WP 2: Source terms and release frequencies

flexRISK final event

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26 June 2012

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Part 1:
Nuclear Landscape in Europe

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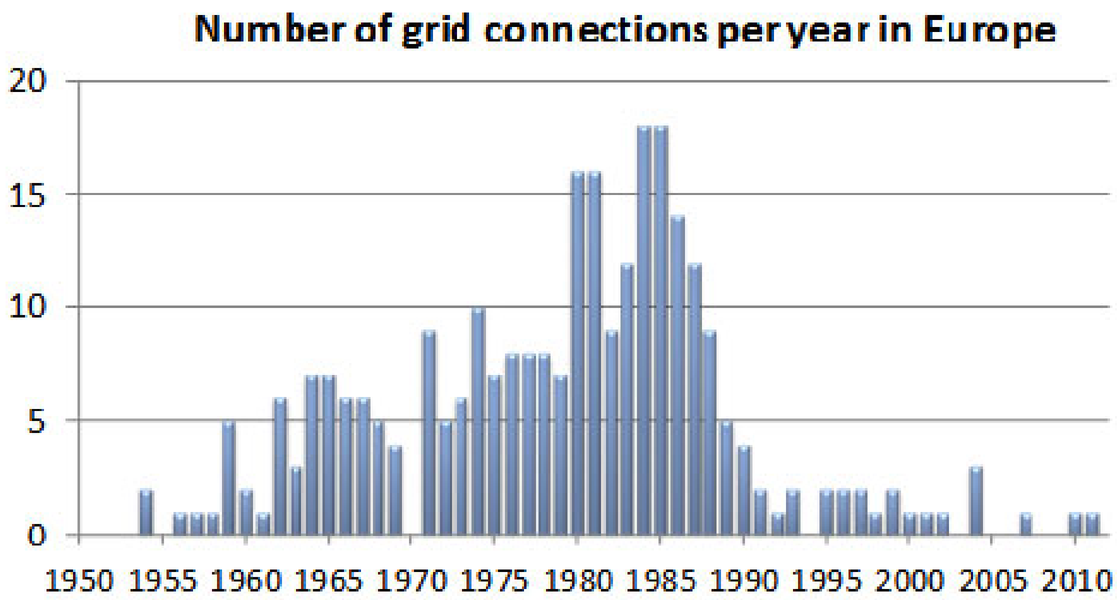
flexRISK

Brief history of nuclear energy in Europe

- 1954 – First commercial NPP connected to the grid (Obninsk, Soviet Union)
- 60´s – Many countries in Europe start a civil nuclear program



- 70´s and 80´s – The boom years
- 1986 – Chernobyl and its impact
- 2000 – Discussion on a nuclear renaissance
- 2011 – Fukushima and its impact

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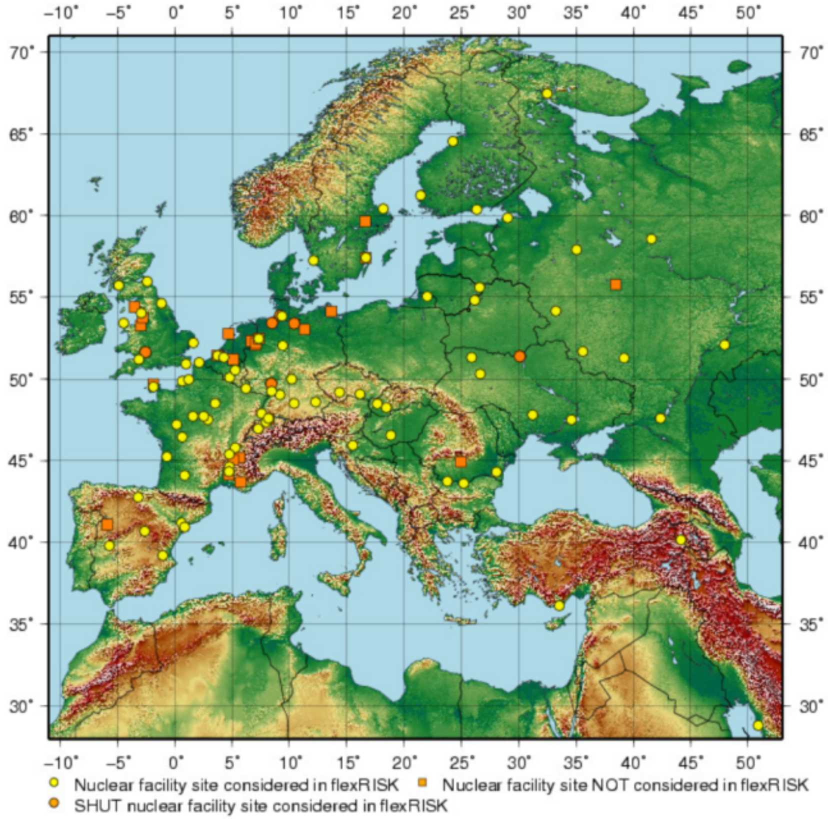
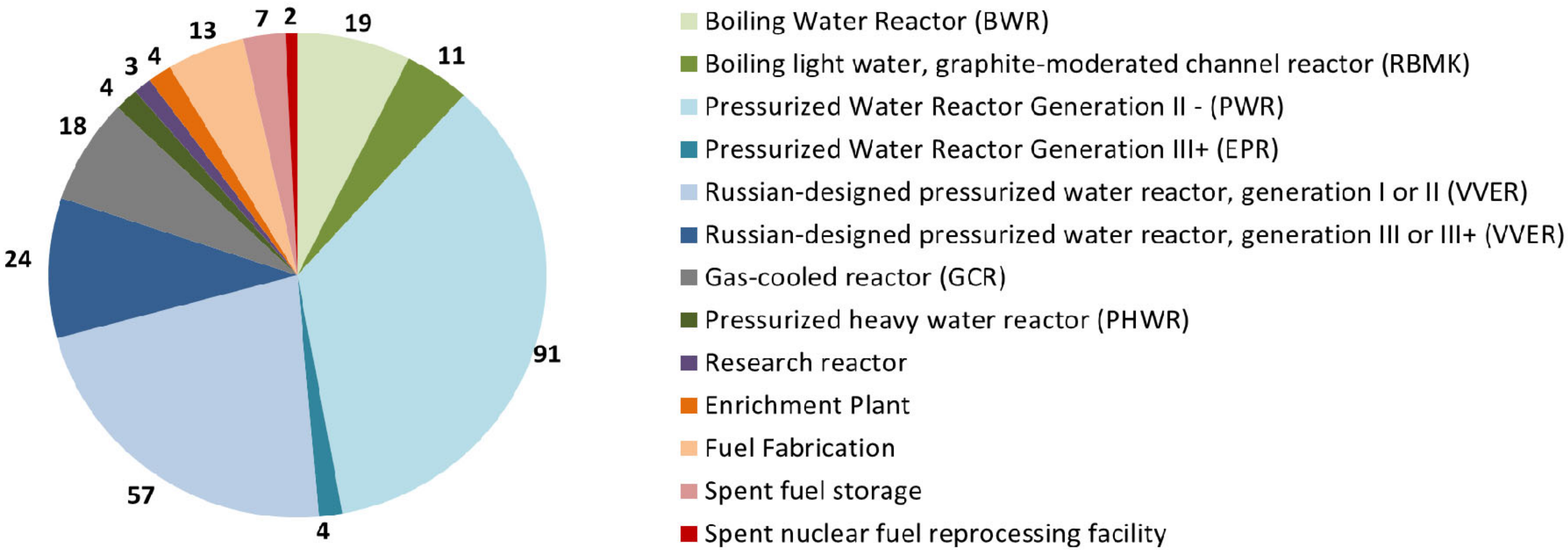
flexRISK Nuclear Facilities in the flexRISK domain

257 Nuclear Facilities

- 228 Nuclear Power Plants
- 26 Nuclear Fuel Cycle Facilities
- 3 Large Research Reactors





Example: Local Maps - Link via Website

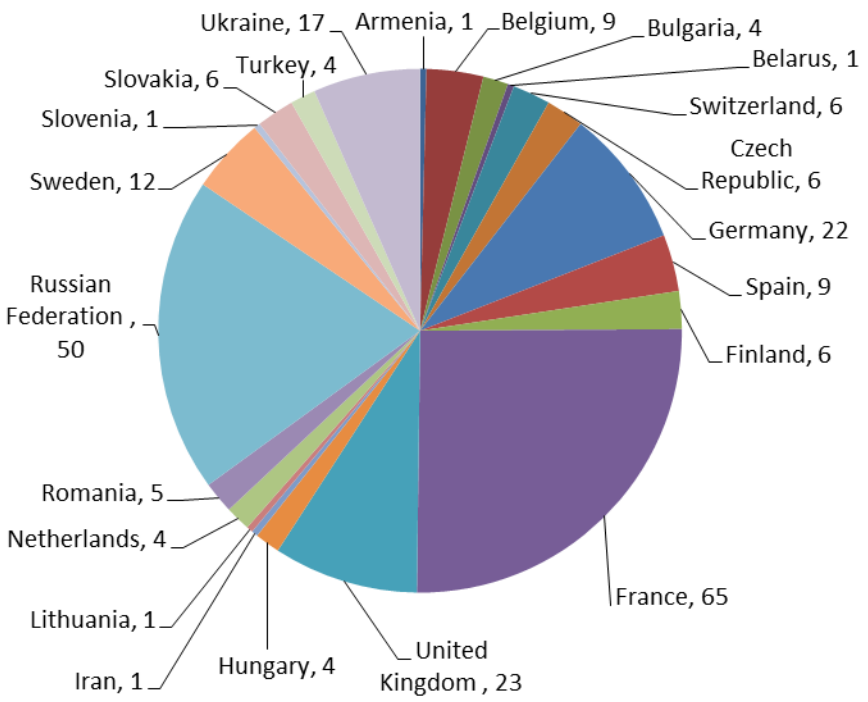
Mochovce NPP

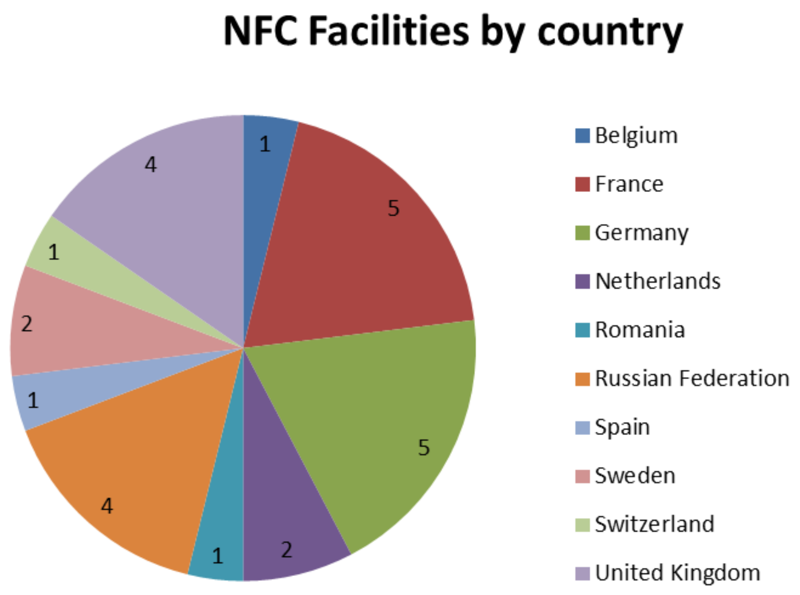
Gravelines NPP

Nuclear facilities by country

Nuclear facilities per country

(operating and planned, as evaluated until 12/2010)





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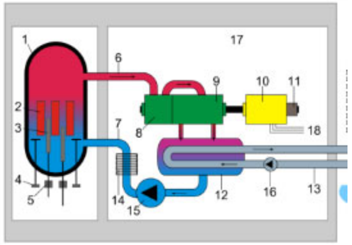
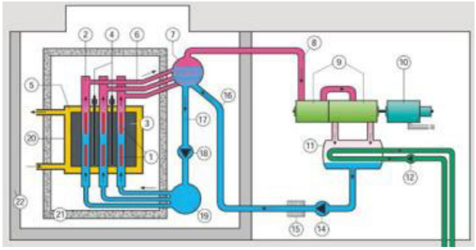
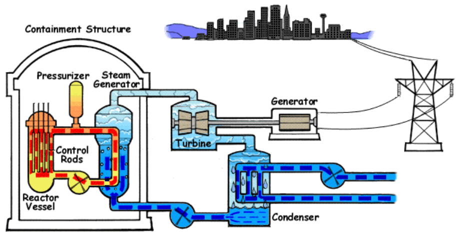
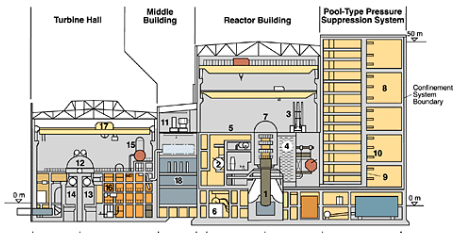
Reactor Types (General)

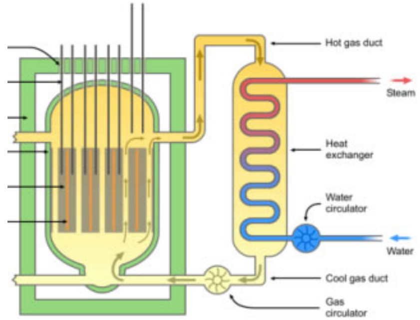


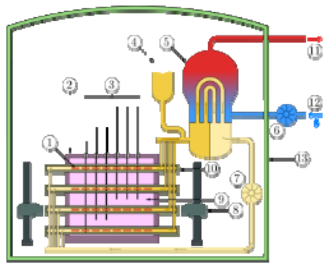




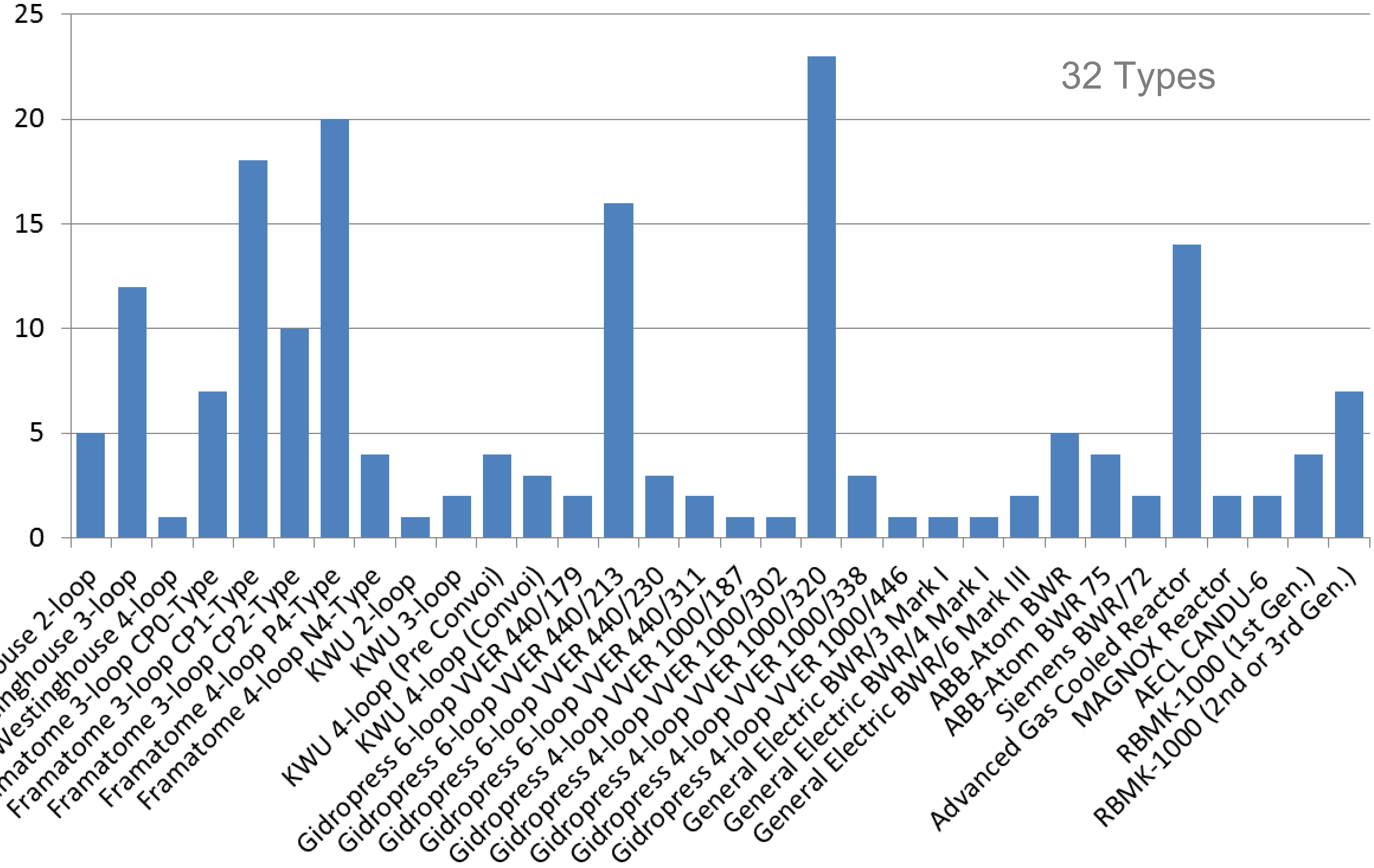


	Total	Operating	Construction or planned	Shutdown
Boiling Water Reactor (BWR)	19	15	0	4
Boiling light water, graphite-moderated channel reactor (RBMK)	11	11	0	0
Pressurized Water Reactor Generation II (PWR)	91	87	0	4
Pressurized Water Reactor Generation III+ (EPR)	4	0	4	0
Russian-designed pressurized water reactor, generation I or II (VVER)	57	51	6	0
Russian-designed pressurized water reactor, generation III or III+ (VVER)	24	1	23	0
Gas-cooled reactor (GCR)	18	16	0	2
Pressurized heavy water reactor (PHWR)	4	2	2	0
Total	228	183	35	10





flexRISK Operating Reactor Types (Detail)



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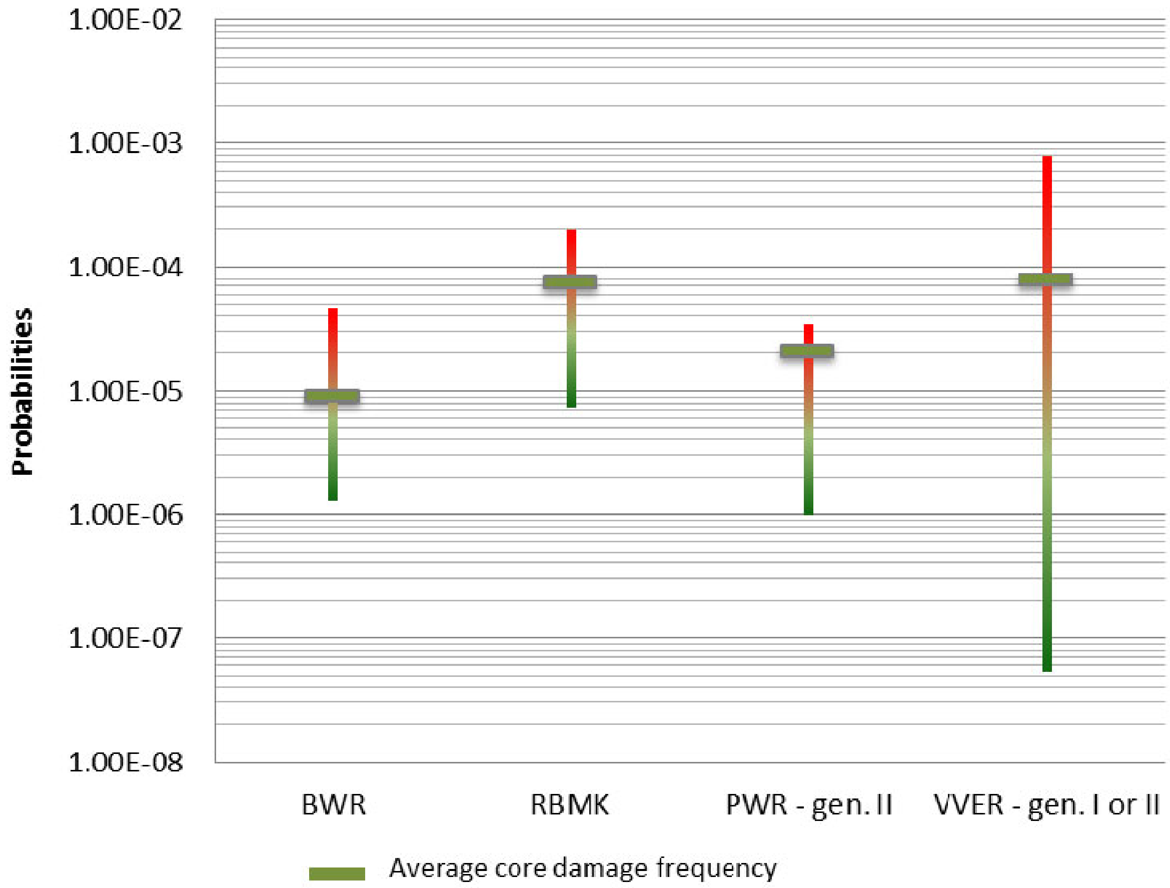
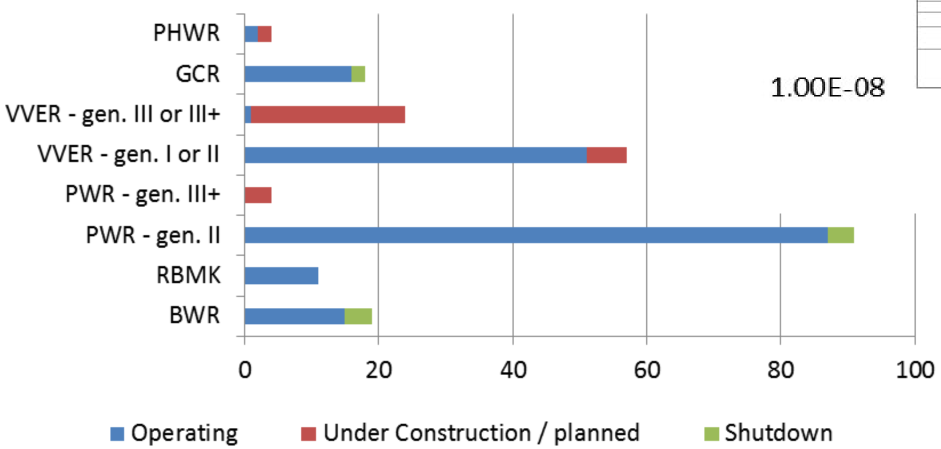
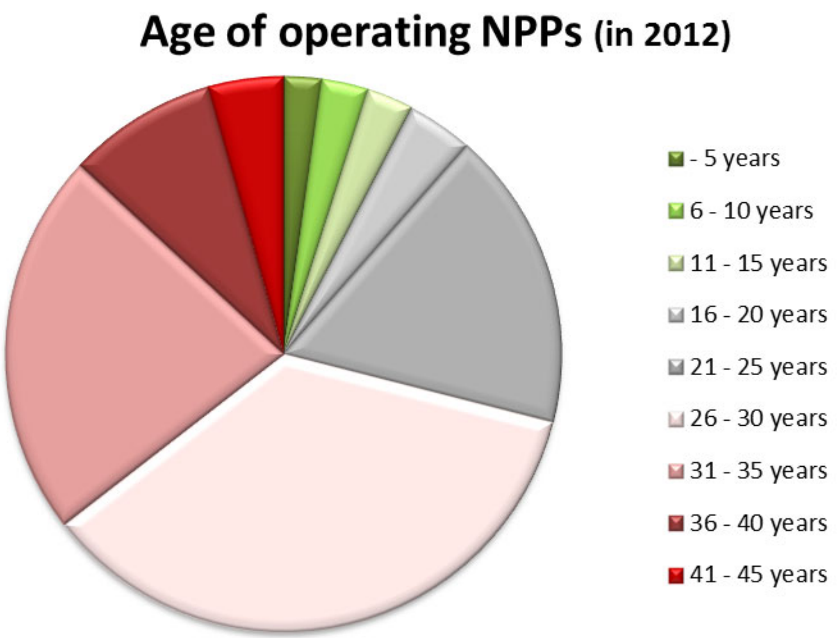
CDFs

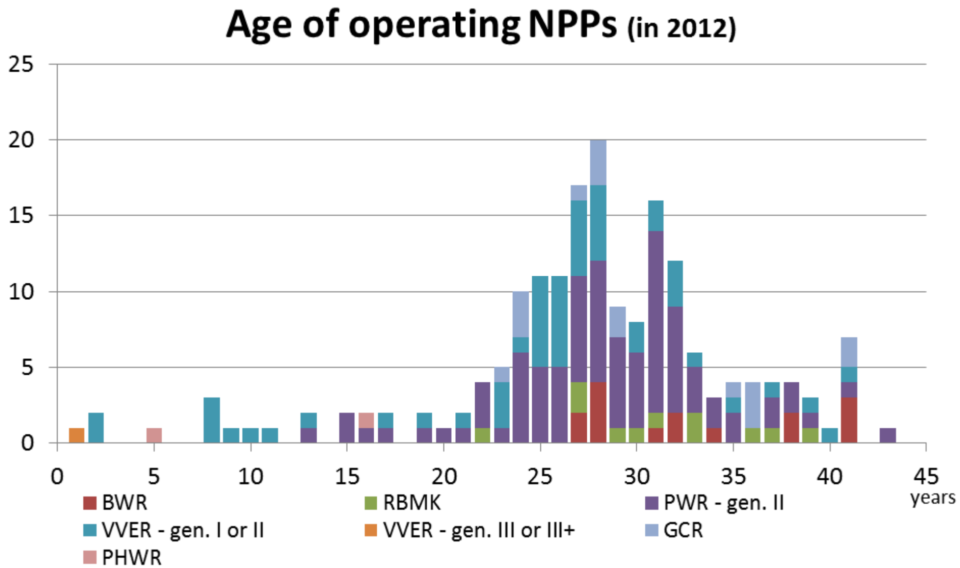
Limited data set!

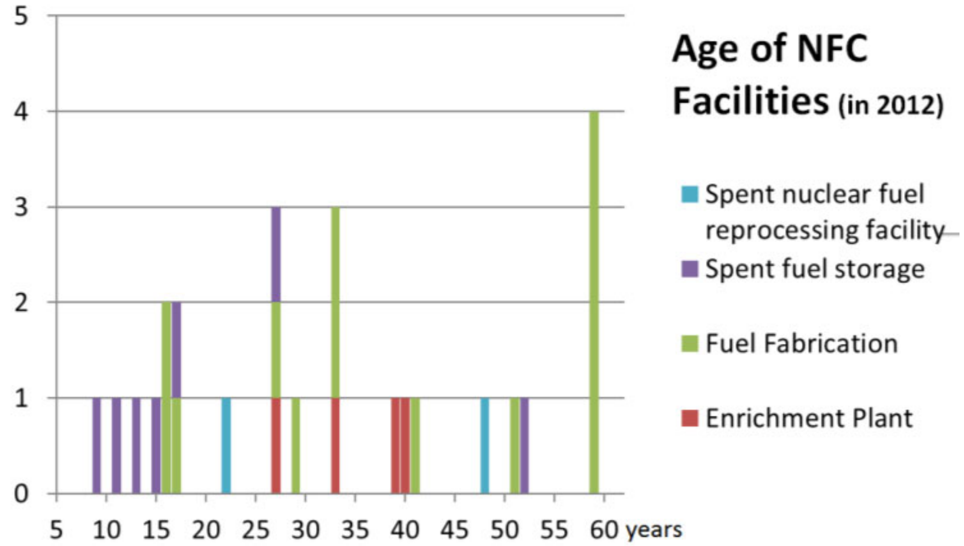




Age of operating facilities

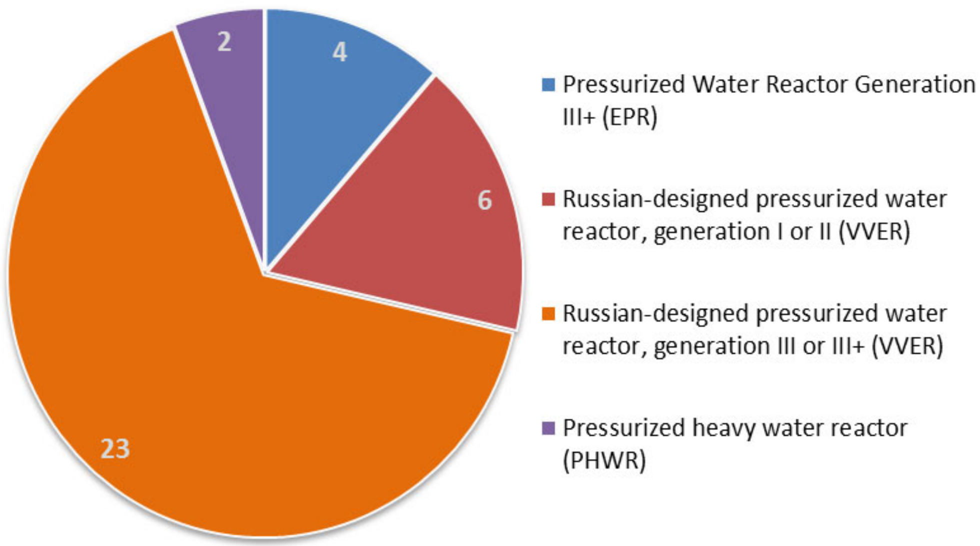


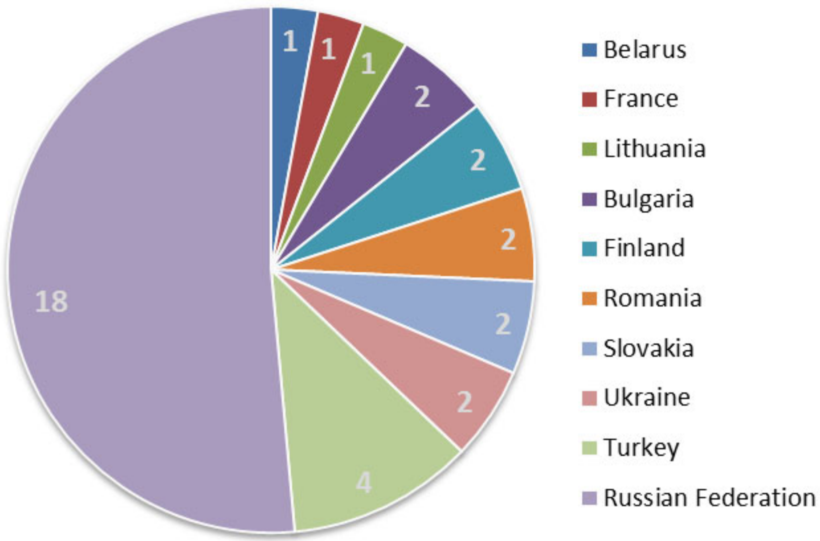




flexRISK Scenarios on future nuclear capacities

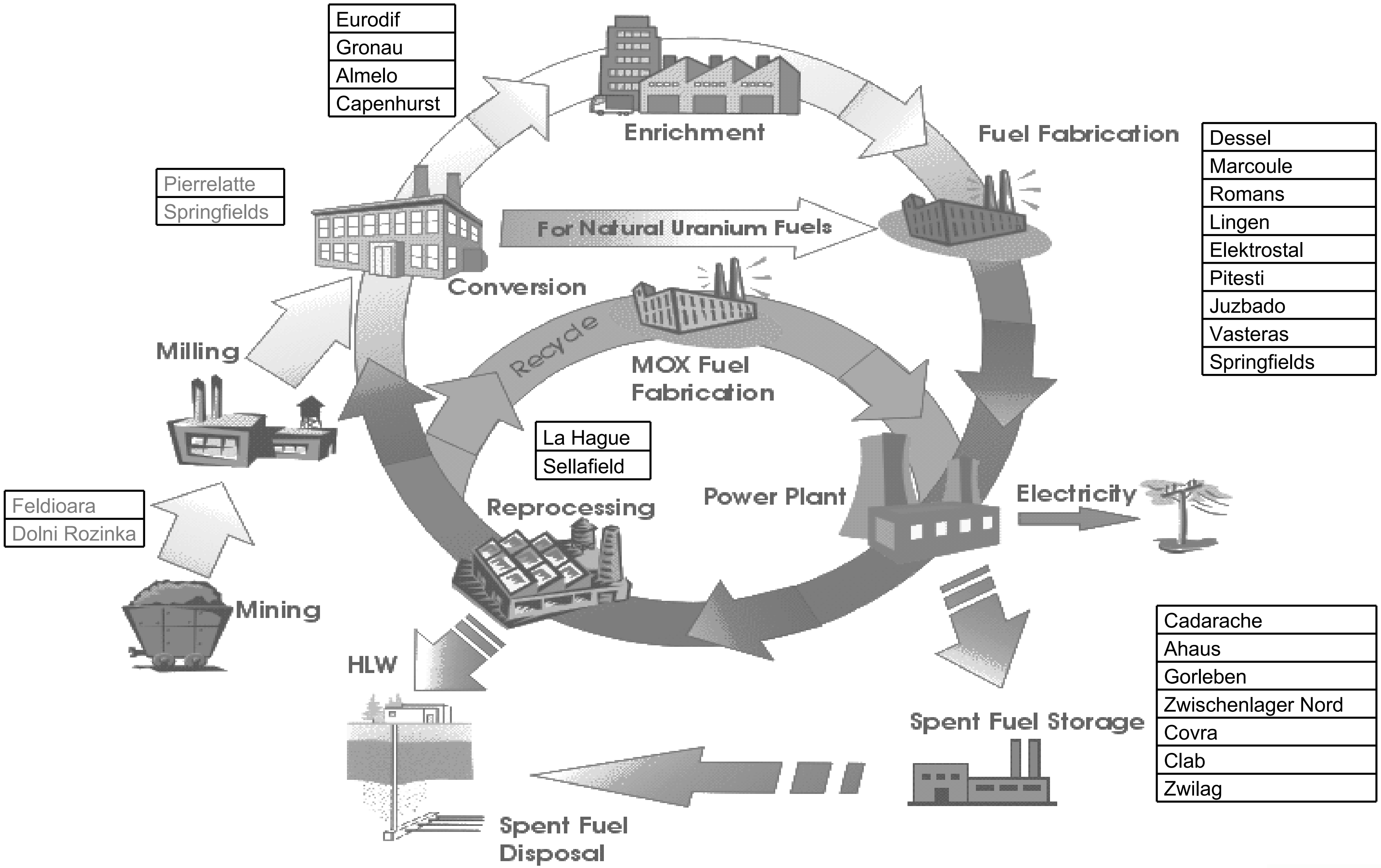
- Forecasts of nuclear power plant capacity in 2030
  - Evaluated with due date 12/2010
  - no unique list of forecasted capacity
    - different forecasts between 414 and 1350 GWe globally
    - under construction / siting process finished
    - 35 new NPPs with 40 GWe





flexRISK

Nuclear fuel cycle



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Part 2:
Accidents and source terms

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General approach

- Collection of data
  - Data not easily accessible
    - Inventories, source terms, release frequencies
  - Source of information
    - Plant-specific probabilistic safety analyses (PSA)
    - Reports of the IAEA, NEA, NRC and the EU
    - Journal publications
  - Reactor type code list
    - plant type, thermal power, electrical power, core damage frequency, large release frequency, scheduled shutdown year
- Source Terms – basis for dispersion calculation
  - equilibrium core radionuclide inventory
  - release fraction (amount radioactive material released)
  - release shape (time, duration and height of the release)

Accidents

- Two potential severe accidents
  - relatively high frequency, relatively low radioactive release (usually a late release)
  - lower frequency, greater radiological impact (large early release)

- Grouped NPPs
  - 13 groups for release shapes
  - 24 groups for release fractions
- Types of accidents e.g.
  - Steam generator tube ruptures (late)
  - Core melt accident with failure of containment isolation (early)
  - ISLOCAs (early)
  - Core power excursion – RBMK (early)
  - Loss of carbon dioxide coolant – GCR (late)

Limitations

- Limitations in data avaliability and comparability
  - A full-scope probabilistic safety assessment (PSA) for each nuclear power plant would be necessary
  - PSAs not always based on comparable assumptions
    - accidents caused by failure of components, external triggers
    - aging of materials, human error
  - Similar accidents assumed for similar plants
    - Limited number of accident scenarios
  - Number of available core inventories

Limitations

- Limitation in selection of accidents
  - Only two accidents from a large spectrum
  - Incomplete portrayal of risk in its total scope
  - Very specific accidents vs. rather generic accidents

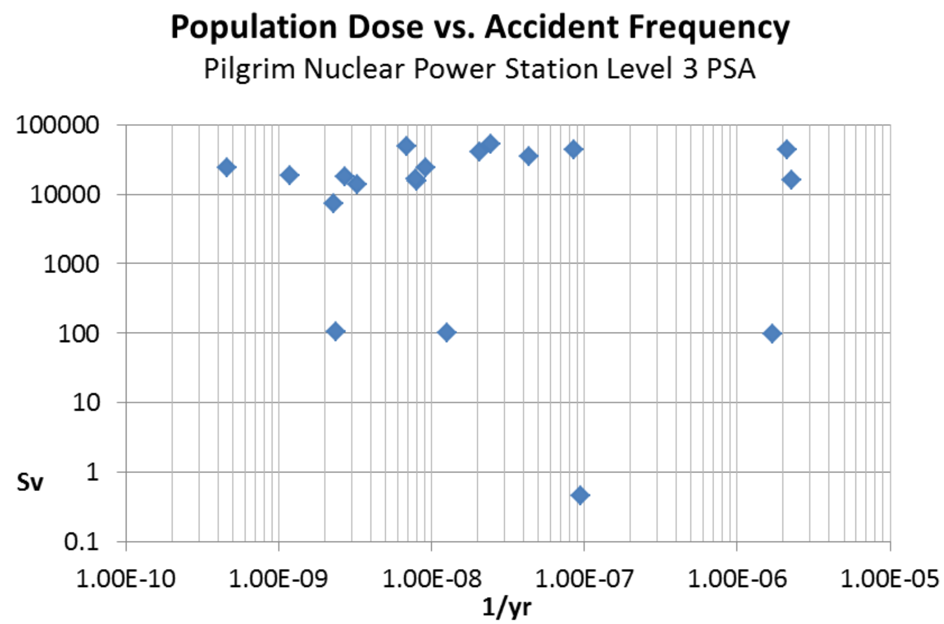
Generic consequences	Major contributing factors	
PDS 1	LOCA:	21.2 %
	ATWS:	20.9 %
	Secondary system transients:	20.0 %
	LOOP, CCF LH:	11.5 %
	LOCC, TLOCC, LUHS:	11.9 %
	HOM.DILUTION (FP):	2.0%
PDS 2	LOCC, TLOCC, LUHS:	6.9 %
	LOOP:	49.3 %
	LOCA:	31.8 %
	Secondary system transients:	11.5 %
PDS 3	ATWS:	39.5 %
	SGTR+MSLB,	
	SGTR:	18.9 %
	HETER.DILUTION EXT.:	13.5%
	BYPASS:	9.7 %
	LOCC, TLOCC, LUHS:	6.7 %
	Secondary system transients:	2.9 %
	LOCA:	3.7 %

TAB2: MAJOR CONTRIBUTORS TO THE MACRO-CONSEQUENCES (PDS 1, PDS 2 AND PDS3)

Source: UK-EPR: Level 2 Probabilistic Safety Assessment (PSA)

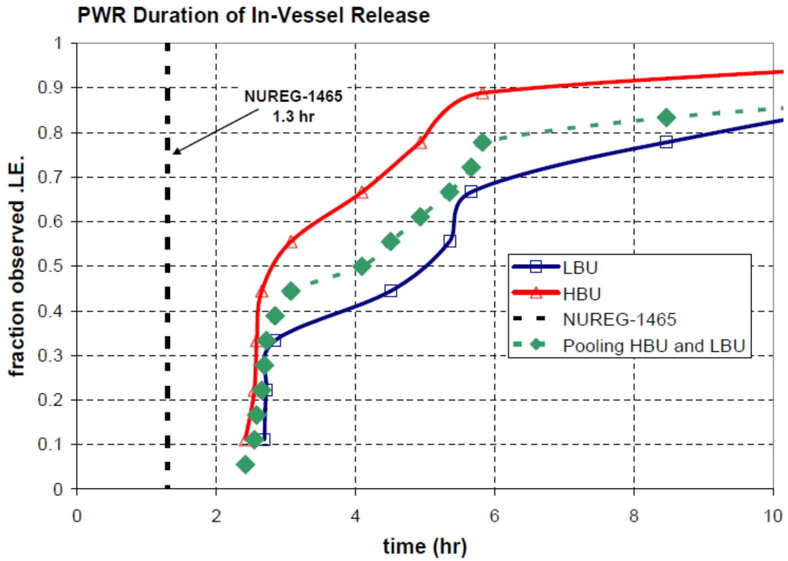
"The source term analysis results in hundreds of source terms for internal initiators, making calculation with the MACCS2 consequence model cumbersome. Therefore, the source terms were grouped into a much smaller number of source term groups defined in terms of similar properties, with a frequency weighted mean source term for each group."

Pilgrim Nuclear Power Station Applicant's Environmental Report Operating
License Renewal Stage, PSA Model – Level 2 Analysis



Data: Pilgrim Nuclear Power Station Applicant's Environmental Report Operating License Renewal Stage

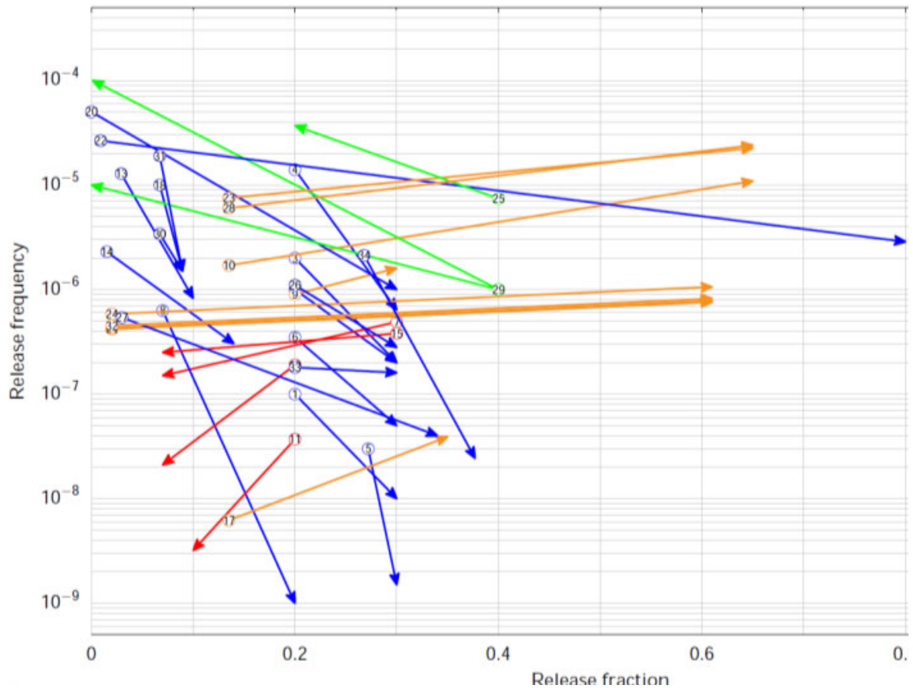
Limitations



Source: R.O. Gauntt; Severe Accident Predictive Tools and their Application to Reactor Regulation, Sandia National Laboratories

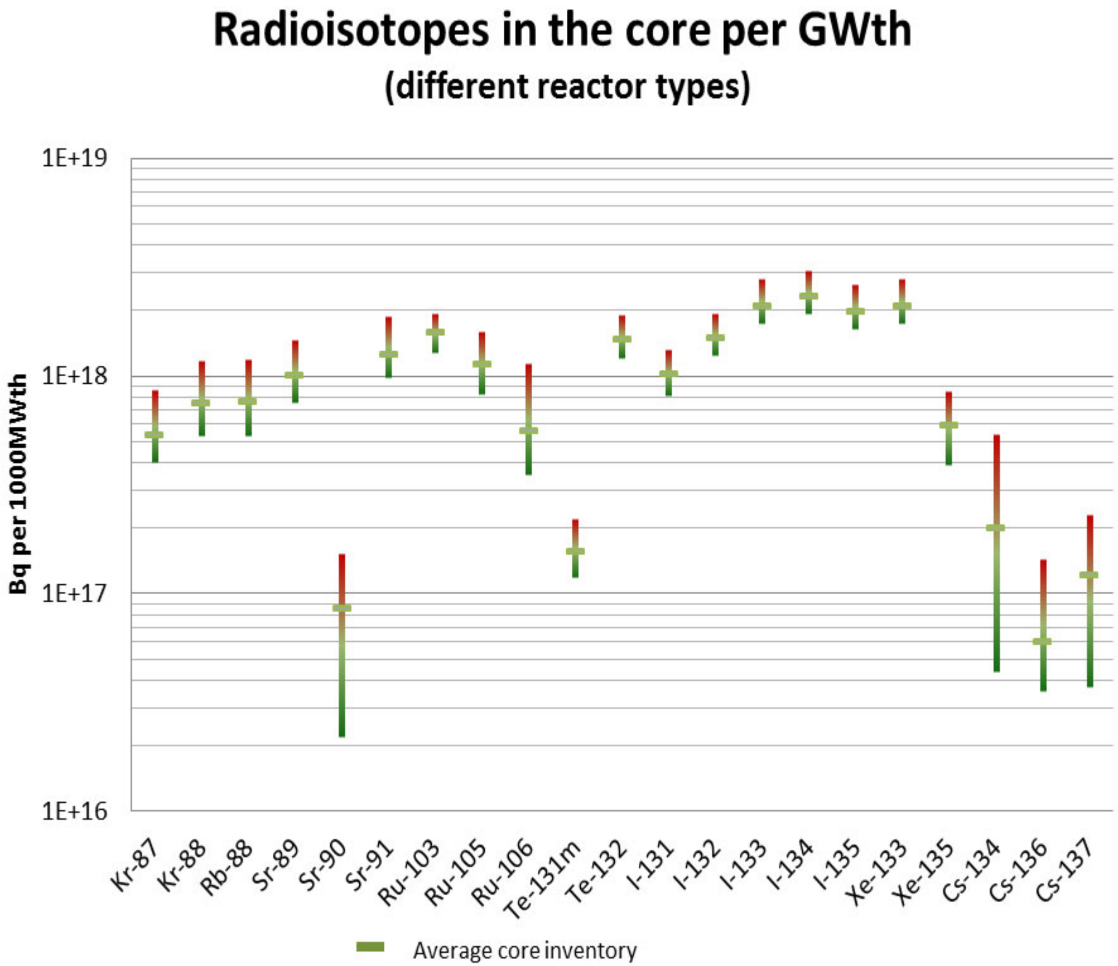
- Limitations in the source term
  - Limited number of release shapes
  - Limited release time (no Fukushima like release)
  - Limitations in boundary conditions (different assumptions in data basis)

- **One accident for every reactor, with large release but also reasonable probability**
  - Even if all accidents could have been taken into account: enormous calculation effort



Core Inventories

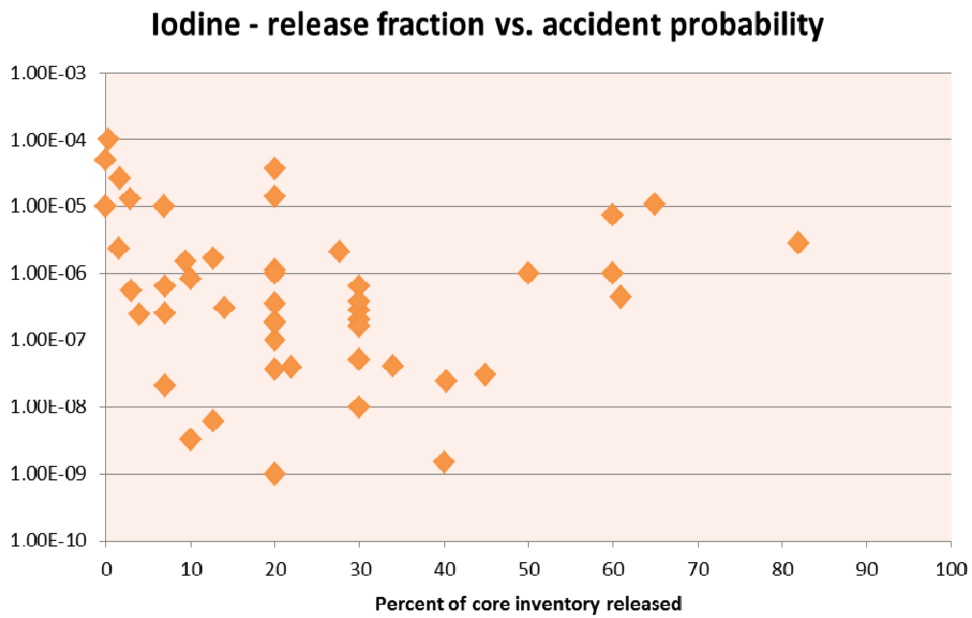
- 17 core inventories form available literature
  - equilibrium burnup
  - different reactor types
  - Selection of nuclides (see release fractions)
  - scaled linearly, according to thermal reactor power
  - No “trends” in CI



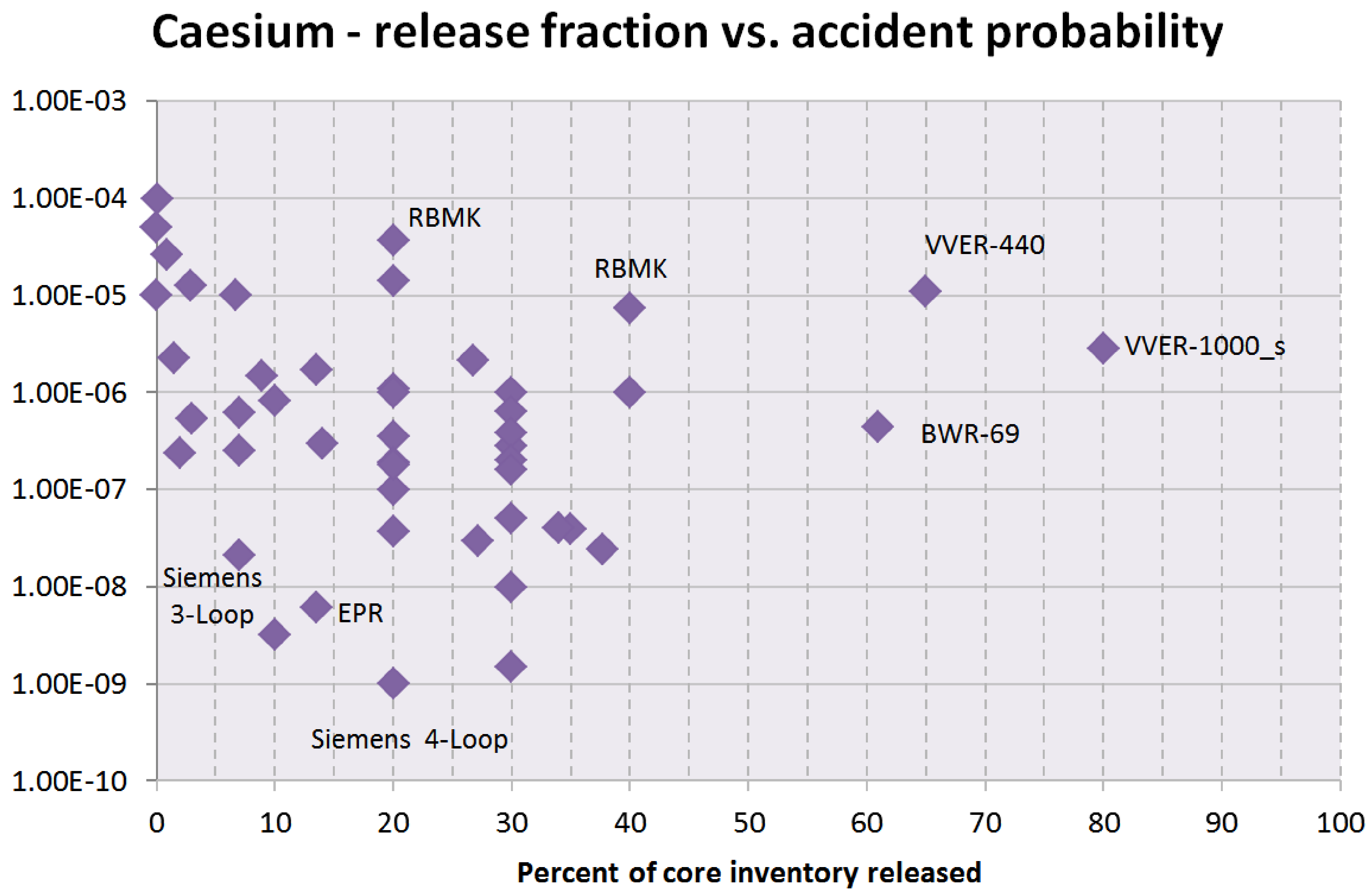
Release fraction

- 47 accidents (one double AGR/GCR)
  - Selection of nuclides according to radiobiological relevance
  - Release as fraction of core inventory in groups of elements
  - Generic accident frequencies for every group - except where specific accident frequencies for one reactor were found

Group	Nuclides
Noble Gases Group	Kr-87, Kr-88, Xe-133, Xe-135
Iodine Group	I-131, I-132, I-133, I-134, I-135
Cesium Group	Rb-88, Cs-134, Cs-136, Cs-137
Tellurium Group	Te-131m, Te-132
Strontium Group	Sr-89, Sr-90, Sr-91
Ruthenium Group	Ru-103, Ru-105, Ru-106



Release fraction (Cs)



Release shapes

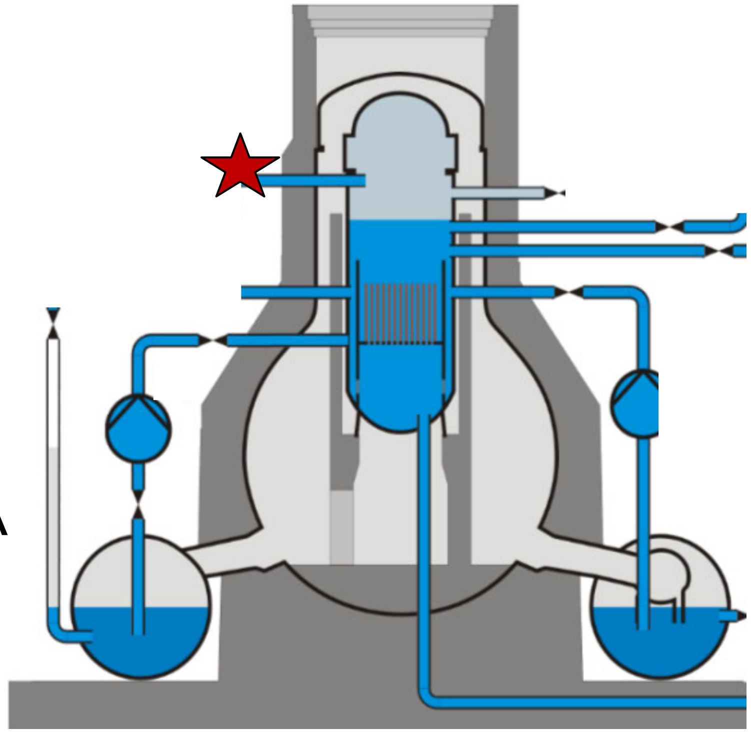
- Release shape
  - starting time of release, duration of release and the release height
  - up to two phases of the release
- Grouped into installations with similar characteristics
  - Basically one early and one late release shape per group
  - 10 Groups, 17 shapes (only one for AGR, RR, Aircraft)

Accident	Type	Beginning and end of 1st release phase [s]		Range of release height, phase 1 [m]		End of 2nd release phase [s]	Range of release height, phase 2 [m]	
PWR - Steam generator tube rupture	late	28800	30600	100	300			
VVER 440 - core melt accident, confinement ineffective (RPV failure, CCI)	early	10800	10920	0	50	18120	0	50
CANDU - core melt, late containment overpressure failure	late	84600	88200	0	50			
RBMK 1 core power excursion and steam explosion (Chernobyl Unit 4)	early	0	60	1000	3000	432000	50	150

Example

- Collapsed Accident Progression Bin (CAPB) 19
  - BWR/3 Mark I
  - ISLOCA with coolant loss outside containment
  - Probability: 2.43E-08/yr
  - Releases: 97.2% Noble Gases, 40.3% Iodine, 37.7% Caesium
  - Start of release after 6h, for 2.5h at 30m.

- Accident Progression
  - Large break interfacing system LOCA outside containment occurs



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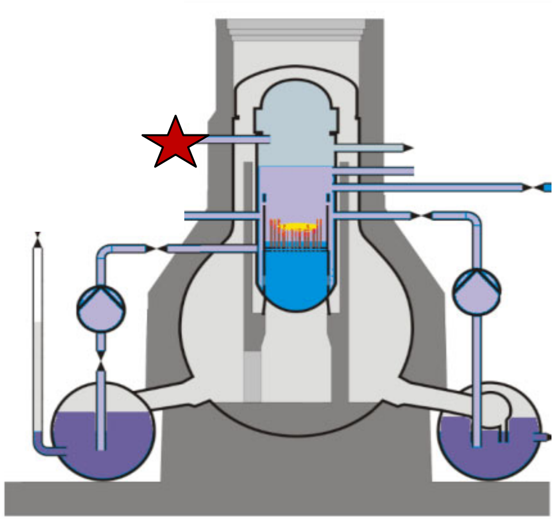
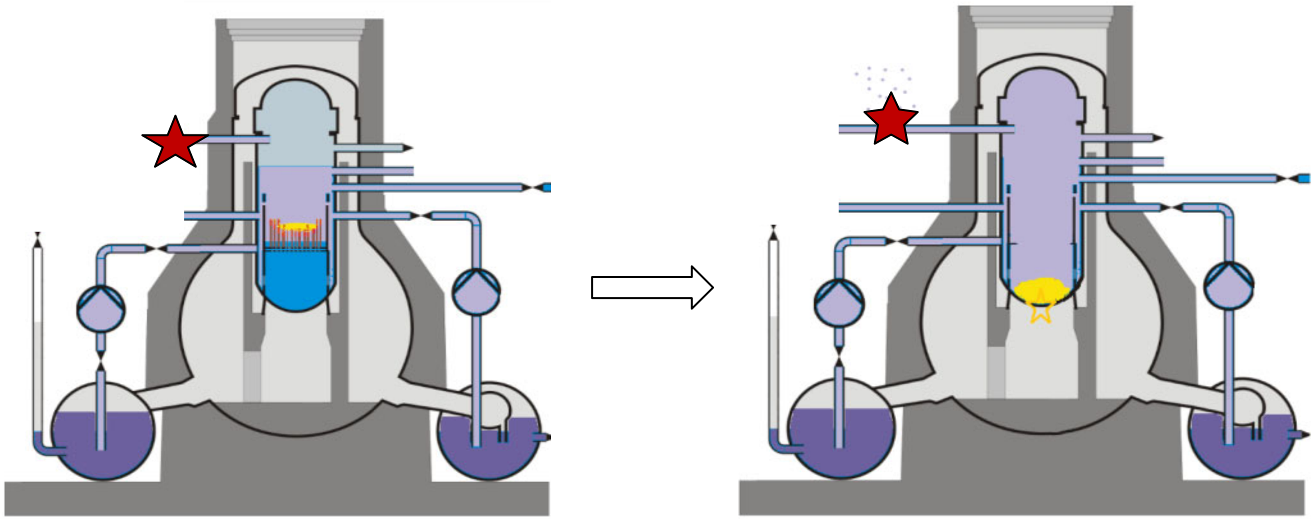
Example



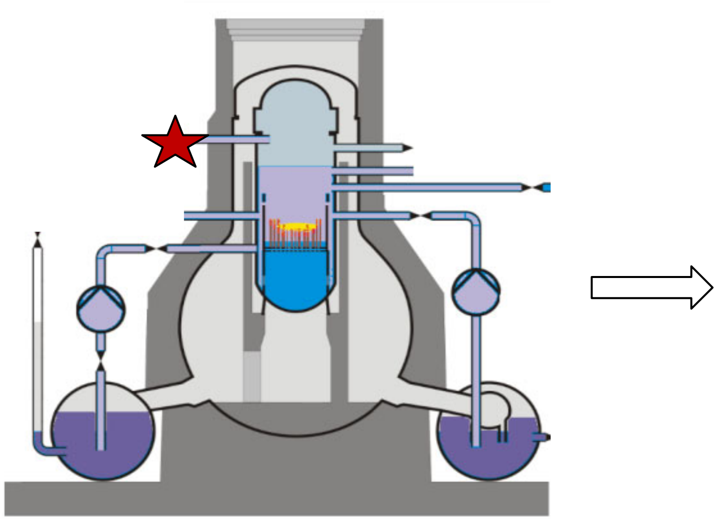
- Core damage (CD)

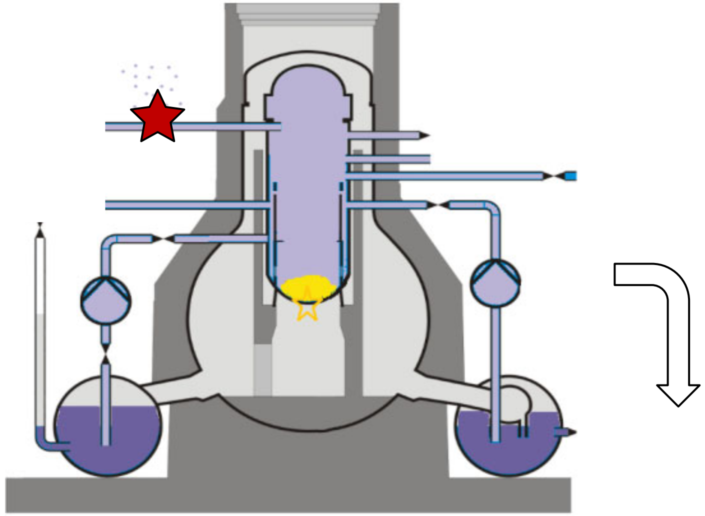
Example



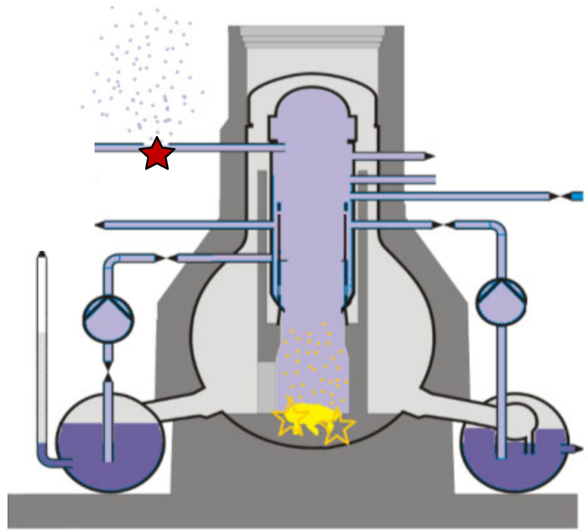
- Core damage (CD)
- and subsequent vessel breach (VB) results at low RPV pressure with a bypassed containment.

Example





- Core damage (CD)
- and subsequent vessel breach (VB) results at low RPV pressure with a bypassed containment.
- Following vessel breach, core-concrete interaction occurs (CCI).



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