2.1 The follow table shows the data calculated in a risk study for assessing the risk of an LNG terminal.

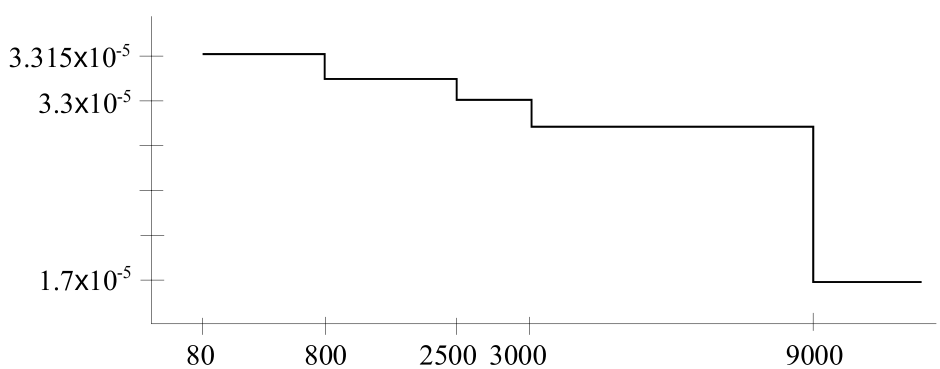
Group	Expected fatalities per year	Number of people sharing the risk	Risk per person per year	Probability of exceeding x	Number of fatalities (x)
Permanent population in Port O'Connor	2.0×10^{-8}	800	2.5×10^{-11}	3.315×10^{-5}	80
Permanent population in Indianola	1.3×10^{-7}	80	1.7×10^{-9}	3.302×10^{-5}	800
Transient daytime visitors	2.5×10^{-6}	2500	9.9×10^{-10}	$3.3 \text{ x } 10^{-5}$	2500
Individuals in boats	1.35×10^{-5}	3000	4.5×10^{-9}	3.05×10^{-5}	3000
All individuals exposed to risk	1.7×10^{-5}	9000	1.9×10^{-9}	1.7×10^{-5}	9000

a) Based on the data in this table plot the risk profile in terms (Annual frequency of exceeding the given number of fatalities vs. number of fatalities). That is the so-called Farmer's Curve.

b) What is the frequency of exceeding 100 fatalities?

Solution

a)



b) Interpolate between 3.315 x 10-5 and 3.302 x 10-5 close to $3.315 \text{ x } 10^{-5}$

2.2 A new manufacturing process is proposed for installation at a factory. It is believed that this process releases a known chemical carcinogen gas during its operation. If the expected toxicity of the gas is 1.44×10^{-4}gram-carcinogen per cubic meter of air and a worker's breathing rate is 2.32×10^{-4} m^3/second, determine and plot the individual risk cancer (cancer likelihood here) as a function of time (e.g., years). Use the following data:

a) There are 2000 hours of work per year

b) Exposure-consequence relationship is linear and can be obtained from

$$P_c = 5\times10^{-4} \cong \text{Dose(s)}$$

where

P_c = probability of consequence (cancer here)

Dose(s) = accumulated grams of the carcinogen in the lung

c) 10% of the inhaled carcinogen will absorb and remain in the lung, the rest will immediately exit the body.

Solution

T_A = Toxicity of air = 1.44×10^{-4}gram-carcinogen/m^3

B_W = Worker's breathing rate = 2.32×10^{-4} m^3/sec

T_E = Time of exposure = 2000 work-hr/year

$CA_{\%}$ = Percent of carcinogen absorb = 10%

$$\text{Dose}(s)_{\text{individual}-\text{year}} = B_W \cdot T_E \cdot T_A \cdot CA_{\%}$$

$$\text{Dose}(s)_{\text{individual}-\text{year}} = 2.32\times10^{-4}\,\frac{m^3}{s}\left(2000\,\frac{hr}{yr}\right)\left(\frac{60m}{hr}\right)\left(\frac{60s}{m}\right)1.44$$

$$\times10^{-4}\,\frac{gm-carinogen}{m^3}\left(\frac{10}{100}\right)$$

$$\text{Dose}(s)_{\text{individual}-\text{year}} = 0.02405\,\frac{gm-carinogen}{yr}$$

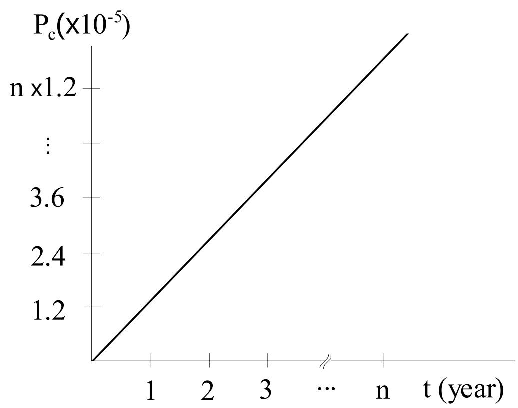
2.2 cont)

Probability of cancer:

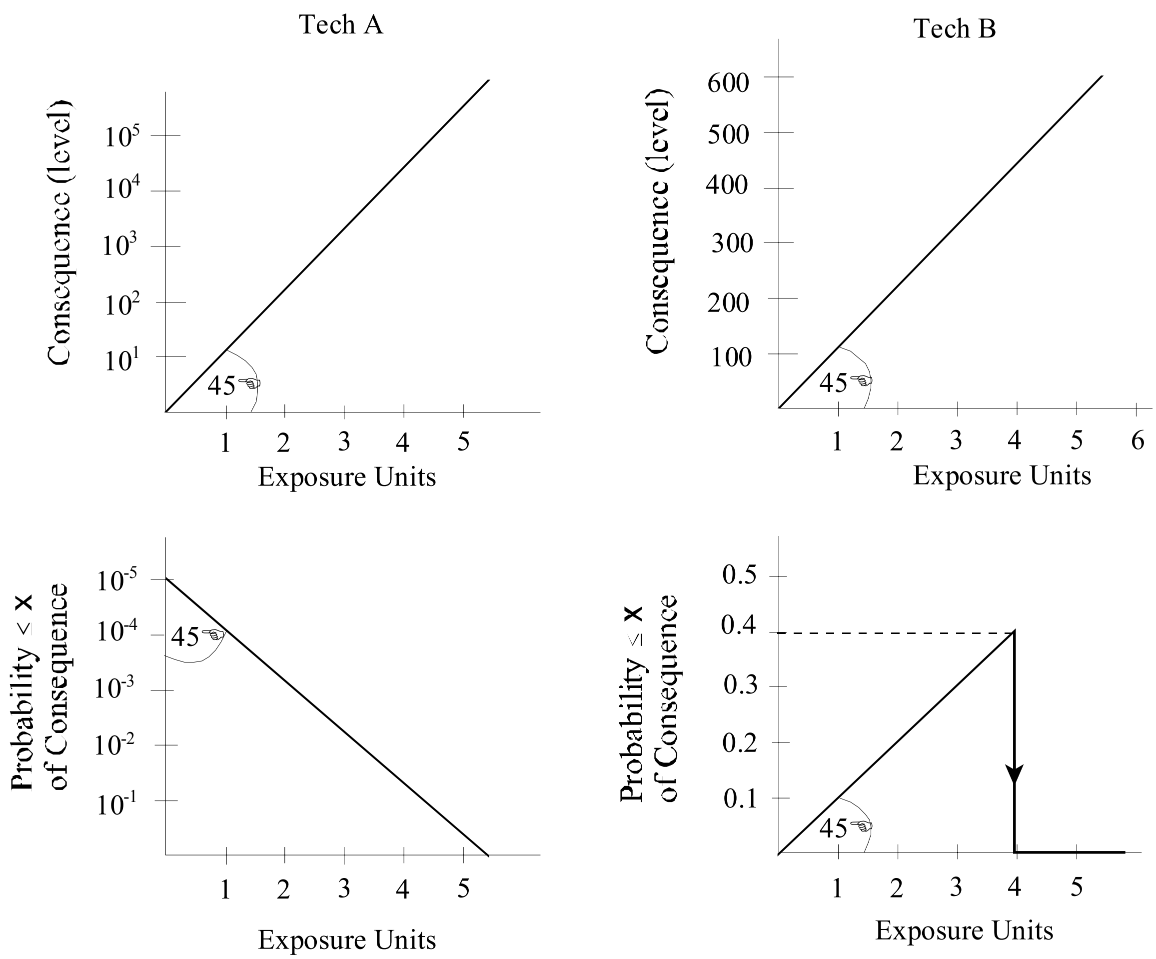
$$\begin{aligned} Pr_{cancer} &= 5\times10^{-4}\cdot \text{Dose}(s) \\ &= 5\times10^{-4}\cdot 0.02405\ \frac{\text{gm}-\text{carinogen}}{\text{yr}} \\ &= 1.2\times10^{-5}\ \frac{\text{gm}-\text{carinogen}}{\text{yr}} \end{aligned}$$

As a function of time:

$$Pr_{cancer} = 1.2\times10^{-5}\cdot t \quad \text{where } t = 1, 2, \ldots, n \text{ year}$$



2.3 Which of the following two technologies is riskier?



Solution

$$\text{Risk} \equiv R = \sum_{i=1}^{N} P_{C_i} C_i$$

where P_{C_i} is the probability of consequence i and C_i is the level of consequence i.

For continuous functions:

$$R = \int_0^{\infty} P(x)C(x)dx$$

where in this problem x is the exposure units.

2.3 cont)

For technology A:

$$C(x) = 10^x$$

and

$$P(x) = \begin{cases} 10^{x-5} & 0 \le x \le 5 \\ 0 & x > 5 \end{cases}$$

thus

$$R_A = \int_0^5 C(x)P(x)dx + \int_5^\infty C(x)P(x)dx$$

$$= \int_0^5 10^x 10^{x-5}\,dx + \int_5^\infty 10^x(0)dx = \int_0^5 10^{2x-5}\,dx$$

$$= \int_0^5 \exp\left[\ln 10^{2x-5}\right]dx = 10^{-11.5}\int_0^5 \exp(4.6x)dx$$

$$= 2.17 \times 10^4$$

For technology B:

$$C(x) = 100x$$

and

$$P(x) = \begin{cases} x/10 & 0 \le x \le 4 \\ 0 & x > 4 \end{cases}$$

thus

$$R_B = \int_0^4 C(x)P(x)dx + \int_4^\infty C(x)P(x)dx$$

$$= \int_0^4 100x\left(\frac{x}{10}\right)dx + \int_4^\infty 100x(0)dx = \int_0^4 10x^2\,dx = \frac{10}{3}x^3\bigg|_0^4$$

$$= 213.3$$

Thus technology A is riskier.

2.4 The frequency of a scenario of events leading to accidental exposure of a toxic chemical is 3×10^{-4}/year. Such an accident can expose people to toxic air containing 10 microgram/m^3 of a carcinogen.

a) What is the individual annual risk of such an accident to an exposed person?

Use the following information:

Human breathing rate:	5 m^3/hr
Body absorption fraction of the toxic material by the body:	0.1
Heath effects:	10 cancer death/gram absorbed
Average exposed time in a year:	10 minutes
Population exposed:	1,500

b) What are the "odds" of cancer-death in this case?

c) How long of an exposure could lead to an individual annual risk of 10^{-6}.

Solution

a) $R = f \cdot C$

$$R_{\text{individual}} = \text{gram/m}^3$$

$$= \underbrace{\frac{10\times10^{-6}}{\text{m}^3}\left(\frac{5\text{ m}^3}{\text{hr}}\right)(0.1)\left(\frac{10}{60}\text{hr}\right)\left(\frac{3\times10^{-4}}{\text{yr}}\right)}_{\text{Absorbed dose frequency}}\underbrace{\left(10\,\frac{\text{cancer death}}{\text{gram - person}}\right)}_{\text{Consequence}} = \frac{2.5\times10^{-9}}{\text{yr}}$$

$$R_{\text{societal}} = 1500\left(2.5\times10^{-9}\right) = \frac{3.75\times10^{-6}}{\text{yr}}$$

b)

$$\text{Odds}: \quad \frac{1\text{ in }267{,}000\text{ for Societal Risk}}{1\text{ in }400{,}000{,}000\text{ for Individual}}$$

c)

$$\frac{3\times10^{-4}}{\text{yr}}\left(\frac{10\times10^{-6}\,\text{gram}}{\text{m}^3}\right)\left(\frac{5\text{ m}^3}{\text{hr}}\right)(0.1)(\text{Time})\left(10\,\frac{\text{cancer death}}{\text{gram - person}}\right) = 10^{-6}$$

$$\text{Time} = 66.667\text{ hr/yr}$$

2.5 The following information about risk of school-bus accidents are known: There are 448,000 school buses in the U.S., annually 130 accidental deaths occur. Approximately 3% of all fatalities are fire fatalities of which 8% are occupants of the bus, the rest are pedestrians and occupants of other cars involved in the accidents with the buses. Each bus travels an average 9,500 miles/year. Determine:

a) Frequency of fire related fatalities for both occupants and non-occupants of the school-buses.

b) Fire related fatality for occupants and non-occupants per unit of distance traveled (e.g., per 100-million-miles traveled).

c) Mean length of operation time per bus so that the total fire risk reaches 10^{-6}/person.

Solution

a) Frequency of fire fatality for bus occupants:

$$F_b = 130\,\frac{\text{accidents}}{\text{year}}\left(0.03\,\frac{\text{fire accidents}}{\text{accidents}}\right)\left(0.08\,\frac{\text{bus occupants}}{\text{fire accidents}}\right) = 0.312/\text{year}$$

Frequency of fire fatality for non-bus occupants:

$$F_n = 130\,\frac{\text{accidents}}{\text{year}}\left(0.03\,\frac{\text{fire accident}}{\text{accidents}}\right)\left(0.92\,\frac{\text{non - bus occupants}}{\text{fire accidents}}\right) = 3.59/\text{year}$$

b) Fire fatality per distance for bus occupants:

$$F_b = 130\,\frac{\text{accidents}}{\text{year}}\left(\frac{1\text{ year}}{9{,}500\text{miles}}\right)(0.03)(0.08) = 3.28\times10^{-5}/\text{mile}$$

Fire fatality per distance for non-bus occupants:

$$F_n = 130\,\frac{\text{accidents}}{\text{year}}\left(\frac{1\text{ year}}{9{,}500\text{miles}}\right)(0.03)(0.92) = 3.78\times10^{-4}/\text{mile}$$

c)

$$10^{-6}\,\frac{\text{total fire risk}}{\text{person}} = 130\,\frac{\text{fatality}}{\text{year}}\left(0.03\,\frac{\text{fire fatality}}{\text{fatality}}\right)\left(\frac{1}{448{,}000\text{ buses}}\right)(\text{Time})$$

$$\text{Time} = 0.115\text{ year} = 1.38\text{ month} = 42\text{ days}$$

Chapter 3 Probabilistic Risk Assessment