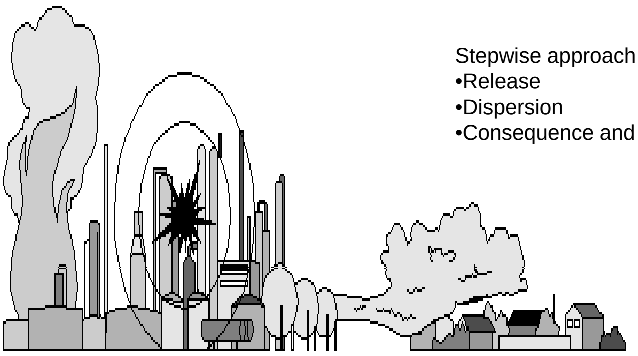
Risk Analysis of Highly-integrated Systems

RA VI: Scenario Development, Accidental Releases
Characterization of Accidents caused by Releases
Dispersion Consequence Modeling
Representation of Results
Characterization of Service Interruptions

Accidental release scenarios of hazardous substances

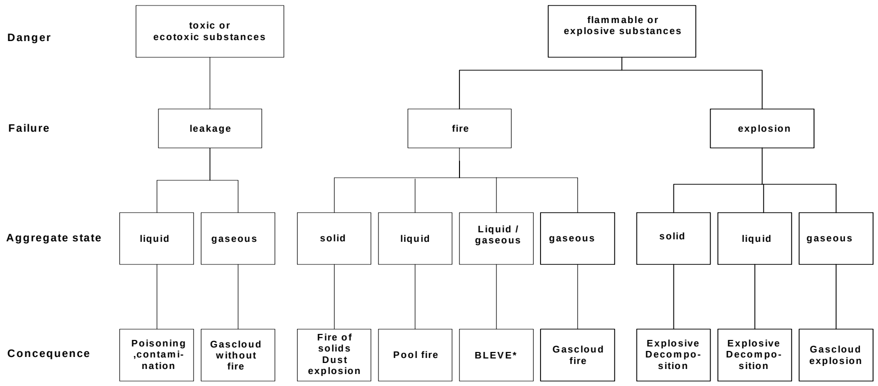


Stepwise approach by modelling of:
•Release
•Dispersion
•Consequence and Exposure

Release Dispersion Consequence and Exposure

A scenario is a brief description of an event or a series of events

Matrix for selecting accidental release scenarios



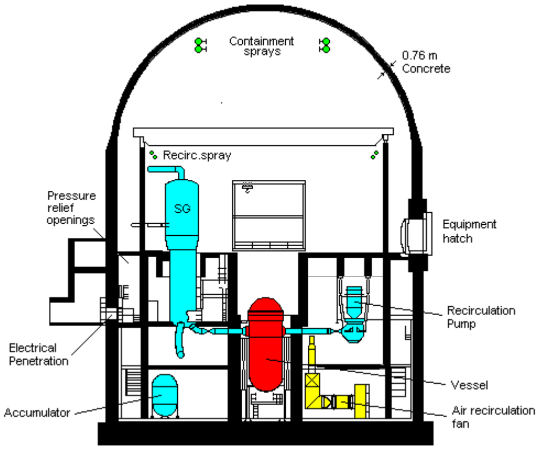
*BLEVE: Boiling Liquid Expanding Vapour Cloud Explosion

Elements for the description of accidental release scenarios of hazardous substances

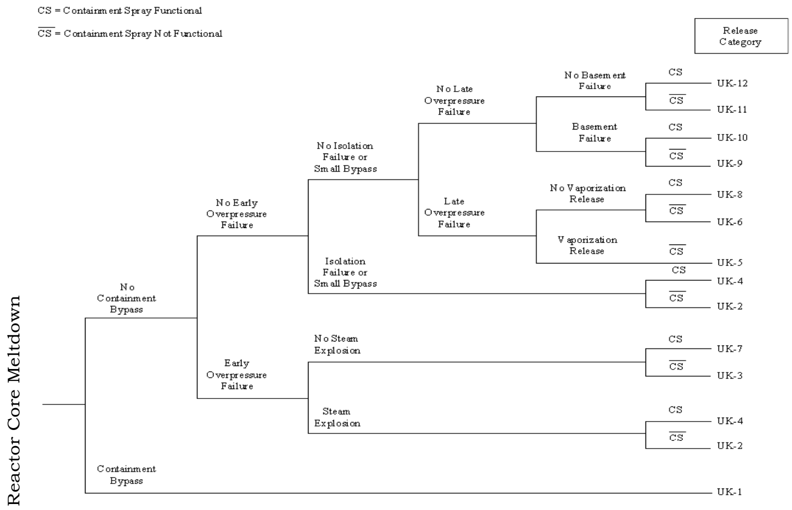
	Specification factors	Influencing parameters
Release	Begin and duration Type and size of leakage Number of leakes, rate, location of the leakage Pool size Evaporation rate	Cause of the leakage Aggregate state of the released substance - gaseous, liquid, in two-phase Total release minus spontaneous evaporating and aerosol forming quantity Evaporation mechanism (additional heat)
Dispersion	Concentration of the released substance at place X	Release type / source - spontaneous, continuous Density of the gas cloud > air (dense cloud) = air (neutral cloud) < air (buoyant cloud) Ground conditions Wind characteristics Atmospheric conditions
Conse-quence	Consequence at place X	Acute toxicity Fire / radiated heat Explosion / pressure wave
Expo-sure	Exposure	Population density Time of exposure Degree of protection (sheltering / staying outdoors)

Developing of release scenarios

E.g. containment of a nuclear power plant



... By using Event Trees



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

Dispersion

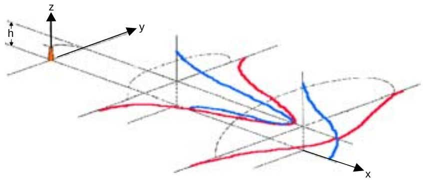
	Dispersion		Measures
Air	Fast, depending on • Wind speed / direction • Atmospheric conditions • Topography	Mean wind speeds in Zürich SMA: 2.35m/s Jungfrau Joch: 8.34m/s	Staying indoors Keeping windows and doors shut Nourishment control
Flowing water	Moderate, depending on • Flow speed • River bed profile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

Air Dispersion

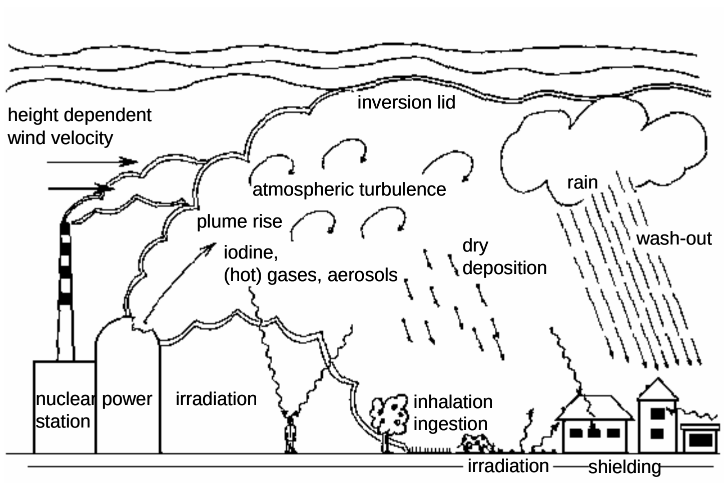
$$C(x,y,z) = \frac{Q'}{2\pi\sigma_y\sigma_z u} \cdot \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \cdot \left(\exp\left(-\frac{(z-h)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+h)^2}{2\sigma_z^2}\right)\right)$$

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 correspond to the wind direction

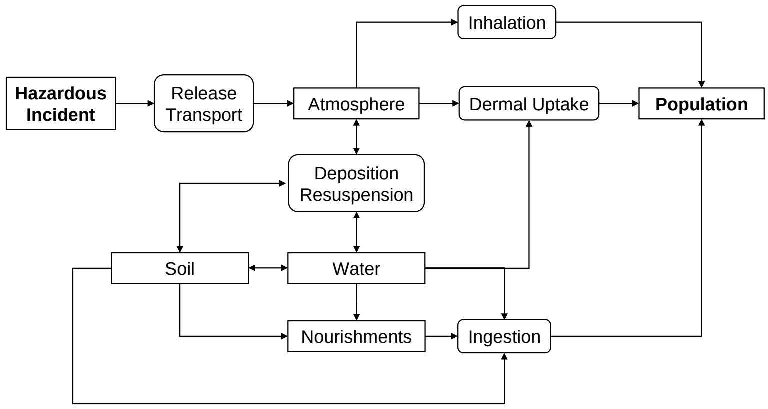
σ_y, σ_z = Parameter of dispersion for the distribution of concentration in *y*- / *z*-direction
σ_y, σ_z are functions of *x*



Dispersion and exposure paths of an accidental release of radioactive substances



Exposure paths from the source to the population after an atmospheric release



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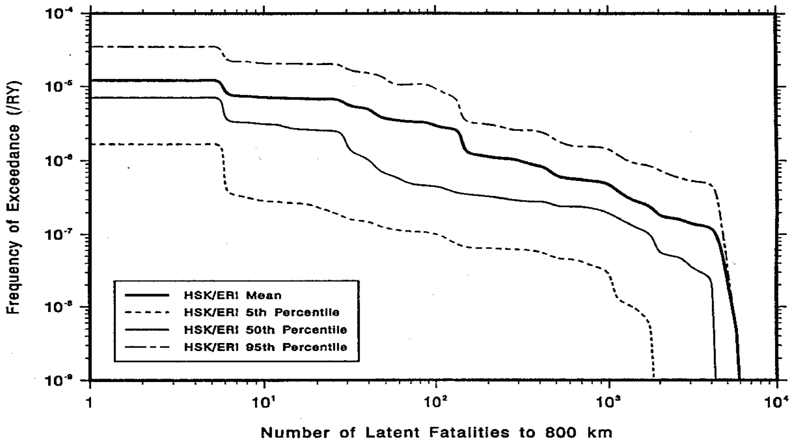
Representing results of a risk analysis

- Risk is represented by the parameters frequency and consequence of an undesired event
  - The frequency of an event is estimated by the use of accident statistics, assessments and models (FMEA, Event- / Fault Trees)
  - The consequences for the public are estimated by the use of dispersion and dose-effect models.
- The results of the risk analysis are often represented in frequency-consequence diagrams. The cumulative frequency and the frequency are plotted against each other. For a given extent of an event the frequency can be read out of the diagram.

Cumulative frequencies of carcinogenic death of long term damage

(study of nuclear power plant Mühleberg)



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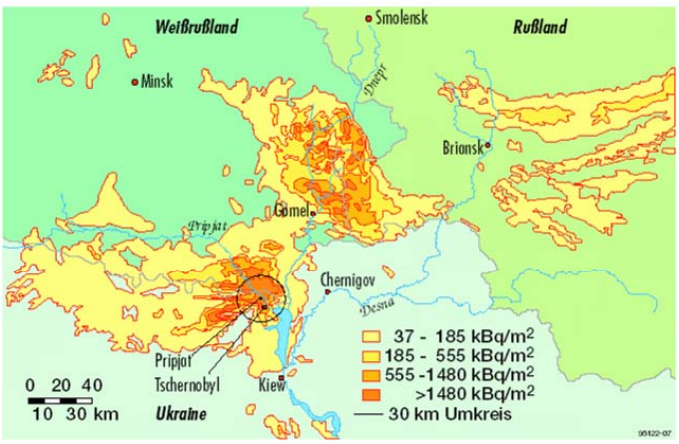
Cs-137 contamination in the Ukraine, Belarus and Russia

(during the first months after the Chernobyl release)



Modelling consequences and damage of chemical substances

The Probit-Approach

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

Parameters used to express the lethal effects are:

- The probability of death, P_E – of an individual dying from exposure used for Individual Risk contour.
- The fraction of the population dying, F_E – 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 Societal Risk.

The following approach is based on TNO methodology.

Evaluation of toxic effects of a release

Known approaches for quantification apply threshold values:

- If the MAK (maximum workplace concentration value) is not exceeded, then 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 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 odor.
  - 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-threatenting health effects.

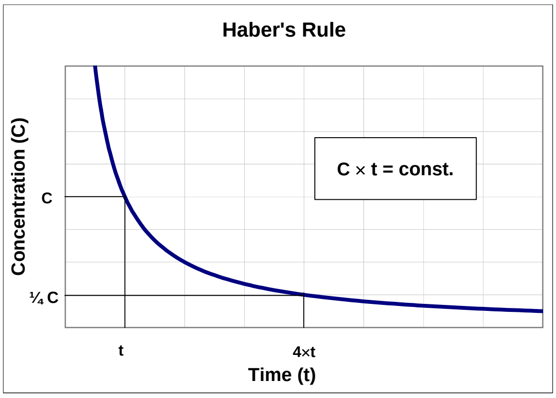
It is important to know, if a released substance has mutagenic, carcinogenic or teratogenic characteristics.

Dose calculation

Principles of Toxicology

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

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



Dose and Probit-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 by discrete numerical computation, but it is difficult to interpret the dose.

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.

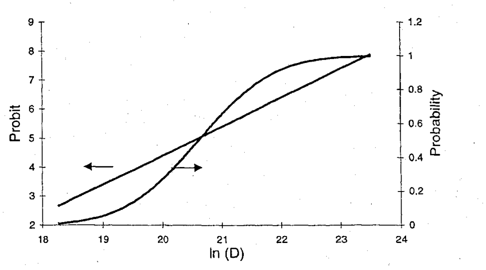
$$P_E = 0.5\left[1 + erf\left(\frac{\Pr - 5}{\sqrt{2}}\right)\right]$$

where

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

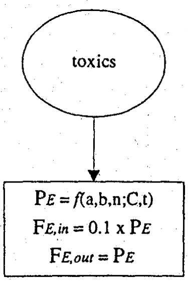
P_E is the probability of an effect (death)

Pr is probit value



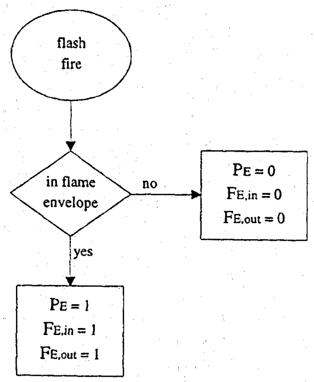
The probability, P, and the probit, Pr, as a function of exposure to ammonia. The exposure is represented by ln (D), with D the toxic dose. The figure shows how the sigmoid curve is replaced with a straight line if the probit is used.

1. Toxic exposure



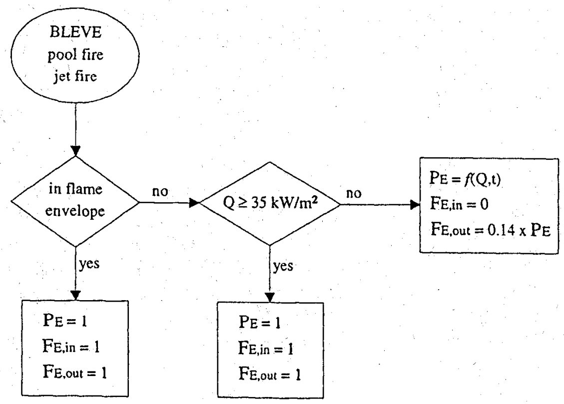
Calculation of the probability of death, P_E, and the respective fractions of the population dying indoors and outdoors, $F_{E,in}$ and $F_{E,out}$, due to exposure to a toxic cloud. The function f(a,b,n;C,t) is the probit function for exposure to toxic substances (toxics).

2. Fire

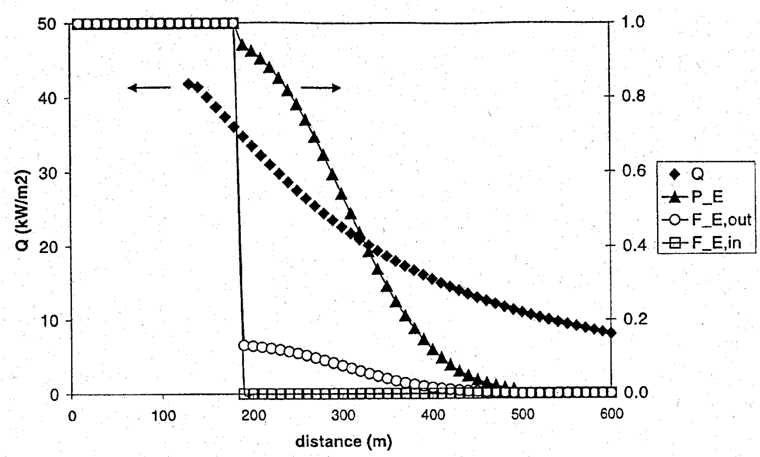


Calculation of the probability of death, P_E, where the respective fractions of the population dying indoors and outdoors are $F_{E,in}$ and $F_{E,out}$ on exposure to a flash fire.

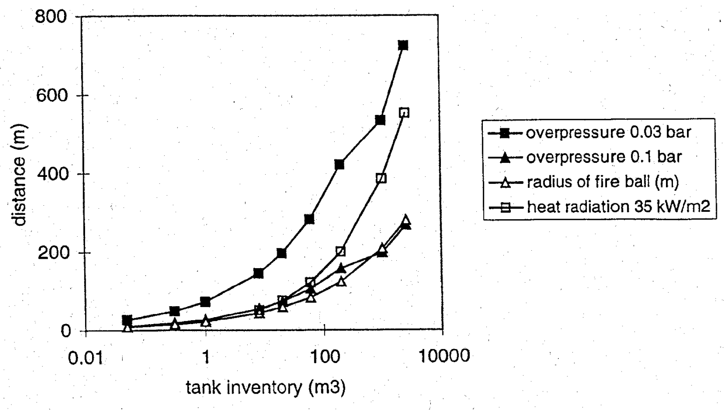
3. BLEVE: Boiling Liquid Expanding Vapour Cloud Explosion



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, $F_{E,in}$.

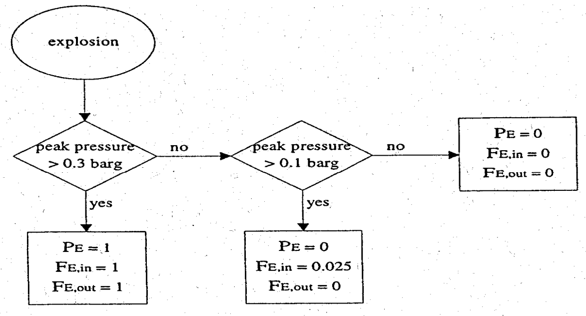


Distances to various effect levels of a BLEVE as a function of tank inventory [TNO98d]. Indicated effect levels are the radius of the fireball, heat radiation equal to 35 kW m^{-2} and overpressure levels of 0.1 bar and 0.03 bar.

The probability of death due to the exposure to heat readiation 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 coresponding 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.

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Population

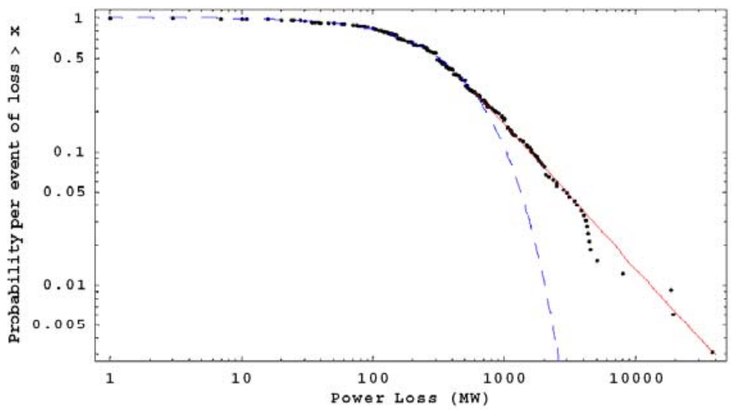
- Presence of population in the environment should be surveyed
- In some cases it is considered that the density is of 2.4 persons per house
- Fractions indoors and outdoors:

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

Service interruption in large area networks: electricity blackouts

Blackout		Loss of load [GW]	Duration [h]	People affected	Main causes
Aug. 14, 2003	Great Lakes, NYC	~ 60	~ 16	50 mio	Inadequate right-of-way maintenance, EMS failure, poor coordination among neighboring TSOs
Aug. 28, 2003	London	0,72	1	500´000	Incorrect line protection device setting
Sept. 23, 2003	Denmark / Sweden	6,4	~ 7	4,2 mio.	Two independent component failures (not covered by N-1 rule)
Sept. 28, 2003	Italy	~ 30	up to 18	56 mio.	High load flow CH-I, line flashovers, poor coordination among neighboring TSOs
July 12, 2004	Athens	~ 9	~ 3	5 mio.	Voltage collapse
May 25, 2005	Moscow	2,5	~ 4	4 mio.	Transformer fire, high demand leading to overload conditions
June 22, 2005	Switzerland (railway supply)	0.2	~ 3	200´000 passengers	Non-fulfillment of N-1 rule, false documentation of line protection settings, inadequate alarm processing
Aug. 14, 2006	Tokyo	?	~ 5	0.8 Mio households	Damage of a main line due to construction work
Nov. 4, 2006	Western Europe	~ 14	~ 2	15 Mio. households	High load flow D-NL, violation of the N-1 rule, poor inter TSO- coordination, but controlled load shedding

North American blackouts



Cumulative probability of North American blackouts as a function of power loss. The exponential distribution (dashed line) fitted for small events significantly underestimates the probability of large events which rather follows a power law (solid line) [Talukdar 2003]