For ammonia

$$Y = -35.9 + 1.85 \ln\left[(300\,\text{ppm})^2(120\,\text{min})\right]$$
$$= -5.94 \Rightarrow \% = 0\%$$

Chlorine

$$Y = -8.29 + 0.92 \ln\left[(10\,\text{PPM})^2(120\,\text{min})\right]$$
$$= 0.351 \Rightarrow 0\%$$

Ethylene oxide

$$Y = -6.19 + (1.0) \ln\left[(800\,\text{PPM})(120\,\text{min})\right]$$
$$= 5.28 \Rightarrow 61\%\ \text{deaths}$$

Hydrogen chloride

$$Y = -16.85 + 2.0 \ln\left[(50\,\text{ppm})(120\,\text{min})\right]$$
$$= 0.549 \Rightarrow 0\%$$

(2)

Conclusion: probit for ethylene oxide not consistent with IDLH.

SOLUTION PROBLEM 2-17

50% = 5 Probits (Table 2-4)

From the ethylene oxide deaths equation in Table 2-5,

$Y = -6.19 + \ln CT$

$= -6.19 + \ln C(30 \text{ min})$

$5 + 6.19 = \ln C(30)$

$11.19 = \ln C(30)$

$e^{11.19} = C(30) = 72,403$

$C = 72,403/30 = 2413 \text{ ppm}$

This is higher than the IDLH of 800 ppm.

SOLUTION PROBLEM 2-18

Use equation for phosgene deaths in Table 2-5

$Y = -19.27 + 3.69 \ln \sum CT$

$Y = -19.27 + 3.69 \ln[(10 \text{ ppm})(30 \text{ min})]$

$Y = 1.77$

From Table 2-4 this is less than 1%

At 1 ppm for 30 min, get same numerical answer and same result.

SOLUTION PROBLEM 2-19

Use equation for carbon monoxide deaths from Table 2-5.

$Y = -37.98 + 3.7 \ln \sum CT$

From Table 2-4, at 0% fatalities, $Y = 2.0$; at 50% fatalities, $Y = 5.0$

Substituting for Y=2

$2.0 = -37.98 + 3.7 \ln(1500T)$

$39.98 = 3.7 \ln(1500T)$

$\ln(1500T) = 10.80$

$1500T = 4.93 \times 10^4$

$T = 32.8 \text{ min}$

For less than 0% fatalities.

For 50% fatalities,

$$5.0 = -37.98 + 3.7\ln(1500T)$$
$$42.98 = 3.7\ln(1500T)$$
$$\ln(1500T) = 11.62$$
$$1500T = 1.11\times10^5$$
$$T = 73.9 \text{ min}$$

SOLUTION PROBLEM 2-20

Use Equation (2-7) to convert the TLV in ppm to mg/m^3. Assume 25°C and 1 atm pressure. TLV values are in Appendix G.

From Equation (2-7):

$$C_{ppm} = 0.08205\left(\frac{T}{PM}\right)\left(\text{mg/m}^3\right)$$
$$\text{mg/m}^3 = \left(\frac{C_{ppm}}{0.08205}\right)\left(\frac{1 \text{ atm}}{298 \text{ K}}\right)M$$
$$= 4.090\times10^{-2}C_{ppm}M$$

Chemical	M	TLV (ppm)	mg/m^3
Benzene	78.11	0.5	1.60
Carbon monoxide	28.01	25	29.6
Chlorine	70.91	0.5	1.45

$\boxed{2\text{-}21}$ The procedure is to divide the distance between 10 and 500 ft into shells of equal thickness :

Assume that the 500 people are equally dispersed throughout the area

$$A_{Total} = \pi R_2^2 - \pi R_1^2 = 3.14\,(500^2 - 10^2)$$
$$= 784{,}687 \ ft^2$$

The distribution of people $= \frac{\text{people}}{ft^2} = \frac{500}{784687}$

$$P_A = 6.37 \times 10^{-4} \ \text{people}/ft^2$$

Process for each shell ;

1) Compute the radius a center of each shell
2) Compute the pressure at the center of each shell : $\log_{10} P = 4.21 - 1.8 \log_{10} R$
3) Compute probits for eardrum ruptures and lung hemorrhage using equation from Table 2-5
4) Convert probits to percentages using function @VLOOKUP and values from Table 2-4
5) Calculate the total area of shell

$$A = \pi\,(R_2^2 - R_1^2)$$

2-21 Continued

6) Determine the total people in shell

$$P = P_A A$$

7) Multiply by percentages effected (via probit equation) to acquire the total effected in each shell.

The total people effected for each situation is determined by summing for each shell.

The answer should be independent of spatial increment size. That is, the shell thickness should be small enough. This must be checked using your spreadsheet printout. We found that an increment of 5 to 10 feet is fine. Larger number of increments give essentially the same results.

Final answer: People with eardrum ruptures = 13.7

People killed by lung hem = 3.0

This does not include the dead people due eardrum ruptures. The probit % is determined using a lookup table: @VLOOKUP function in Quatro Pro.

No.	:	1	2	3	(See Table 2-4)	...	111
L	:	-90	2.67	2.95			50
M	:	0	1	2			100

If the Probit is P13 @VLOOKUP(P13, L1 ... M111, 1)

result

The first sheet of the spreadsheet is on the next page.

Problem 2-21 Explosion problem

Total people in area:	500	
Inner radius:	10	ft
Outer radius:	500	ft
Total Area:	784686	ft**2
People/ft**2:	0.000637	
Distance increment:	5	ft
Total increments:	98	

Total people with eardrum rupture:	13.72314
Total people killed by lung hem:	2.997668

SUM   SUM of the column

Distance ft	Pressure psi	Pressure N/m**2	Probit Eardrum	Probit Lung	Percent Eardrum	Percent Lung	Area ft**2	People Eardrum	People Lung
12.5	168.0978	1158673	11.34818	19.38285	100	100	392.6991	0.250227	0.250227
17.5	91.73425	632310.4	10.17927	15.19781	100	100	549.7787	0.350318	0.350318
22.5	58.35411	402226.1	9.306206	12.07196	100	100	706.8583	0.450408	0.450408
27.5	40.66316	280285.1	8.609076	9.576017	100	100	863.938	0.550499	0.550499
32.5	30.10301	207495.5	8.02873	7.498198	99.8	99.3	1021.018	0.649289	0.646036
37.5	23.26718	160377.2	7.531597	5.71831	99.4	76	1178.097	0.746177	0.570517
42.5	18.57376	128026.2	7.096781	4.161531	98	20	1335.177	0.833756	0.170154
47.5	15.20378	104797.4	6.710383	2.778106	95	1	1492.257	0.903319	0.009509
52.5	12.69735	87520.96	6.362693	1.533268	91	0	1649.336	0.956367	0
57.5	10.77948	74301.35	6.046657	0.401761	85	0	1806.416	0.978387	0
62.5	9.27718	63946.21	5.756989	-0.63534	77	0	1963.495	0.963374	0
67.5	8.077058	55673.95	5.489627	-1.59258	68	0	2120.575	0.918833	0
72.5	7.102179	48954.25	5.241378	-2.48139	59	0	2277.655	0.856276	0
77.5	6.298787	43416.6	5.009692	-3.31089	50	0	2434.734	0.775703	0
82.5	5.628373	38795.53	4.792497	-4.08852	41	0	2591.814	0.677114	0
87.5	5.062739	34896.7	4.588085	-4.82038	32	0	2748.894	0.560508	0
92.5	4.580837	31575.03	4.395035	-5.51156	27	0	2905.973	0.499953	0
97.5	4.166695	28720.4	4.212151	-6.16634	21	0	3063.053	0.409872	0
⋮	⋮	⋮	⋮	⋮	⋮		⋮		⋮

2-22 Solution

For 3 psi, the controlroom would need to be 118 ft from the vessel.

For 1 psi, the controlroom would need to be 212 ft from the vessel.

2-23 Solution. Equation 2-6 is:

$$P = 50\left[1 + \frac{Y-5}{|Y-5|}\,\mathrm{erf}\left(\frac{|Y-5|}{\sqrt{2}}\right)\right]$$

$$P_{3.72} = 50\left(1 - \mathrm{erf}\,\frac{1.28}{1.414}\right) = 50\left(1 - \mathrm{erf}\,0.905\right)$$

$$= 10.05\ \%$$

$$P_5 = 50(1) = 50\ \%$$

$$P_{6.28} = 50\left(1 + \mathrm{erf}\left(\frac{1.28}{1.414}\right)\right) = 50\left(1 + \mathrm{erf}\ 0.905\right)$$

$$= 89.9\ \%$$

erf (0.905) = 0.799 (via Math Cad)

Y	Calculated %	Table %
3.72	10.05	10
5.0	50	50
6.28	89.95	90

SOLTUION PROBLEM 2-24

Use equation for phosgene deaths in Table 2-5.

$Y = -19.27 + 3.60 \ln \sum CT$

From Table 2-4, for 80% deaths, $Y = 5.84$

Substituting,

$5.84 = -19.27 + 3.69 \ln(C)(4 \text{ min})$

$25.11 = 3.69 \ln(4C)$

$6.80 = \ln(4C)$

$\frac{e^{6.80}}{4} = C$

$C = 225$ ppm

SOLUTION PROBLEM 2-25

Use the equation for chlorine deaths in Table 2-5.

$Y = -8.29 + 0.92 \ln\left(C^{2.0}T\right)$

At 80% fatalities, $Y = 5.84$ from Table 2-4.

Substituting,

$5.84 = -8.29 + 0.92 \ln\left(C^{2.0}T\right)$

$\ln\left[C^{2.0}(4 \text{ min})\right] = 14.13$

$C^{2.0} = \frac{e^{14.13}}{4} = 3.42 \times 10^5$

$C = \sqrt{3.42 \times 10^5} = 585$ ppm

SOLUTION PROBLEM 2-26

Use the equation for chlorine deaths in Table 2-5

$Y = -8.29 + 0.92 \ln\left(C^{2.0}T\right)$

C (ppm)	$C^{2.0}$	T	$C^{2.0}T$
200	4.00×10^4	15	6.00×10^5
100	1.00×10^4	5	5.00×10^4
50	2.50×10^3	2	5.00×10^3
			$\Sigma = 6.55 \times 10^5$

$$\sum C^{2.0}T = 6.55 \times 10^5$$
$$Y = -8.29 + 0.92 \ln\left(6.55 \times 10^5\right)$$
$$Y = 4.03$$

From Table 2-4, the percentage is 5.7% fatalities.

SOLUTION ~ Problem 2-27

2-27. Use Probit equation for chlorine provided in Table 2-5

$$Y = k_1 + k_2 \ln V \qquad \dots (2\text{-}5)$$

For chlorine, from Table 2-5

$k_1 = -8.29$

$k_2 = 0.92$

$V = \sum C_i^2 T_i$

	C (ppm)	C^2	T_i (min)	$C^2 T$
a.)	200	4.0×10^4	150	6.0×10^6
b)	100	1.0×10^4	50	5.0×10^5
c.	50	2.5×10^3	20	5.0×10^4

$\sum C^2 T = 6.55 \times 10^6$

$$Y = -8.29 + 0.92 \ln\left[\sum C^2 T\right]$$
$$= -8.29 + 0.92 \ln(6.55 \times 10^6)$$
$$= -8.29 + 14.44$$
$$= 6.15$$

From Table 2-4 % deaths = 87%

2-28 Use the library[6] to find the toxicity levels (high, medium, low) for the inhalation of toxic chemicals.

Solution: Most books that disuss toxicity will include the following (or similar) guidelines:

Level of Toxicity	Acute Toxicity (LC50 mg/ℓ)	Chronic Toxicity (EC50 mg/ℓ)
High	≤ 1.0	≤ 0.01
Medium	> 1.0 to 100	> 0.01 to 1
Low	> 100	≥ 1.0

2-29 Use the library[6] to find the toxicity levels (high, medium, low) for the single dose of a chemical that causes 50% deaths

Solution:

Level of Toxicity	LD_{50} (oral to rats) (mg/kg body weight)
Very Toxic	< 25
Toxic	> 25 to 200
Harmful	> 200 to 2000

[6] Louvar, J.F. and Louvar, B. D. (Upper Saddle River, NJ: Prentice Hall PTR, 1998) pp. 287, 288.

2-30 Using the data below, determine the probit constants and the LC_{50}.

Dose of rotemone (mg/l)	Number of insects	Number affected (Deaths)
10.2	50	44
7.7	49	42
5.1	46	24
3.8	48	16
2.6	50	6

Solution

Dose (mg/l)	Affected (%)	Probit
10.2	88	6.18
7.7	85.7	6.06
5.1	52.2	5.06
3.8	33.3	4.57
2.6	12.0	3.82

$$Pr = k_1 + k_2 \ln V$$

Let V = Dose and run a regression program (e.g. MINITAB) to determine k_1 & k_2

The result as an $r^2 = 98$

$$Pr = 2.13 + 1.82 \ln(\text{Dose})$$

Now determine the LC_{50}

$$\ln \text{Dose} = (Pr - 2.13)/1.82$$

$$Pr \text{ for } 50\% = 5.0$$

$$\ln \text{Dose} = (5 - 2.13)/1.82 = 1.577$$

$$\text{Dose} = e^{1.577} = 4.74 \text{ mg/l}$$

SOLUTION PROBLEM 2-31

1 lb-mole = 359 ft^3 at 32^{o}F = 491.7^{o}R

$$C_{ppm} = \left(\frac{359 \text{ ft}^3 / \text{lb-mole}}{M}\right)\left(\frac{1}{491.7^o \text{R}}\right)\left(\frac{1}{P}\right)\left(\text{lb}_m / \text{ft}^3\right)$$
$$C_{ppm} = 7.301\times10^5\left(\frac{T}{PM}\right)\left(\text{lb}_m / \text{ft}^3\right)$$

SOLUTION PROBLEM 2-32

Volume fraction of benzene = $\left(10\times10^{-6}\text{ liters benzene}\right)$/ liter bulk gas

Total volume inhaled per shift

$=\left(0.5\text{ liters/breath}\right)\left(12\text{ breaths/min}\right)\left(60\text{ min/hr}\right)\left(8\text{ hr/shift}\right) = 2880$ liters

Volume of benzene inhaled

$=\left(2880\text{ liters}\right)\left(10\times10^{-6}\text{ liters benzene/liter bulk gas}\right) = 0.0288$ liters benzene

For benzene the molecular weight, M is 78.11.

From the ideal gas law:

$$n = \frac{PV}{R_gT} = \frac{\left(1\text{ atm}\right)\left(0.0288\text{ liters benzene}\right)}{\left(0.082057\text{ L atm/gm-mole K}\right)\left(298\text{ K}\right)} = 1.18\times10^{-3}\text{ gm-moles}$$

The mass of benzene $=\left(1.18\times10^{-3}\text{ gm-moles}\right)\left(78.11\text{ gm/gm-mole}\right) = 0.0920$ gm

The specific gravity of benzene is 0.879 gm/cm^3. Thus, the total volume is

$=\left(0.0920\text{ gm}\right)/\left(0.879\text{ gm/cm}^3\right) = 0.10\text{ cm}^3$

One drop of liquid contains about 0.05 cm^3, so this represents about 2 drops of benzene! Ugh!

Of course, this assumes that all of the vapor is absorbed by the lungs, which is not the real case.

SOLUTION PROBLEM 2-33

From Table 2-5, for deaths due to lung hemorrhage:

$Y = 771. + 6.91\ln P$

For damage to structures:

$Y = -23.8 + 2.92\ln P$

For 50% fatalities, from Table 2-4, $Y = 5.00$

a.) Substituting into the first probit equation:

$5.00 = -77.1 + 6.91 \ln P$

$82.1 = 6.91 \ln P$

$11.88 = \ln P$

$P = 144{,}500 \text{ Pa} = 1.43 \text{ atm} = 21.0 \text{ psi}$

b.) Substituting into 2nd probit equation

$5.00 = -23.8 + 2.92 \ln P$

$28.8 = 2.92 \ln P$

$\ln P = 9.86$

$P = 19{,}200 \text{ Pa} = 0.190 \text{ atm} = 2.79 \text{ psi}$

c.) The people are more likely to be found in the structures. When the structures collapse the people inside are killed. Thus, 3 psi is frequently used as the lower pressure for fatalities due to structure collapse.

SOLUTION PROBLEM 2-34

a.) IDLH = 10 ppm, time exposure period, T = 30 min

From the probit equation in Table 2-5 for chlorine deaths,

$Y = -8.29 + 0.92 \ln\left[C^2 T\right]$

For C = 10 ppm and T = 30 min

$Y = -8.29 + 0.92 \ln\left[(10 \text{ ppm})^2 (30 \text{ min})\right] = -0.29$

Since this result is negative, the percent fatalities is 0%

b.) For 1% fatalities, from Table 2-4, $Y = 2.67$

Substituting into the probit equation from chlorine fatalities

$2.67 = -8.29 + 0.92 \ln\left[(10 \text{ ppm})^2 T\right]$

$11.913 = \ln(100T)$

$e^{11.913} = 1.492 \times 10^5 = 100T$

$T = 1490$ minutes