Lecture 8 – Safety Goals

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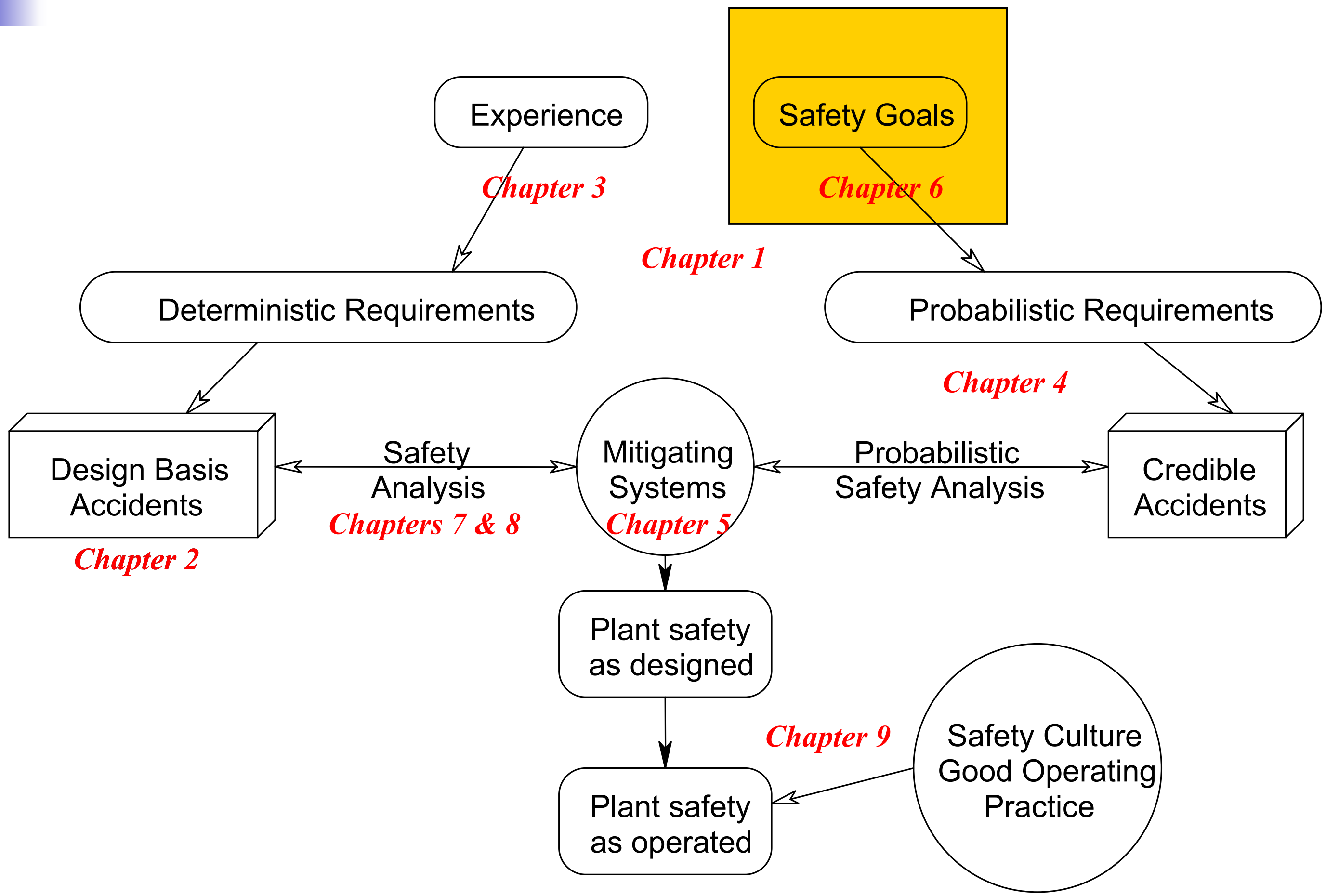
***Material on human error from R. Duffey gratefully acknowledged**

Where We Are



Experience
Safety Goals
Chapter 3
Chapter 6
Chapter 1
Deterministic Requirements
Probabilistic Requirements
Chapter 4
Design Basis Accidents
Safety Analysis
Chapters 7 & 8
Mitigating Systems
Chapter 5
Probabilistic Safety Analysis
Credible Accidents
Chapter 2
Plant safety as designed
Chapter 9
Safety Culture Good Operating Practice
Plant safety as operated

Is this a useful safety goal?

European Pressurized Reactor:

"Accidents liable to lead to significant early radioactive releases, in particular accidents involving high-pressure core meltdown, must for their part be 'practically eliminated'"

How Safe is Safe Enough?

- Require numerical, not qualitative goal, e.g.:
- *"The annual risk of death to the most exposed member of the public due to accidents in a reactor should be small in comparison to his/her total risk of premature death."*

Concepts

1. Compare like to like – risk of premature death
2. Compare risk from nuclear power to risk from all other sources – why?
   - Where are *benefits* compared?
   - How much of the fuel cycle is included?
   - What about global effects?

Concepts – cont'd

3. Limit risk to *individual*
   - Exclude (or assume bounded): population exposure, land contamination, effects on animals & plants, psychological effects
4. Goal refers to *public*, not workers
   - Acceptance of risk is 'part of a job'
   - Industrial hazards dominate anyway
5. What is the risk of *not* having nuclear power?

Safety Goal is not unique; other models.

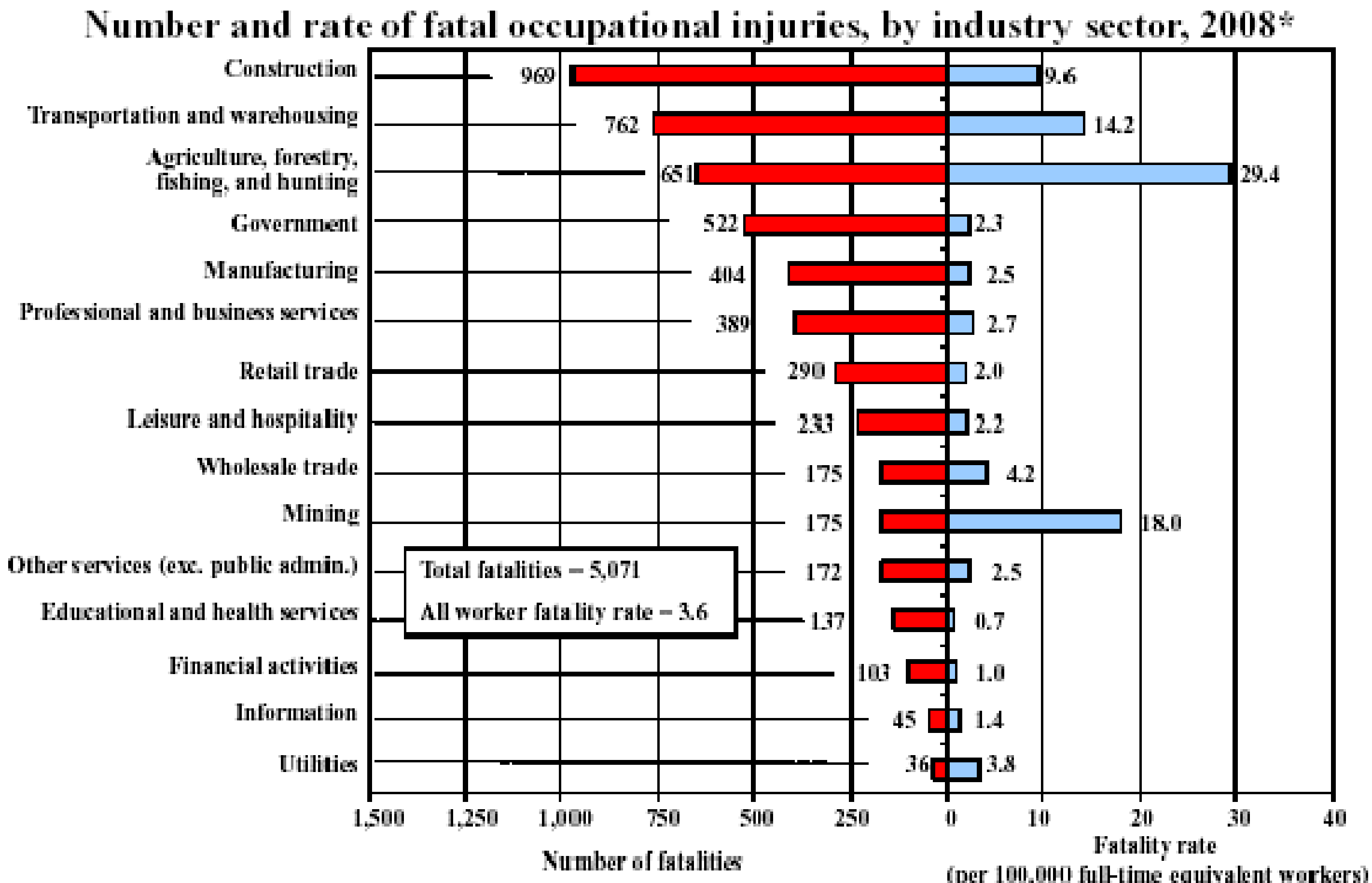
Sub-Goals

- The annual risk of *prompt* death to the most exposed member of the public due to accidents in a reactor should be small in comparison to his/her total annual risk of prompt death due to all accidents.
- The annual risk of *fatal cancer* to the most exposed member of the public due to accidents in a reactor should be small in comparison to his/her total annual risk of fatal cancer due to all causes.

Risk of Dying in Canada

- Accidents fifth leading cause of death
- Rate of 27.6 deaths / 100,000 people /a
- Average person's risk of death from an accident is 3 x 10^{-4} per year, so e.g.:
- **'The likelihood of a large release from a nuclear power plant in an accident should be less than 3 per 10^6 reactor years'**

Occupational Risk of Death in the U.S.



*Data for 2008 are preliminary.
NOTE: In 2008, CFOI implemented a new methodology, using hours worked for fatality rate calculations rather than employment. For additional information on the fatality rate methodology changes please see http://www.bls.gov/iif/oshnotice10.htm.
SOURCE: U.S. Bureau of Labor Statistics, U.S. Department of Labor, 2009.

Table 6-2 - Cause of Death in Canada (Accident, non-Occupational)

Cause of Death	Mortality rate (/100,000-year)
Motor vehicle accidents	8.7
Falls	5.4
Poisoning	2.8
Homicide	1.7
Drowning	0.8
Fire	0.7

Risk of Cancer in Canada

- Malignant neoplasm second leading cause of death
- Rate of 173 deaths per 100,000 people /a
- Average person's risk of dying from cancer is 1.7×10^{-3} per year (~ 13% over 75-years)
  - 100 person-Sv ⇒ ~5 fatal cancers
  - "Averaged" risk of 5×10^{-2} fatal cancers per Sv
  - Equivalent dose is 0.035 Sv per year per person

Possible Safety Sub-Goal for Delayed Fatalities

- **Maximum time-averaged individual dose from accidents should be less than 0.35 mSv per year, averaged over a group of people**
  - ~ 35% natural background radiation
  - Should nuclear power be 'safer' than background radiation?
- Requires summation of all accidents

Risk Acceptance

- Higher values accepted for:
  - Occupational risk
  - Voluntary risk
  - Familiar risk
  - Perceived direct benefit
- Lower values accepted for:
  - Involuntary risk
  - Unfamiliar risk
  - 'Dread'

ACNS Again

- Requires PSA
- 6 dose bins
- In each bin, *summed* frequency of accidents must be < frequency limit
- 10^{-7} /year cutoff
- Average dose of 2.5 mSv / year

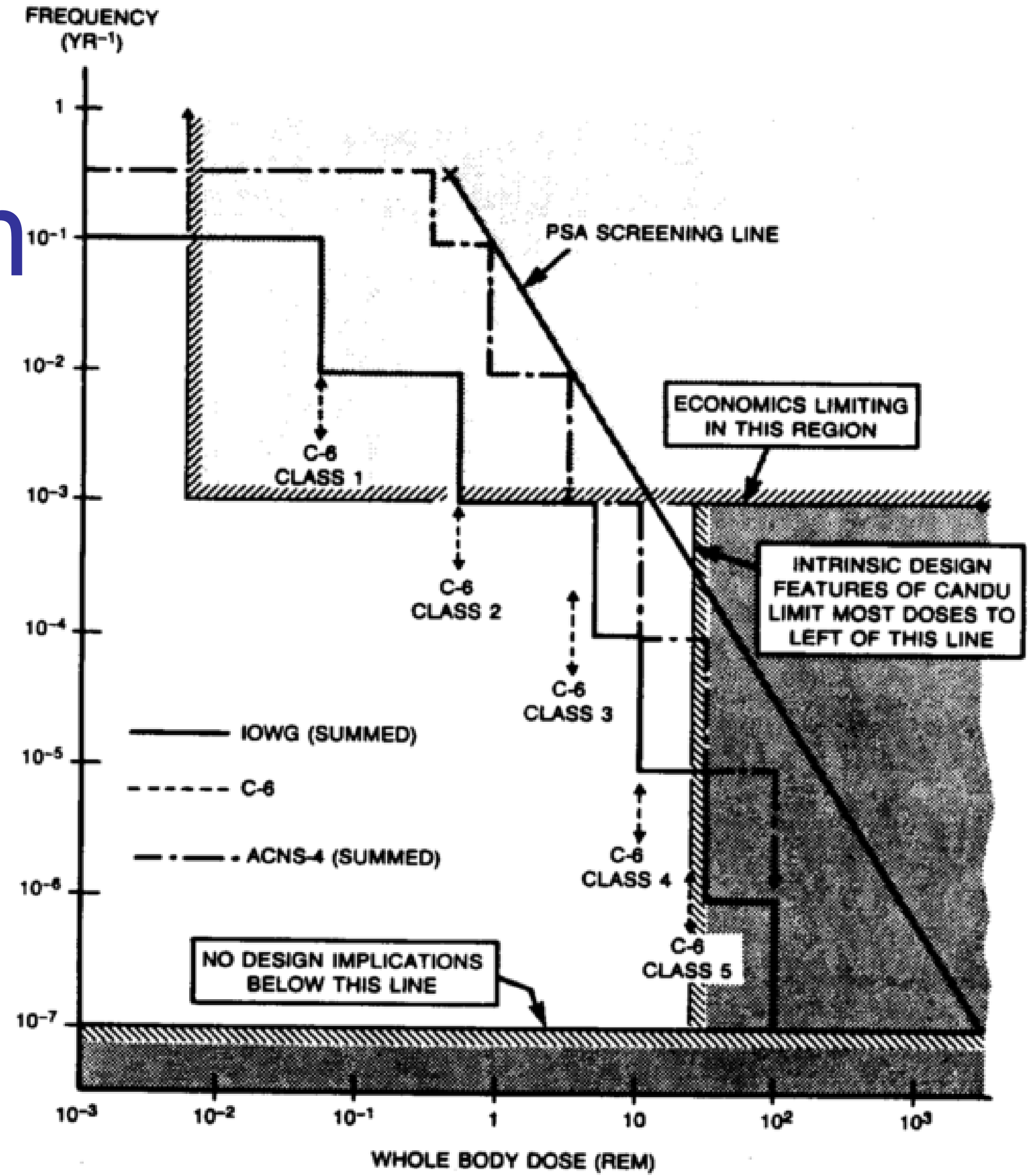


FIGURE 2 COMPARISON OF SAFETY GOALS AND "NATURAL" RESTRICTIONS

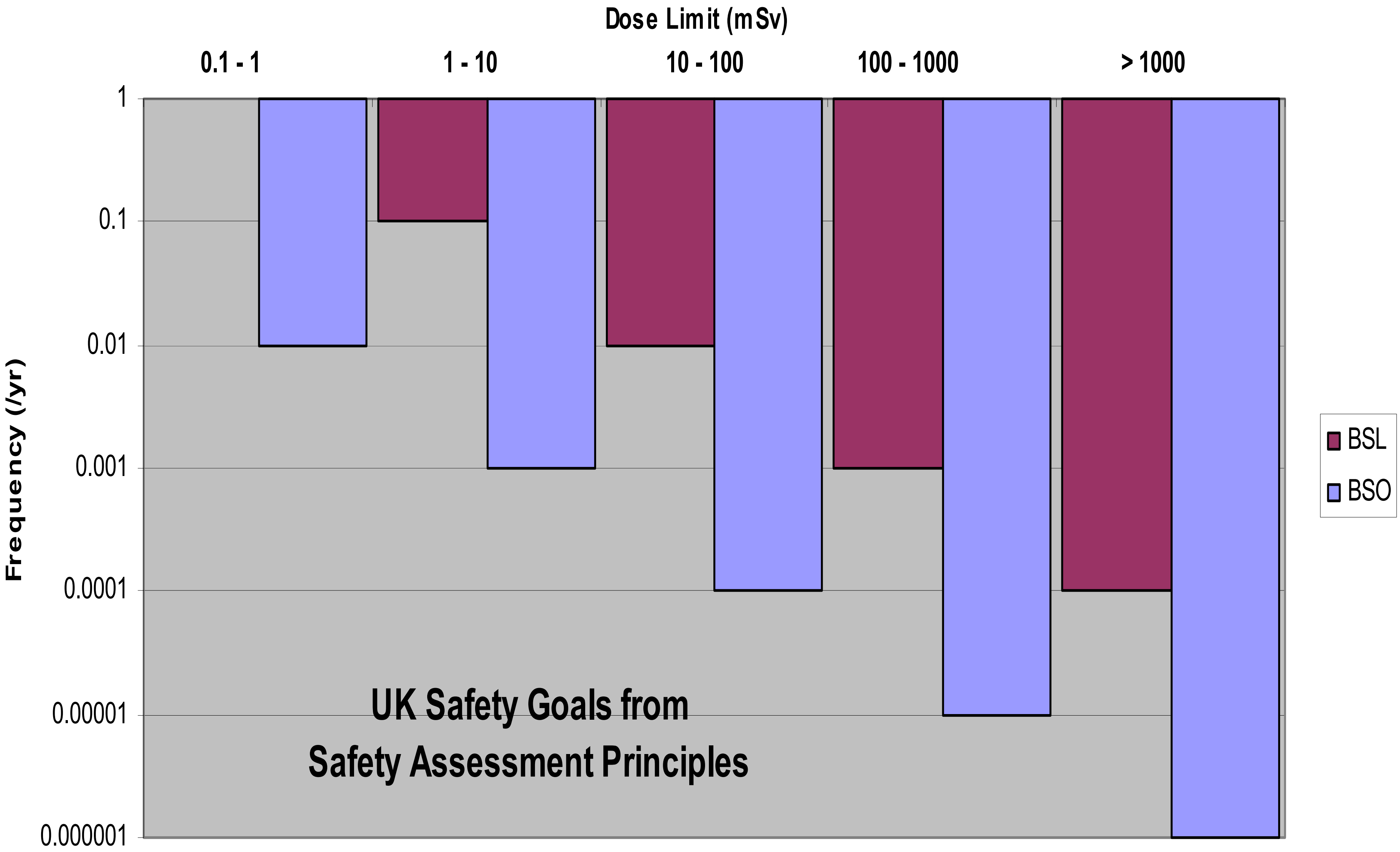
Figure 2-4 Consultative Document C-6 Limits

International Goals

- Existing reactors:
  - The frequency of a core melt (severe core damage) accident must be less than 10^{-4} per reactor-year
  - The frequency of a large release must be less than 10^{-5} per reactor-year
  - i.e., CCF probability < 0.1
- New reactors: factor of 10 lower

UK Safety Assessment Principles

Maximum effective dose (mSv)	Total predicted frequency, per year	
	Basic Safety Limit	**Basic Safety Objective**
0.1 - 1	1	10^{-2}
1 - 10	10^{-1}	10^{-3}
10 - 100	10^{-2}	10^{-4}
100 - 1000	10^{-3}	10^{-5}
>1000	10^{-4}	10^{-6}


Dose Limit (mSv)
0.1 - 1
1 - 10
10 - 100
100 - 1000
> 1000
Frequency (/yr)
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
BSL
BSO
UK Safety Goals from
Safety Assessment Principles

RD-337 - CNSC Safety Goals

- Basis:
  - Individuals should bear no significant additional risk to life and health
  - Societal risks to life and health shall be comparable to or less than the risks of generating electricity by viable competing technologies and should not be a significant addition to other societal risks

Numerical Values

Core Damage Frequency: The sum of frequencies of all event sequences that can lead to significant core degradation is less than 10^{-5} per reactor year

Small Release Frequency: The sum of frequencies of all event sequences that can lead to a release to the environment of more than 1015 becquerel of iodine-131 is less than 10^{-5} per reactor year. A greater release may require temporary evacuation of the local population.

Large Release Frequency: The sum of frequencies of all event sequences that can lead to a release to the environment of more than 10^{14} becquerel of cesium-137 is less than 10^{-6} per reactor year. A greater release may require long term relocation of the local population.

Limitations of Risk Approach

- *All* events have to be identified and summed
  - Hard to do early in design, no useful measure
- No risk aversion in simplest application
  - Is it necessary?
- Frequency must be cut-off
  - What does a frequency of 10^{-8} / year mean?
- Not all events can be quantified
  - Severe external events; sabotage, terrorism & war
- Innovative designs
  - Incomplete reliability database

Are We Kidding Ourselves?

- Safety goals aimed at design
  - Essential to give design a logical base
  - Not readily confirmed in practice
- Assume that technology continually improves, so safety goals get more and more stringent
- Ignores the learning/forgetting hypothesis

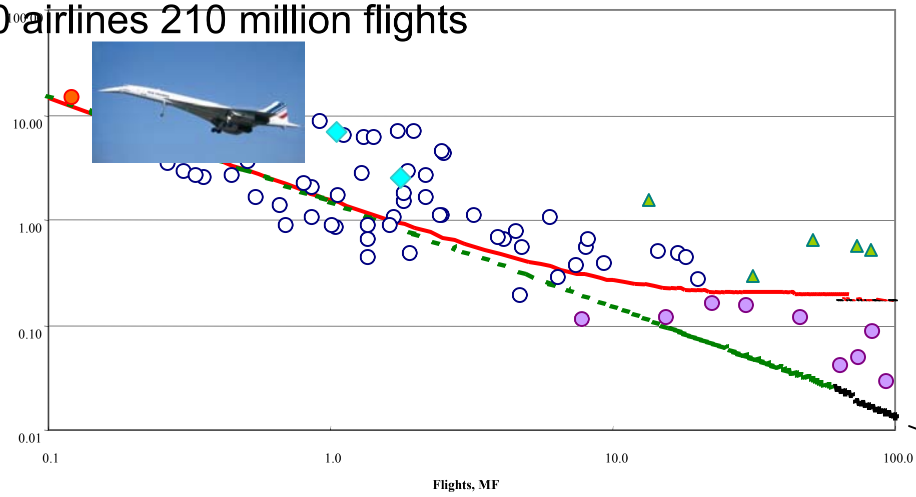
From R. Duffey…

- The major cause of accidents is human error
- The causes are always obvious and preventable – afterwards
- There is usually a confluence of factors as a cause
- There is/are no "Zero Defects"

Airlines

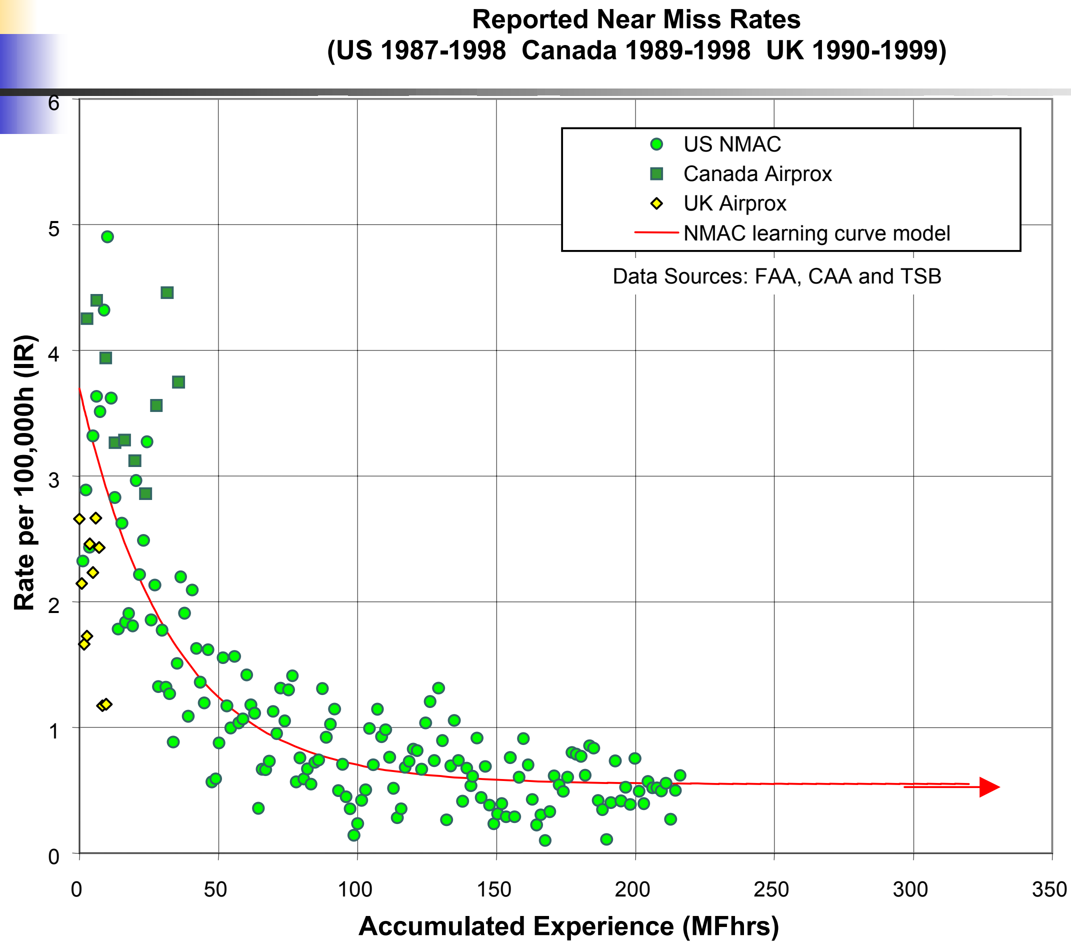
- Airbus Airsafe Data
- Boeing Airsafe Data
- JAA and North America CAA Data
- A* Prediction (Duffey and Saull, 1999)

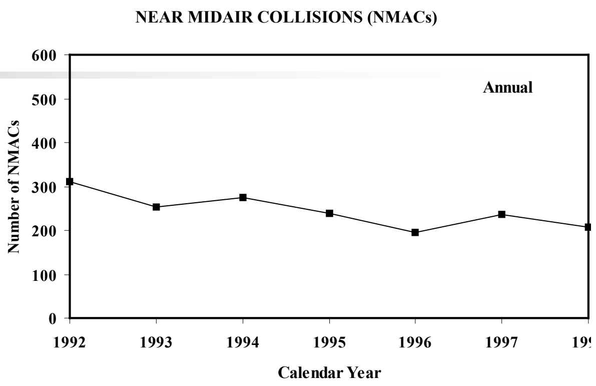
Airsafe.com fatal accident data 1970-2000
110 airlines 210 million flights



1 per 200,000 hours

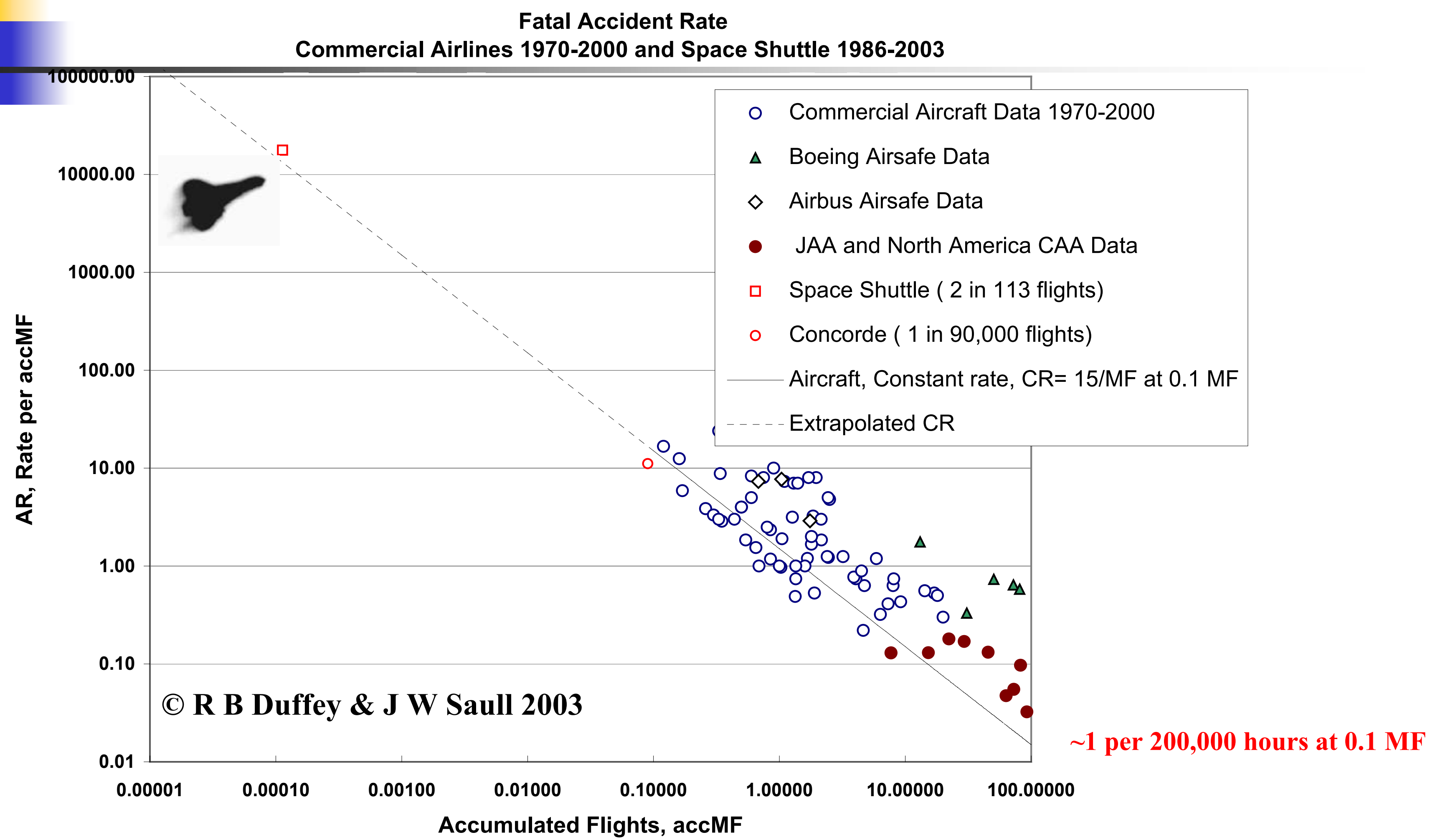
Commercial Aircraft Near Miss Rates





1 per 200,000 hours

Is 1 per 200,000 the Best One can Do?



How To Learn From Mistakes

- Mistakes are necessary to learn
- Technology change is not enough
- Be careful when using safety goals outside design
- Comprehensive indicator sets are now in use which are risk and performance-based
- Wide sharing of industry near-misses