Uncertainty of the Level 2 PSA for NPP Paks

Gábor Lajtha,
VEIKI Institute for Electric Power Research, Budapest, Hungary

Attila Bareith, Előd Holló, Zoltán Karsa, Péter Siklóssy, Zsolt Téchy
VEIKI Institute for Electric Power Research, Budapest, Hungary

1. Introduction

In the Level 1 PSA for internal initiators and internal hazards of Paks NPP 60 initiating events starting from nominal power operation were studied and over 500 sequences were found to lead to „core damage" end state.

As the Level 2 PSA is based on the Level 1 PSA, Level 2 PSA also covers all the internal technological events occurring at nominal power and shut down states and also the influence of fire and flooding at nominal power.

This paper is a short summary of the uncertainty analyses performed so far within the level 2 PSA for NPP Paks [1]. Some important analysis steps and methods are highlighted with examples of results obtained. The uncertainty in containment failure state frequencies for NPP Paks is in the focus of attention in this paper.

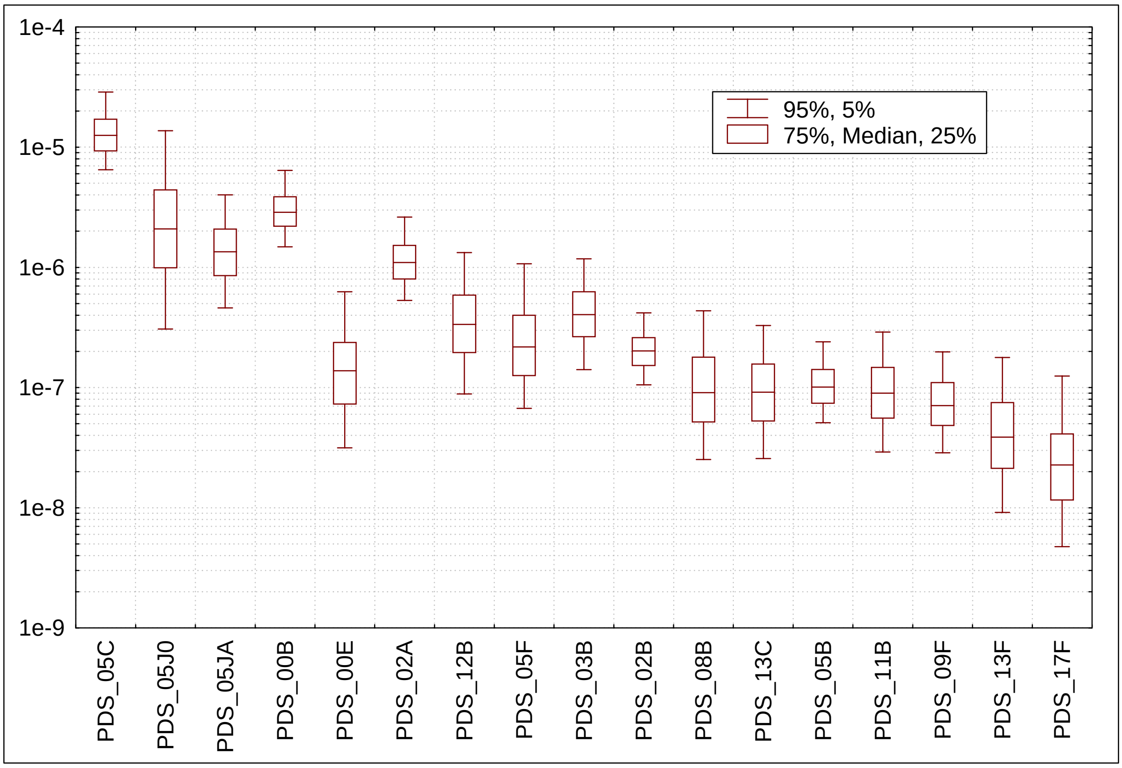
2. Uncertainties propagated from level 1 PSA to level 2 PSA

Propagation of uncertainties from the level 1 analysis to the level 2 PSA was expressed by determining uncertainties in plant damage state frequencies. Quantification was based on the use of the minimal cut sets for the different plant damage states. The reliability parameters for the basic events in a minimal cut set were treated as random variables with the associated probability distributions. Typically, lognormal distributions were assumed for component failure rates as taken from the level 1 PSA with some extensions required for modelling system and component failures that appear in the level 1 – level 2 interface model only (e.g. containment spray, containment isolation). Uncertainties in human error rates had originally been assessed on the basis of expert opinion in the level 1 PSA. The same approach and data were used for the PDS frequencies.

Monte Carlo simulation was applied to generate samples of basic event probabilities and these samples were used to determine PDS frequencies by means of propagating uncertainties through the PDS level minimal cut sets. Dedicated software was developed and used for this purpose, because the structure and complexity of the PSA model did not allow uncertainty calculations with the Risk Spectrum code (which was otherwise used for PSA model development). Software validation was performed by comparisons with results from Risk Spectrum calculation using a minimal cut set list that could be processed by Risk Spectrum too.

Figure 1 shows the distribution of PDS frequencies obtained for the dominant plant damage states.

Figure 1. Uncertainty in PDS frequencies



3. Uncertainties considered in the Containment Event Tree (CET)

Monte Carlo method was used to quantify uncertainty of the CET. Severe accident progression for CET branches was calculated by the MAAP4/VVER [2] code. The code input parameters were varied to determine the uncertainties in parameters, models as well as the numerical solution. Uncertainties in the different phenomena modelled in the containment event tree were determined on the basis of the results from these calculations.

Latin Hypercube Sampling (LHS) [3] was applied to generate 200 sample sets for each simulation cycle. The total number of parameters treated as uncertain was 50. 40 of these are the MAAP code parameters and 10 are representative for hydrogen ignition and containment fragility. The statistically independent parameters were chosen to cover each physical phase and process of a severe accident. The parameter ranges and distributions of these parameters were determined by the use of expert judgement and, also, by taking into account the suggestions of MAAP developers and literature data. Correct selection of varied parameters and their distribution is a difficult task. The final parameter ranges and distribution functions were determined as a result of discussions of the experts.

200 MAAP calculations were performed for each branch of the CET. It means that thousands of code runs were necessary for the uncertainty study. With the help of the MAAP output, supporting calculations were done to determine 200 probability values of each branching node in the CET. As a further step the H2AICC code was used for hydrogen load calculations and a special code for joint treatment of containment loads and fragility curves.

A master computer program was developed to automatically perform the simulation cycles for each branch of the CET. This master code updates the input for the MAAP code using the result of LHS, then initializes the severe accident calculation. The master code then transfers the output of MAAP for other codes, as H2AICC and it performs these runs. Finally the probability distribution of the branches are produced.

The probabilities of the branching nodes were determined using different numerical methods, depending on the nature of the phenomena modelled in the branch. Typical methods will be demonstrated in the next sections.

3.1. Melt progression arrested and spray system recovery

In the CET two nodes cover the important recovery actions:

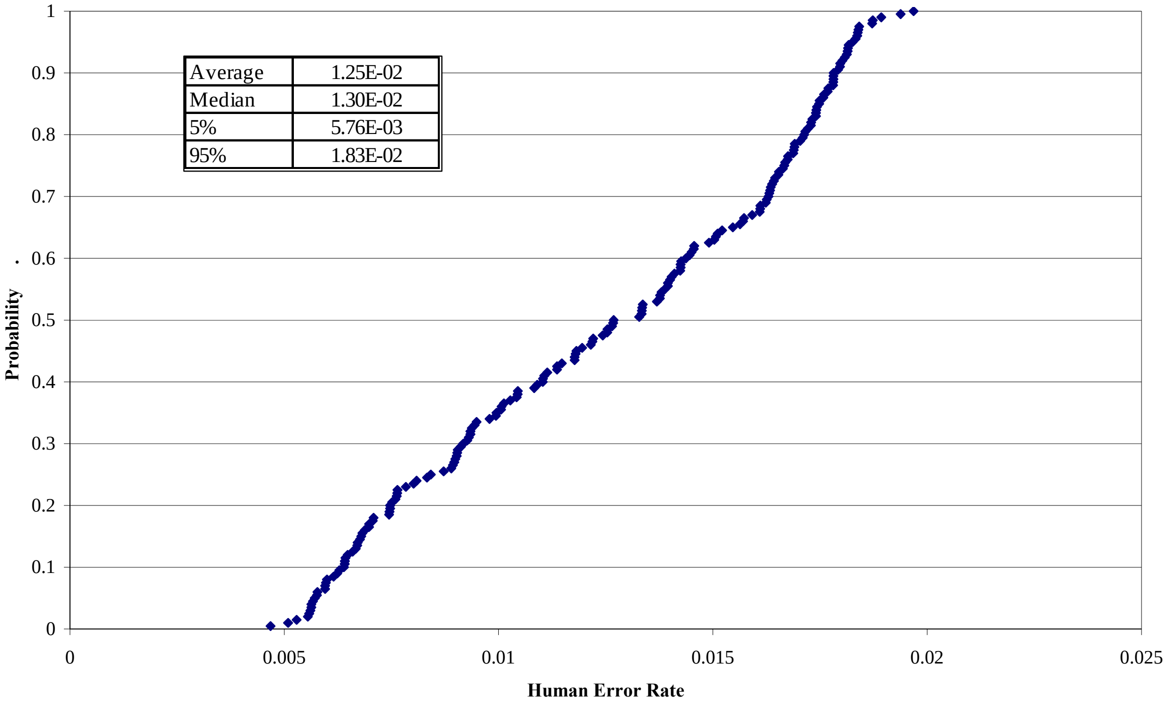
Melt progression arrested – there is a theoretical possibility that melt progression may be arrested by restoration of the emergency core cooling (ECC) system. Success depends on the contextual conditions for recovery and on the time window. Contextual conditions are considered in human reliability analysis based on the nature of the sequences that contain ECCS failure, whereas the available time is calculated by MAAP simulation. The 200 time values obtained from MAAP are considered when the uncertainty is quantified for this branch point.

Spray system recovery – Recovery of the containment spray system to limit fission product releases. It may happen as a result of recovery action for PDS with a non-functioning spray system. The approach to uncertainty assessment is the same as for the previous event.

Variability in the available time (i.e. time window) for the above recovery actions was taken into account in the uncertainty analysis based on the results of MAAP4/VVER calculations. The probability of recovery was calculated for the 200 time window values obtained from the MAAP analyses. This yielded uncertainty distributions for recovery probabilities in the respective event tree branches.

Variability in the context of recovery actions (performance influencing factors other than time) was not assumed in the quantitative uncertainty analysis, i.e. the same contextual conditions were considered valid as those assumed during point estimate calculations. However, sensitivity analysis was performed to study the changes in containment state and release frequencies as a function of recovery probability. Figure 2 demonstrates the uncertainty in recovery for a given plant damage state.

Figure 2. Uncertainty in ECCS Recovery for PDS_12B



3.2. Hydrogen burn, early containment failure

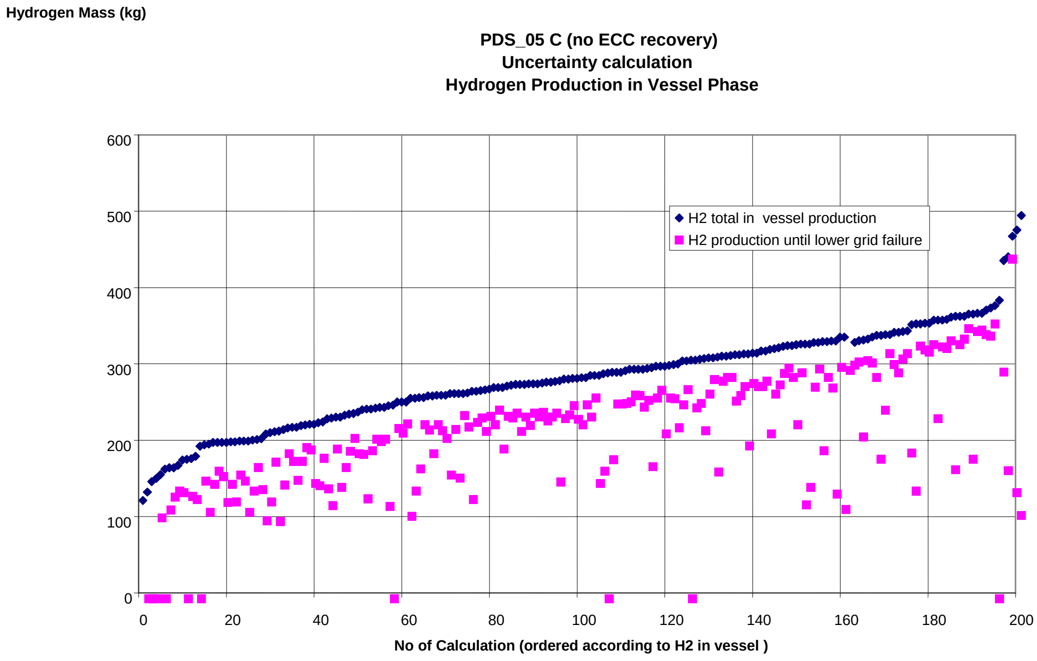
The uncertainty of the following two nodes was handled together:

Hydrogen burn – hydrogen is produced during fuel oxidation both in case of core melt and also during successful cooling. The uncertainty of the produced hydrogen is determined from MAAP results. The ignition probability is very uncertain, 4 parameters were chosen to express this uncertainty.

Containment failure: early rupture – potential containment failure mode due to hydrogen burn. It is calculated from the pressure load distribution and from the fragility distribution for each branch. 200 pressure load versus probability curves were developed from MAAP results using the H2AICC code and 10 fragility curves were chosen by LHS for convolution calculation of the containment failure probability. The uncertainty of containment failure probability is determined by the distribution of the probability values.

Hydrogen production and distribution in the containment were calculated by the MAAP code. A partial result of the calculations is the uncertainty of hydrogen production. Figure 4 shows the uncertainty range of hydrogen production for one branch (without ECC recovery) of the most probable PDS_05 C. It can be seen that for PDS_05 C the total amount of hydrogen varies between 100 and 500 kg, and the hydrogen production before the melt relocation to the bottom of the reactor vessel (squares in Figure 3) correlates with the total amount of produced hydrogen.

Figure 3. Result of MAAP calculation for PDS_05C, without ECCS recovery branch



The calculated range of containment failure probability is wide, and the uncertainty is considerable, as it is shown in Table 1.

Table 1. Analysis results for early containment failure due to hydrogen burn in case of PDS_05C without ECC recovery

Average	0,078
Median	$5{,}29 \cdot 10^{-5}$
Max.	1
Min.	0
Std. dev.	0,187
5% percentile	0
90% percentile	0,31
95% percentile	0,49

Thermal-hydraulic parameters and gas concentrations in the containment are calculated by the MAAP code. As a next step the probability of hydrogen ignition (varying 4 parameters of ignition probability distribution together and the hydrogen concentration in the containment) is calculated.

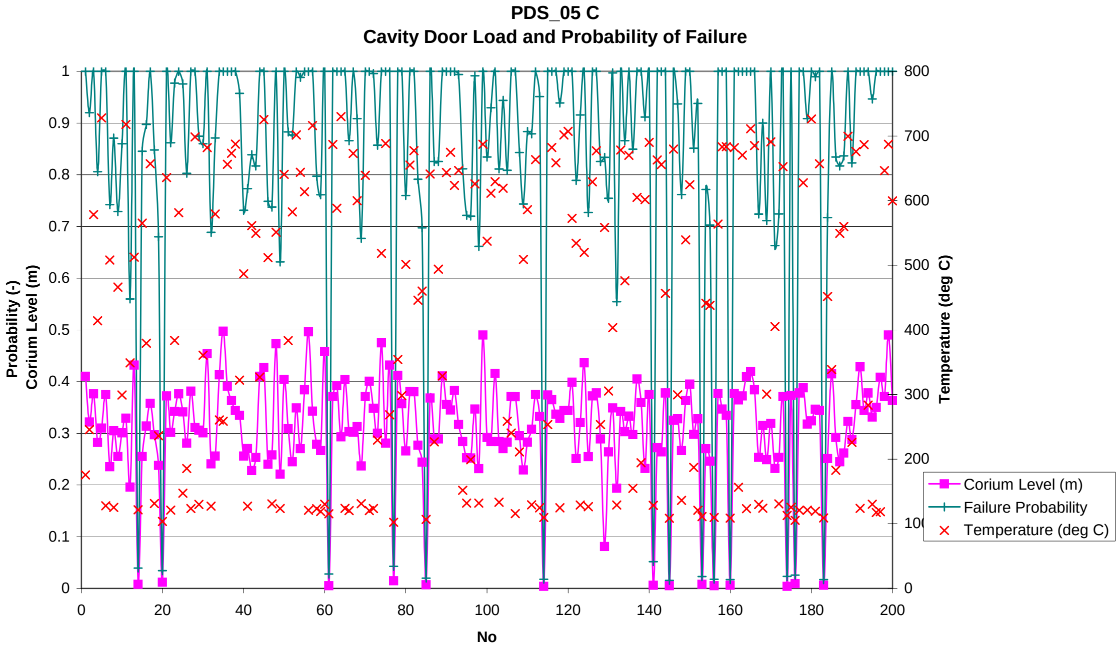
The hydrogen load is calculated 200 times for each branch of the CET by the H2AICC code. The AICC calculations are conservative with respect to pressure loads, especially at lower hydrogen concentrations. Therefore a modified AICC curve was elaborated on the basis of experimental loads. Then combining the 200 ignition probabilities, 200 containment loads and 10 fragility curves, containment failure probability distribution is determined.

3.3. Late containment failure

The most probable late failure mod of the containment is late leakage. The root cause of the leakage is that the reactor cavity door sealing fails due to temperature load. For the determination of the uncertainty of this node, severe accident calculation and expert judgement were employed. MAAP is used to calculate the temperature and the maximum level of the corium in the cavity. Expert judgement is used to determine the probability of the cavity door sealing failure. The uncertainty of this branch point is derived from the 200 simulation runs for each CET sequence.

Reactor cavity can get damaged because of load from high temperature. Temperature load on the cavity depends on the heat transfer from the atmosphere - temperature in the cavity - and on radiation from the melt – level of the melt in the cavity. The probability of the door seal failure was determined according to these parameters. The result of a calculation can be seen in Fig. 4.

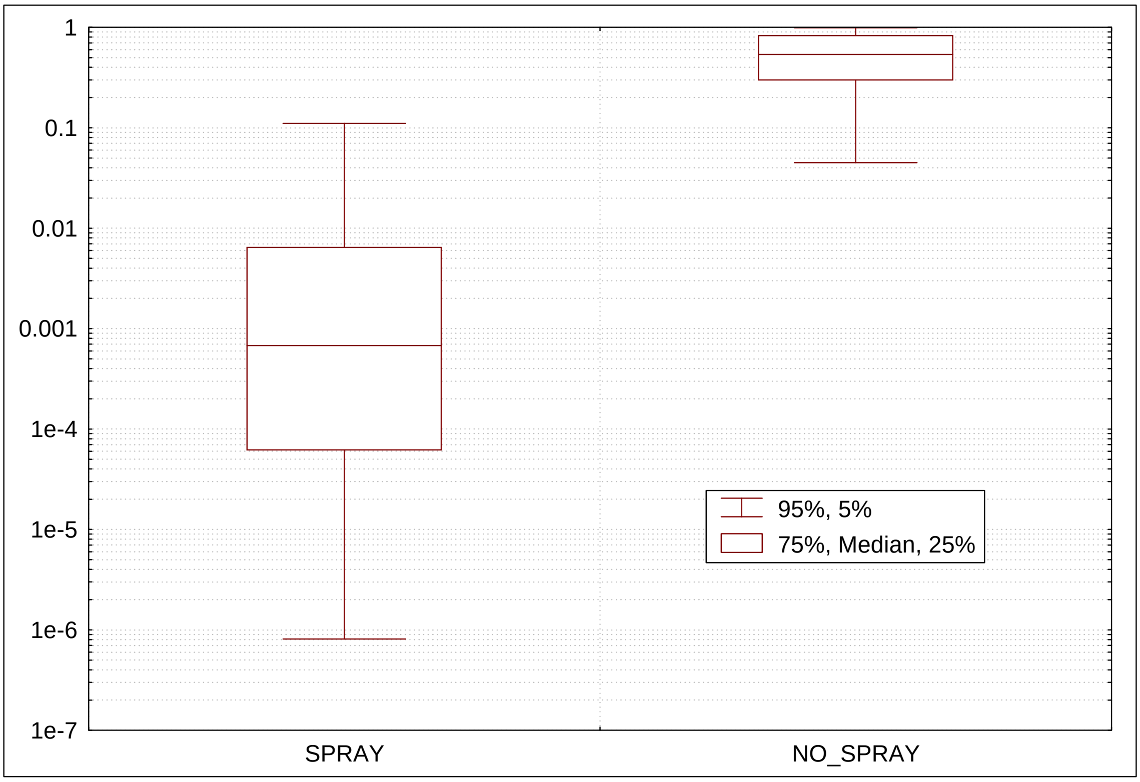
Figure 4. Probability of cavity door seal failure and associated uncertainties



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

Finally, potential late failure due to rupture may occur as a result of overpressurisation. The pressure load from the slow overpressurization is calculated by MAAP. Containment pressure at the time of basemat melt through was compared to the chosen fragility curve. It gives 200 probability values for the late containment failure, the corresponding results can be seen in Figure 5.

Figure 5. Uncertainty of late containment failure

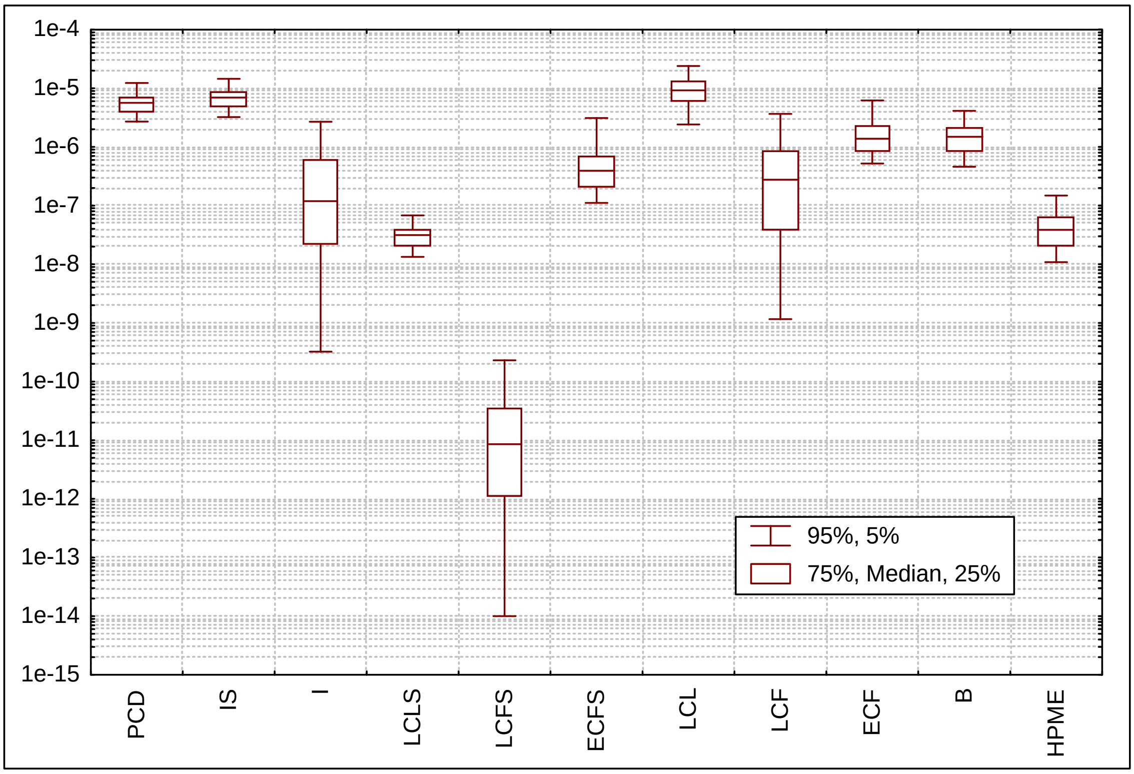


4. Propagation of uncertainties to containment failure states

The uncertainty distributions for the PDS frequencies and for the CET branches were sampled and then the frequencies of containment failure states were calculated on the basis of this sampling in accordance with the logic of the CET sequences. As a result, uncertainty distributions were obtained for each containment state that can develop from a PDS. The total uncertainty for a containment state was determined by combining the PDS level results for the given containment state. Also, the results for the different containment states were further aggregated to obtain overall measures of uncertainty in the consequence categories defined for the purpose of the Paks level 2 PSA [4]. A dedicated spreadsheet based tool was developed and used to propagate uncertainties.

The uncertainty of the containment states is shown in Figure 6. It can be seen that the uncertainty of long term processes is larger than that of early containment failure likelihood.

Figure 6. Uncertainty of containment states



5. Conclusions

Uncertainty analysis for the level 2 PSA of NPP Paks has been performed by a combination of multiple severe accident simulations and by 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 thanks to 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 allowed to perform this work in a reasonable time frame.

References

[1] E. Holló, A. Bareith, G. Lajtha: Paks NPP level 2 PSA Uncertainties VEIKI 21.51.-413/2 Budapest October 2004
[2] WENX-93-25 Rev. 1, MAAP4/VVER , User Guide
[3] R. L. Iman, M.J. Shortencarier: A FORTRAN 77 Program and User's Guide for generation of Latin Hypercube and Random Samples for Use with Computer Models, NUREG/CR -3624, M
arch 1984
[4] Zs. Téchy, G. Lajtha, Z. Karsa, P. Siklóssy, A. Bareith, E. Holló: Level 2 PSA Uncertainty Study (in Hungarian) Budapest 2004 Sept. VEIKI Biztonságtechnika^{+} Mérnöki Iroda Kft 194-31-000.