Systems Safety
— Risk Representation and Safety Goals —

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What is safety goals?

- Management levels to be achieved for safety
  - Qualitative goals
    - Limit the release of toxic substances to the atmosphere at an allowable level
  - Quantitative goals
    - Relative goals
      - Reduce occupational injuries by half in five years
    - Absolute goals
      - Limit the death rate from cancer caused by air pollution below 10^{-6} per year
    - Represented in general with a risk limit

Why safety goals are required?

- Specialists can rationally carry out tasks of risk management.
- The public can easily monitor specialists' performance of risk management.
- The public can discuss easily how much resources should be invested for safety.

Risk representation (1)

- Annual risk of death
  - Death probability of an individual per year
- Lifetime risk of death
  - Death ratio of an individual from a particular cause
- Risk of death per activity
  - Death probability per one occasion of a particular activity

Road crossing	2×10^{-8}	Air flight	1×10^{-6}
Pregnancy	9×10^{-5}	Rail travel	2×10^{-10}

Various risks around us

Cause of death	Annual risk of death	Death ratio (%)
All diseases	7.1×10^{-3}	92.9
Cancer	2.5×10^{-3}	31.1
Heart disease	1.3×10^{-3}	15.5
Cerebrovascular disease	1.1×10^{-3}	13.8
Pneumonia	7.6×10^{-4}	9.2
Consenescence	1.9×10^{-4}	2.3
All accidents	3.0×10^{-4}	3.7
Traffic accidents	8.4×10^{-5}	1.0
Falls	6.9×10^{-5}	0.8
Suicide	2.4×10^{-4}	2.9
Murder	5.0×10^{-6}	0.06
Total	8.2×10^{-3}	100

Population Statistics of Japan, 2004

Risk representation (1)

- Risk of death per output
  - Death probability accompanying a unit amount of output (locomotion, production, etc.)

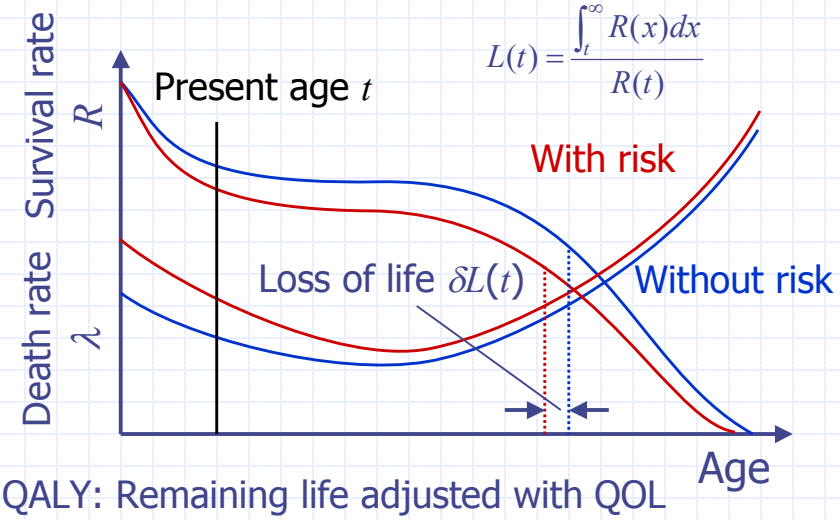
    Car drive 8.4×10^{-9}/km Rail travel 1.2×10^{-11}/km

    Domestic flight 1.4×10^{-9}/km
- Loss of life
  - Shortening of lifetime from to a particular cause
  - Consideration of serious casualty below death

Life Loss Equivalence (LLE)

$$R(t) = \exp\left[-\int_0^t \lambda\, dx\right]$$

$$L(t) = \frac{\int_t^\infty R(x)dx}{R(t)}$$



QALY: Remaining life adjusted with QOL

Catalogue of risks (LLE/day)

Male	2,800
Smoking (male)	2,300
Bachelor	2,000
Cancer	980
Accidents in total	400
Car accident	180
Murder	90
Air pollution	80
Indoor (radon)	35
Coffee (2.5 cups)	26

Peanuts butter	1.1
Air accident	1
Energy saving	47
Coal fire	30
Oil fire	4
Natural gas	2.5
Nuclear (anti.)	1.5
Solar	1
Nuclear (gov.)	0.04

Cohen, 1994

Representation of societal risks

- An event that yields devastating losses is serious from a societal point of view, though the probability is very low.
- It is sometimes improper to represent risks just as the expectation of losses.
- Risk histogram
  - Bar graph where the event probabilities are plotted for various losses classified by some categorization

Probability density and CCDF

- Probability density function

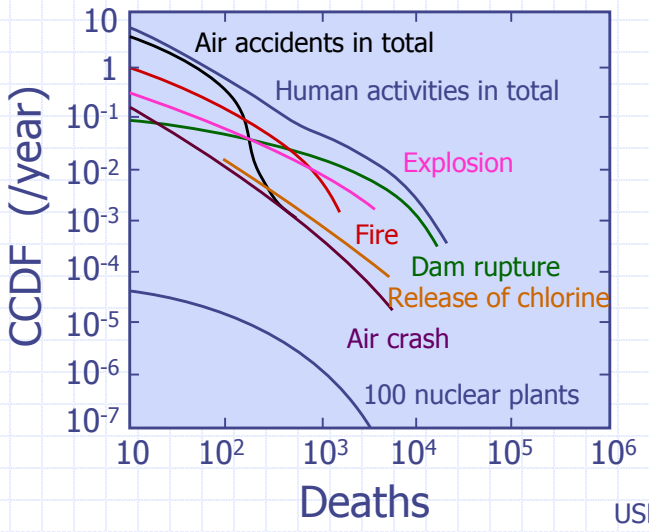
  $f(C)dC$ = Probability of an event where the scale of losses falls between C and $C+dC$

- Complementary Cumulative Distribution Function (CCDF)

  $F(C)$ = Probability of an event where the scale of losses exceeds C

$$F(C) = \int_C^\infty f(x)dx = \sum_{C_i \geq C} f_i$$

Social risks from human activities

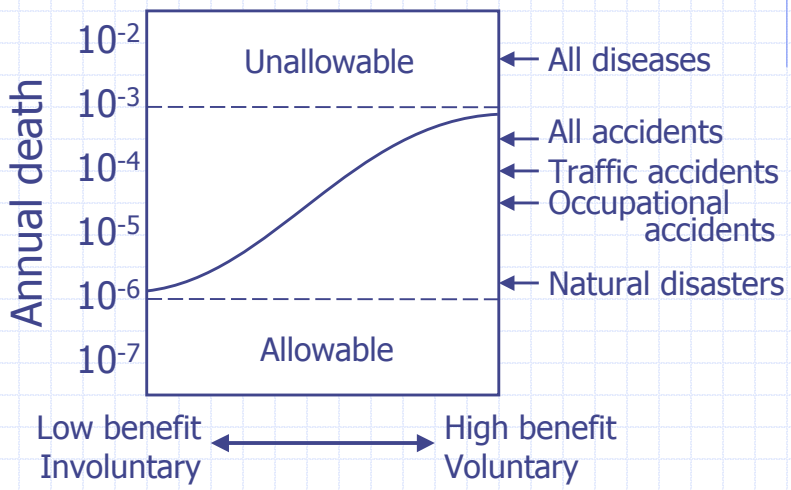


USNRC, 1975

How safe is safe enough ?

- Tradeoff against benefit to be obtained
  - Voluntary or occupational risks are easily accepted.
- Comparison with natural phenomena
  - All diseases 7 x10^{-3}/yr Cancer 2 x10^{-3}/yr
- Comparison with similar risks already accepted
  - All accidents 3 x10^{-4}/yr
  - All occupational accidents 3 x10^{-5}/年

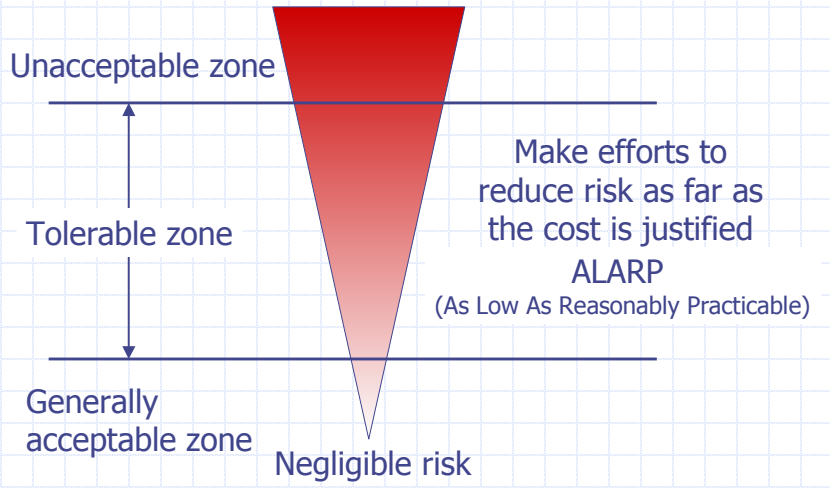
Framework of risk limit



Example of safety goals

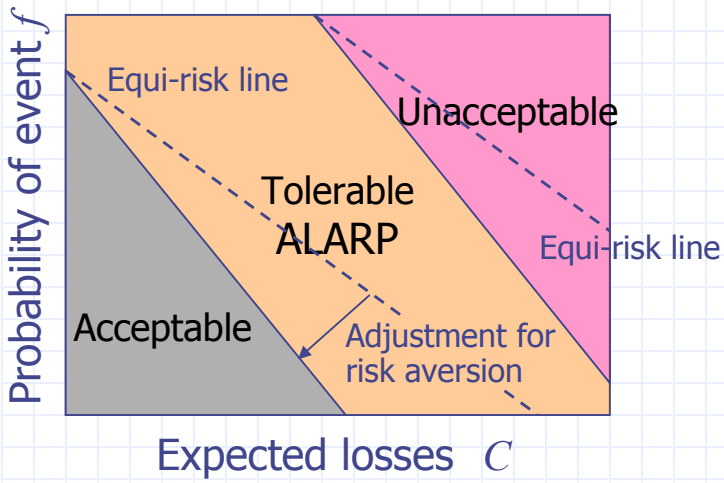
- Nuclear Power Plants (US)
  - Individual: acute death < 0.1% death of all accidents (5×10^{-7}/yr)
  - Public: death of cancer < 0.1% death of all cancer (1.4×10^{-6}/yr)
- Airplane design (US)
  - Fatal event < 10^{-9}/flight hour
- Air pollution (Holland)
  - Additional death of cancer < 10^{-4}/lifetime
- Water service (Japan)
  - Additional death of cancer < 10^{-5}/lifetime

Safety goal with a margin



UKHSE, 1992

Safety goals with profile



Retention and transfer of risk

- Risk retention
  - Accept losses that are negligibly small
    - (Do not mind thinking it of bad luck)
    - Budget for expected small losses
    - Consider crisis management for residual risks
- Risk transfer
  - Transfer the burden of loss to a third party
    - (Get compensation by legal action)
    - Buy insurance

Countervailing risk

- Target risk
  - Risk to be reduced
- Countervailing risk
  - Risk that is brought about as a result of reducing target risk
  - Every effort of risk reduction necessarily generates some countervailing risk
  - No actions also generate some risk

Risk tradeoffs

- Balance target risk and countervailing risk to minimize risks as a whole

		Risk type	
		Same	Different
Risk sharer	Same	Compensation	Substitution
	Different	Transfer	Transformation

Examples of risk tradeoffs

- Switch fuel from oil to natural gas (Compensation)
  - Global warming by CO2 ➔ Global warming by CH4
- Recycle of lead buttery (Transfer)
  - Health risk around incineration plant ➔ Health risk around secondary smeltery
- Chlorination of drink water (Substitution)
  - Infection of bacteria ➔ Cancer from trihalomethane
- Ban of food import for residual pesticide (Transform)
  - Cancer of domestic consumers ➔ Economic loss of exporters