Uncertainty of the Level 2 PSA for NPP Paks

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Outline

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- Uncertainties propagated from level 1 to level 2 PSA
- Uncertainties considered in CET
    - Melt progression arrested (ECC restoration)
    - Hydrogen burn, early containment failure
    - Late containment failure
- Propagation of uncertainties to containment failure states
- Summary

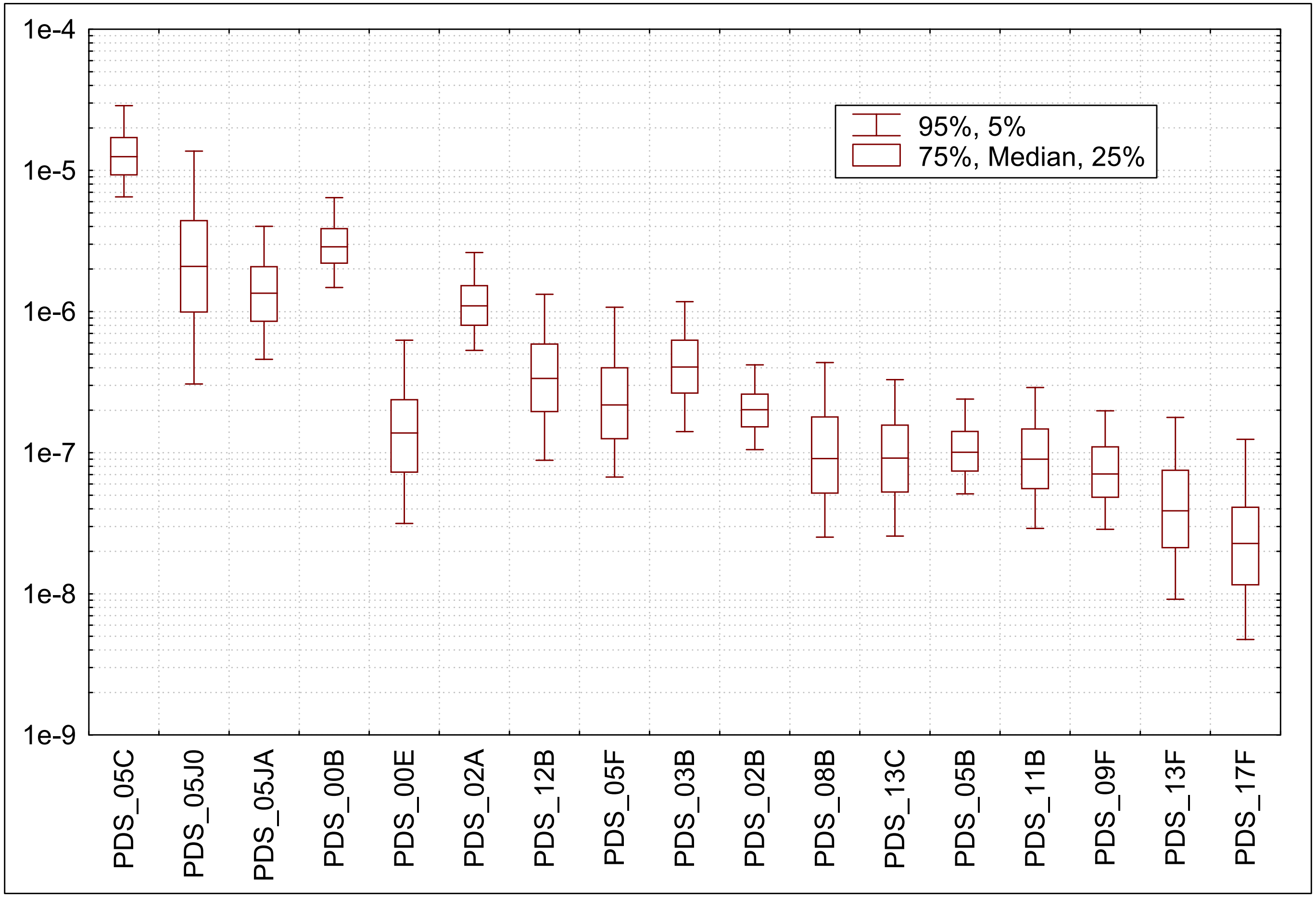
Introduction

- Level 1 PSA for internal initiators and internal hazards
  - Nominal power and shutdown state
- Over 500 core damage sequences considered
- Level 2 PSA is based on Level 1
  - 17 PDS, 13 release categories
- Uncertainty analysis
  (aleatoric and epistemic uncertainties)

Level 1 – Level 2 Interface: Uncertainty Analysis

- Aleatory uncertainties were propagated numerically from level 1 PSA results to PDS frequencies
- Basic event level uncertainty parameters were taken from level 1 model
- Additional estimations were made for component failures and human actions not included in level 1 analysis
- Quantification was performed on PDS level minimal cut sets
- Special purpose computer programme was developed due to complexity of model and limitations of PSA software applied
- Monte Carlo simulation was applied for quantification

Level 1 – Level 2 Interface: Uncertainty Analysis cont'd



Level 1 – Level 2 Interface: Sensitivity Analysis

- Focus on operator action for primary depressurisation upon severe accident signal
  - New EOP action not considered previously in level 1 PSA
  - Interest in examining changes in profile of dominant plant damage states as a function of this action

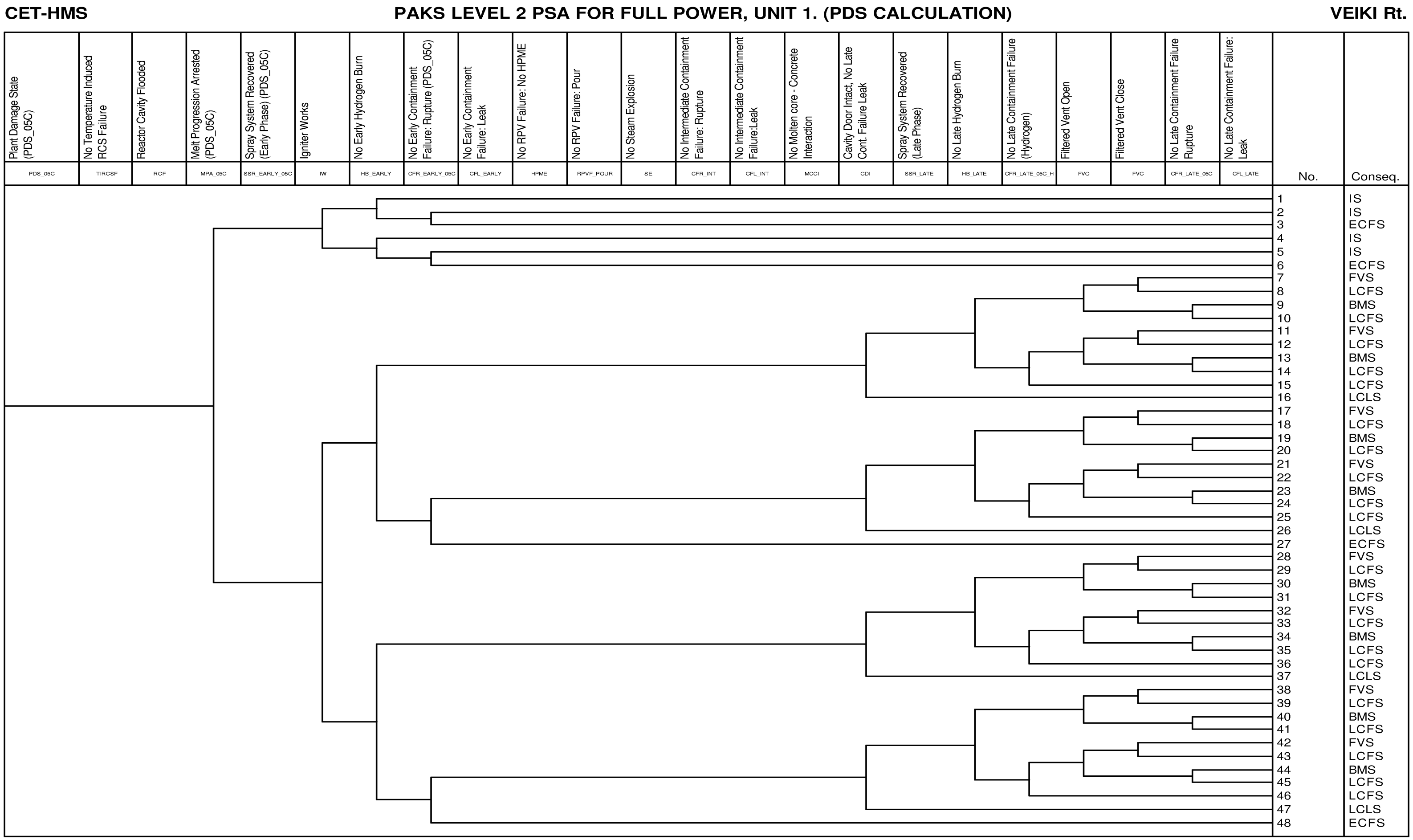
- Importance and sensitivity measures were calculated for the given human failure event
  - Re-generation of PDS level cut sets with modified assumptions on failure probability
  - Calculation of most common measures of change

- Results show that no significant changes can be expected upon moderate changes in human error probability except for one high pressure PDS

Uncertainties in the Containment Event Tree

- Severe accident simulations (MAAP4/VVER code) for each PDS by sampling important process parameters as random variables
  - 40 MAAP parameters
  - 10 parameters for hydrogen ignition and containment fragility
  - Latin hypercube sampling
  - 200 simulations for each PDS/branch in CET
- Generation of uncertainty distributions for CET headings
  - Use of results from multiple severe accident analyses
  - Considerations of human failure probabilities, structural and equipment failures
- Propagation of uncertainties from plant damage states to containment states and release/consequence categories

Containment Event Tree

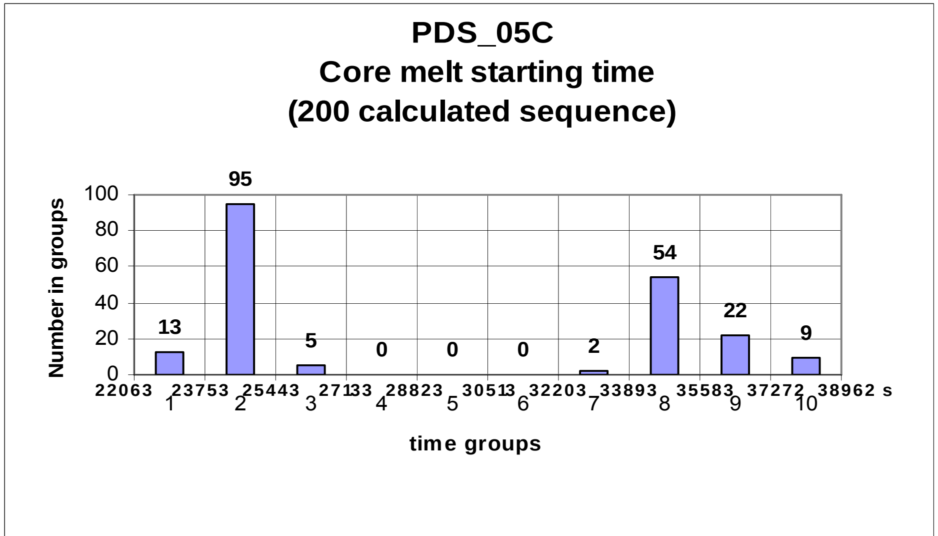


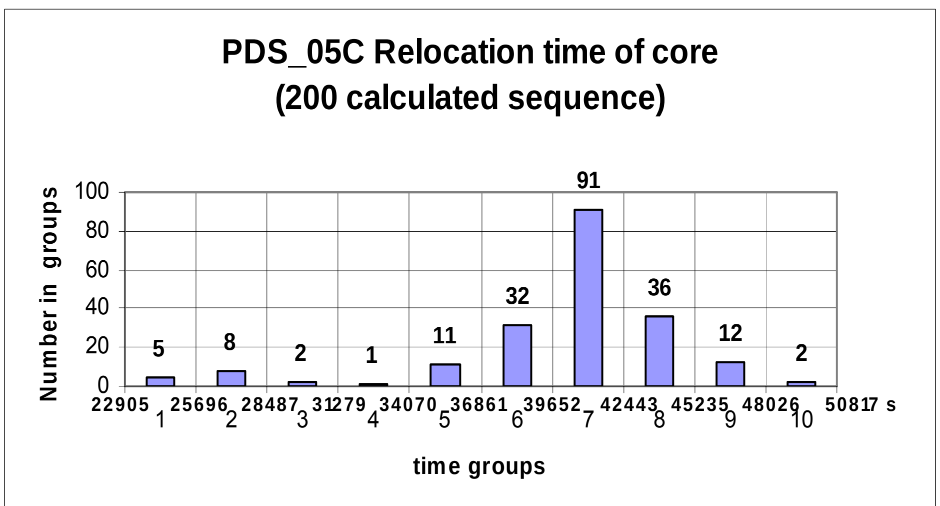
Example 1 :Melt progression arrested and spray system recovery

- Uncertainty analysis
  - – Variability in available time (i.e. time window) for ECCS and spray system recovery actions was considered using the results of MAAP4/VVER calculations
  - – Probability of recovery was calculated from the time window values of the sampled MAAP analyses.
  - – Variability in the context of recovery actions (performance influencing factors other than time) was not assumed in quantitative uncertainty analysis.

- Sensitivity analysis
  - – Studying sensitivity of overall results to likelihood of recovery (by numerical analysis)
  - – Basemat melthrough is largely affected but not shown in release categories

Example 1: Melt progression arrested and spray system recovery cont'd



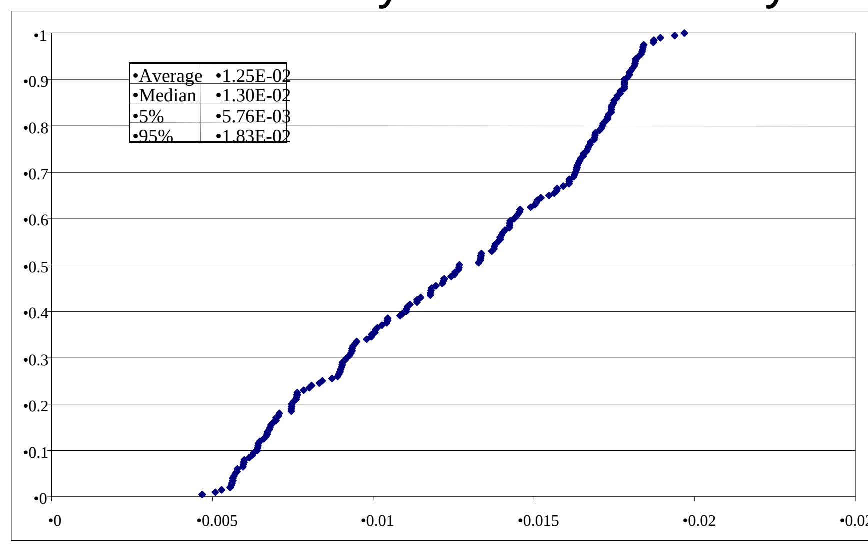


Estimate

- type of failures (recoverable or not)
- time for recovery

$$P_{non-recovery} = A + B \cdot e^{-\frac{T}{3,17}} + C \cdot e^{-\frac{T}{2}}$$

Uncertainty in ECCS Recovery



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Example 2: Hydrogen burn, early containment failure

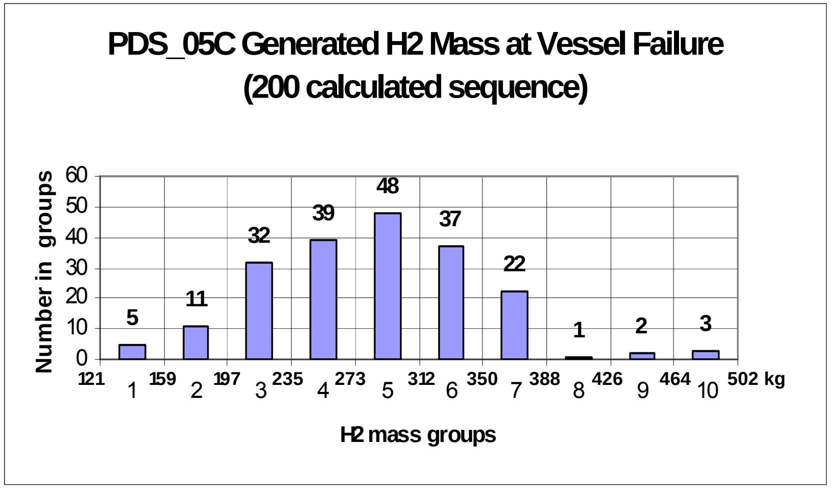
- A complicated process appears in a simplified manner in the CET. For the quantification of burn probabilities and in order to evaluate consequences the DET concept is introduced.

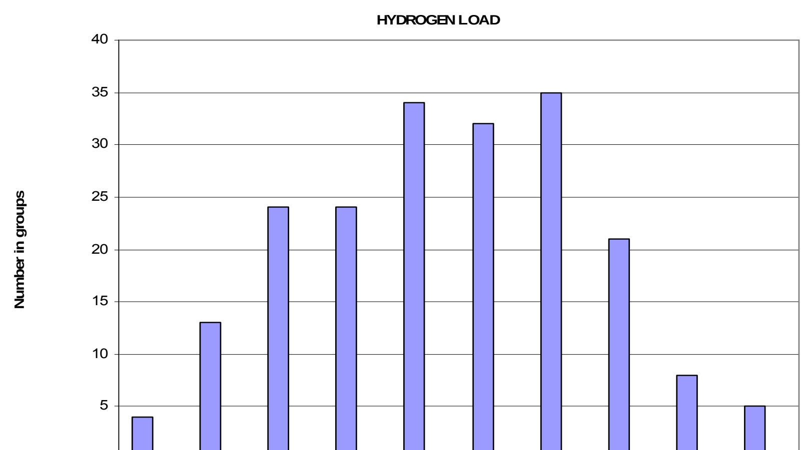
  - *Hydrogen mole fraction* – different hydrogen quantities are produced in each sample (MAAP4/VVER code calculation)
  - *Ignition* – probability of ignition depends on the existence of

    igniting sources (spontaneous ignition, recombiner) and also on the hydrogen concentration
  - *Combustion mechanism* – three combustion mechanisms are

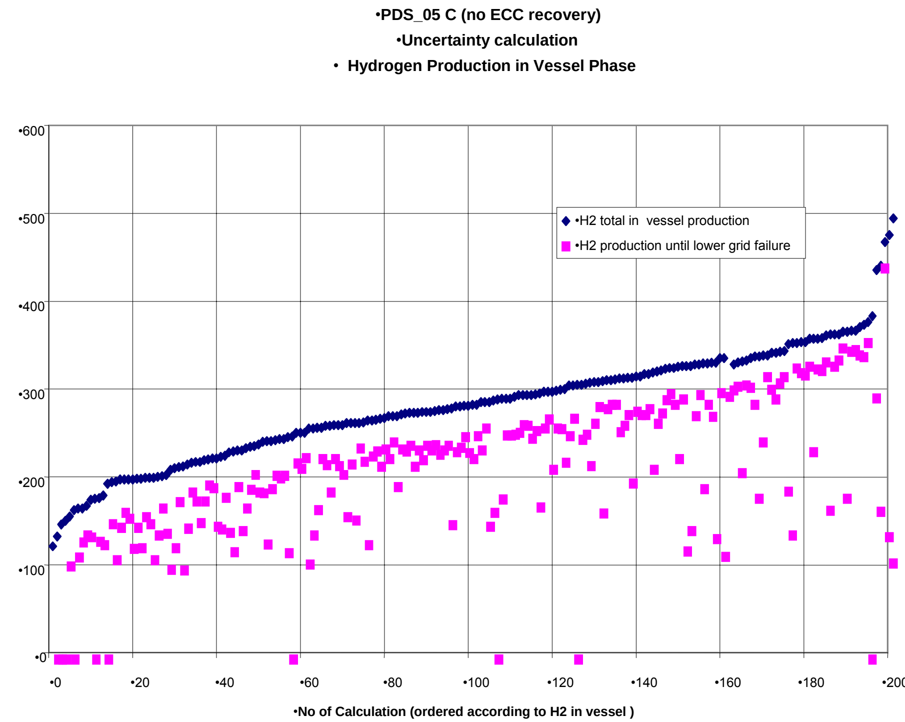
    distinguished (burn, accelerated flames and DDT) for the determination of containment pressure load the H2AICC is used with Modified Adiabatic Isochoric Complete Combustion (AICC) model
  - *Containment failure* - Joint treatment of containment loads and fragility curves

Example 2: Hydrogen burn, early containment failure cont'd





	1	2	3	4	5	6	7	8	9	10
Number in groups	4	13	24	24	34	32	35	21	8	5
Pressure (bar)	1.8	2.2	2.6	3	3.5	3.9	4.3	4.8	5.2	5.5



Hydrogen production - MAAP4/VVER

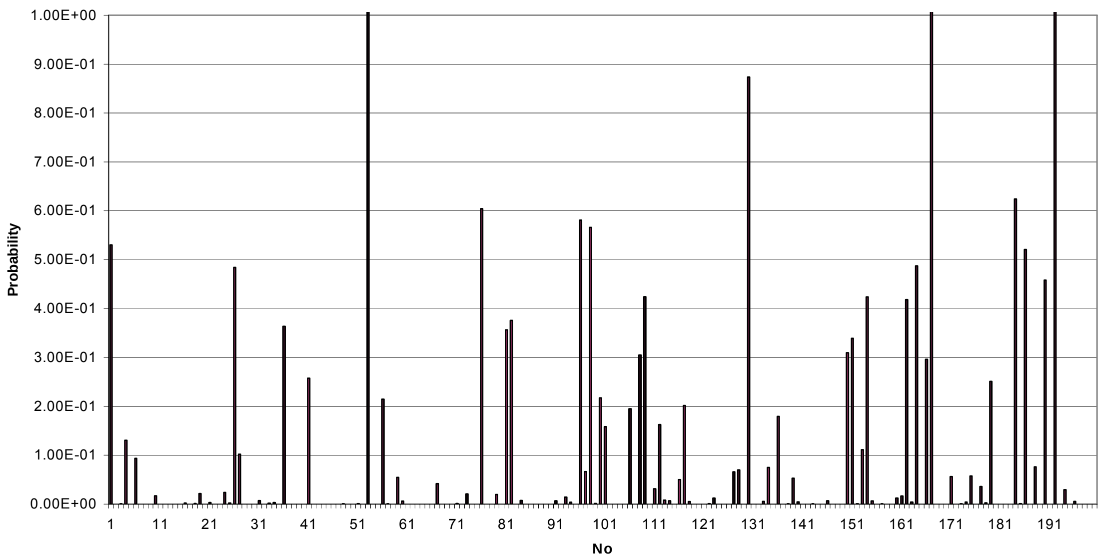
Hydrogen concentration - MAAP4/VVER

Containment load - H2AICC

Ignition probability - 4 variables (LHS)

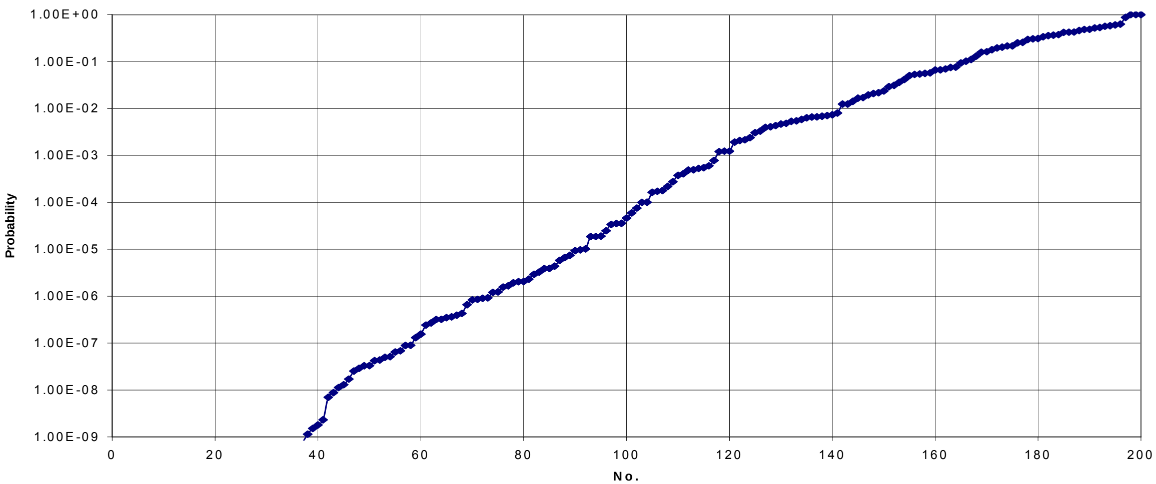
Example 2: Hydrogen burn, early containment failure
(Cont'd)

PDS_05 C Containment Early Failure Rupture Probability



Average	0,078
Median	$5{,}29\cdot10^{-5}$
Max.	1
Min.	0
Std. dev.	0,187
5% percentile	0
90%percentile	0,31
95% percentile	0,49

PDS_05C
Containment Early Failure, Rupture



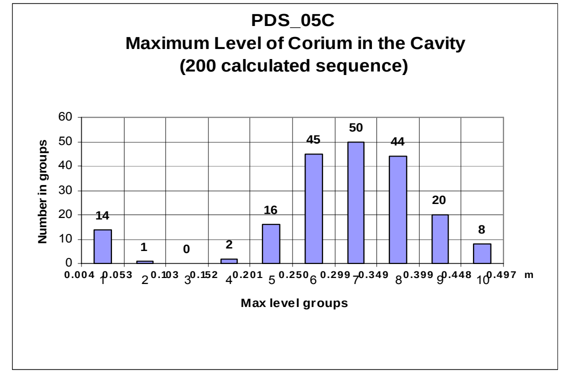
Fragility curve: *Frag(p) = P(pfail < p)*

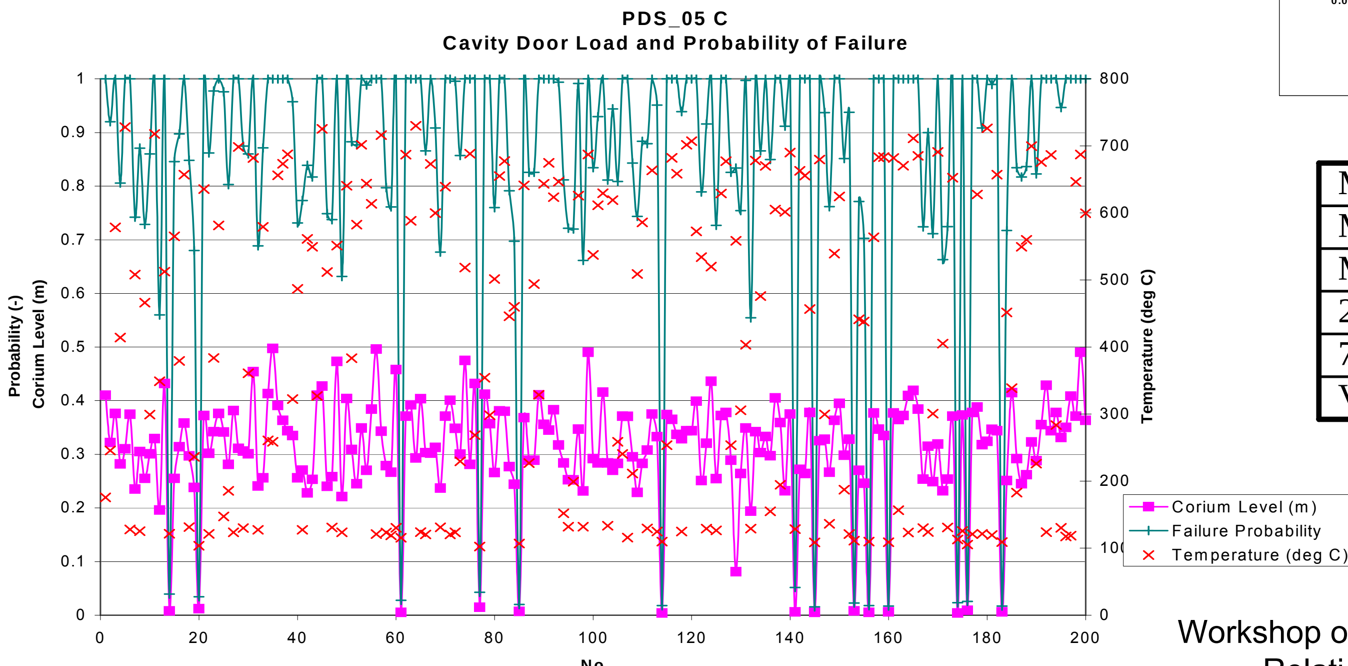
The probability of the load pressure is in the interval *(p, p+dp):*
P(pload = p) = F(p+dp) –F(p) = f(p)dp.

The Containment Failure Probability :
CFP(pload = p) = f(p)dp·Frag(p).
CFP = integral dp f(p) Frag(p)

Example 3: Late containment failure
Cavity Damage

- Reactor vessel cavity damage leads to late enhanced leakage
- Probability of cavity (door) damage determined as a function of two major factors (by using the results of MAAP calculations)
  - Temperature in the cavity
  - Corium level in the cavity
- Discrete probability values calculated from sampled simulations for each PDS

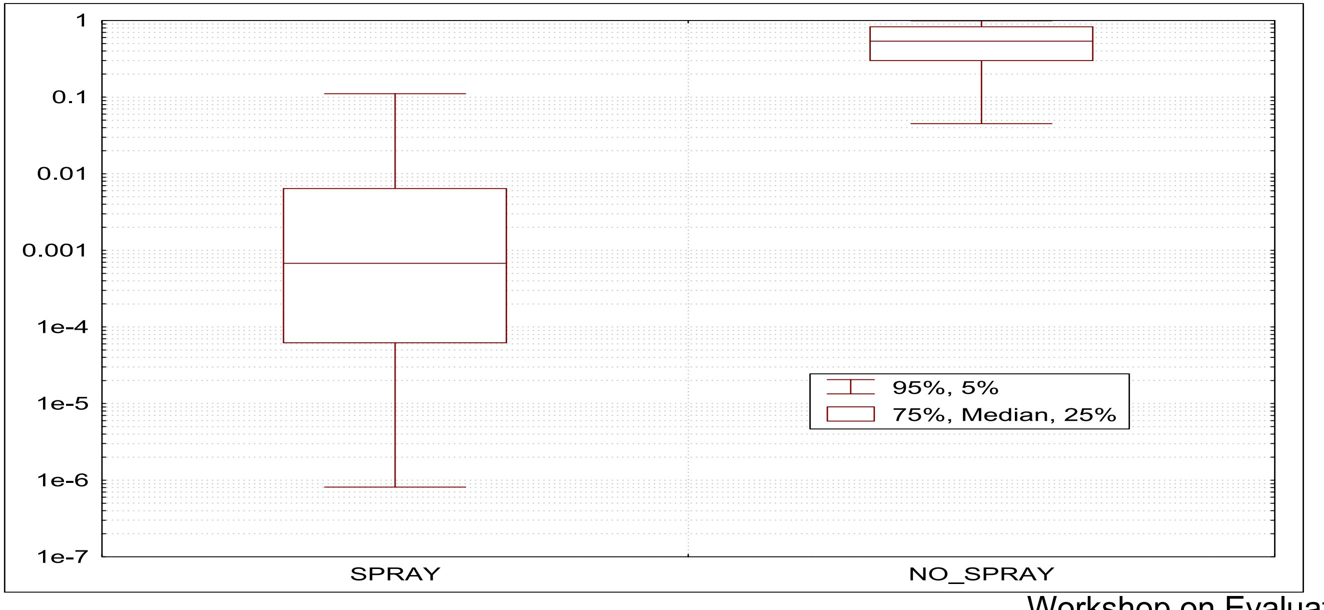




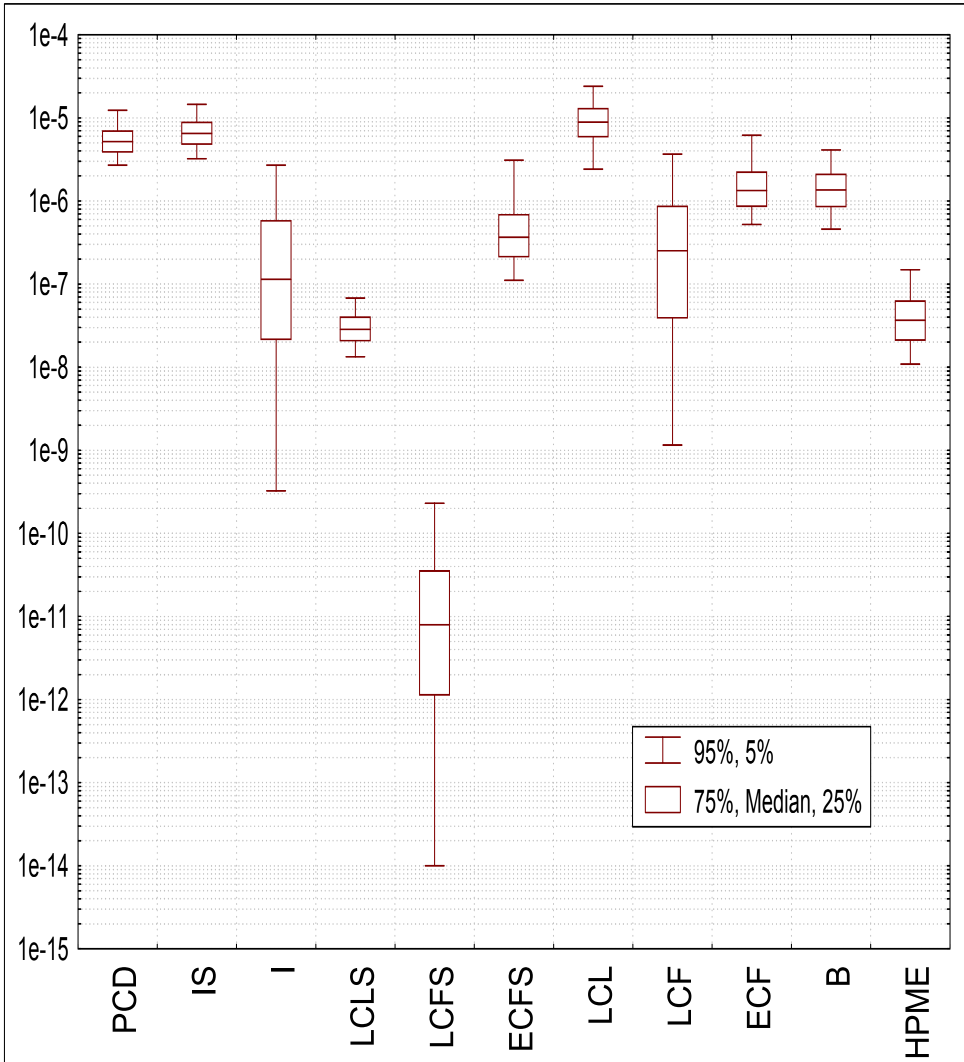
Mean	0,85
Median	0,99
Minimum	0,015
25%	0,81
75%	1
Variation	0,25

Example 4: Late Containment Failure Overpressurization

- Without enhanced leakage the containment pressure in late phase depends mostly on spray system operation
- Containment pressure at basemat melt-through was calculated for each sample
- Failure probability distribution was obtained by comparing calculated pressure values with that of the sampled fragility (pressure capacity) curves



Results of Uncertainty Propagation



	Containment State	Frequency, 1/year			
		Average	Median	95%	5%
1	Higy Pressure Melt Ejection	$5{,}38 \cdot 10^{-8}$	$3{,}64 \cdot 10^{-8}$	$1{,}47 \cdot 10^{-7}$	$1{,}09 \cdot 10^{-8}$
2	By-pass	$1{,}70 \cdot 10^{-6}$	$1{,}34 \cdot 10^{-6}$	$4{,}04 \cdot 10^{-6}$	$4{,}59 \cdot 10^{-7}$
3	Early Containment Failure	$2{,}05 \cdot 10^{-6}$	$1{,}32 \cdot 10^{-6}$	$6{,}17 \cdot 10^{-6}$	$5{,}22 \cdot 10^{-7}$
4	Early Containment Leakage	0,00			
5	Late Containment Failure	$8{,}77 \cdot 10^{-7}$	$2{,}50 \cdot 10^{-7}$	$3{,}65 \cdot 10^{-6}$	$1{,}24 \cdot 10^{-9}$
6	Late Containment Leakage	$1{,}09 \cdot 10^{-5}$	$8{,}83 \cdot 10^{-6}$	$2{,}39 \cdot 10^{-5}$	$2{,}43 \cdot 10^{-6}$
7	Early Containment Failure with Spray	$7{,}54 \cdot 10^{-7}$	$3{,}63 \cdot 10^{-7}$	$3{,}06 \cdot 10^{-6}$	$1{,}12 \cdot 10^{-7}$
8	Early Containment Failure with Spray	0,00			
9	Late Containment Failure with Spray	$4{,}88 \cdot 10^{-11}$	$7{,}87 \cdot 10^{-12}$	$2{,}26 \cdot 10^{-10}$	$1{,}35 \cdot 10^{-14}$
10	Late Containment Leakage with Spray	$3{,}32 \cdot 10^{-8}$	$2{,}83 \cdot 10^{-8}$	$6{,}73 \cdot 10^{-8}$	$1{,}33 \cdot 10^{-8}$
11	Intact containment	$6{,}92 \cdot 10^{-7}$	$1{,}13 \cdot 10^{-7}$	$2{,}67 \cdot 10^{-6}$	$3{,}29 \cdot 10^{-10}$
12	Intact containment with Spray	$7{,}47 \cdot 10^{-6}$	$6{,}43 \cdot 10^{-6}$	$1{,}45 \cdot 10^{-5}$	$3{,}23 \cdot 10^{-6}$
13	Partly Damaged Core	$6{,}03 \cdot 10^{-6}$	$5{,}12 \cdot 10^{-6}$	$1{,}23 \cdot 10^{-5}$	$2{,}71 \cdot 10^{-6}$

SUMMARY

- Uncertainty analysis for the level 2 PSA of NPP Paks has been performed with a combination of multiple severe accident simulations and the use of dedicated probabilistic methods and tools to express uncertainties of accident phenomena and consequently, containment states.
- The main advantage of this method is that it has proven capable of determining aleatory uncertainty of a level 2 PSA. Also, the method is robust and easy to use with the elaborated computer program.
- On the other hand the calculations were very time consuming in spite of the fast running code, MAAP. The automation of producing input for the codes and of running the MAAP and H2AICC code and finally uncertainty processing was allowed to perform this work in a reasonable time frame.