CANDU Safety
#2 - Risk from Nuclear Power Plants

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What is the Public Hazard?

- chemical? Chlorine for water treatment as in fossil plants
- biological? None
- physical? Nuclear explosion impossible
- radiological? Small risk of delayed health effects, very small risk of prompt health effects, even in severe accidents

The Chernobyl Disaster

- More than 12,500 of the 350,000 people who worked on the Chernobyl cleanup have since died

- For a population of the age and sex distribution of the "liquidators" in 1986, the normal mortality rate was 3 per 1000 per year. Thus the "expected" number of deaths would be:

  350,000 people x 12 years x 3/1000

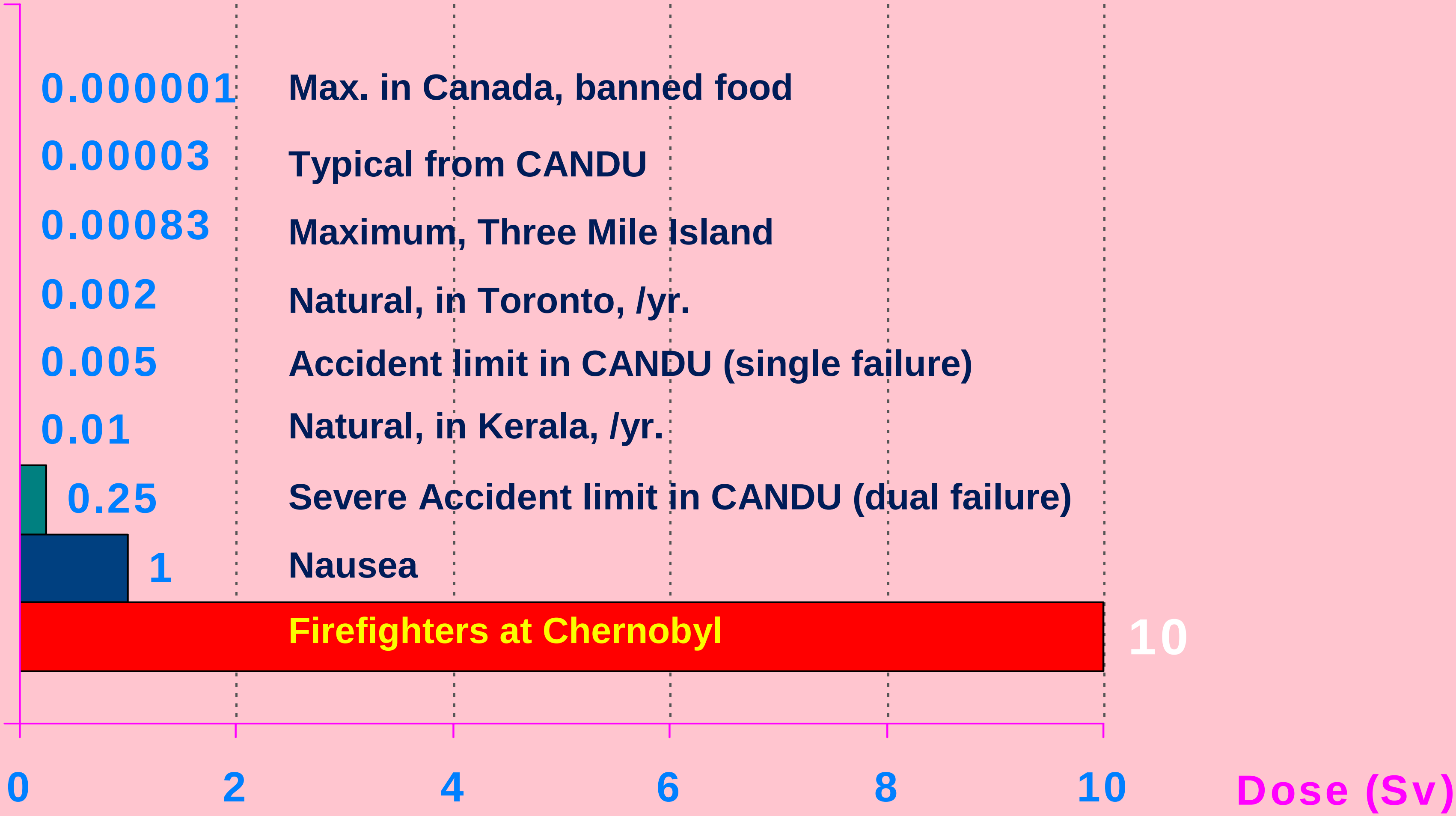
  = 12,600

- The number should be larger (by 50%) because the normal rate of 0.3% increases as the group ages
- Is reporting inadequate? Does monitoring improve the life expectancy of the liquidators?

Effects of Radiation

- prompt health effects (deterministic, non-stochastic)
  - dose of >1 Sv: illness
  - dose of >3 Sv: increasing risk of death (LD 50 is 3 to 10 Sv)
- delayed health effects (random, stochastic)
  - risk of cancer
    - 0.25 Sv gives approx. 0.5% increase in individual risk
  - risk of damage to foetus
  - risk of genetic damage
    - not observed in humans

EXAMPLES OF RADIATION DOSE



What Is Risk?

Risk = Frequency of an event x consequences of the event

- **Examples of risk:**
  - annual individual risk of death
  - annual nuclear plant risk of core damage
  - annual nuclear plant risk of a large release of radioactivity
  - risk of psychotic reaction to malaria drug, per dose

Safest and Most Dangerous Occupations*

Occupation	Fatalities / 100,000 / year
Administrative support, clerical	1
Executive & Managerial	3
News Vendors	16
Police	17
Truck drivers	26
Farm Workers	30
Construction labourers	39
Miners	78
Pilots & navigators	97
Lumberjacks	101
Sailors	115

*US, 1995

"Acceptable" (since accepted) Occupational Risk?

5 per 100,000 per year (5 x 10^{-5} per year)

to

100 per 100,000 per year (1 x 10^{-3} per year)

Non-Occupational Accidental Fatalities*

Accident	Fatalities / 100,000 / year
Lightning	0.06
Poisoning	1.5
Firearms	1.1
Drowning	3.6
Fires	3.6
Falls	8.6
Motor vehicle	27

*US, 1970

“Acceptable” (since accepted) Public Risk?

4 per 100,000 per year (4 x 10^{-5} per year)

to

27 per 100,000 per year (3 x 10^{-4} per year)

Total risk of accidental death = 4 x 10^{-4} per year

Note that these are population-average risks

Some groups will be considerably more (or less) at risk than others.

Many Factors Determine "Acceptability"

- **occupational risk vs. public risk**
- **presence of offsetting benefit**
- **voluntary vs. involuntary risk**
  - **can one really eliminate risk from motor vehicles by not driving??**
- **"dread" factor (cancer vs. automobile accident)**
- **perceived ability to control risk**
- **knowledge and familiarity (coal mining vs. operating nuclear plant)**

Safety Goals for Nuclear Power Plants

- Safety goal - an acceptable value of risk
  – risk from NPPs chosen to be very small in comparison to comparable activities
- Risk of prompt fatality from NPP should be << risk of prompt fatality from all other causes
- Risk of fatal cancer from NPP should be << risk of cancer from all other causes

Risk of fatal cancer *just* from "natural" radiation in Canada =

$$0.002 \text{Sv/year} \times 0.02 \text{ cancers/Sv} = 4 \times 10^{-5} \text{ per year}$$

(according to linear dose-effect hypothesis)

Risk Goals

The only significant health effects from a nuclear power plant are from a large release

A large release can only occur if:
1) There is severe core damage, *and*
2) The containment does not work or is damaged

Nuclear safety goals therefore focus on:
1) preventing a large release
2) preventing severe core damage

Example #1

- Three Mile Island
  - severe core damage (~20 tons of molten fuel)
  - the pressure vessel was thinned but did not fail
  - the containment was not damaged but some liquids and gases escaped through lines which bypassed the containment
  - public health effects were minor: ~1 additional (statistical) cancer case in the surrounding population

Example #2

- Chernobyl
  - the core was severely damaged due to a reactivity increase which was made *worse* by the shutdown systems
  - the containment was ineffective as the steam explosion blew off the top cover of the reactor & exposed the core
  - about 32 prompt fatalities among station staff
  - most volatile fission products were released to atmosphere
  - public health effects: predict several thousand (additional) cancer cases in the surrounding area
  - an increase in thyroid cancers in children has been observed (mostly curable)

Numerical Safety Goals for Nuclear Power Plants

- For existing nuclear power plants:
  - risk of a severe core damage accident must be < 10^{-4} per plant per year
  - risk of a large release must be < 10^{-5} per plant per year
- For new nuclear power plants:
  - factor of 10 lower on both counts
- the factor of 10 must therefore come from:
  - severe accident management & mitigation procedures
  - residual containment effectiveness

How is Risk Calculated?

- For frequent events - easy - just collect the *observed* statistics
- For rare events - build up from combinations of more frequent components
- e.g., risk / year of plane crash on Shanghai University =

  risk of a plane crash per kilometer of steady flight

  x number of flights / year landing or taking off from Shanghai airport

  x fraction of flights which fly over the University

  x diameter of University in km.

  – does not account for evasive action, skyjacking

Fault trees and Event trees

- to determine the risk from rare events:
  - calculate frequency or probability of a system failure (fault tree)
  - calculate consequences of the system failure (event tree)
  - in the event tree, assume each mitigating system either works or fails; if it fails, account for the probability of failure
- end result is the frequency or probability and consequences of a family of events

Douglas Point

- an early risk assessment in Canada in the 1960s for the first prototype CANDU
- goal: risk from nuclear power plant must be 5× less than coal
- only prompt effects well known then, so compared prompt fatalities from mining and nuclear power
- e.g., large release frequency = initiating event frequency × unavailability of shutdown × unavailability of containment
- must set targets for & *measure*:
  - frequency of initiating events (process system failures)
  - unavailability of each safety system

Frequency and Reliability Targets

- process system failures:
  - must be less than 0.3 events / year
  - deliberately chosen high so it could be confirmed
- safety system unavailability:
  - each must be less than 10^{-3} years / year (8 hours / year or 1 failure in 1000 tries)
- can one multiply the numbers?
  - e.g., small LOCA + LOECC + containment failure to isolate

  $= 10^{-2}$ / year $\times$ 10^{-3} years/year $\times$ 10^{-3} years / year

  $= 10^{-8}$ / year ???
- *only if there are no cross-links*