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Methods of Technical Risk Assessment in a Regional Context

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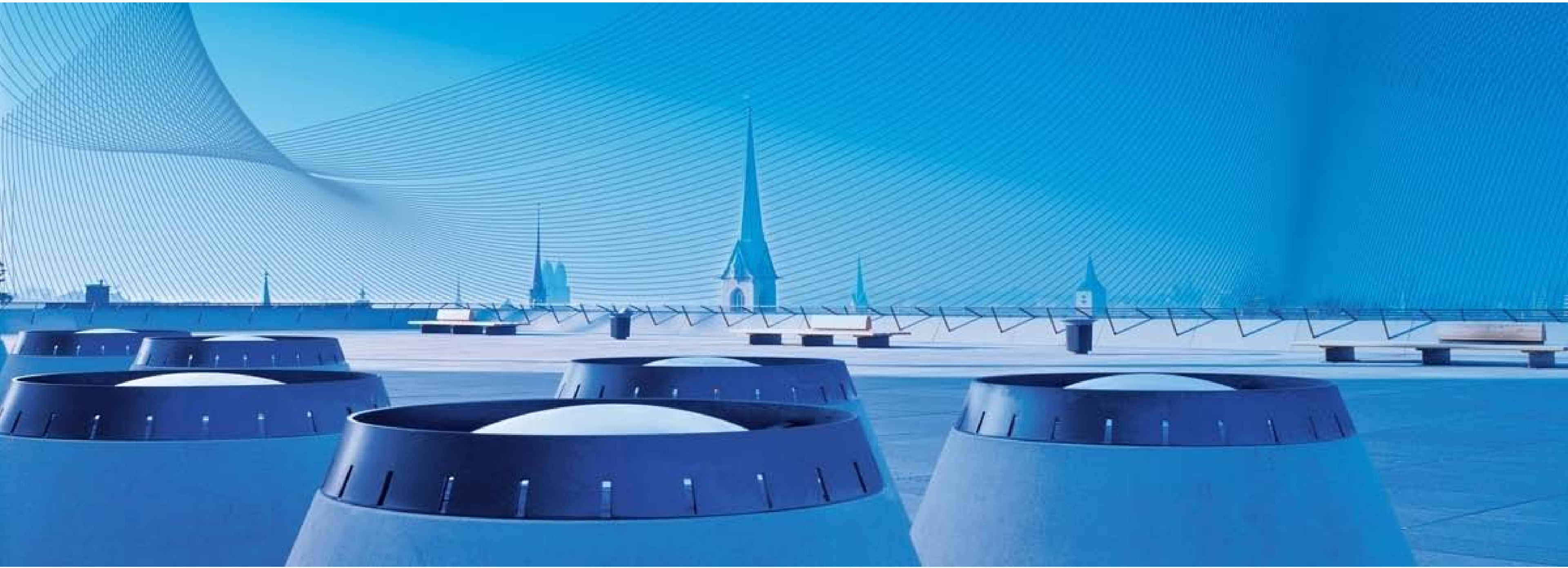
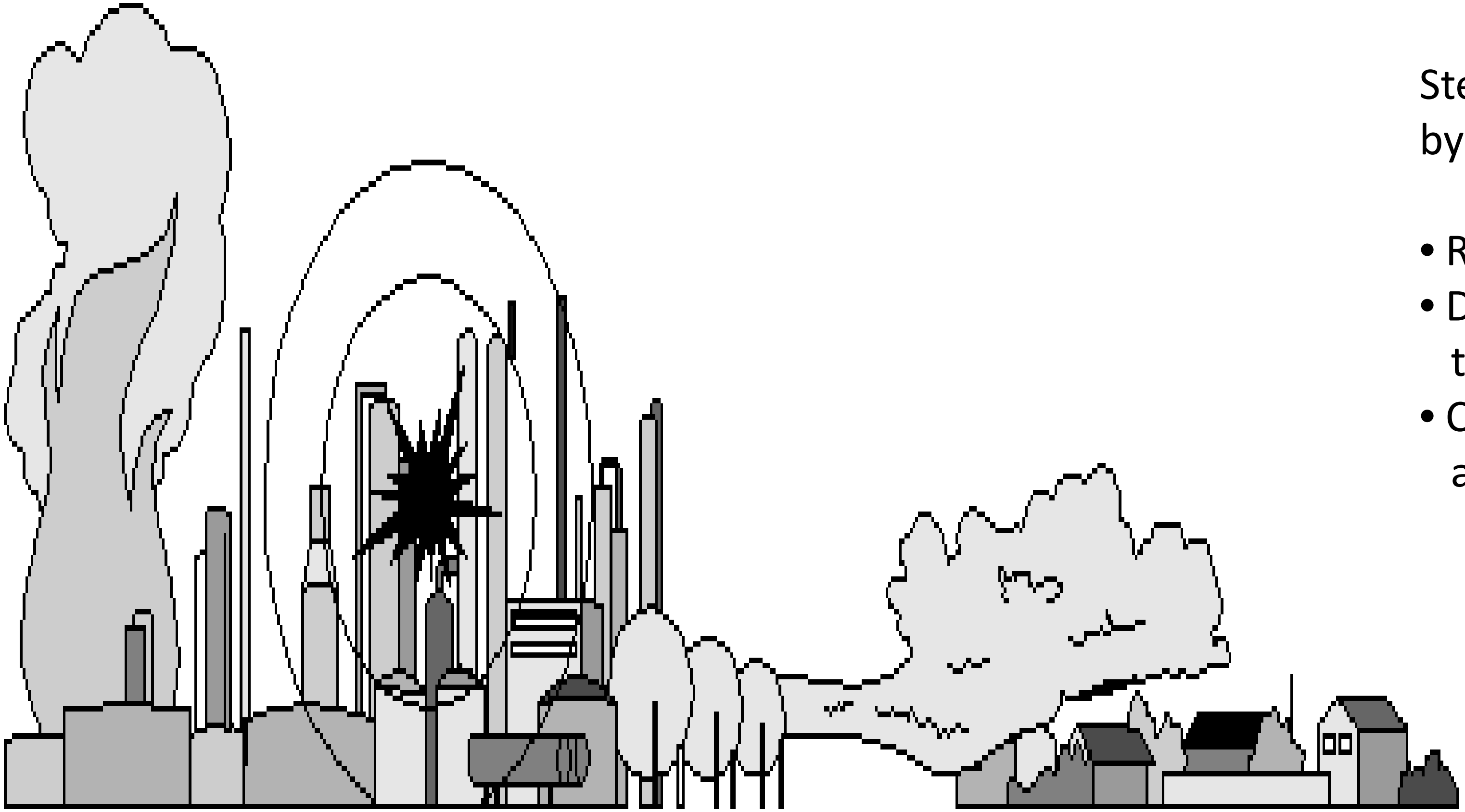


Techniques for source term estimation Health and environmental impact assessment (atmospheric transport/dispersion of released substances, dose-risk relationships)

- Accidental release scenarios of hazardous substances
- Dispersion and transport
- Modelling consequences and damage of chemical substances
  (The Probit-Approach)
- Exposure pathways and impact assessment for radiotoxic substances
- Representation of results
- References

Accidental release scenarios[1] of hazardous substances and related consequences



Stepwise approach by modelling of

- Release
- Dispersion and transport
- Consequence and exposure

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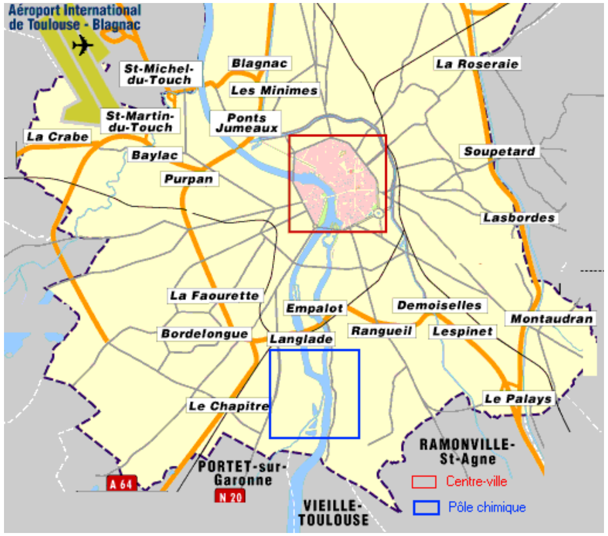
[1] A scenario is a brief description of an event or a series of events (http://en.wikipedia.org)

Ammonium Nitrate Explosion in Toulouse, France (21/9/2001)

Situation:
- AZF (Azote de France) is largest fertiliser producer in France.
- 470 employees, 3km away from the centre of Toulouse.
- Ammonium, chlorine and ammonium nitrate is stored on-site.
- Plant is one of 1250 “high risk” facilities.
- Plant was established in 1924 “in the countryside", is now next to other chemical plants (e.g. Société Nationale des Poudres et Explosives).

Incident: Explosion of 200–300t ammonium nitrate in a storage building (explosive power of 20–40t TNT equivalents).

Consequences:
- 31 fatalities (22 on-site, 9 in surrounding area) and approx. 2500 injured.
- Huge orange coloured cloud of gas, smelling of ammonia, moved towards the city centre. (dispersion)
- Crater of explosion is 50m in diameter and 10m deep. (direct impact)
- Debris piled up 10m high in certain parts. (indirect mechanical impact)
- Within a radius of 700 to 1500m doors and windows were shattered, roofs and walls damaged; windows burst in the centre of Toulouse (3 km away; direct pressure impact).
- 500 flats were uninhabitable, 86 schools were had to be closed.
- Toulouse airport, main railway station and metro system closed.
- Many citizens tried to leave Toulouse on cars while police blockaded roads around the site, leading to extensive traffic jams.
- Telephone network collapsed.



Sources:
http://www2.ac-toulouse.fr/histgeo/monog/azf/azf.htm
http://www.uneptie.org/pc/apell/disasters/toulouse/home.html

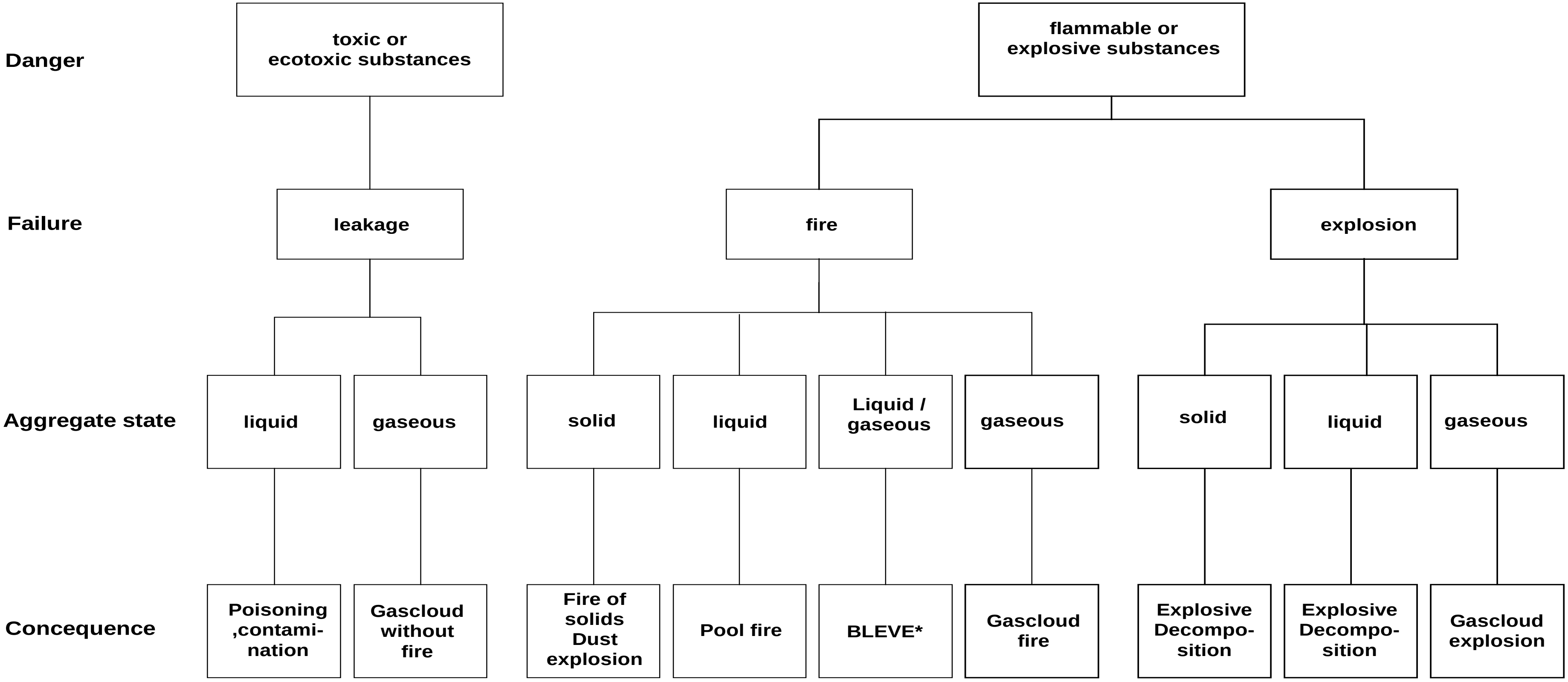
There is still a controversy on the direct causes of the explosion between the Justice, the company and the media

According to the judicial enquiry, the explosion was caused by a human handling error. A worker from a subcontracting company is said to have mistaken a 500-kilo sack of a chlorine compound (dichloroisocyanuric acid) for nitrate granules and poured it onto the stock of ammonium nitrate in the storage building a quarter of an hour before the explosion. The mixture is said to have produced nitrogen trichloride, an unstable gas that explodes at normal temperatures.

But according to owner of AZF, has suggested another hypothesis through its own commission of enquiry, claiming that the explosion was caused by an electric arc between two transformers located outside the plant.

A newspaper in Toulouse, alleges that the ammonium nitrate that caused the explosion at the AZF factory was stacked "in a real dump" with minimal surveillance and security, and "incredible negligence". The newspaper also reported that the storage area was excluded from the area to be inspected by a regional industry and environment authority in May 2001.

Matrix for selecting accidental release scenarios



*BLEVE: Boiling Liquid Expanding Vapour Cloud Explosion

[2] Security measures and installations are included

Elements for the description of accidental release scenarios of hazardous substances

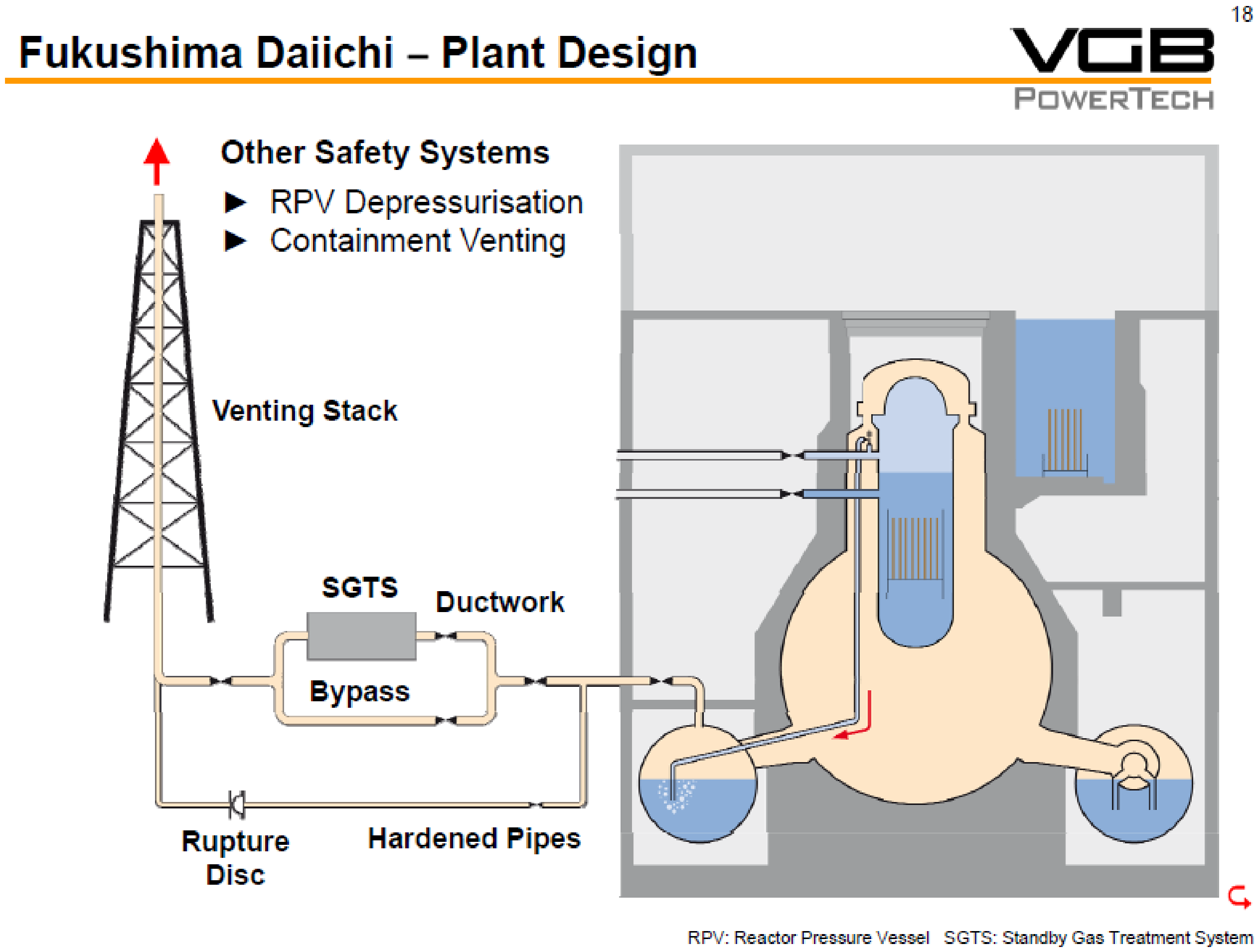
	Specification factors	Influencing parameters
Release	•Begin and duration • Type and size of leakage • Number of leaks, rate, location of the leakage • Pool size • Evaporation rate	• Cause of the leakage • Aggregate state of the released substance - gaseous, liquid, in two-phase • Total release minus spontaneous evaporating and aerosol forming quantity • Evaporation mechanism (additional heat)
Dispersion	• Concentration of the released substance at place X	• Release source type - spontaneous, continuous • Density of the gas cloud > air (dense cloud) = air (neutral cloud) < air (buoyant cloud) • Ground conditions • Wind characteristics, atmospheric conditions

Elements for the description of accidental release scenarios of hazardous substances

	Specification factors	Influencing parameters
Consequence	• Consequence at place x	• Acute toxicity • Fire / radiated heat • Explosion / pressure wave
Exposure	• Exposure	• Population density • Time of exposure • Degree of protection (sheltering / staying outdoors)

Developing of release scenarios

E.g. containment of a nuclear power plant – Fukushima Dai-ichi 1



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Fukushima Daiichi – Plant Design

VGB POWERTECH

Other Safety Systems

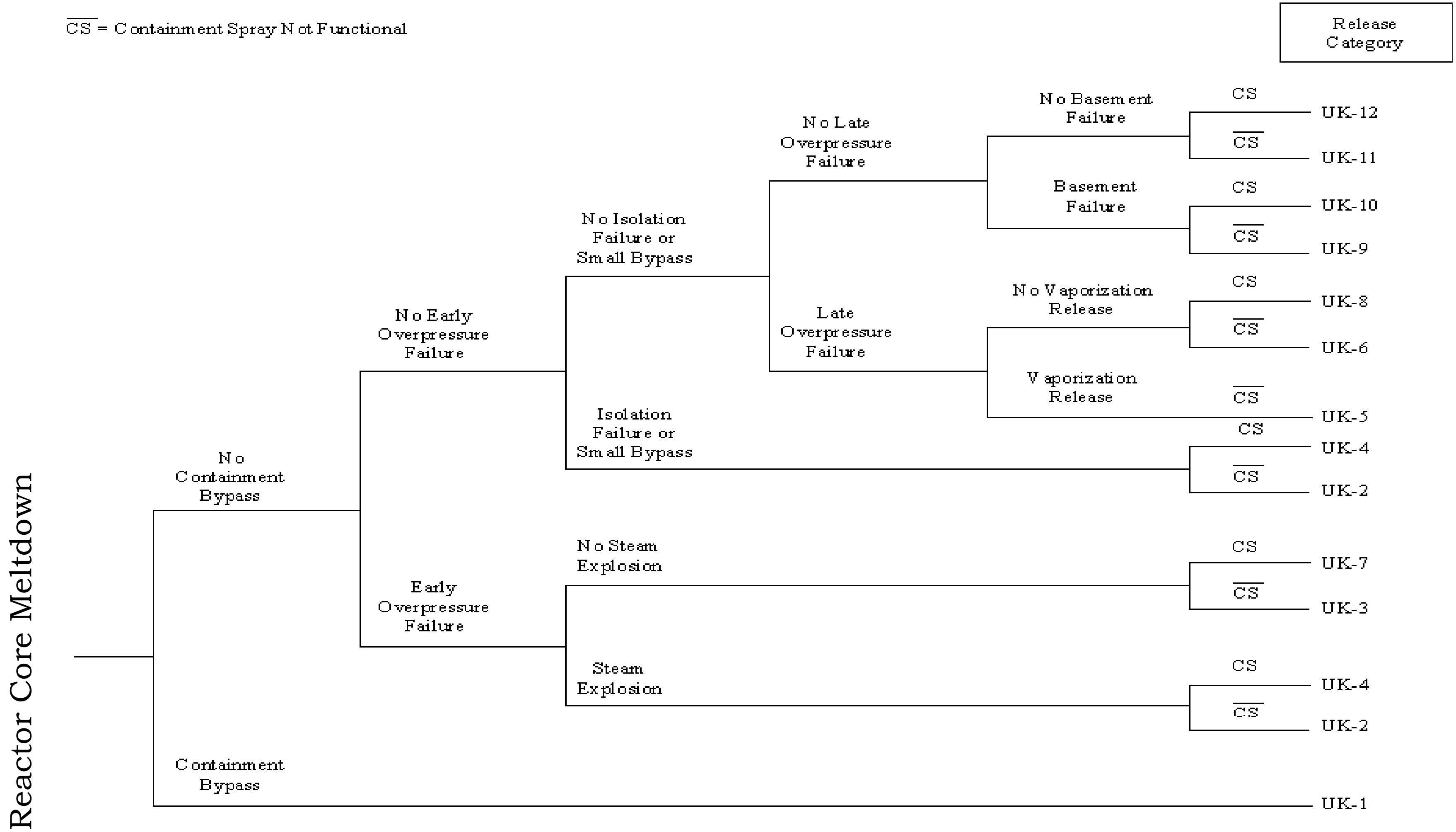
- RPV Depressurisation
- Containment Venting

RPV: Reactor Pressure Vessel SGTS: Standby Gas Treatment System

Using Event Trees for Scenario Development

CS = Containment Spray Functional

$\overline{CS}$ = Containment Spray Not Functional



Release Category

Reactor Core Meltdown

No Containment Bypass

No Early Overpressure Failure

No Isolation Failure or Small Bypass

No Late Overpressure Failure

No Basement Failure

CS — UK-12

$\overline{CS}$ — UK-11

Basement Failure

CS — UK-10

$\overline{CS}$ — UK-9

Late Overpressure Failure

No Vaporization Release

CS — UK-8

$\overline{CS}$ — UK-6

Vaporization Release

$\overline{CS}$ — UK-5

Isolation Failure or Small Bypass

CS — UK-4

$\overline{CS}$ — UK-2

Early Overpressure Failure

No Steam Explosion

CS — UK-7

$\overline{CS}$ — UK-3

Steam Explosion

CS — UK-4

$\overline{CS}$ — UK-2

Containment Bypass

UK-1

Selected Release Categories and Source Term Values

Release Category, Description and Frequency	Release Characteristics					Release Fractions of Core Inventory			
	Release starts [hrs]	Duration [hrs]	Warning Time [hrs]	Energy [MBTu/hr]	Height [m]	Xe-Kr	I	Cs-Rb	Ba-Sr
UK-1 Containment bypass 2.4e -9	1	3	0	0.3	10	9e -1	7e -1	5e -1	6e -2
UK-2 Early containment faie Steam explosion 4.0e -10	1	0.5	0	20	10	9e -1	7e -1	4e -1	5e -2
UK-5 Late containment faie Vaporisation release 8.0e -9	8	0.5	4	20	10	1e 0	6e -2	3e -1	4e -2
UK-6 Late containment faie No vaporisation release 4.2e -9	12	0.5	8	20	10	9e -1	9e -3	2e -1	2e -2

Note: 1 Btu/hr = 0.29 watts; 2.4e -9 means 2.4 x 10-9 per reactor year

Source: [1]

Dispersion

	Dispersion		Measures
Air	Fast, depending on • Wind speed / direction • Atmospheric conditions • Topography	Mean wind speeds[2] in Zürich SMA: 2.35m/s Jungfraujoch: 8.34m/s	Staying indoors Keeping windows and doors shut Nourishment control
Flowing water	Moderate, depending on • Flow speed • River bed profile	Mean flow rate of Rhine[3]: 1.1m/s Elbe[4]: 0.8m/s	Stopping ground water enrichment
Groundwater	Slow, depending on • Porosity	Flow rate[5]: 1m/day	Stopping ground water pumps
Standing water	Slow, depending on • Inflow / outflow rate • Depth, size	Water renewable time Lake Konstanz[6]: 4.5 years Lake Sempach[7]: 15 years	Stopping ground water enrichment
Soil	Slow, depending on • Porosity • Soil horizons	Diffusion	Soil decontamination, disposal

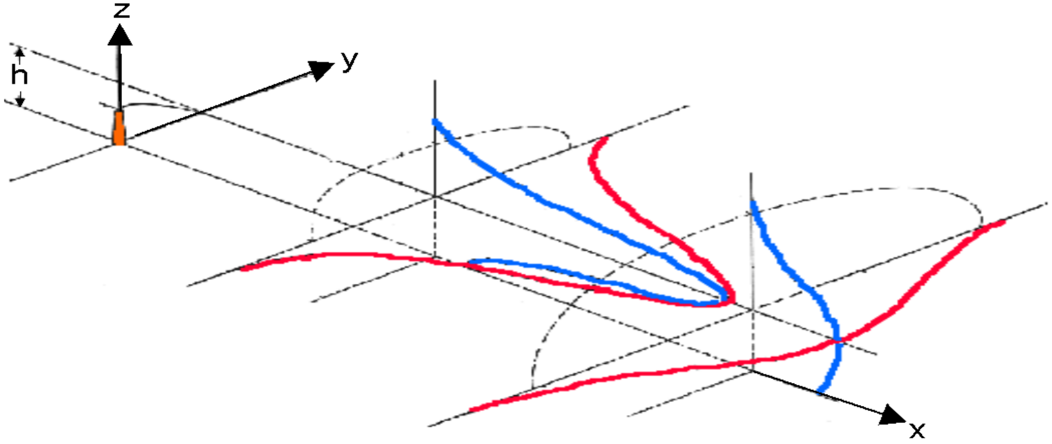
[2] Source: http://stratus.meteotest.ch/mme/a_meanwind1983_97.asp?lang=d
[3] Source: http://www.hochwasserkarte.de/Seiten/der_Rhein.htm
[4] Source: http://de.wikipedia.org/wiki/Elbe
[5] Source: http://www.ifu.ethz.ch/GWH/education/graduate/Grundwasser1/Script_GW_I.pdf
[6] Source: http://www.lubw.baden-wuerttemberg.de/servlet/is/3603/
[7] Source: http://www.lu.ch/download/afu/ap/9/SeZu9297.pdf

Air Dispersion

Gauss'sches Fahnen-Modell

$$C(x,y,z) = \frac{Q^{'}}{2\pi\sigma_y\sigma_z u} \cdot \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \cdot \left(\exp\left(-\frac{(z-h)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+h)^2}{2\sigma_z^2}\right)\right)$$

C(x,y,z) = Concentration of immissions at referenced point *(x, y, z)*
Q' = Release rate (amount of pollutant per time unit)
u = Average velocity
H = Source term height
x,y,z = Distance of the reference point to the point of origin, the *x*-coordinate corresponds to the wind direction
σ_y, σ_z = Parameter of dispersion for the distribution of concentration in *y*/*z*-direction; σ_y, σ_z are functions of *x*



Evaluation of toxic effects released substances

Known approaches for quantification apply threshold values:

If the **MAK** (maximum workplace concentration) value is not exceeded, the public is not in danger.

The **IDLH** value (Immediately Dangerous to Life and Health) refers to healthy male adults (expose of 30 minutes) who are not fully representative of the population in general.

The **ERPG**’s (Emergency Response Planning Guidelines) are used in the USA.

The ERPG-1 is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing more than mild, transient adverse health effects or without perceiving a clearly defined objectionable odour.

The ERPG-2 is the maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective action.

The ERPG-3 is the maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to 1 hour without experiencing or developing life-threatening health effects.

It is important to know, whether a released substance has mutagenic, carcinogenic or teratogenic characteristics.

Modelling consequences and damage of chemical substances

- **Contours of release of dangerous toxic cloud, pressure or heat waves, etc. and subsequent impact**

- **The Probit-Approach (based on TNO methodology)**

Exposure and effects following release and dispersion of dangerous substances into the environment

Parameters used to express the lethal effects are:

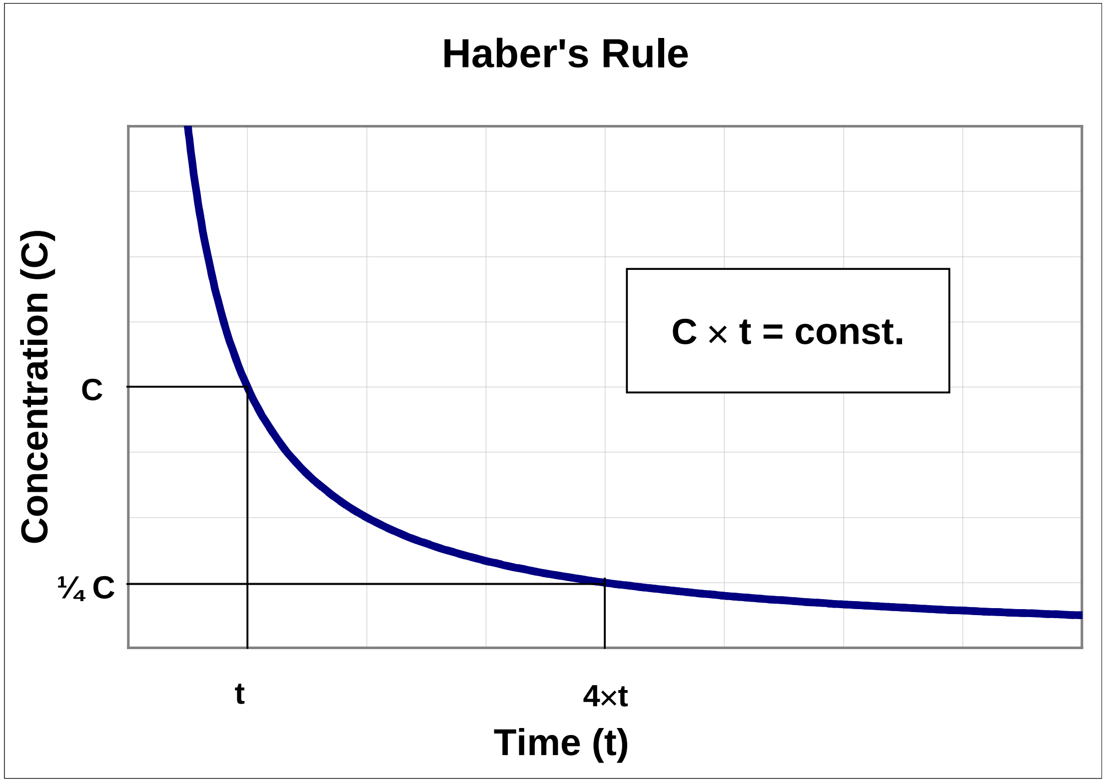
<u>The probability of death, P_E</u> – of an individual dying from exposure used for <u>Individual Risk</u> contour.
<u>The fraction of the population dying, F_E</u> – the fraction of the population dying at a certain location due to a given exposure (indoors and outdoors fraction) – used in the calculation of the <u>Societal Risk.</u>

Dose calculation

Principles of Toxicology

Effects = f(Concentration, Duration and Frequency of Exposure)

Haber's Rule: $C \times t = \text{const.}$



Dose and Prohibit-Approach

Definition of a dose:

D = Constant · Concentration · Exposure time

The constant is related to the transition from the air to blood and is usually set to 1. The integral of the dose can easily be done by discrete numerical computation, but it is difficult to interpret the dose.

Therefore the toxic load is used.

Toxic load:

$$V = \Sigma C_i^n \cdot t_i$$

There are constants for a limited number of chemical substances, which allow to conclude (by a **Probit-Approach** ,Pr) from the toxic load to the percentage of a populations mortality.

$$Pr = a + b \cdot \log_e (C^n \cdot t)$$

C:	Concentration
t:	Exposure time
a,b,n:	Constants of the substance

Substance	**a**	**b**	**n**
Acrolein	-4.1	1	1
Acrylonitrile	-8.6	1	1.3
Allylalcohol	-11.7	1	2
Ammonia	-15.6	1	2
Azinphos-methyl	-4.8	1	2
Bromine	-12.4	1	2
Carbon monoxyde	-7.4	1	1
Chlorine	-6.35	0.5	2.75
Ethylene oxyde	-6.8	1	1
Hydrogen chloride	-37.3	3.69	1
Hydrogen cyanide	-9.8	1	2.4
Hydrogen fluoride	-8.4	1	1.5
Hydrogen sulfide	-11.5	1	1.9
Methyl bromide	-7.3	1	1.1
Methyl isocyanate	-1.2	1	0.7
Nitrogen dioxide	-18.6	1	3.7
Parathion	-6.6	1	2
Phosgene	-10.6	2	1
Phosphamidon	-2.8	1	0.7
Phosphine	-6.8	1	2
Sulfur dioxide	-19.2	1	2.4
Tetraethyllead	-9.8	1	2

Probit Function

Probit: Number directly related to probability by a numerical transformation.

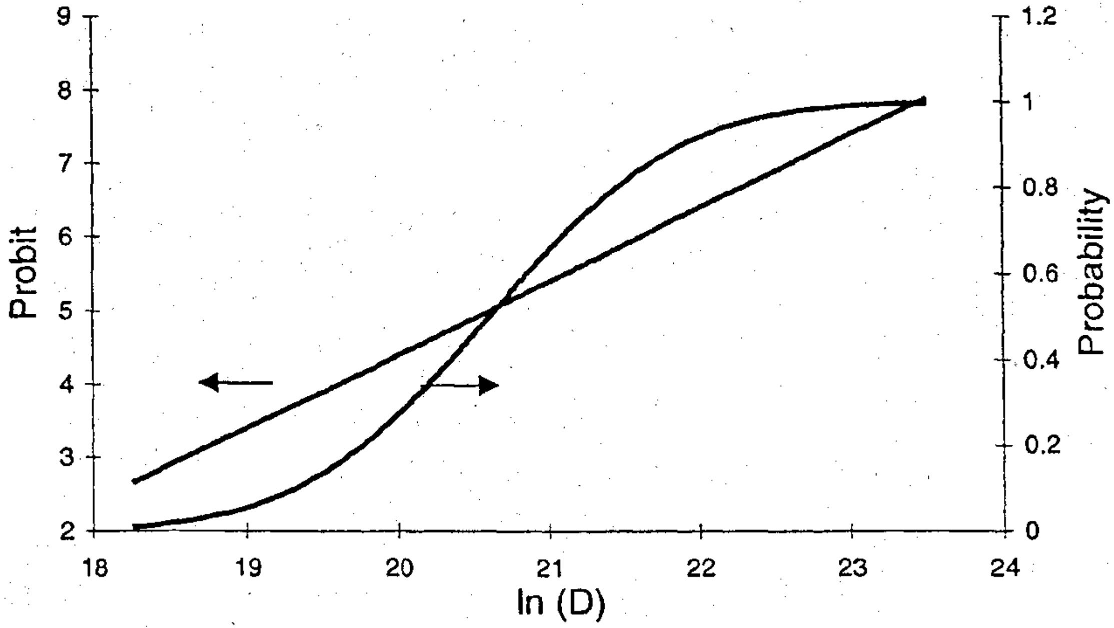
$$P_E = 0.5\left[1 + erf\left(\frac{\mathrm{Pr} - 5}{\sqrt{2}}\right)\right]$$

where

$$erf(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt$$

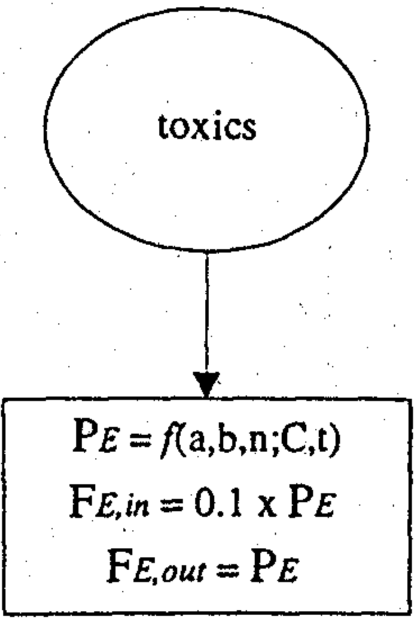
P_E is the probability of an effect (death)

Pr is probit value



The probability, P, and the probit, Pr, as a function of exposure to ammonia. The exposure is represented by ln (D), with D the toxic dose. The figure shows how the sigmoid curve is replaced with a straight line if the probit is used.

1. Toxic exposure



toxics

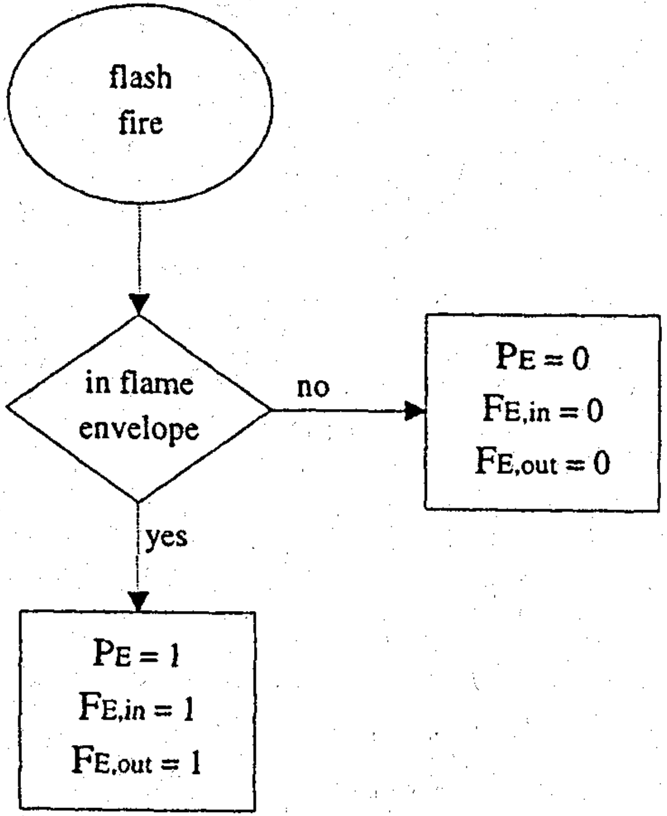
$$P_E = f(a,b,n;C,t)$$

$$F_{E,in} = 0.1 \times P_E$$

$$F_{E,out} = P_E$$

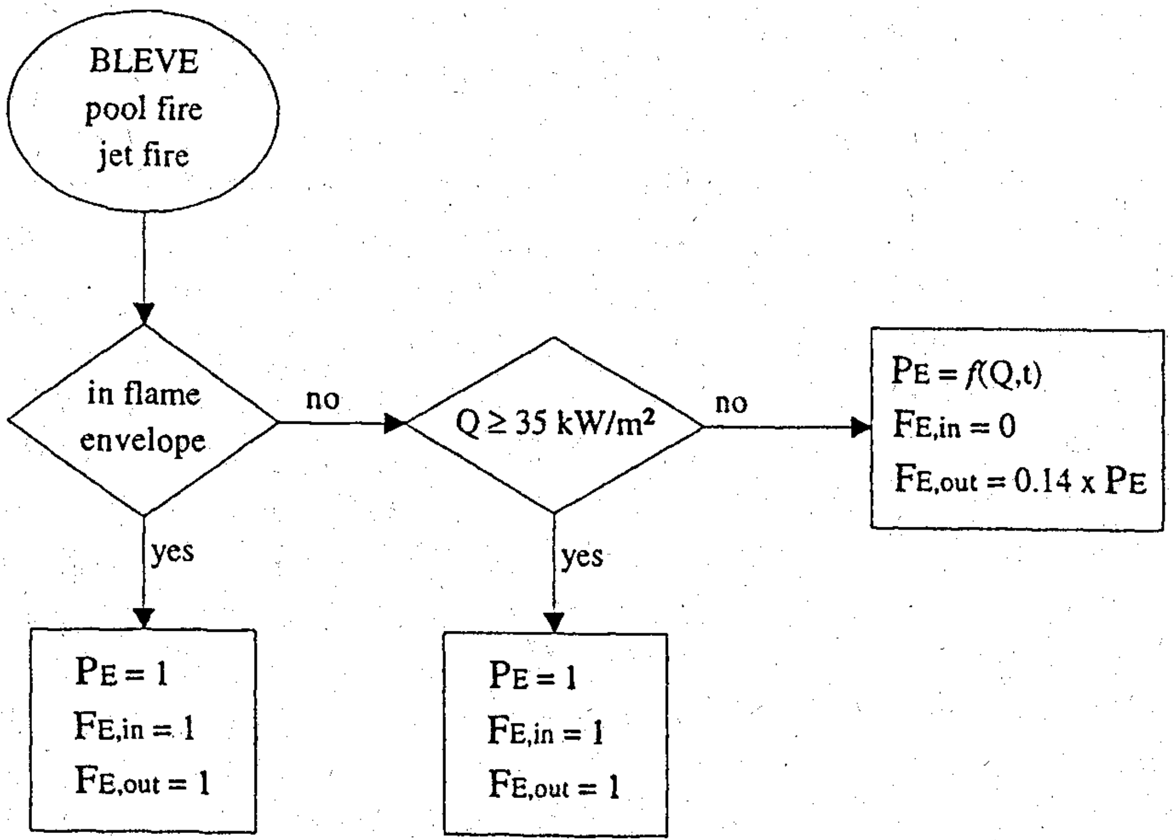
Calculation of the probability of death, P_E, *and the respective fractions of the population dying indoors and outdoors,* $F_{E,in}$ *and* $F_{E,out}$, *due to exposure to a toxic cloud. The function* $f(a,b,n;C,t)$ *is the probit function for exposure to toxic substances (toxics).*

2. Fire

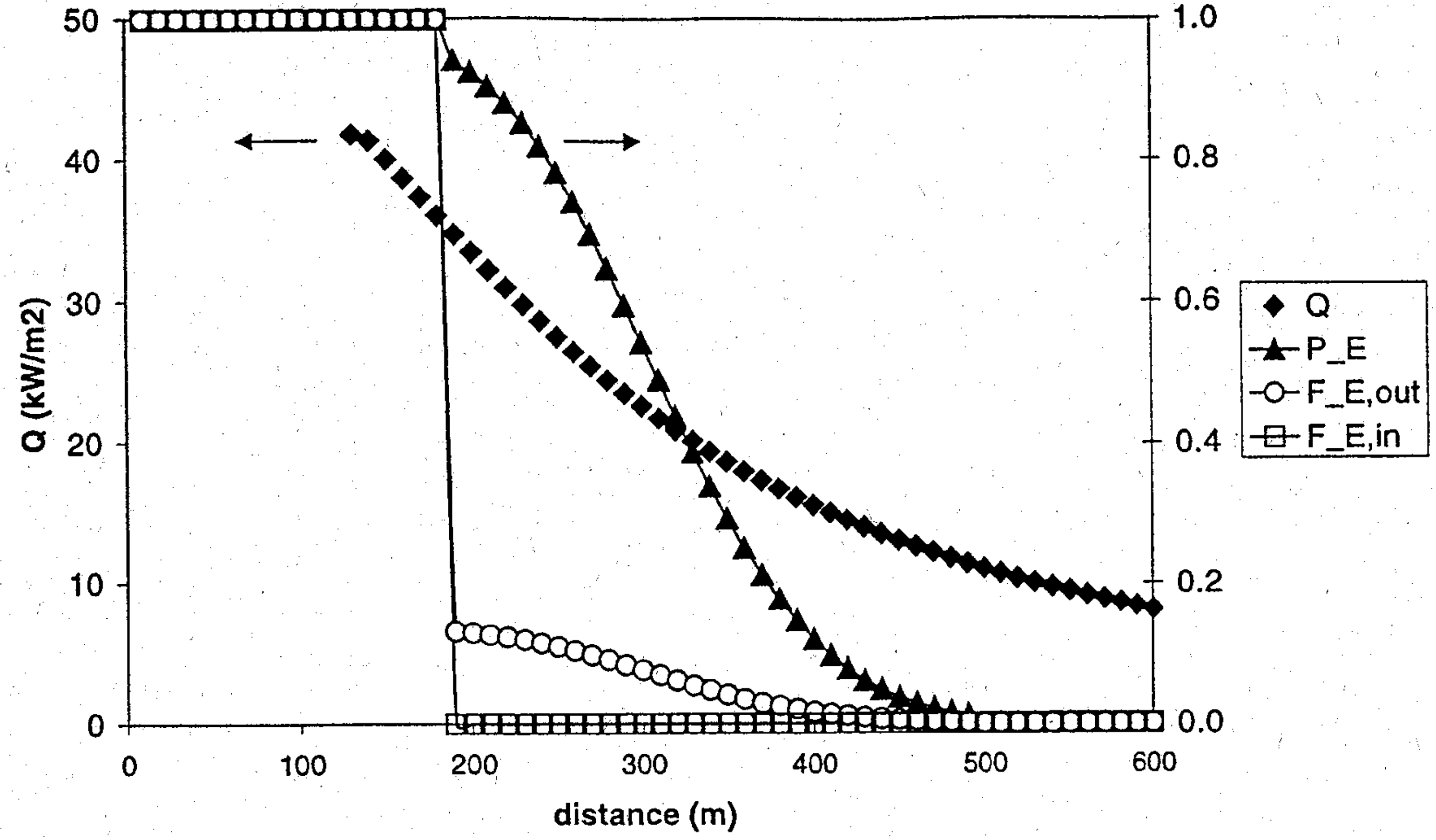


Calculation of the probability of death, P_E*, where the respective fractions of the population dying indoors and outdoors are* $F_{E,in}$ *and* $F_{E,out}$ *on exposure to a flash fire.*

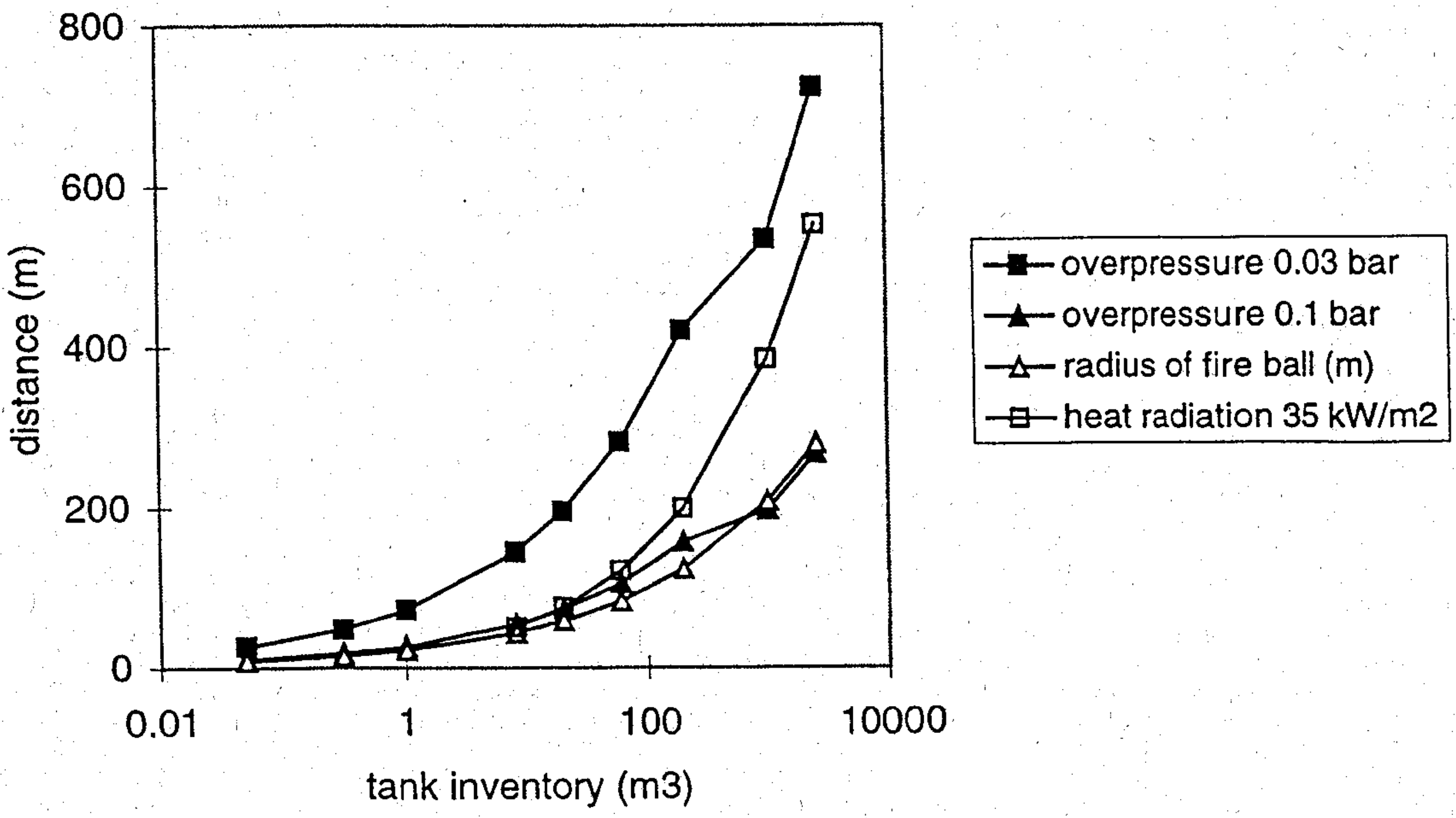
3. BLEVE: Boiling Liquid Expanding Vapour Cloud Explosion



Calculation of the probability of death, P_E, *where the respective fractions of the population dying indoors and outdoors are* $F_{E,in}$ *and* $F_{E,out}$, *for exposure to a BLEVE, pool fire and jet fire. The probit function for heat radiation is* $f(Q,t)$.



Example calculation of a BLEVE of 100 tonne propane (burst pressure 15 bar). The exposure time is set at the maximum value of 20 s. Indicated are heat radiation, Q, probability of death, P_E, fraction of people dying outdoors, $F_{E,out}$, and fraction of people dying indoors, $F_{E,in}$.



Distances to various effect levels of a BLEVE as a function of tank inventory [TNO98d]. Indicated effect levels are the radius of the fireball, heat radiation equal to 35 kW m^{-2} and overpressure levels of 0.1 bar and 0.03 bar.

The probability of death due to the exposure to heat radiation is calculated using a probit function.

Probit function for death due to heat radiation is given by:
$Pr = - 36.38 + 2.56 \ln (Q^{4/3} t)$

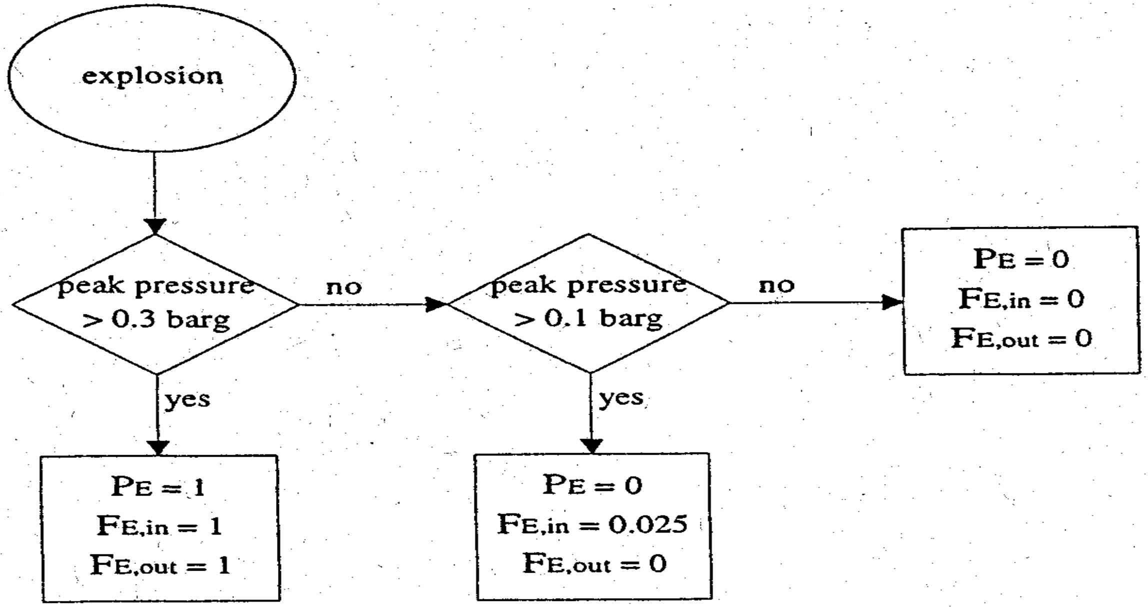
Pr – Probit corresponding to the probability of death
Q – heat radiation (Wm^{-2})
T – exposure time (s)

Exposure time is limited to 20 seconds

The threshold for the ignition of buildings is set at 35 kWm^{-2}
$F_{E,in} = 1$ if $Q > 35\ kWm^{-2}$
$F_{E,in} = 0$ if $Q < 35\ kWm^{-2}$

For societal risk calculation:
$F_{E,out} = 1$ if $Q > 35\ kWm^{-2}$
$F_{E,out} = 0.14\ P_E$ if $Q < 35\ kWm^{-2}$

4. Pressure effects for a vapour cloud explosion



Calculation of the probability of death, P_E, and the respective fractions of the population dying indoors and outdoors, $F_{E,in}$ and $F_{E,out}$ from exposure to a blast/explosion.

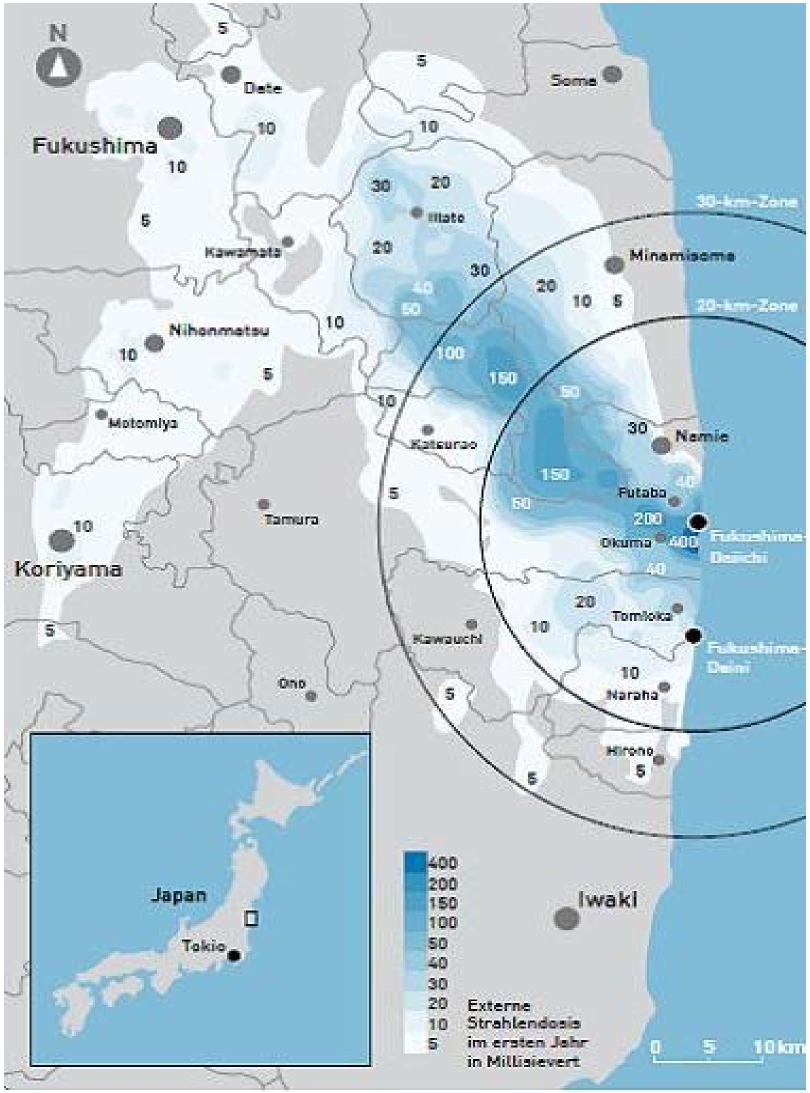
Population

- Presence of population in the environment should be surveyed
- In some cases it is considered that the density is of 2.4 persons per house
- Fractions indoors and outdoors:

	$f_{pop.in}$	$f_{pop.out}$
Daytime	0.93	0.07
Night – time	0.99	0.01

External Radiation Dose (mSv) for Individual for Staying Outside for 1st Year

(for comparison: average annual dose 4.0 – 5.6 mSv; evacuation threshold value 20 mSv)



Exposure to radioactivity

Units

Activity Number of radioactive nuclear transformations per time unit

SI-Unit: 1 Becquerel (Bq) = 1 s^{-1}

Historical: Curie (Ci) 1 Ci = 3.7×10^{10} Bq

Absorbed dose absorbed radiation per mass unit

SI-Unit: 1 Gray (Gy) = 1 J kg^{-1} = 100 rad

Historical: rad = radiation dose

1 rad = 100 erg g^{-1}

1 erg = 1 g × 1 $cm^2 s^{-2}$ = 10^{-7} J

Equivalence dose The biological effects of an absorbed dose depends on the type of radiation. The equivalence dose is represented with a factor (relative biological effectiveness, RBE) which represents the weighted dose.

Radiation	**RBE**
Termionic-, gamma-, x-rays	1
Alpha particle	20
Neutrons <10 keV 10-100 keV 100-2000 keV	5 10 20

SI-Unit: 1 Sievert (Sv) = 1 Gy × RBE

Historical: rem = radiation equivalent man

1 rem = 1 rad × RBE = 0.01 Sv

Types of damage

Deterministic radiation damages (Frühschäden)

The cardiotoxic dose is the threshold dose of the cell killing rate and the body's cell building rate. The degree of damage of a dose depends on whether a part or the whole body is radiated.

Typical non stochastic radiation damages are burnt skin and radiation illness.

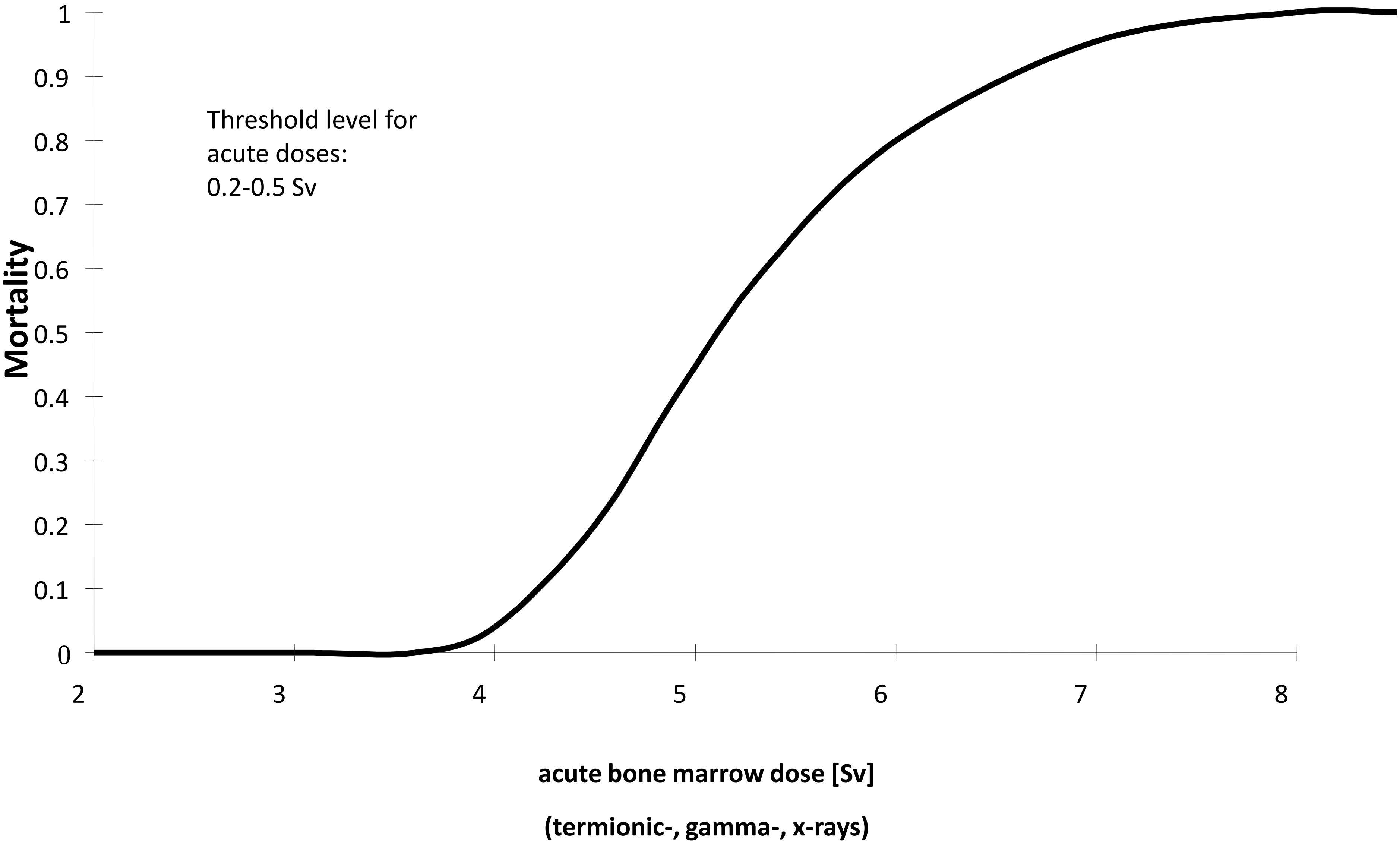
The **LD_{50}** lays around **4 to 5 Sv** (400-500 rem).

The threshold level lies between **0.2 and 0.5 Sv** (20-50 rem)

Stochastic radiation damage (Spätschäden):

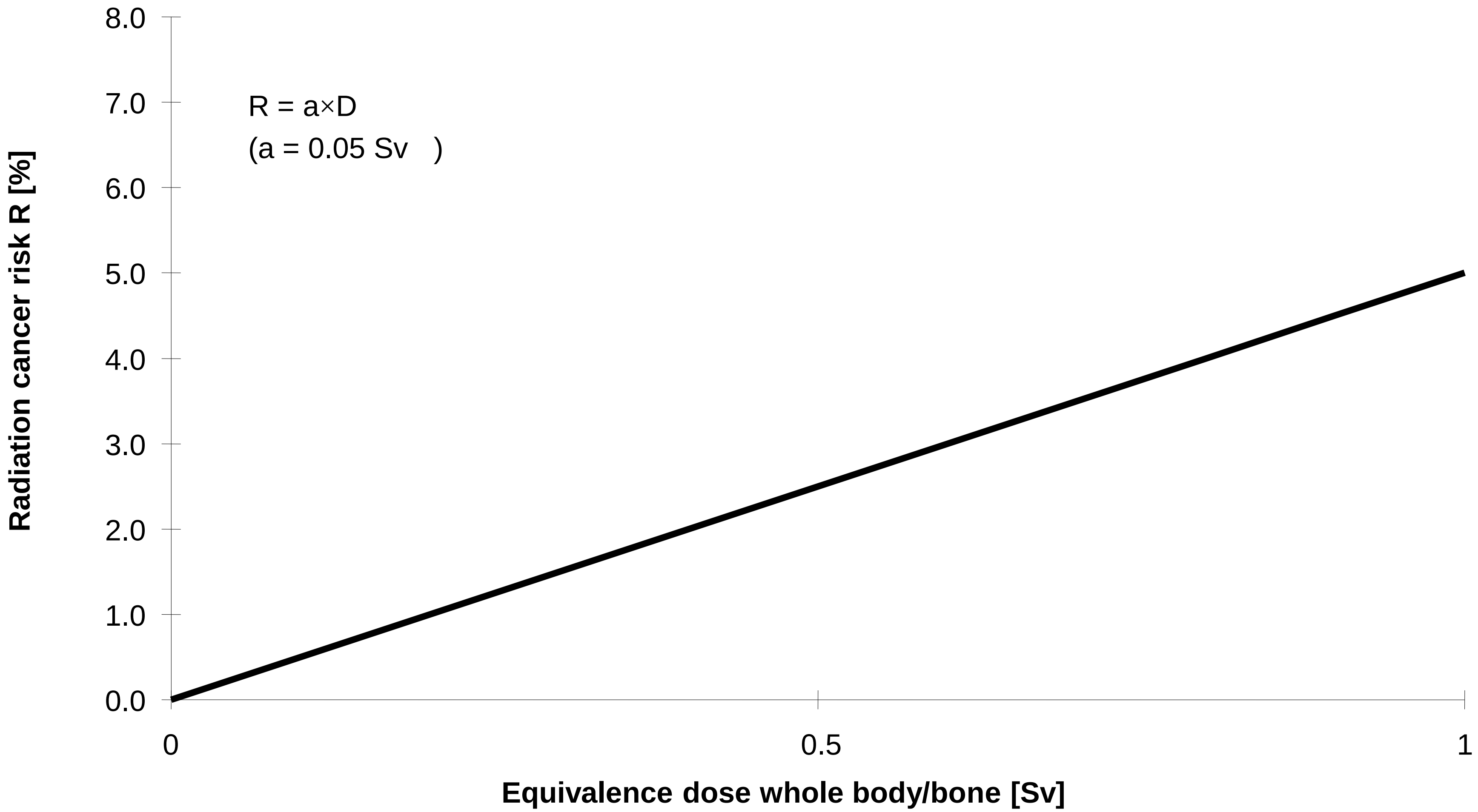
Typical stochastic radiation damages are latent diseases like leukaemia, tumours and damaged genes. Radiation cancer can't be distinguished from normal cancer.

Lethality of acute dose of radiation



Threshold level for
acute doses:
0.2-0.5 Sv

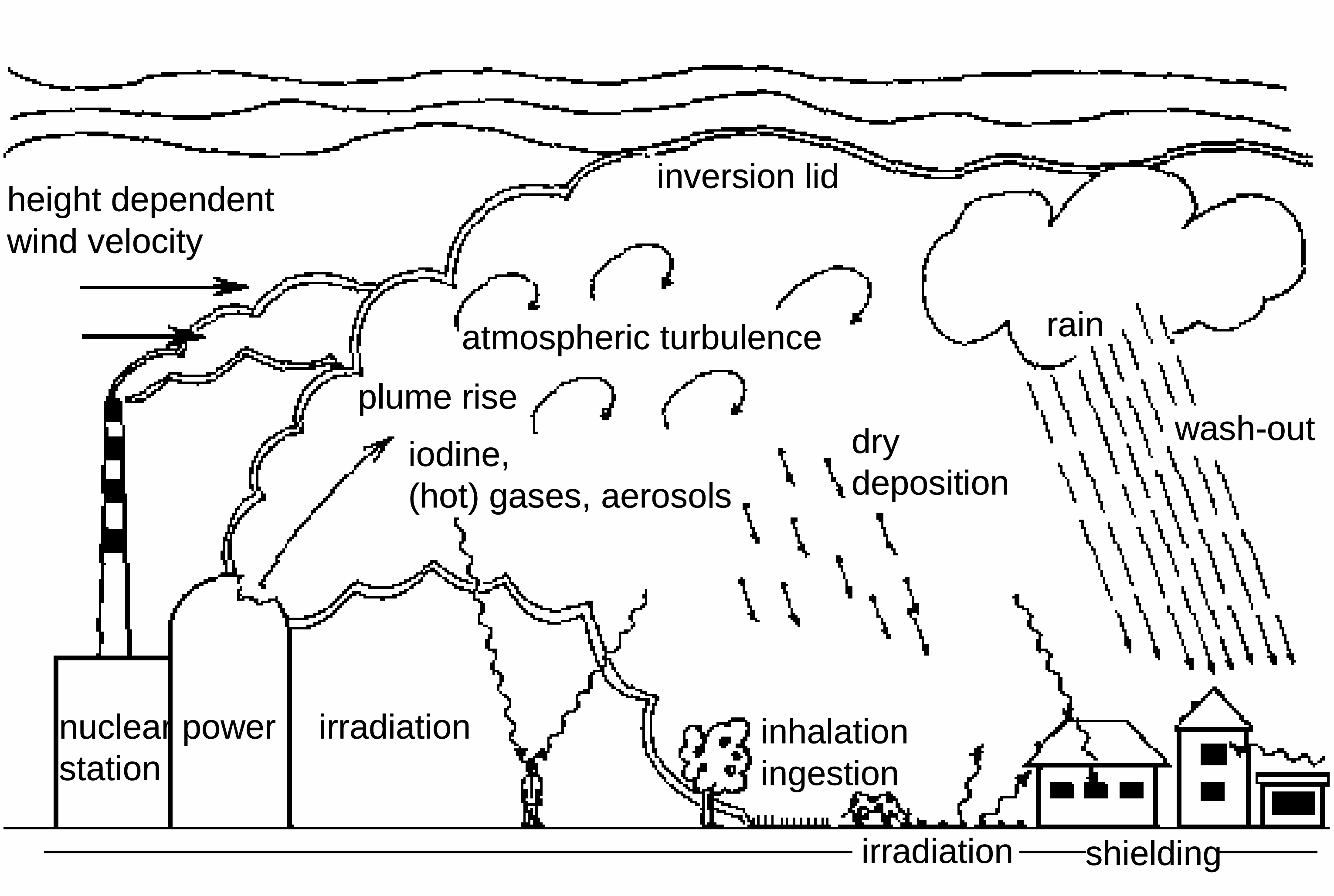
Longterm effects of dose of radiation



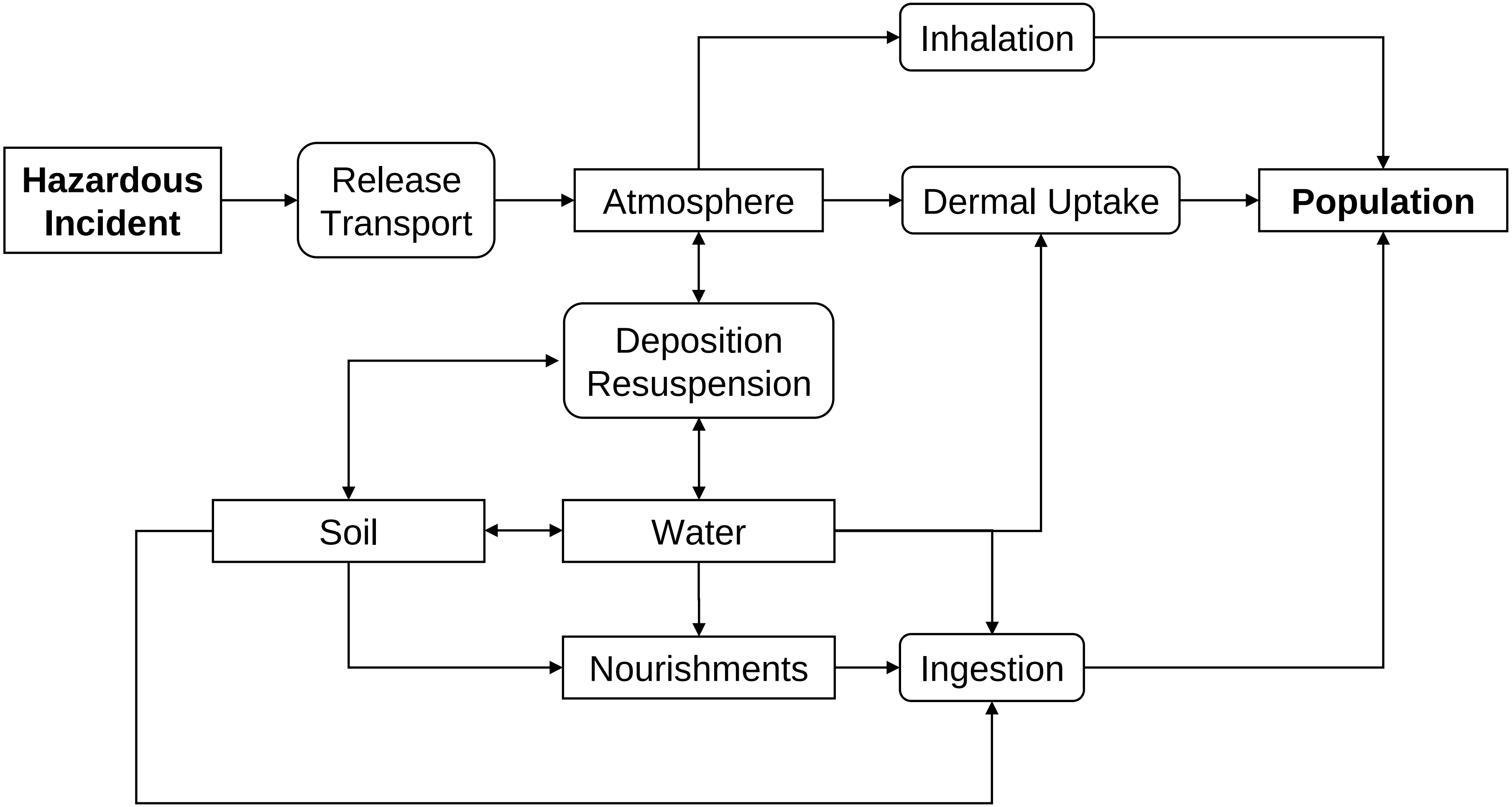
R = a×D

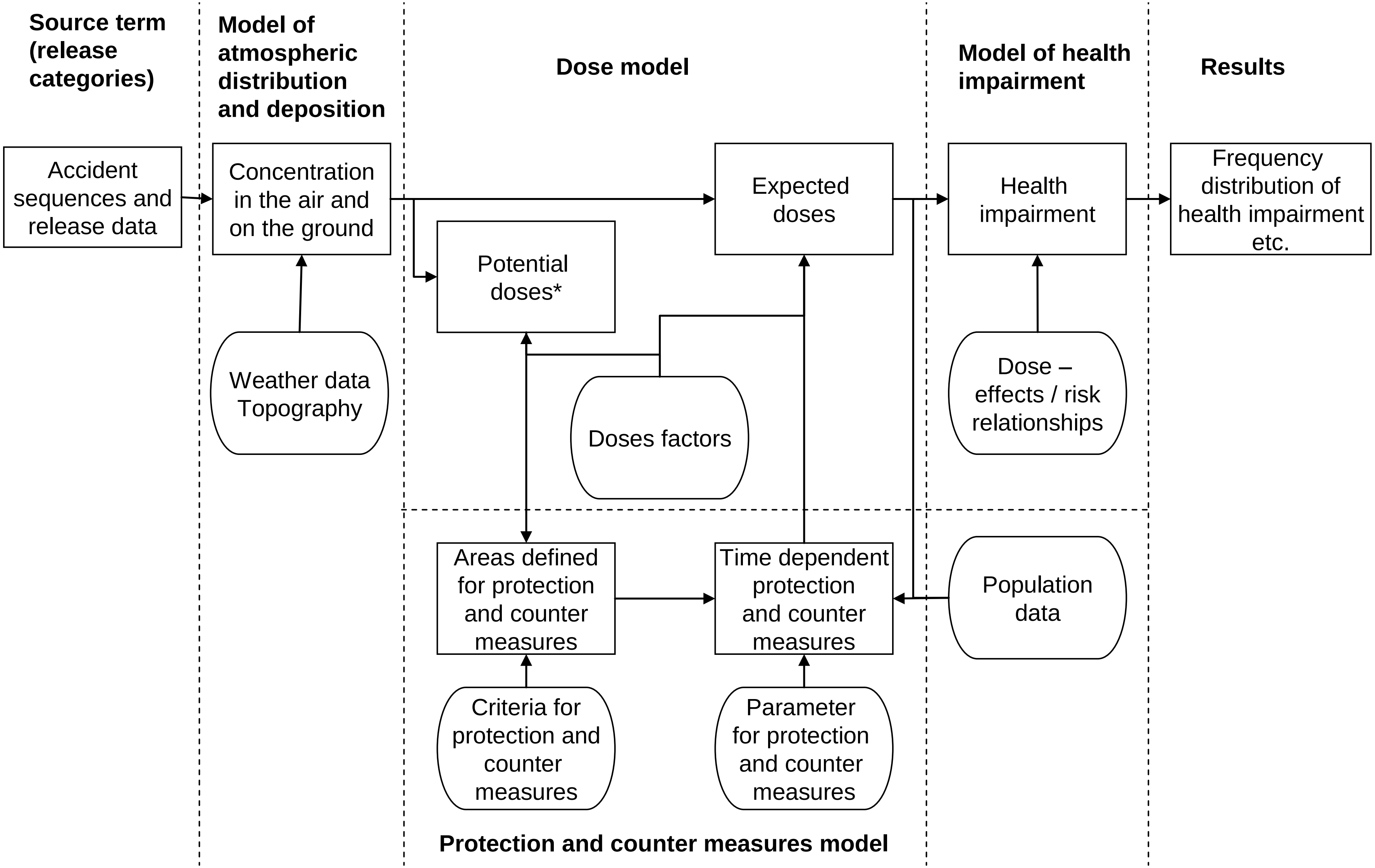
(a = 0.05 Sv   )

Dispersion and exposure paths of an accidental release



Exposure paths from the source to the population after an atmospheric releaseof radiotoxic substances





Source term (release categories)

Model of atmospheric distribution and deposition

Dose model

Model of health impairment

Results

Accident sequences and release data

Concentration in the air and on the ground

Weather data Topography

Potential doses*

Doses factors

Expected doses

Health impairment

Dose – effects / risk relationships

Frequency distribution of health impairment etc.

Areas defined for protection and counter measures

Time dependent protection and counter measures

Population data

Criteria for protection and counter measures

Parameter for protection and counter measures

Protection and counter measures model

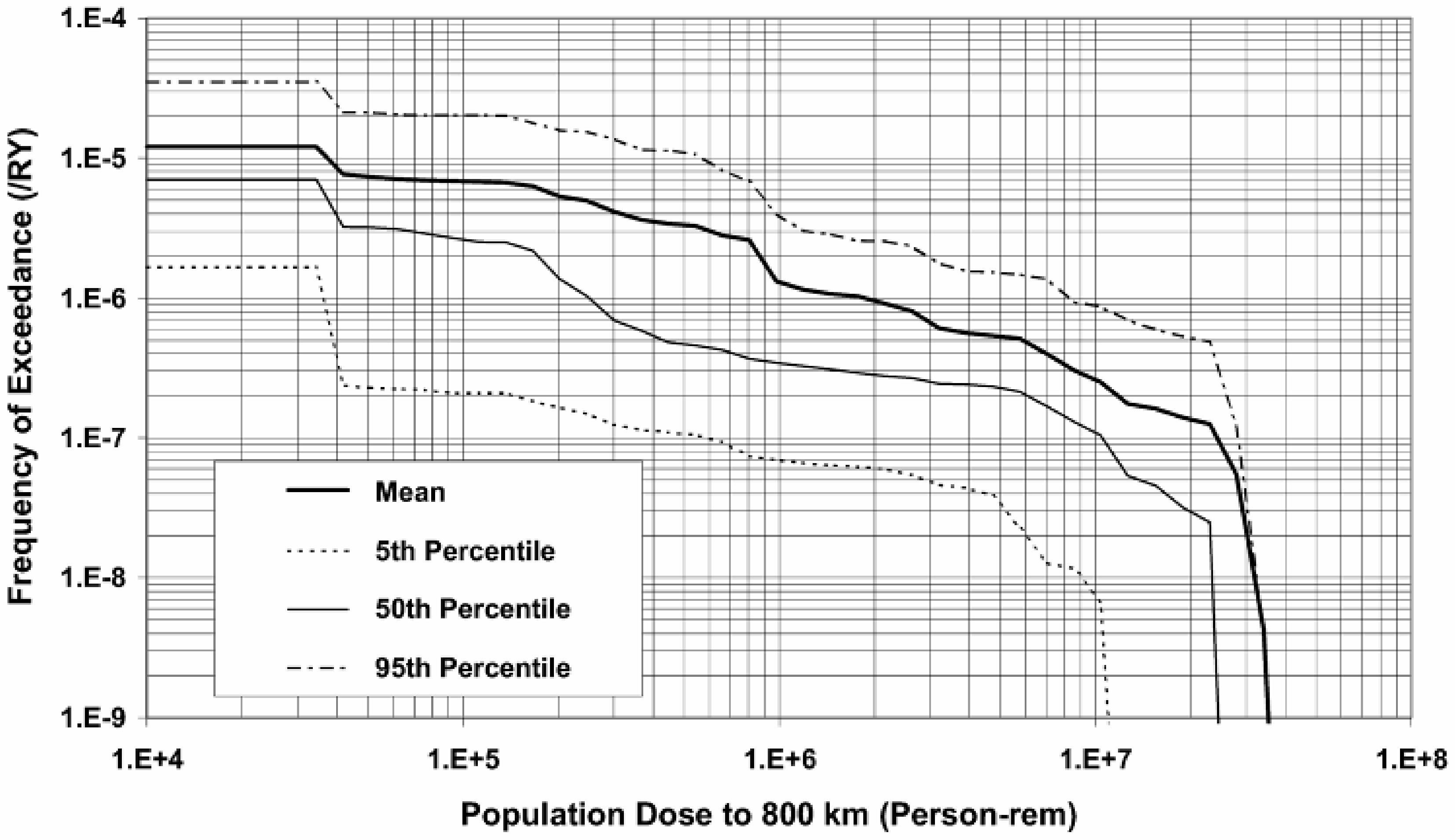
* Permanent stay (exposure) in the open assumed

Representing results of a risk analysis

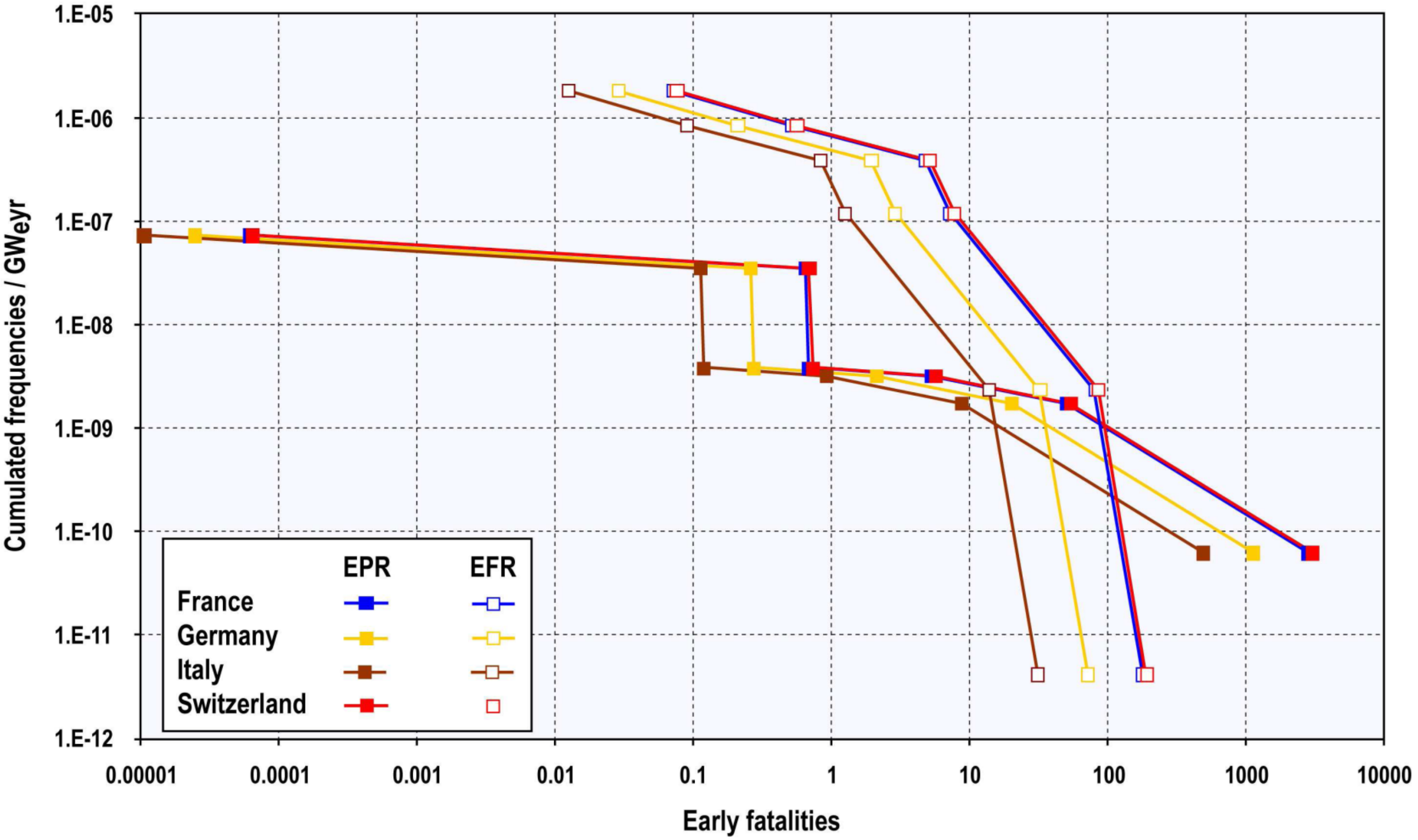
- **Risk** is represented by the parameters **frequency** and **consequence** of an undesired event and related **scenarios**
  - The **frequency** of an event is estimated by the direct use of accident statistics, assessments and models (FMEA, Event/Fault Trees) with statistical data at components' level
  - The **consequences** for the public and the environment are estimated by use of dispersion/transport models and dose-effect relationships.
- The **results** of the risk analysis are often represented in frequency-consequence diagrams with cumulative frequency and consequences plotted against each other. For a given extent of an event the frequency and associated uncertainties can be read out of the diagram.

Examples of estimating consequences:

A complementary cumulative yearly frequency of a calculated social dose

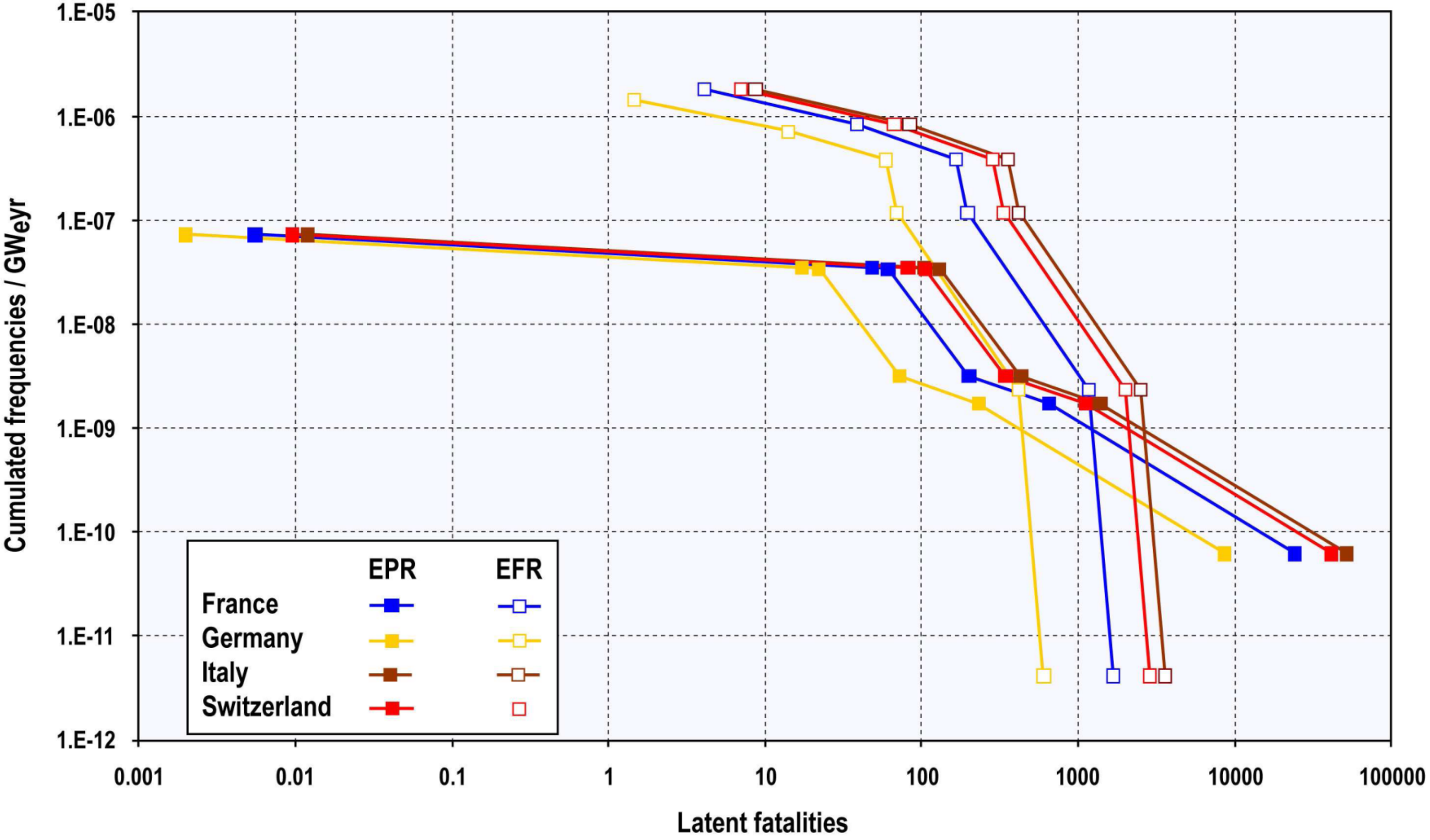


Frequency-consequence curve for early fatalities



EPR and EFR technologies in four countries as defined in the NEEDS technology set; generic source term and 6 release categories; dose-acute effect- relationship with 0.2 – 0.5 threshold value

Frequency-consequence curve for latent fatalities



EPR and EFR technologies in four countries as defined in the NEEDS technology set; generic source term and 6 release categories; linear dose-stochastic risk- relationship

References

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