Approach to Quantification of Uncertainties in the Risk of Severe Accidents at NPP Neckarwestheim Unit 1 (GKN I) and the Risk Impact of Severe Accident Management Measures

A. Strohm, L. Ehlkes, W. Schwarz (EnBW Kernkraft GmbH)
M. Khatib-Rahbar, M. Zavisca, Z. Yuan, A. Krall, A. Lyubarskiy (ERI)
D. Rittig (ISaR)
W. Werner (SAC)

Dr. Andreas Strohm
Kernkraftwerk Neckarwestheim
a.strohm@kk.enbw.com

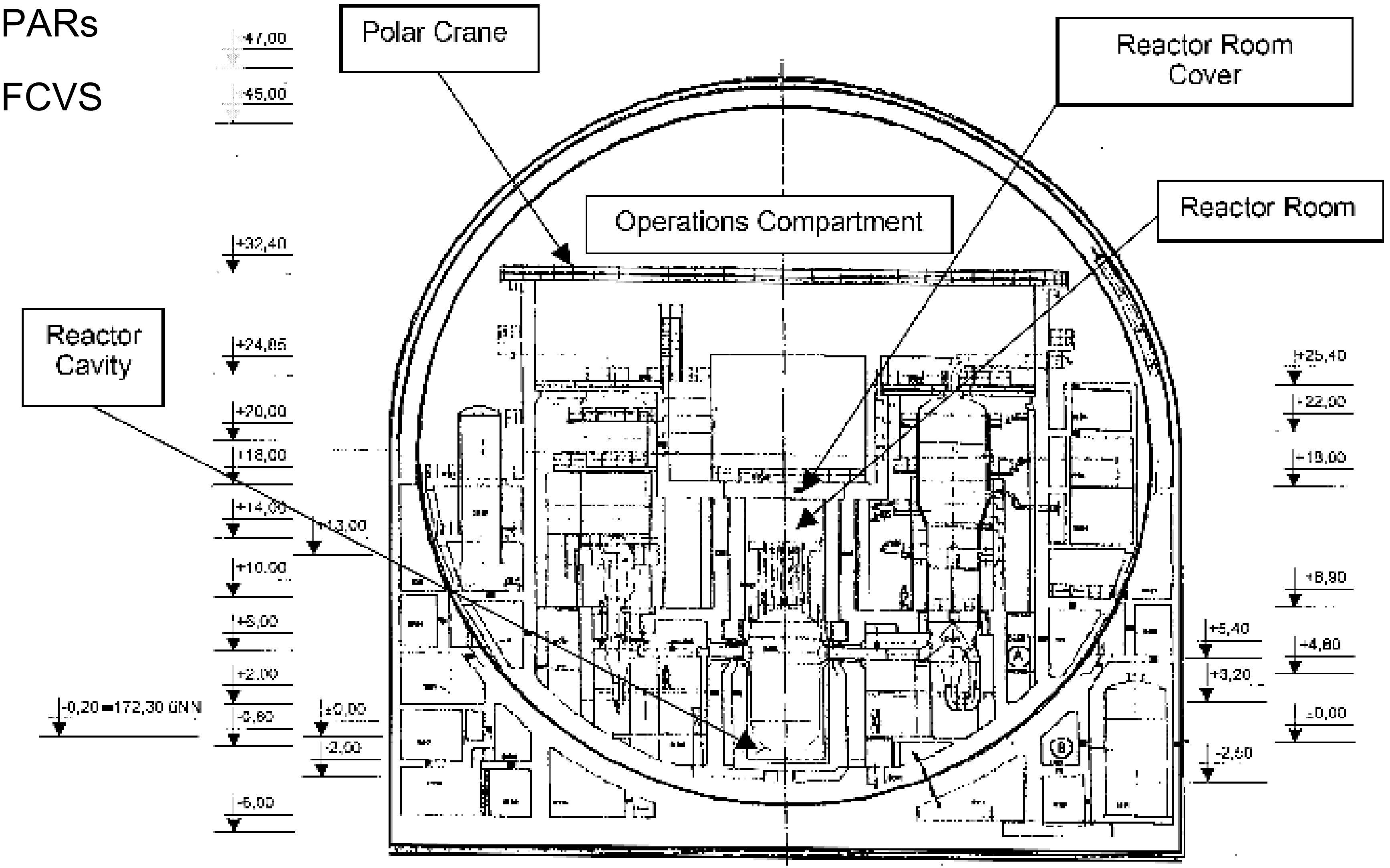
PSAM9, Hong Kong / 2008-05-23

EnBW
Energie
braucht Impulse

NPP Neckarwestheim Unit 1 (GKN I)

equipped with

- PARs
- FCVS



Level-2 PSA of NPP GKN I with Focus on Uncertainties

Overview

1. Fundamentals for NPP PSA in Germany

Fundamentals for NPP PSA in Germany

EnBW

Specification Level	Essential Content
Atomic Law (Amendment) (27th April 2002)	› Periodic safety review (PSR) › Mandatory dates for all NPP › 10-year-periodicity
Official Guidelines › Principles of PSR › Deterministic Analyses › Safety Status (1) › Physical Protection	Scope, presentation/evaluation of results
› PSA Guideline (2)	› Full-power Level-1 PSA - internal initiators - internal and external hazards › Off-power Level-1 PSA › Full-power Level-2 PSA
Subordinated Documents (1) Generic Safety Principles (2) PSA-Methods, Data	Details for technical performance

Part 1
German PSA
Fundamentals

2. Characteristics of PSA Levels

Characteristics of the PSA Levels

PSA Level	Analyses Concerns	Final Results	Uncertainties
1	*Plant*: components, operators	core damage frequency	reliability data of components and operator actions
2	*Plant*: severe accident phenomena	frequency of containment failure due to core damage amount of release of radionuclides	limited knowledge of severe accident phenomena
3	*Environment*: radionuclide transport, impact	biological and economical consequences of environmental radionuclide release	missing knowledge of radionuclide transport behaviour and biological effectiveness

EnBW

"Risk"

3. Objectives and Scope

Objectives and Scope

Objectives:

- Perform a level-2 PSA consistent with:
  (a) international practices forming the current state-of-the-art
  (b) the specifications of the German PSA guideline
- Assess the efficiency of plant-internal, post-core-damage accident management measures/systems ("mitigative AM")
- Identify other potentially efficient AM measures

Scope

- Classical level-2 PSA with level-1/level-2 interface
  - ➡ frequency of release categories
  - ➡ amount of radionuclide release (source terms)
- Level-2 extension to evaluate AM-efficiency
  - ➡ Integral risk of release activity in the environment

4. Methodology

Methodology of GKN I Level-2 PSA

EnBW

<u>Starting Point</u>: core damage (CD) frequency distribution of level-1 PSA

1. Development of a structured level-1/level-2 interface

- including all 247 level-1 CD-states without cut-off criteria
- binning of CD-states to 60 plant damage states by 9 binning criteria

thereby: complete separation of the diverse uncertainties of level-1 and level-2 PSA

Methodology of GKN I Level-2 PSA

EnBW

<u>Starting Point</u>: core damage (CD) frequency distribution of level-1+ PSA

1. Development of a structured level-1+/level-2 interface

2. Integral deterministic severe accident analyses

- for 12 relevant PDS, representing sequences and scenarios
  (a) that comprise a high percentage of total CD-frequency
  (b) that are likely to be risk-significant
- with MELCOR 1.8.5

→ defining initial and boundary conditions for analyses of particular severe accident phenomenological issues

Methodology of GKN I Level-2 PSA

EnBW

Starting Point: core damage (CD) frequency distribution of level-1+ PSA

1. Development of a structured level-1+/level-2 interface
2. Integral deterministic severe accident analyses
3. **Containment-challenging phenomena uncertainties: identification, quantification, and propagation (major element of the GKN I level-2 PSA)**
   - using initial and boundary conditions provided by MELCOR
   - on plant-specific basis
   - to estimate conditional probabilities and uncertainties for severe accident issues

Examples: Conditional Probabilities and Uncertainties Associated with Relevant Containment Challenges

EnBW

Challenge type/ Condition	Distr.	Percentile		
		0 %	50 %	100 %
Creep-rupture of hot leg or pressurizer surge-line nozzles / high or medium pressure	β	0.90	0.95	0.99
In-vessel core damage arrest long term by water flooding / water injection	log β	0.01	0.10	0.50
Failure to successfully initiate filtered containment venting / requirement to prevent containment failure	log β	$1.40 \cdot 10^{-3}$	$2.93 \cdot 10^{-3}$	$6.15 \cdot 10^{-3}$
Filtered containment venting system (FCVS) failure due to combustion / FCVS is actuated	β	0	0.045	0.14

Part 4
Methodology

Methodology of GKN I Level-2 PSA

EnBW

<u>Starting Point</u>: core damage (CD) frequency distribution of level-1+ PSA

1. Development of a structured level-1+/level-2 interface

2. Integral deterministic severe accident analyses

3. Containment-challenging phenomena uncertainties

4. Probabilistic severe-accident analyses

- integrating results by accident progression event tree (APET) (e.g., MELCOR calculations, AM measures, system information)
- given a PDS, APET computes conditional containment failure probability by various modes using EVNTRE
- binning of APET end states into 11 release categories

APET Release Categories

EnBW

Release Category	Containment Failure Mode	Description of Release Path
RC-A	LOCA outside containment	Large containment bypass → Annulus → Unfiltered release
RC-B	Uncovered SGTR	Release via uncovered steam generator tubes
RC-C	Early containment rupture	Containment failure at or before vessel breach → Annulus → Unfiltered release
RC-D	Containment isolation failure	Containment failure before core damage → Annulus → Unfiltered release
RC-E	Covered SGTR	Release via covered steam generator tubes
RC-F	Sump line failure	Containment failure after vessel breach → Annulus → Unfiltered release
RC-G	Late containment rupture	Containment failure long after vessel breach → Annulus → Unfiltered release
RC-H	Basemat melt-through	Release via penetration of concrete basemat
RC-I	Unfiltered containment venting	Containment venting with loss of filtration capability
RC-J	Filtered containment venting	Containment venting to stack with filtration
RC-K	No containment failure	Small containment leakage → Annulus → Filtered or unfiltered release

LOCA Loss of Coolant Accident
SGTR Steam Generator Tube Rupture

Methodology of GKN I Level-2 PSA

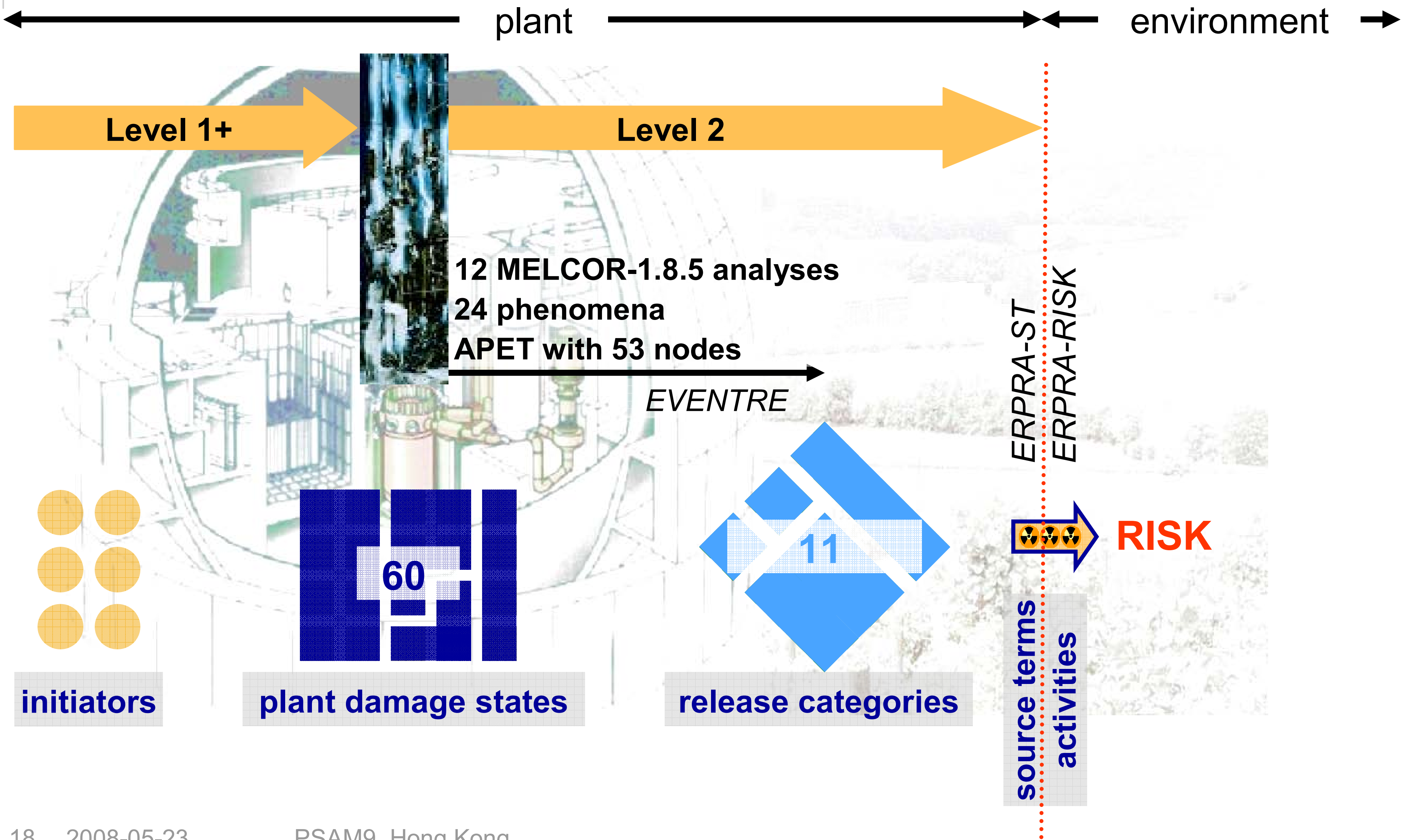
EnBW

<u>Starting Point</u>: core damage (CD) frequency distribution of level-1+ PSA

1. Development of a structured level-1+/level-2 interface
2. Integral deterministic severe accident analyses
3. Containment-challenging phenomena uncertainties
4. Probabilistic severe-accident analyses
5. **Source term analyses for release categories**
   - quantifies released fractions of initial radiological core inventory for 10 radiological groups
   - requires transport, deposition, and radiological release predictions associated with significant uncertainties
   - requires multitude of random samples for uncertainty analyses with computationally simplified parametric code* (ERPRA-ST)

*similar to NUREG-1150

Methodology of GKN I Level-2 PSA: Overview



Methodology of GKN I Level-2 PSA

<u>Starting Point</u>: core damage (CD) frequency distribution of level-1+ PSA

1. Development of a structured level-1+/level-2 interface
2. Integral deterministic severe accident analyses
3. Containment-challenging phenomena uncertainties
4. Probabilistic severe-accident analyses
5. Source term analyses for release categories
6. **Extension by integral risk approach**
   - confined to uncertainty range of level- 2 PSA
   - using integral release activity of 60 radionuclides
   - interpreted as activity in immediate plant vicinity

Methodology of GKN I Level-2 PSA

Quantification of integral Risk of release Activity R_A

- product of
  - release category frequency
  - activity of released fraction of initial radiological core inventory
- integrated over all release categories

$$R_A = \sum_i \sum_d \sum_s [f_i \cdot P(i|d)] \cdot P(d|s) \cdot A(s|a)$$

f_i : frequency of initiating event "i" [per year]

P(i|d) : conditional probability that initiating event "i" leads to PDS "d"

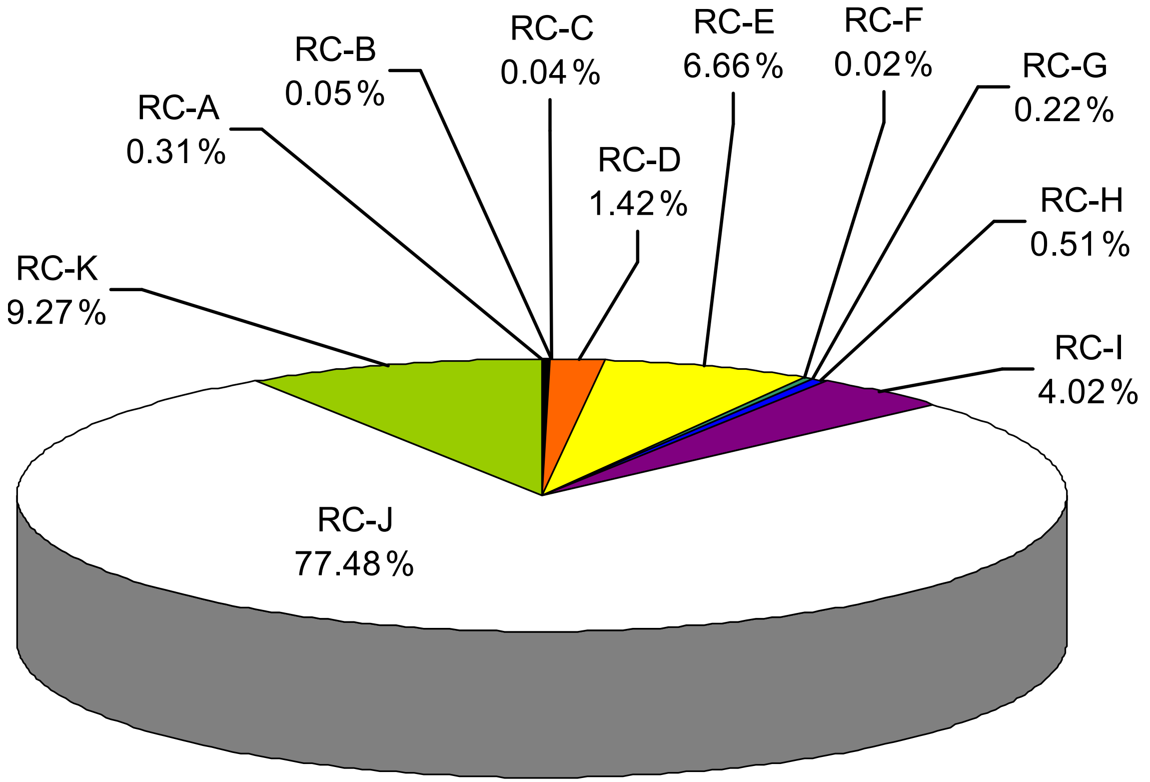
P(d|s) : conditional probability that PDS "d" will lead to source term "s"

A(s|a) : mean value of released activity a [per year], given the occurrence of source term "s"

Part 4
Methodology

5. Results

Release Categories: Relative Proportions at total PDS Frequency

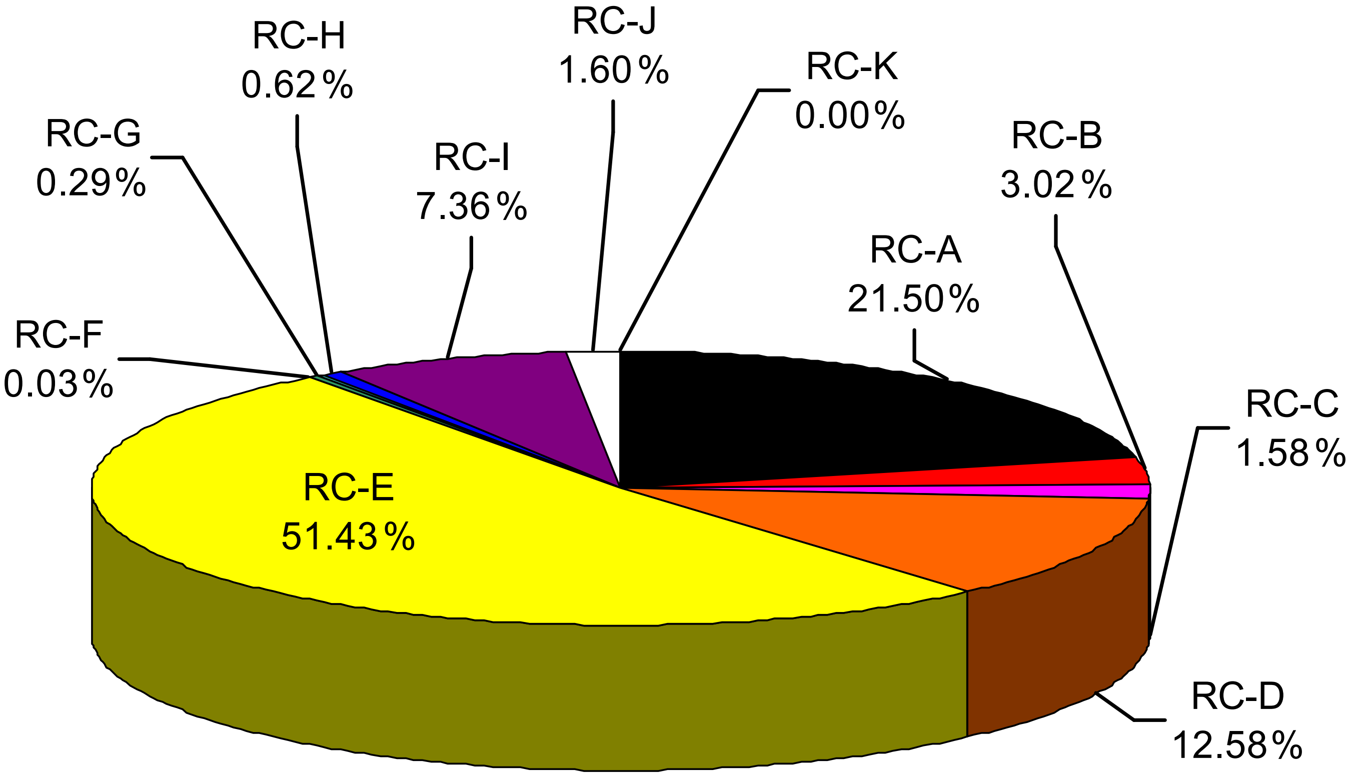


RC-A	LOCA Outside Containment	RC-G	Late Containment Rupture
RC-B	Uncovered SGTR	RC-H	Basemat Melt-Through
RC-C	Early Containment Rupture	RC-I	Unfiltered Containment Venting
RC-D	Containment Isolation Failure	RC-J	Filtered Containment Venting
RC-E	Covered SGTR	RC-K	No Containment Failure
RC-F	Sump Liner Failure		
LOCA	Loss of Coolant Accident	SGTR	Steam Generator Tube Rupture

Part 5
Results

Release Categories:
Relative Contribution to Integral Risk (w/o Noble Gases)

EnBW



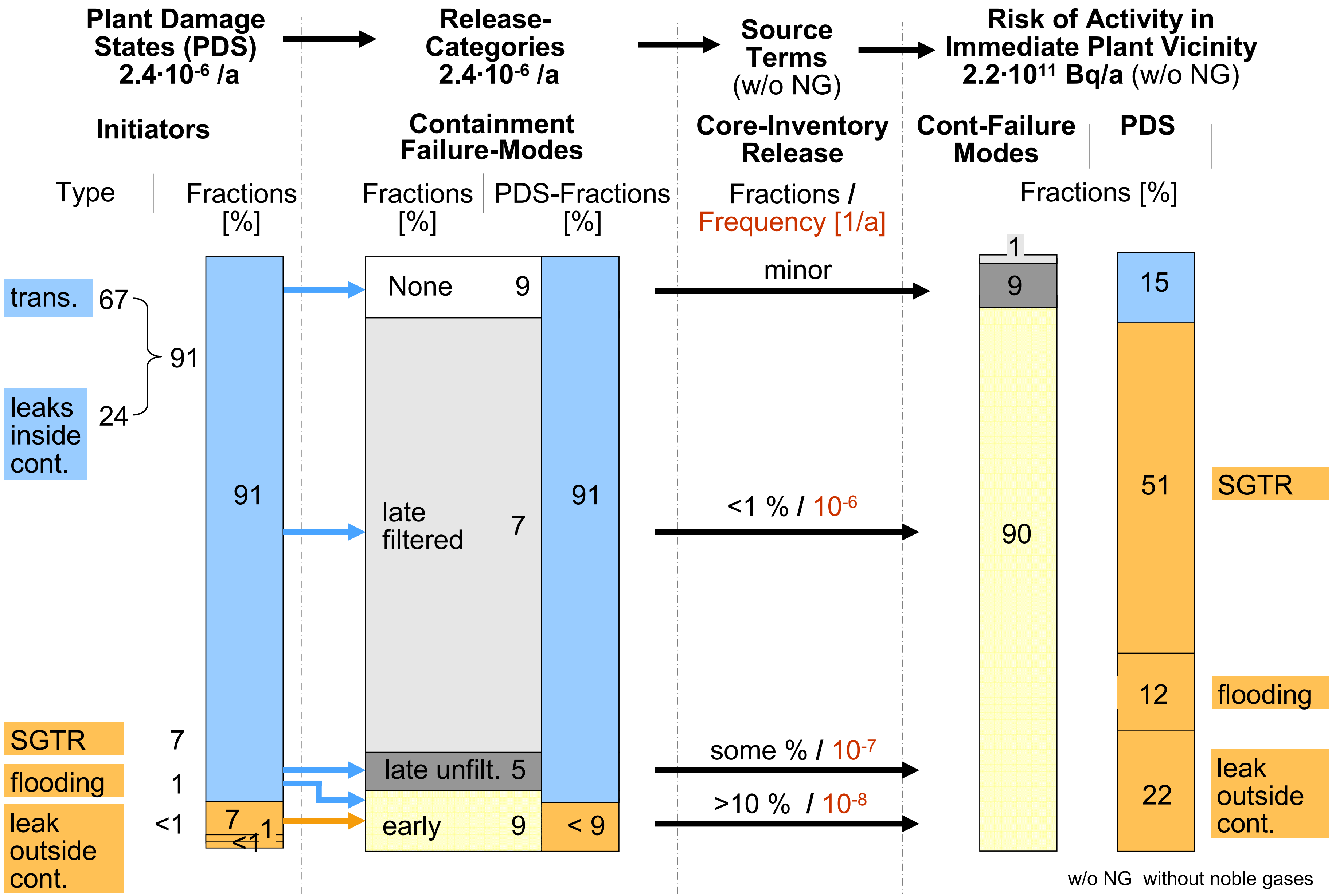
RC-A	LOCA Outside Containment	RC-G	Late Containment Rupture
RC-B	Uncovered SGTR	RC-H	Basemat Melt-Through
RC-C	Early Containment Rupture	RC-I	Unfiltered Containment Venting
RC-D	Containment Isolation Failure	RC-J	Filtered Containment Venting
RC-E	Covered SGTR	RC-K	No Containment Failure
RC-F	Sump Liner Failure		

LOCA Loss of Coolant Accident

SGTR Steam Generator Tube Rupture

Part 5
Results

Overview of Results of GKN I Level-2 PSA



6. Insights and Conclusions

Insights

Plant-related

- Total core damage frequency of GKN I
  comparable to those of modern operating plants of similar design
- Overall risk of activity in vicinity of the plant very low
- Existing equipment and provisions
  - reduce efficiently likelihood of severe accidents
  - mitigate efficiency activity release of severe accidents
- Results are numerically robust

General

- Improvements of level-1 and level-2 PSA results does
  not necessarily imply a reduction of integral risk of activity

EnBW

Part 6
Insights

Conclusions

Potential provisions (resulting from sensitivity analyses)

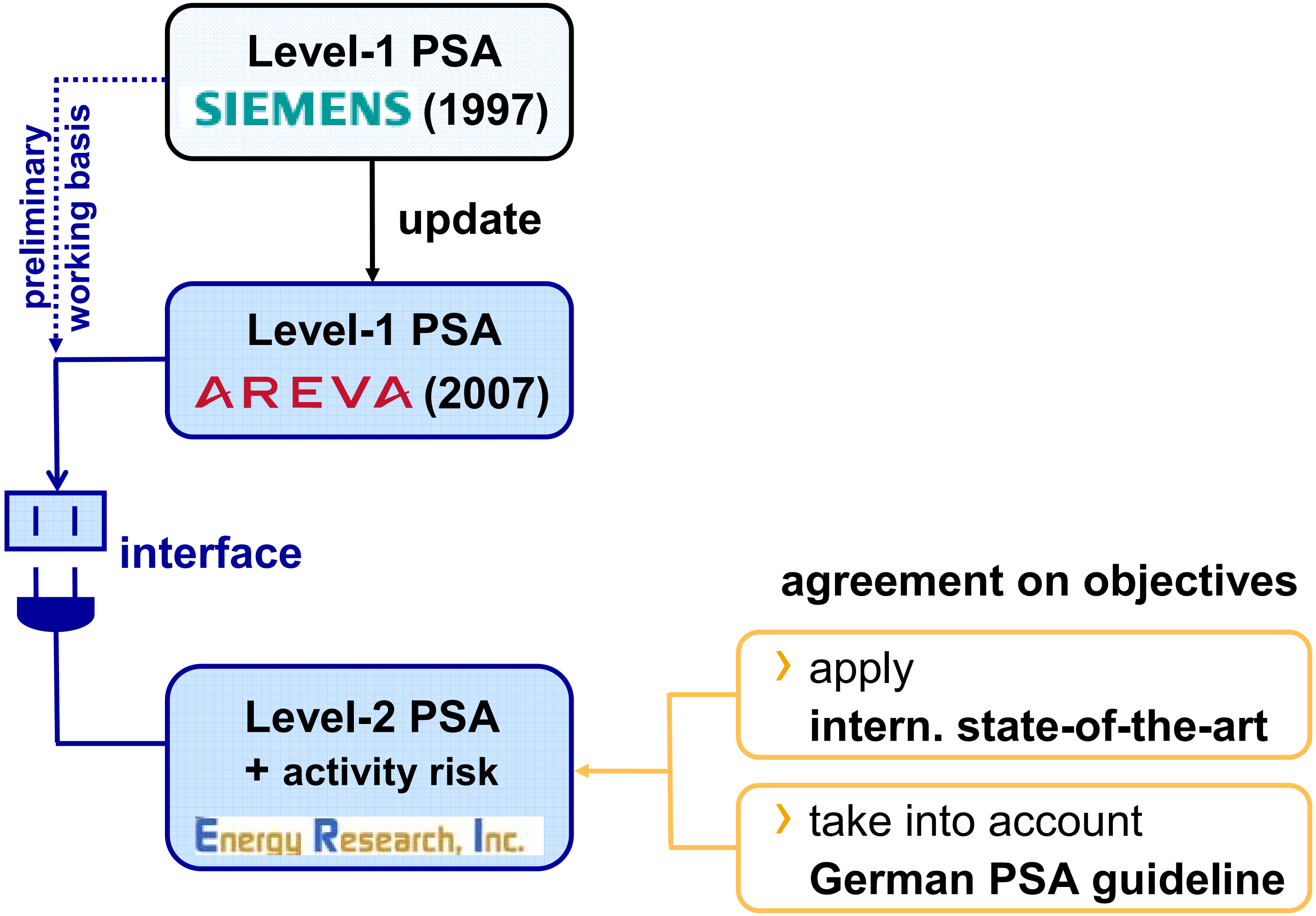
- Additional water injection into damaged steam generator aiming at increasing the aerosol decontamination factor
- Improvements in procedures and training ensuring the high reliability of filtered containment venting system actuation

Review of PSA Level-1 modelling

- Effectiveness of containment isolation under annulus flooding conditions (service-water-line leak)

The End

Performance and Project Management



EnBW

Part 3
Performance

Methodology of GKN I Level-2 PSA

EnBW

Starting Point: **core damage (CD) frequency distribution of level-1+ PSA**

1. Development of a structured level-1+/level-2 interface
2. Integral deterministic severe accident analyses
3. Containment-challenging phenomena uncertainties
4. Probabilistic severe-accident analyses
5. Source term analyses for release categories
6. Extension by integral risk approach
7. **Importance and sensitivity analyses**
   - importance analyses to estimate uncertainty correlations between PSA input variables and integral risk
   - sensitivity analyses to assess the risk impact of existing and potential additional mitigative AM

Methodology of GKN I Level-2 PSA

EnBW

Starting Point: **core damage (CD) frequency distribution of level-1+ PSA**

1. Development of a structured level-1+/level-2 interface
2. Integral deterministic severe accident analyses
3. Containment-challenging phenomena uncertainties
4. Probabilistic severe-accident analyses
5. Source term analyses for release categories
6. Extension by integral risk approach

Final Result: **integral risk of activity of release in immediate plant vicinity**

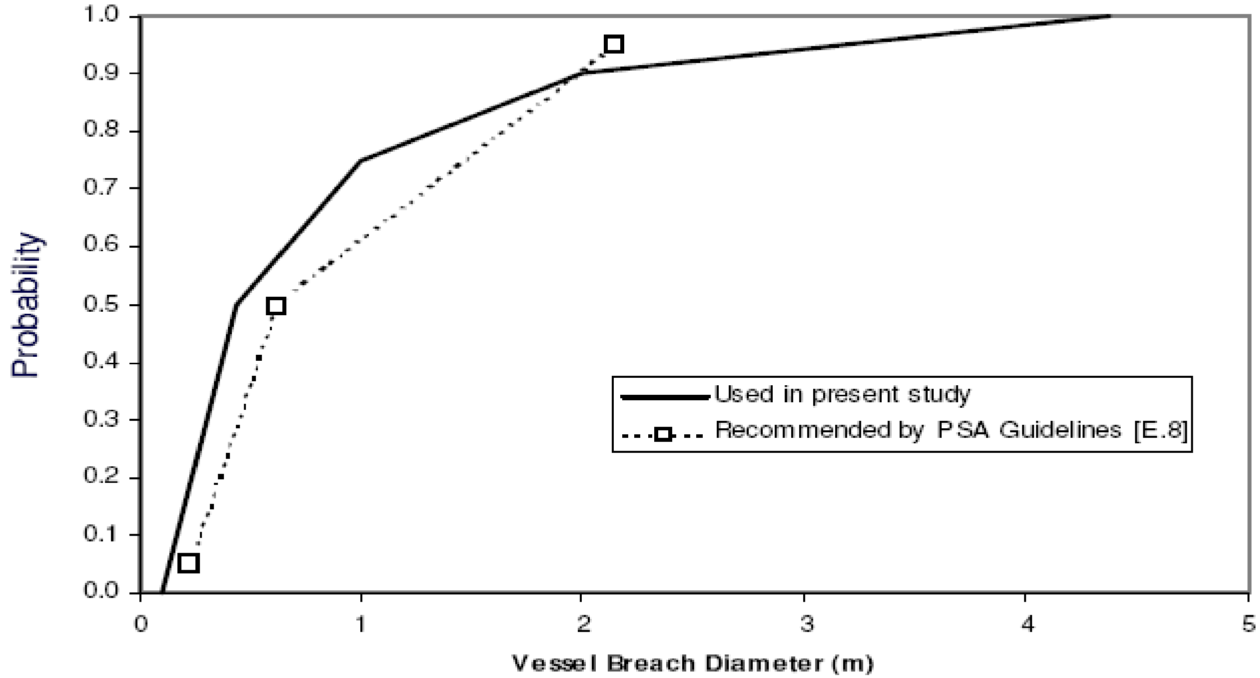
Part 4
Methodology

Selected Phenomena Analyses: Containment Challenge due to Severe Accidents

EnBW

Example: RPV-Failure

- locally and due to temperature-induced creep rupture
- large-area failure with low probability



RPV-Failure