# The Challenge of Risk Control in a Hydrogen based Economy, Part I

**Hans J. Pasman**
**Chemical Risk Management**

*What are the risks, how can we determine them,*
*How can we avoid, how to reduce, when can we be satisfied?*

*We shall look broader than just hydrogen risks sec:*
*Domino effects*

**Summer School UofU**



First European Summer School
HYDROGEN SAFETY
BELFAST, 15-24 AUGUST 2006
UNIVERSITY of ULSTER
Marie Curie Conferences and Training Courses The Commission of the European Communities

TU Delft
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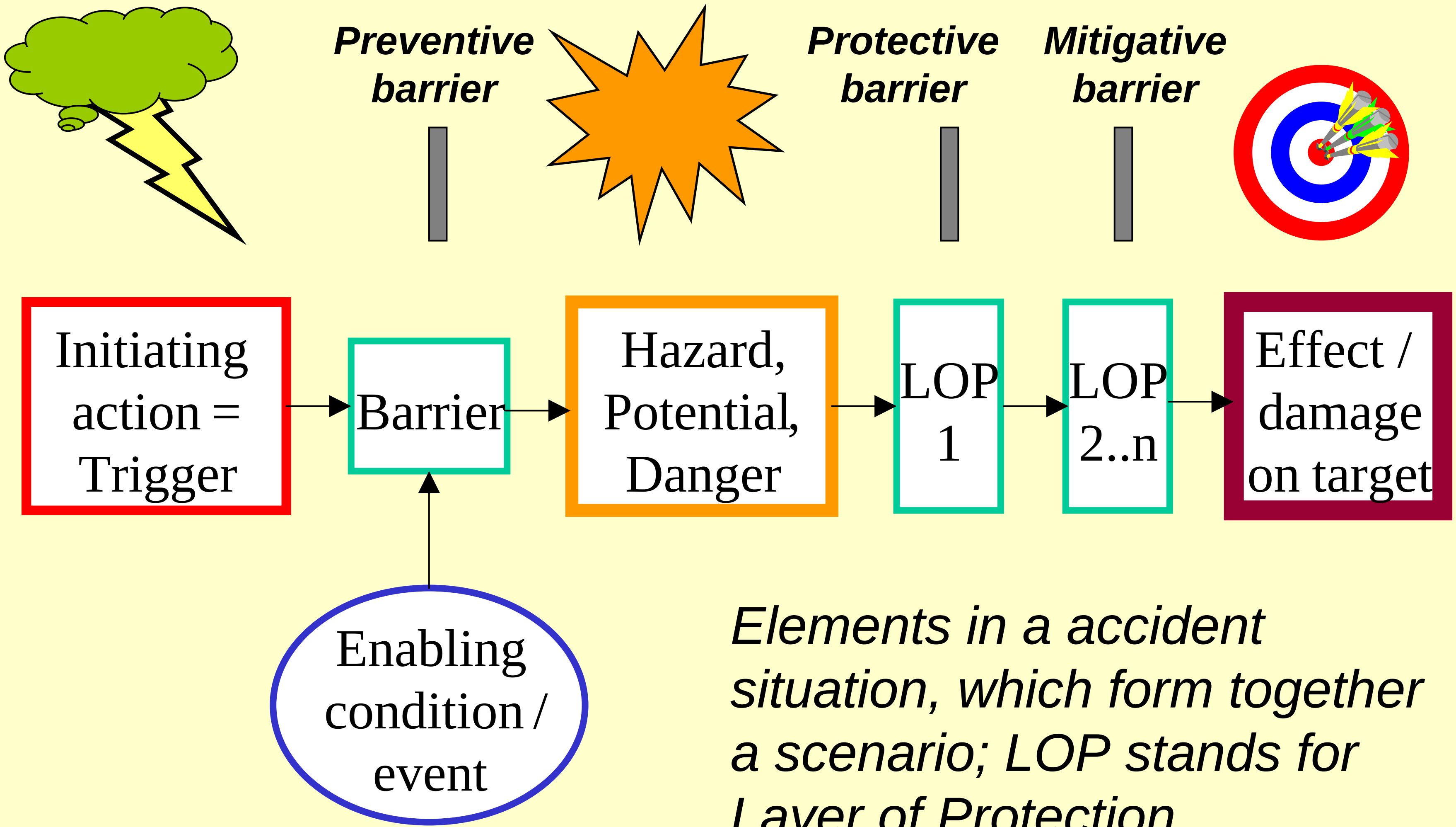
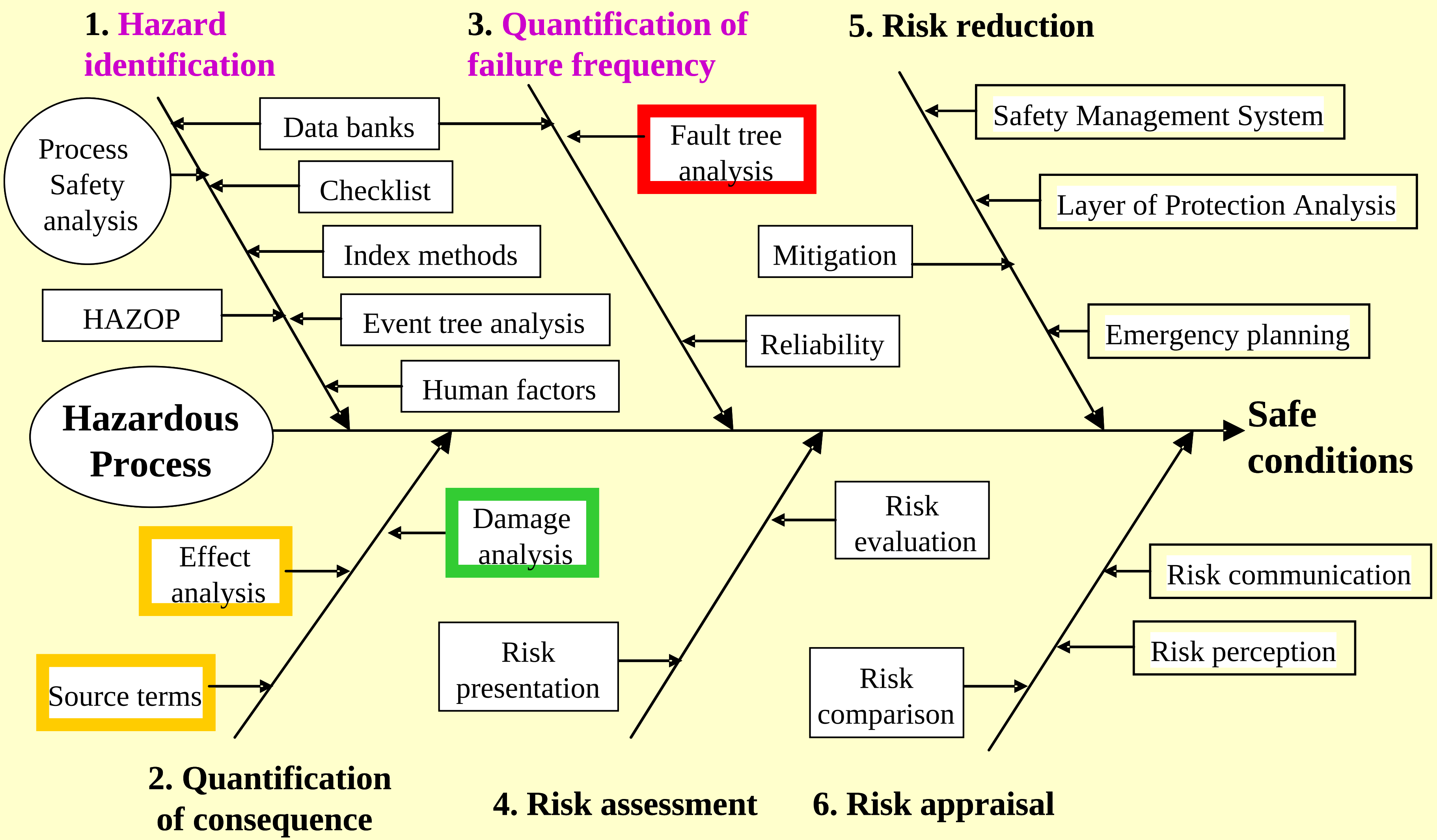
# Definitions:

- *"Hazard"* and "*Danger"* ; *"Risk".*
- *Hazard:* inherent physical or chemical characteristic that has the potential for causing harm to people, property or the environment.
- *Combination* of a hazardous material, an operating environment, and certain unplanned events that could result in an *accident*.
- *Risk:* occurrence of undesired events, the effects resulting from such events, and the probabilities or likelihood that both the undesired events and their consequences do indeed occur: Probability$\times$Consequence
- Probability an event happens over time: Frequency [per time unit]



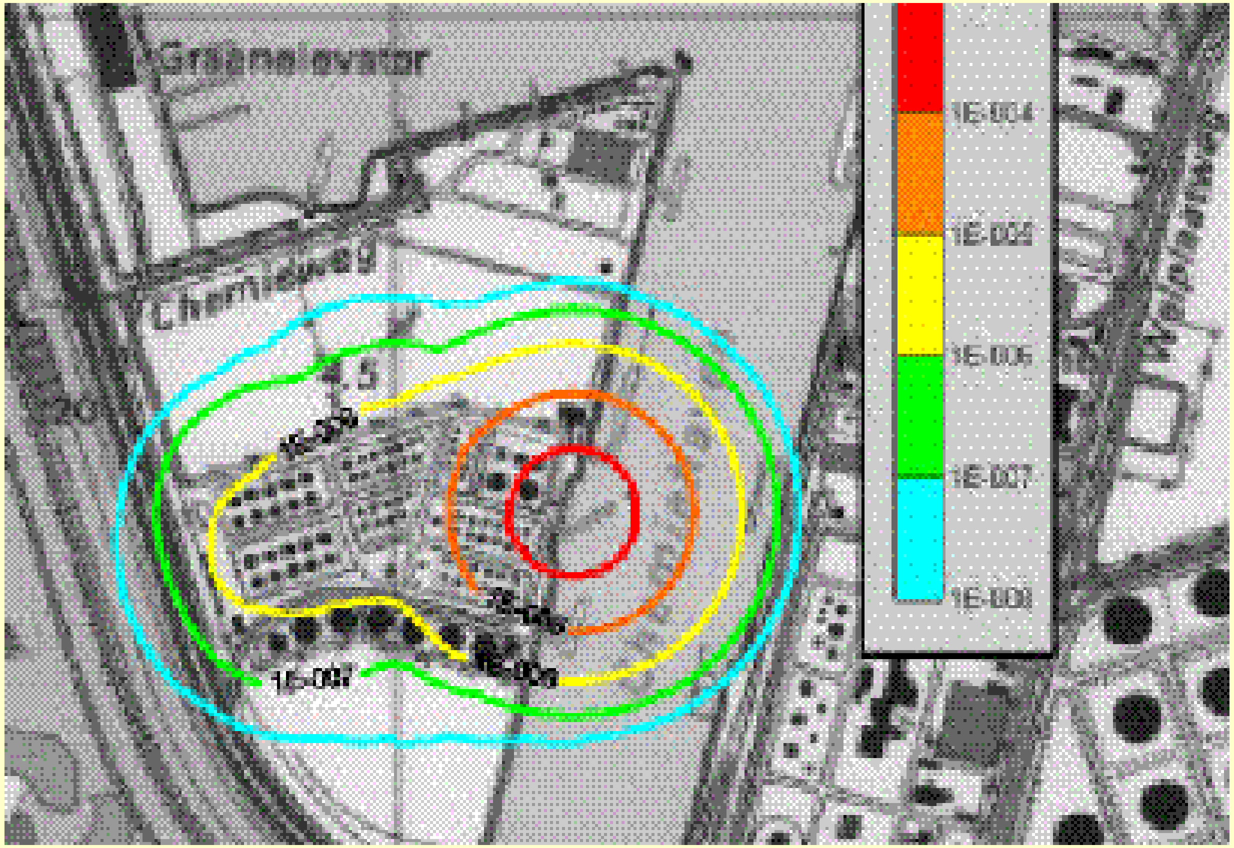

*Elements in a accident situation, which form together a scenario; LOP stands for Layer of Protection*

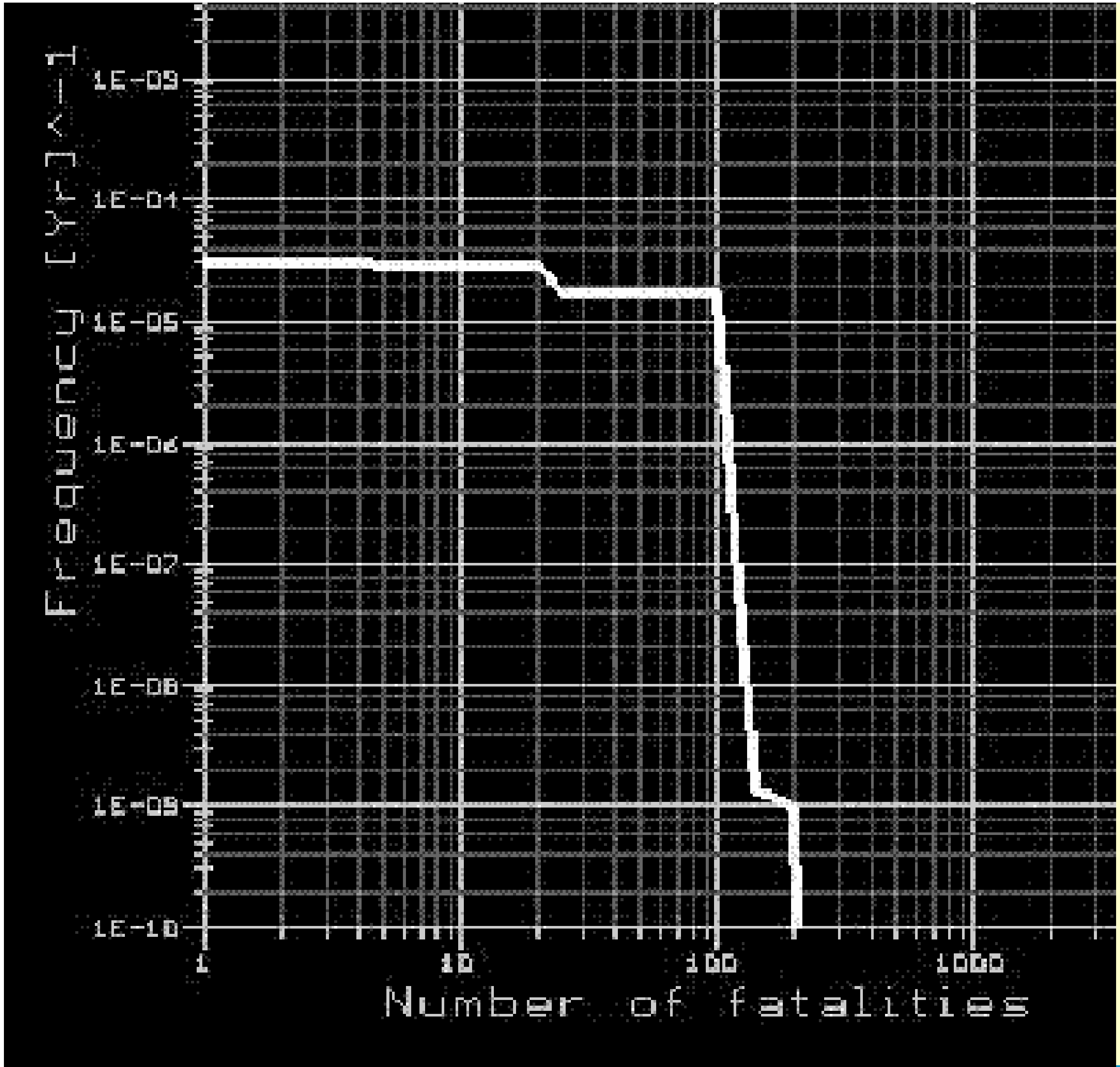



Ishikawa or Fish bone diagram QRA sequence

# Why do a risk assessment?

- Land Use Planning
- Licensing plant
- Operational safety
- Emergency planning



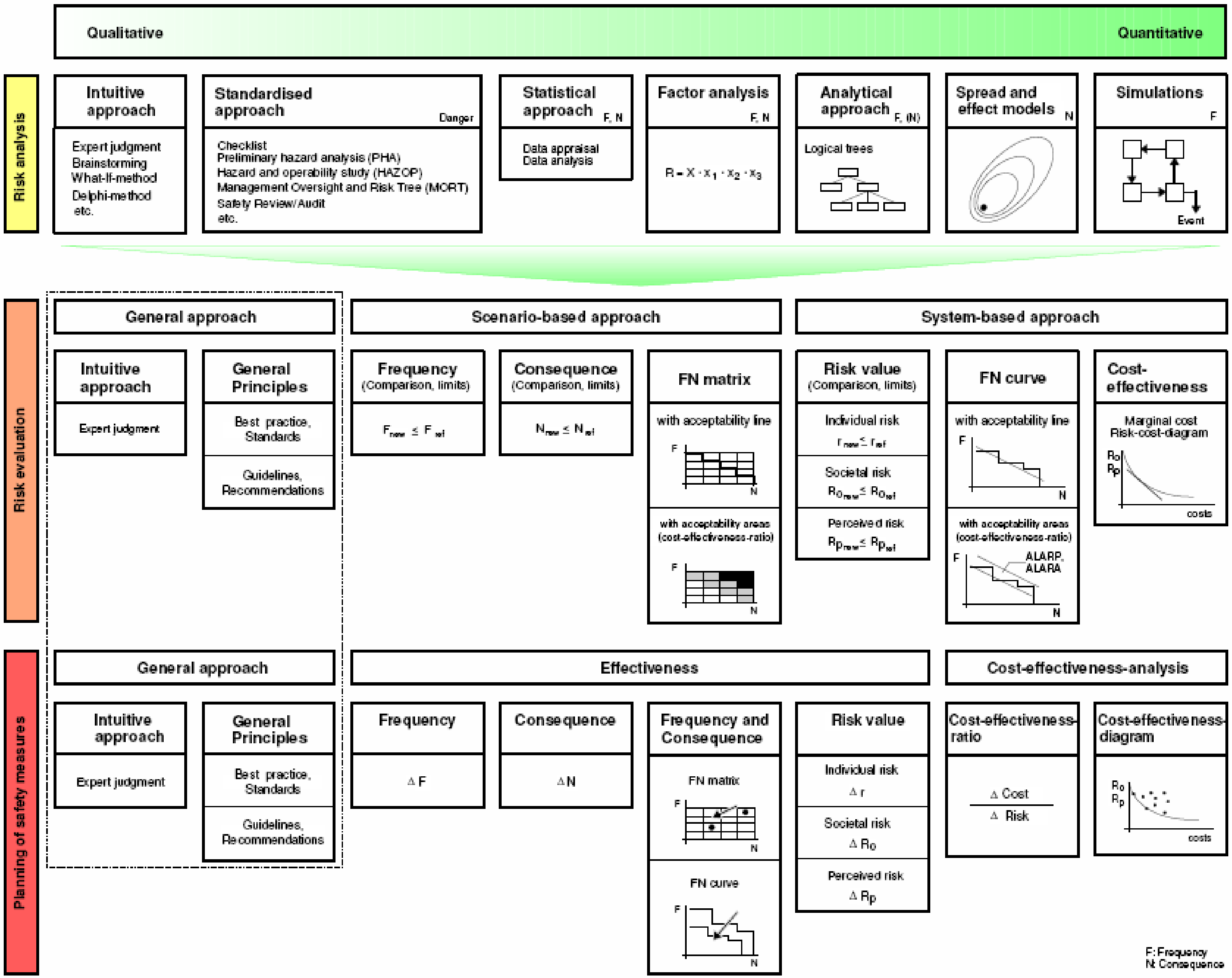



*Group or Societal Risk:*

F, N -curve

F = Frequency of accident resulting in N or more prompt fatalities

N = number of fatalities

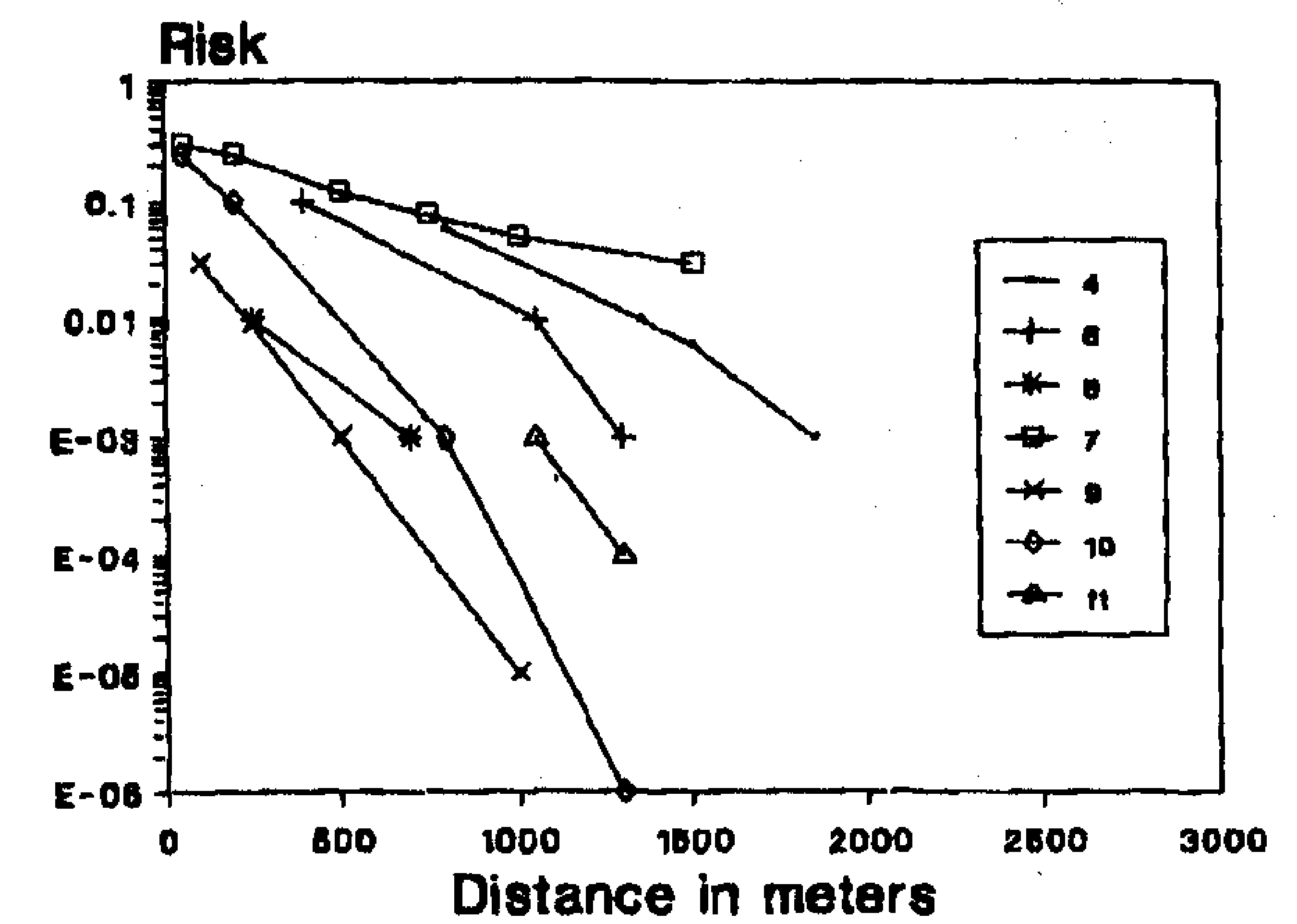



# RA :

Qualitative – Quantitative

Deterministic-probabilistic

# Trivial problem: Dispersion in results



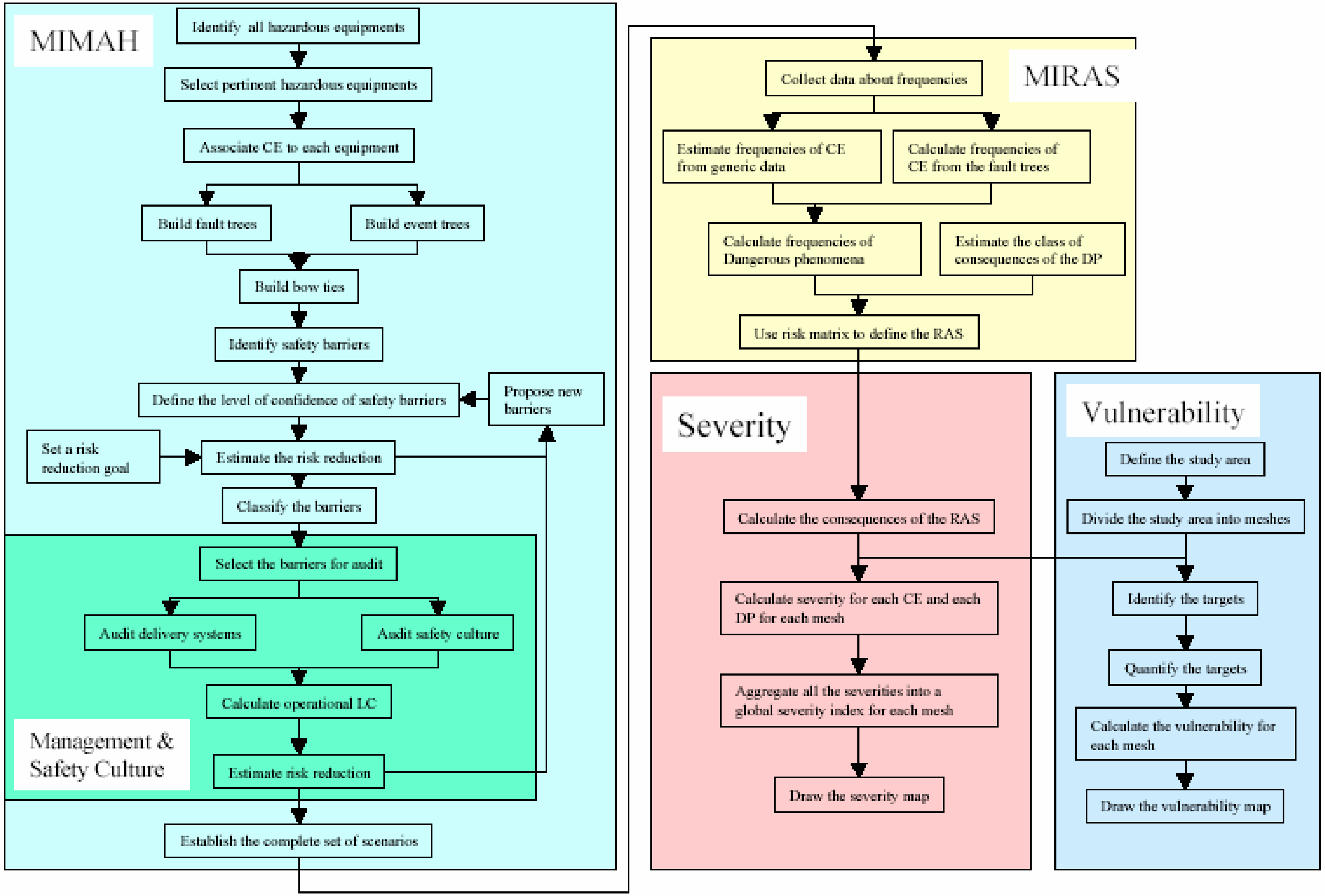

*EU project 1990:*

Ammonia tank release scenario

Scenarios
Dispersion
Damage models
Failure frequencies

Human factor???
Effectiveness of management

# ARAMIS: EU project 2001-2004



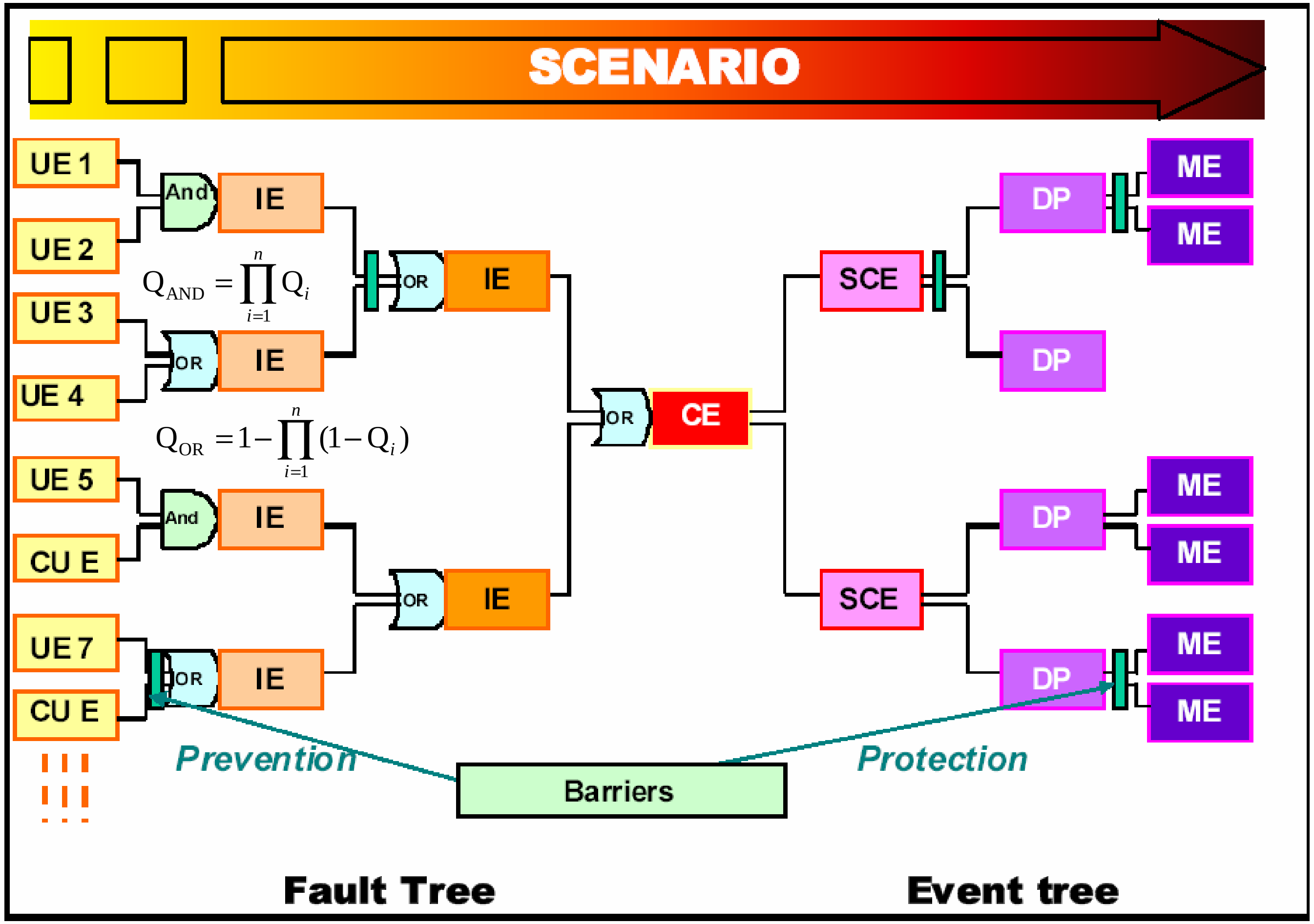

MIMAH
Identification
Hazards

MIRAS
Reference
Accident
Scenarios

Risk=
Severity
×
Vulnerability

Severity=
Frequency
×
Intensity

# Bow tie: old-fashioned man's tie in the shape of a butterfly: ►◄




UE = Unwanted Event e.g. human act

CU E = Current Event condition, direct cause

IE = Initiating Event e.g. pump fails

CE = Critical Event, 12 types: leak, start of fire

SCE = Secondary CE, escalation

DP = Dangerous Phenomena, 13 types VCE, pool fire, jet fire etc.

ME = Major Event, 4 types: overpressure, heat radiation, toxic load, pollution

Barriers: Preventive, Protective, Mitigative

# ARAMIS : Severity and Vulnerability Indexes

$$S(d)=\sum_{j=1}^{m}(f_{\mathrm{CE}_j}\cdot S_{\mathrm{CE}_j}(d))=\sum_{j=1}^{m}\left(f_{\mathrm{CE}_j}\cdot\sum_{i=1}^{n}(P_{\mathrm{DP}_i}\cdot S_{\mathrm{DP}_i}(d))\right)=\sum_{j=1}^{m}\sum_{i=1}^{n}(f_{\mathrm{DP}_{i,j}}\cdot S_{\mathrm{DP}_{i,j}}(d))$$

$$V_{global}=0.752\times V_H+0.197\times V_E+0.051\times V_M$$

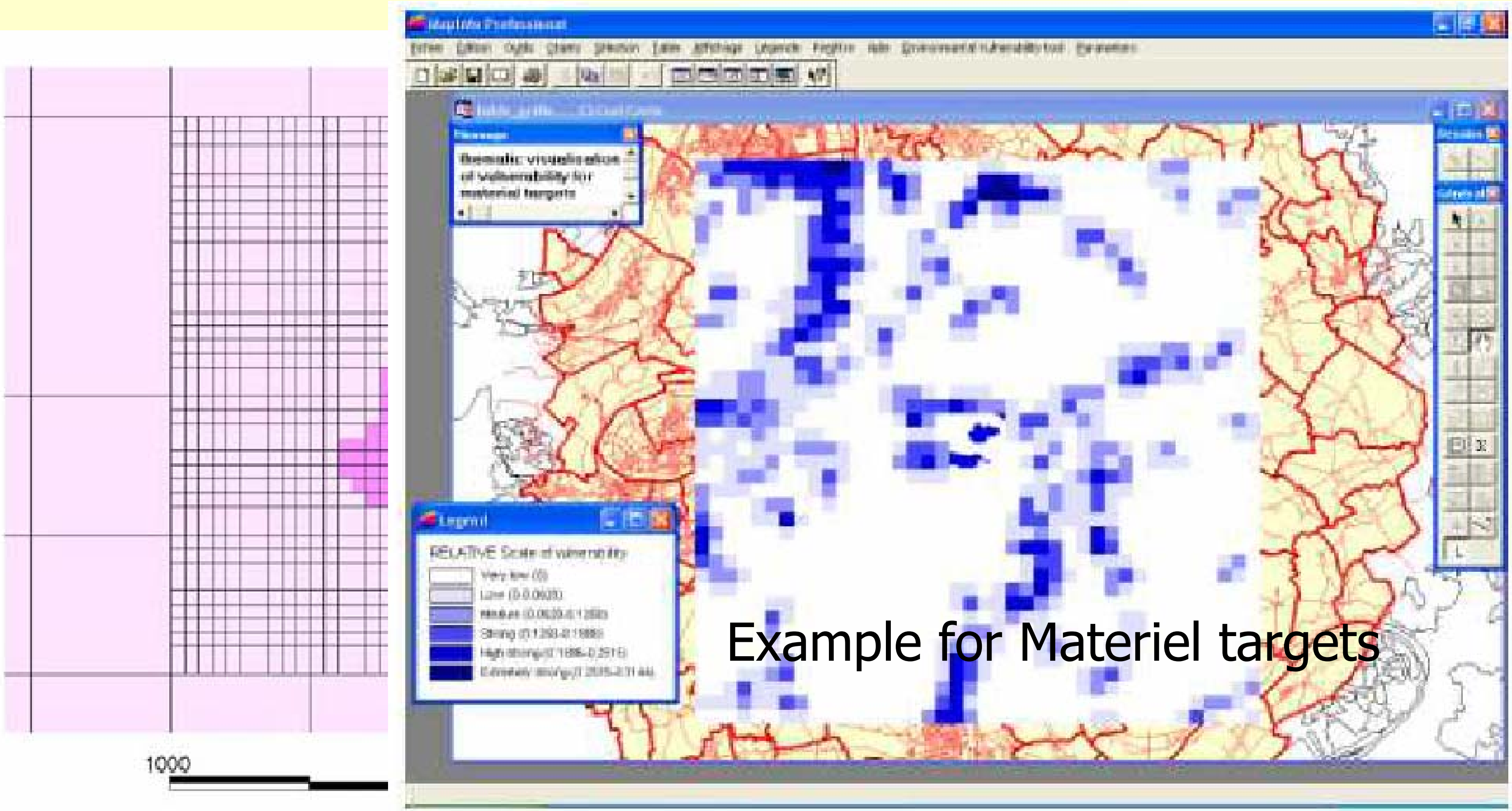
$$V_H=0.242\times V_H^{op}+0.225\times V_H^{tr}+0.466\times V_H^{tox}+0.067\times V_H^{poll}$$

$$V_E=0.071\times V_E^{op}+0.148\times V_E^{tr}+0.277\times V_E^{tox}+0.503\times V_E^{poll}$$

$$V_M=0.446\times V_M^{op}+0.410\times V_M^{tr}+0.069\times V_M^{tox}+0.075\times V_M^{poll}$$

- **$S_{DP}$** negligible, reversible, irreversible effects and lethality or domino effects
- 3 Target categories, each 4 sub-categories
- 144 + 51 weighing factors; MCA, 38 “experts”, 6 countries
- Quite a nuanced risk map can be produced

# Risk Presentation: grid on GIS map




Example for Materiel targets

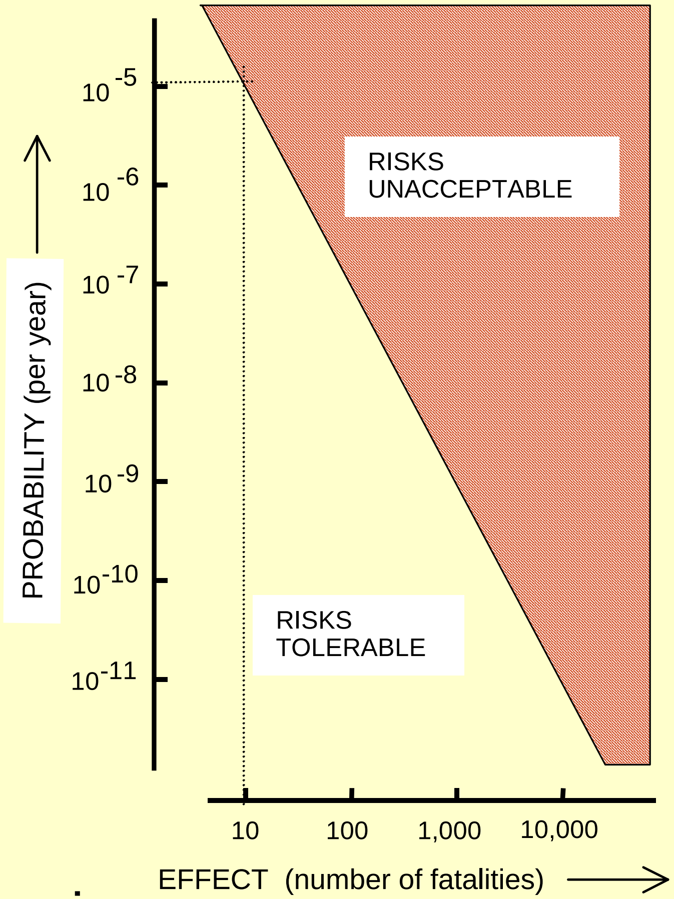
# How to use Risk Assessment :

Effect distance: dispersion model

## Criteria NL 1985:

- Individual risk ≤ $10^{-6}$ ($10^{-5}$) /yr
- Group Risk F(≥ N) ≤ $10^{-3}/N^2$, N ≥ 10
- Transport F(≥ N) ≤ $10^{-2}/N^2$ /km
- ALARA and ALARP

*Group risk of an activity*

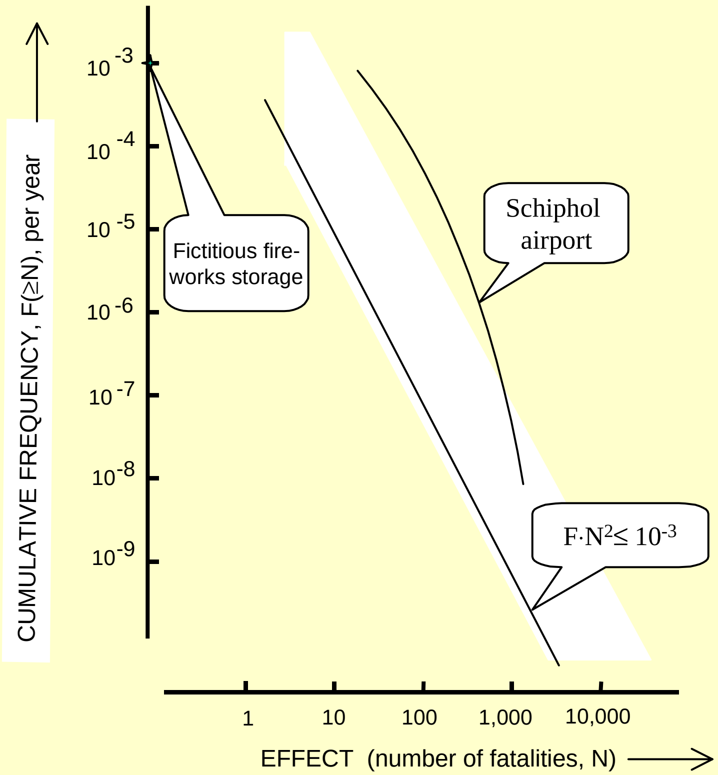


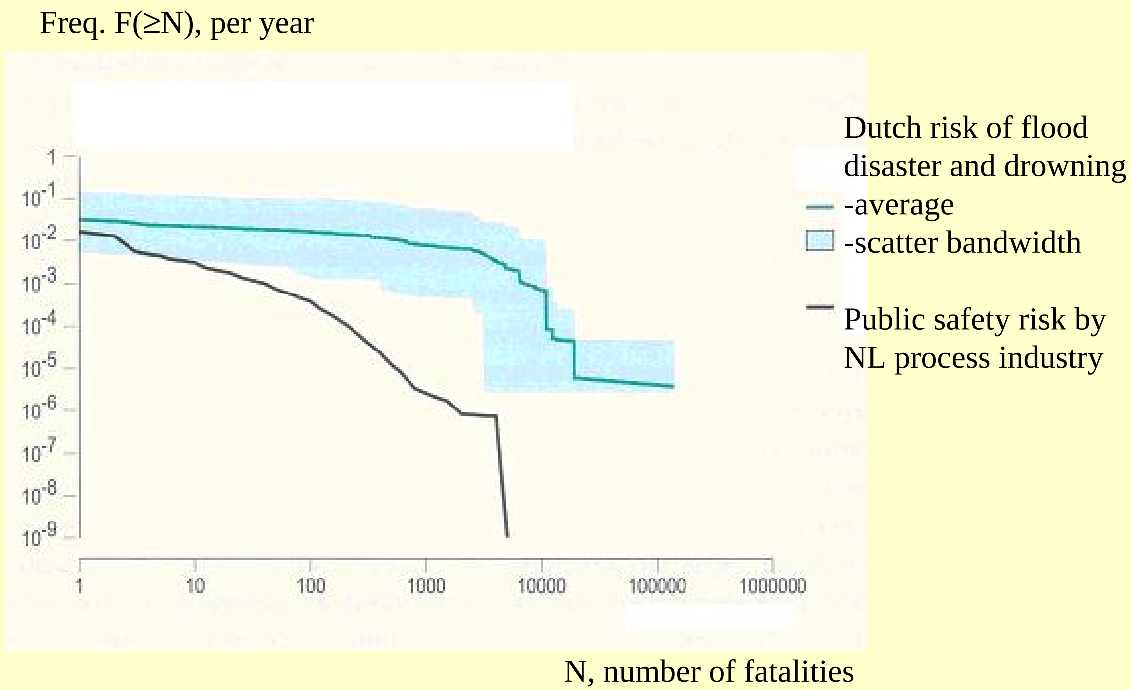

## USA 1996:

- RMP rule
- Worst Case Scenario
- Community committee

France 2006: LUP: ARAMIS + committee, barriers

# Dutch peculiarities group risk:



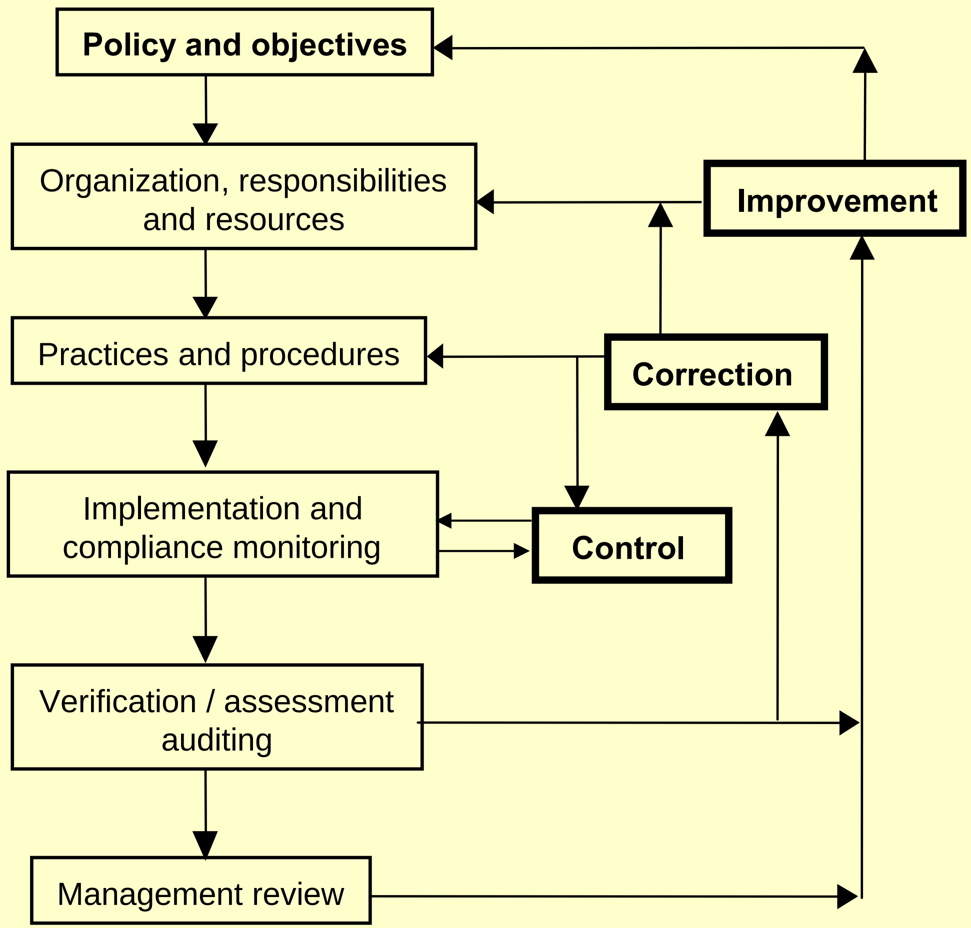



# A factor that helped safety to improve: Legislation

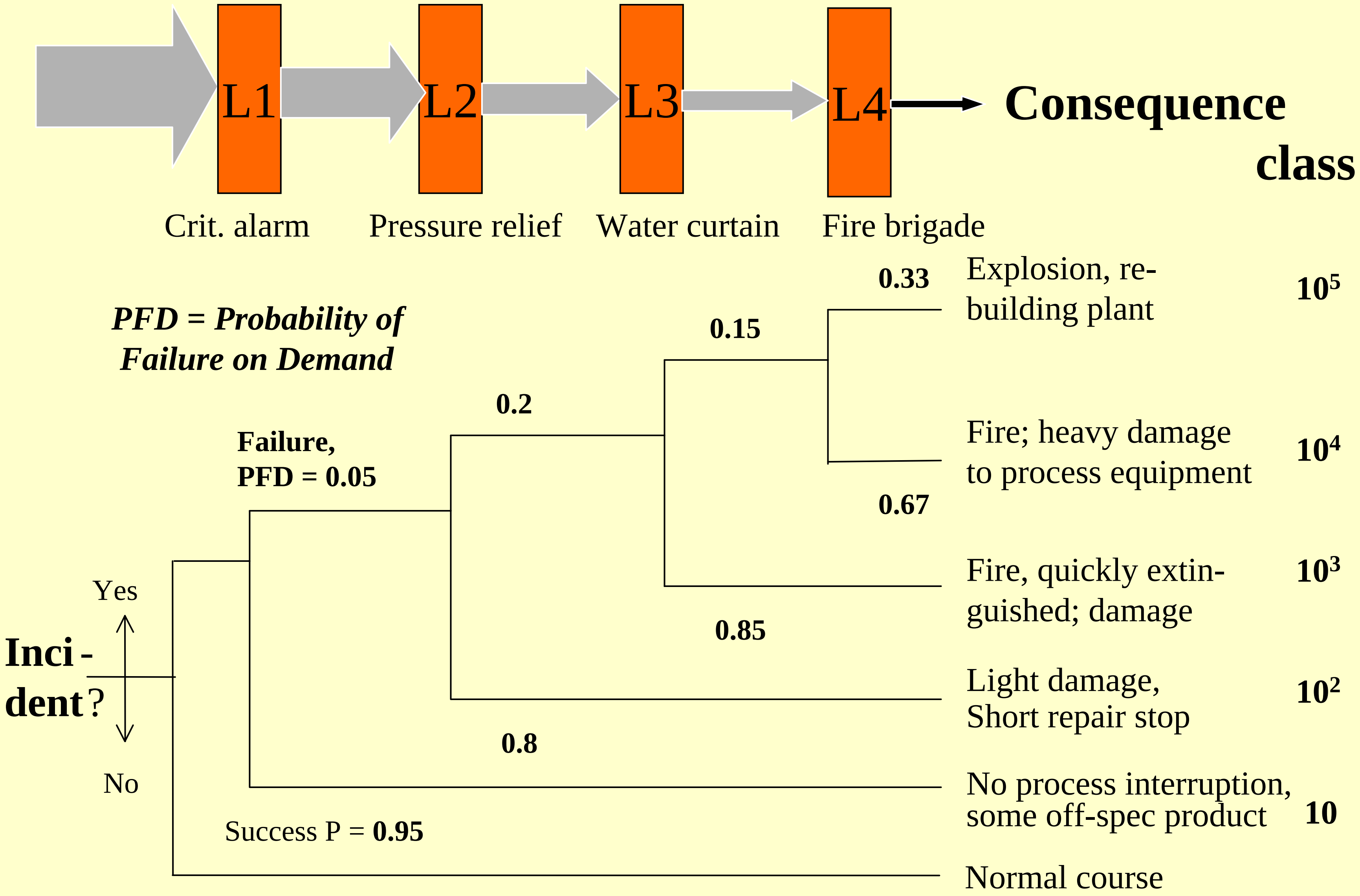
- Seveso I (1982/501/EEC)
- Seveso II (1996/82/EC
- IPPC 1996
- Pressure Equipment Directive
- ATEX 100 (1994/9/EC)
- ATEX 137 (1999/92/EC)

# Safety Management System

- 1. Accountability,
- 2. Process documentation,
- 3. Critical project review
- 4. Process risk management,
- 5. Management of change
- 6. Equipment integrity
- 7. Human factors (KISS)
- 8. Training and performance
- 9. Incident investigation
- 10.Standards, codes and laws
- 11.Audits and corrective actions
- 12. Enhancement of process safety



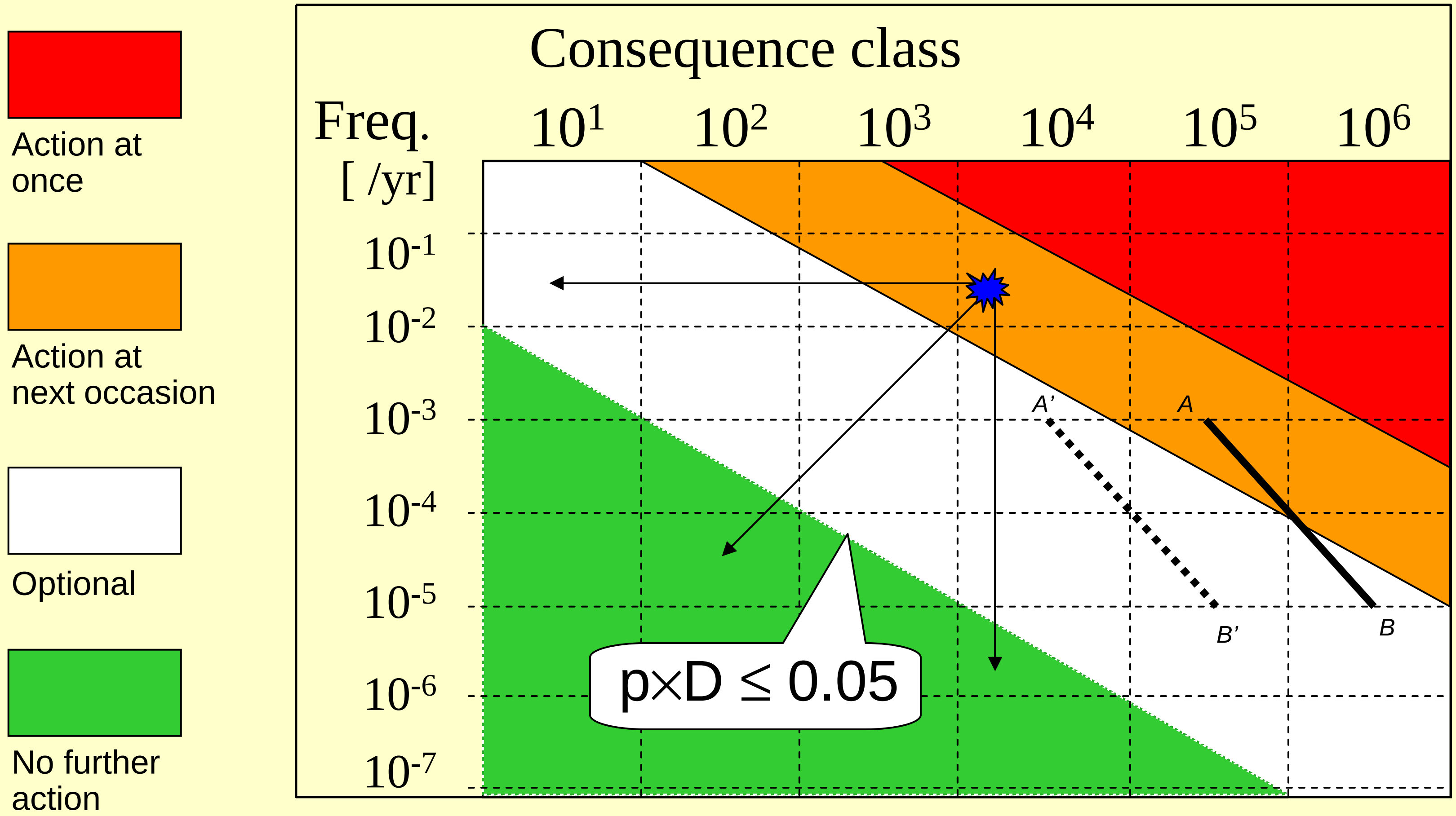
# LOPA effectiveness tree example




L1-4 = Independent Protection Layers: Length of arrow represents severity, thickness frequency

| Consequence Class | Plant personnel | Community | Environment | Financial loss, k€ |
|---|---|---|---|---|
| I / II $10^1$ | No lost time | No hazard | No notification | < 100 |
| III $10^2$ | Single injury | Odor/ noise | Permit violation | > 100 |
| IV $10^3$ | >1 Injury | Injuries; local news | Serious impact | > 1000 |
| V $10^4$ | Fatality | Severe injuries; regional news | Severe, short term effects | >10,000 |
| $10^5$ | Multiple fatalities | Fatality; int'l news | Disastrous effects, long term | >100,000 |
| $10^6$ | Catastrophe Public image severely damaged | Fatalities | Disastrous effects long term | >1,000,000 |

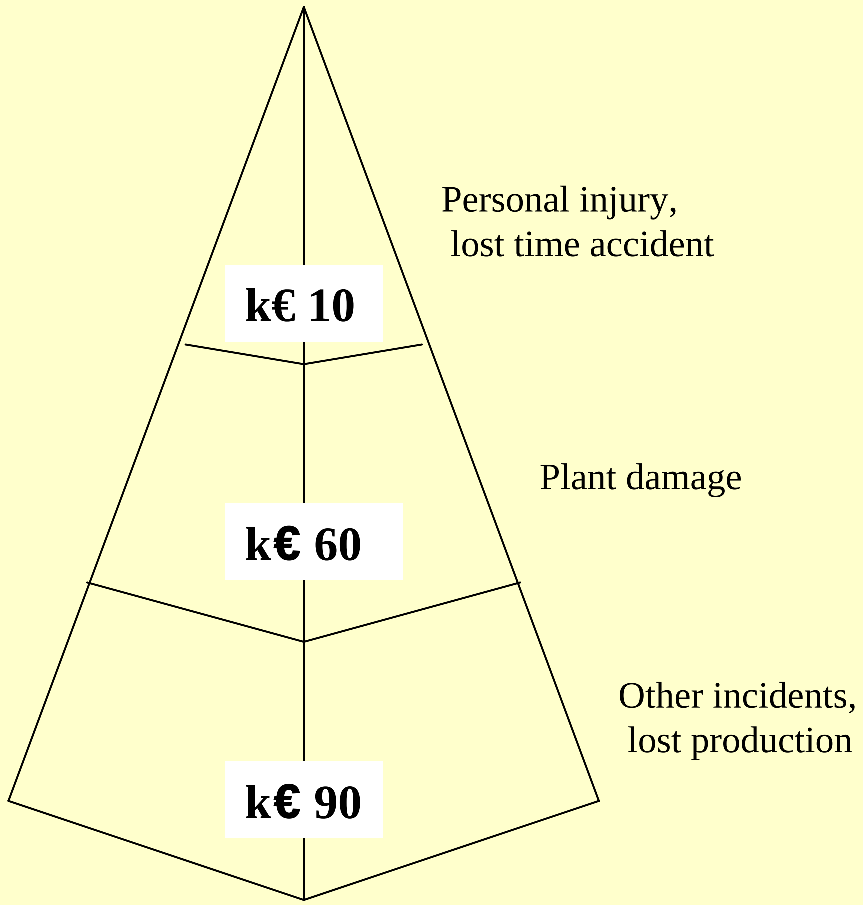
# Risk Matrix




If class $10^4$ or $10^5$, or Freq. $> 10^{-1}$ a semi-quantitative hazard study is required.

If [red] or [orange] a management review is required; if uncertainty exists, a QRA is needed.

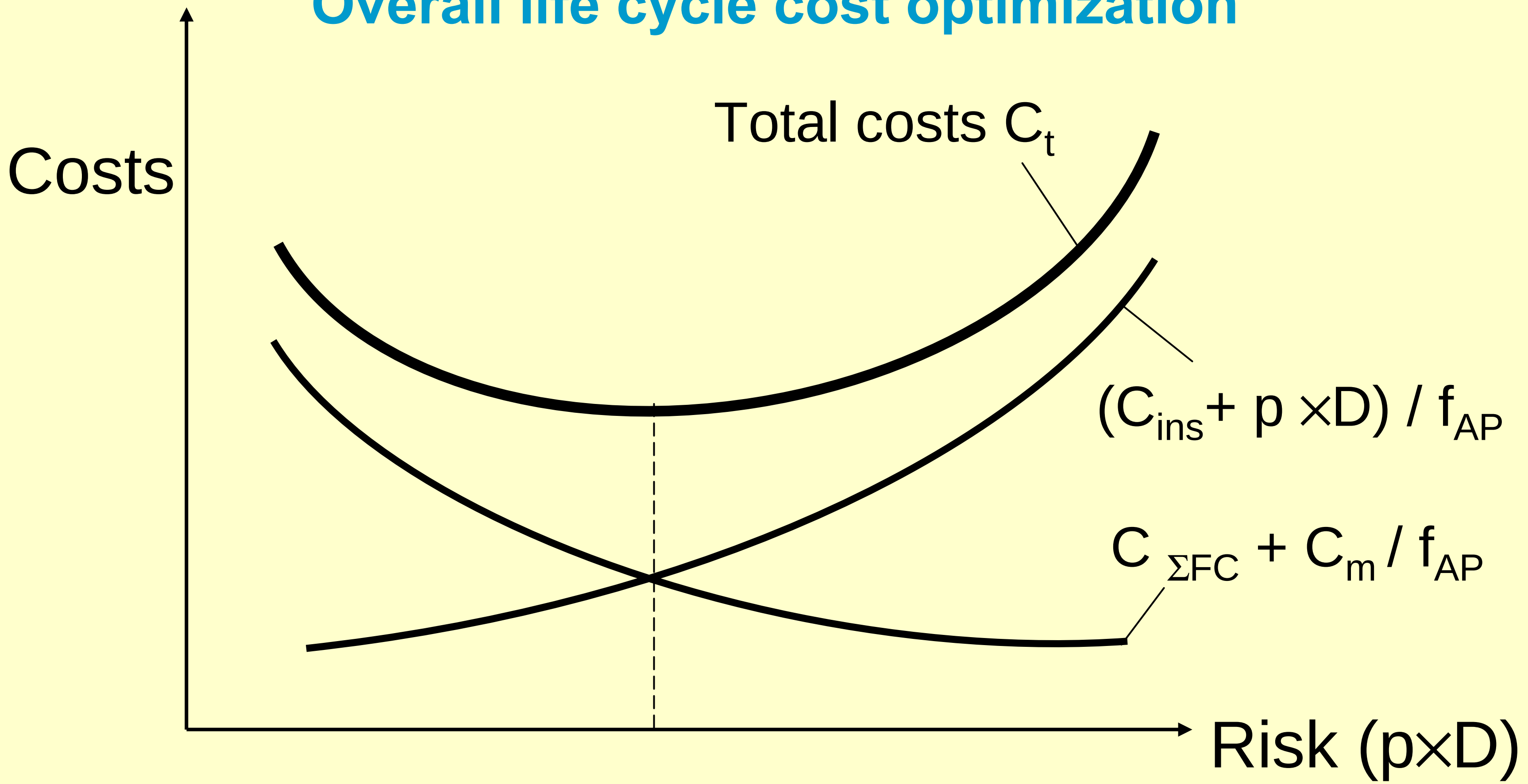
Line piece AB represents the public group risk criterion $FN^2 < 10^{-3}$, A'B' includes worker fatalities.




**Typical Cost Pyramid**

After T.J. Webster, 1st Int’l Symp.
Loss Prevention, Delft, NL, 1974

# Overall life cycle cost optimization



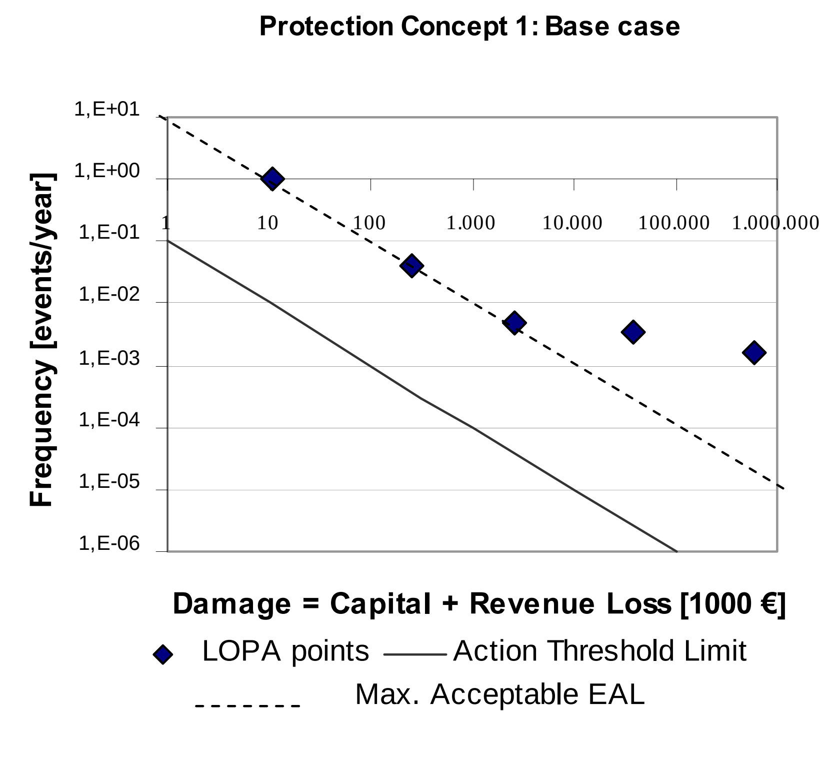

$$C_t = C_{\Sigma FC}(p, D) + C_m(p) / f_{AP} + C_{ins}(p,D) / f_{AP} + (p \times D) / f_{AP}$$

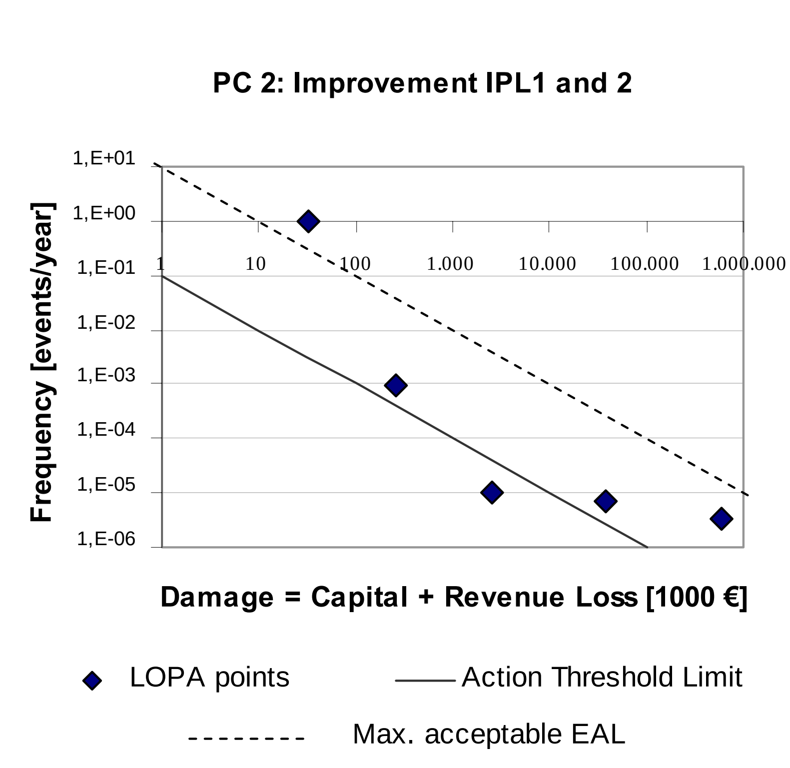
Costs — Safety investments — Maintenance — Insurance — Residual risk

$f_{AP} = \{i \times (1+i)^n\} / \{(1+i)^n - 1\}$ = Annuity Present Worth factor

# How safe is safe enough?

**Quantification**: Suppose initiating event 1 per year



# Conclusions, Part 1:

- For large scale technological systems such as Hydrogen economy, it pays to perform risk assessments
- Identification is a difficult step if no accidents have happened yet
- Concepts and methods are ready to be applied
- Improvements are to be developed in the human factor, management effectiveness measurement
- Consequence analysis is a separate chapter: → Part 2