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RISK AND SENSITIVITY ANALYSIS IN RELATION TO EXTERNAL EVENTS

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ABSTRACT

This paper presents risk and sensitivity analysis of external events impacts on the safe operation in general and in particular the Ignalina Nuclear Power Plant safety systems. Analysis is based on the deterministic and probabilistic assumptions and assessment of the external hazards. The real statistic data are used as well as initial external event simulation. The preliminary screening criteria are applied. The analysis of external event impact on the NPP safe operation, assessment of the event occurrence, sensitivity analysis, and recommendations for safety improvements are performed for investigated external hazards.

Such events as aircraft crash, extreme rains and winds, forest fire and flying parts of the turbine are analysed. The models are developed and probabilities are calculated. As an example for sensitivity analysis the model of aircraft impact is presented. The sensitivity analysis takes into account the uncertainty features raised by external event and its model.

Even in case when the external events analysis show rather limited danger, the sensitivity analysis can determine the highest influence causes. These possible variations in future can be significant for safety level and risk based decisions. Calculations show that external events cannot significantly influence the safety level of the Ignalina NPP operation, however the events occurrence and propagation can be sufficiently uncertain.

1 INTRODUCTION

The Ignalina NPP as a lot of others NPP's made significant safety improvements after Chernobyl accident. Efforts to perform additional deterministic and probabilistic analysis and improve safety of NPP's were also accelerated in Lithuania. Level 1 Probabilistic Safety Assessment (PSA) and Safety Analysis Report (SAR) of the Ignalina NPP were completed in 1994 and 1996 respectively. The results of these analyses clearly indicated the need of continued attention for the risk analysis and safety improvements. More improved models were created and new analysis approaches were attempted as an outcome of new computation and result analyses possibilities. The recent results together with applied sensitivity and uncertainty analysis related to external events are presented in this paper.

The safety of Ignalina NPP in relation to external events is significant in order to evaluate reliability and risk limits and prevent potential failure of the system important to safety. In order to estimate external events' influence to safety of Ignalina Nuclear Power Plant and to determine the contribution to global damage frequency in relation to PSA, Lithuanian Energy Institute in close cooperation with Ignalina NPP staff has performed probabilistic risk assessment. To increase the realism of the risk model a set of deterministic analyses and plant-specific database were used. A general concept for analysing this type of events was developed and the new simulation approach of event occurrence is proposed.

2 EXTERNAL EVENTS ANALYSIS

2.1 Screening of External Events

An extensive review of information on the site region and Ignalina NPP design were performed to identify all external events to be considered. A set of screening criteria was utilised to identify those external hazards which could be screened from further analysis and reduce the amount of detailed bounding analysis required. These criteria were based on those in the standard PSA/PRA methodology (NUREG/CR-2300) and shortly listed below. An external event can be excluded from further consideration if:

1. The event is of equal or lesser damage potential than the events for which the plant has been designed.
2. The event has a significantly lower mean frequency of occurrence than other events with similar uncertainties and could not result in worse consequences than those events.
3. The event cannot occur close enough to the plant to affect it.
4. The event is included in the definition of another event.
5. The event is slow in developing and there is sufficient time to eliminate the source of the threat or to provide an adequate response.

The use of these criteria minimizes the possibility of omitting the significant contributors in total risk estimation and at the same time allows reducing the amount of the detailed analysis. The external events representing danger for Ignalina NPP were identified according to the statistical analysis, reasons of their occurrence and specifications of plant. Sources of this information were: the SAR, the Review of SAR and the statistical data on external events, which were received from the appropriate institutions of the Lithuanian Republic. For the chosen external hazards the detailed analysis was carried out or the criterion was specified, on which the event was excluded from the further analysis. For each external event, the applicable screening criteria (if any) are included in the Table 1.

Table 1. Preliminary screening of external hazards for Ignalina NPP

The screening criteria (shown in brackets) were applied to the number of external hazards such as:	**The following events were identified as requiring further bounding study:**
• Biological events (1); • Fog (1,4); • Meteorite (2); • Coastal erosion (2,5); • Gas or oil pipeline accident (3); • Transportation accidents (3); • Extreme rains (4) • Drought (5).	• Aircraft catastrophe; • Flying parts of the turbine; • External flooding; • Extreme winds and hurricanes; • Forest fire.

In summary, the findings of the preliminary screening are, that the following events were identified as requiring further detailed external hazards analysis, which would asses the occurrence probability and study the events influence on safety of INPP: aircraft impact, extreme winds and tornado, flooding and strong rains, external fire, turbines missiles. The presumptions and results of bounding analyses performed for these events are discussed in the following sections.

2.2 Aircraft Catastrophe

An aircraft crash into the NPP can cause severe damages to the plant. Even if the catastrophe takes place near the NPP it is usually followed by explosion and fire and can significantly influence safe operation of the plant.

Probabilistic model of the aircraft accident was developed to estimate probability of this critical event occurrence near the Ignalina NPP. There is no exact way to model a problem of this type and some of the factors cannot be easily quantified. However, various authors proposed some approximate methods [1]. As there are no airports in the surroundings of the Ignalina NPP the strike probability/year was estimated as:

$$P = P_l \cdot N_c \cdot A \cdot F; \qquad (1)$$

Where P is aircraft strike probability/year, P_l is aircraft strike frequency per flight kilometre, N_c is flight number per year, A is target area, F is function of deviation from initial flight route during an accident.

As all flights below 6000 meters are prohibited in the area of 10 km radius around the Ignalina NPP, aircraft accident sources were considered to be international air corridors <NDB 286 ROK> and <DUBIN>. According to the data of Lithuanian flight control center flight intensity in the Lithuanian corridor <NDB 286 ROK> was approximately 20000 flights per year. As flight intensity data in the Belarussian-Latvian corridor <DUBIN> were not exactly known the maximum number of flights was conservatively estimated to be 50000 per year. To maintain conservative approach air corridors of 50 km width were modelled to pass in 10 kilometres distance from the Ignalina NPP.

Aircraft strike frequency per flight kilometre was obtained from Department of Civil Aviation and is shown in Table 2. Flights are carried out by both western and eastern airlines. Therefore, catastrophe intensity was taken separately for western and soviet type planes.

Table 2: Aircraft strike frequency per flight kilometre for western and soviet type airplanes

Catastrophe frequency	**Western type aircraft**		**Soviet type aircraft**	
	Below 5700 kg	Above 5700 kg	Below 5700 kg	Above 5700 kg
P_l, per flight kilometre	8.4E-08	1.2E-09	1.0E-07	1.3E-09

An area around the Ignalina NPP, which is sensitive to the aircraft strike, was taken as a circle of a given radius. Strike probability was computed for circles of different radius (50, 100, 150, 200 meters). Results of the computations are shown in Table 3. In order to estimate sensitivity of the model, the strike probability was computed for different aircraft catastrophe intensity.

Table 3: Aircraft strike probability on the Ignalina NPP territory

	Aircraft strike frequency per flight kilometre			
Radius r, meters	1.0E-07	8.4E-08	1.3E-09	1.2E-09
50	5.7E-08	4.8E-08	7.4E-10	6.8E-10
100	2.3E-07	1.9E-07	2.9E-09	2.7E-09
150	5.1E-07	4.3E-07	6.7E-09	6.1E-09
200	**9.1E-07**	7.6E-07	1.2E-08	1.1E-08

In summary, aircraft strike probability on the Ignalina NPP was estimated to be lower than 9.1E-07. Therefore the risk of aircraft crash and resulting plant damage is considered negligible. It is however reasonable to perform recalculations if flight intensity grows rapidly in the future.

2.3 Flying parts of the turbine

If turbine missile impacts a barrier enclosing a safety-related component, interest lies in knowing if the missile perforates or scabs the barrier to cause sufficient damage to the component. The needs for providing such barriers depend on the probability of turbine failure and the arrangement of safety-related components with respect to interior missile trajectories.

Probability of serious damage from turbine missiles was estimated as follows:

$$P = P_1 P_2 P_3; \qquad (2)$$

Where P_1 is probability of turbine failure leading to missile generation (event / year), P_2 is probability of missiles striking a barrier which encloses the safety system given that the missile(s) have been generated (event / year) and P_3 is the probability of unacceptable damage to the system in case that one or more missiles strikes the barrier (event / year).

According to the empirical data and conservative assumptions [2] the probabilities for P_1, P_2, P_3, P were estimated for cases with unfavourably orientation of a rotor (the axis of the turbine rotor rotation is perpendicular to a reactor direction) and for a case with favourably orientation of a rotor (the axis of the turbine rotor rotation is parallel to a reactor direction). According to the conservative assumptions and statistical estimation for the second case it is accepted that P_1=1.0E-04 and P_2 P_3=1.0E-02 [2]. However, if a plant has an in-service inspection program, the conservative probability of turbine failure leading to missile generation can be estimated as $P1 \leq$ 1.0E-05 1/year and then the probability of serious damage from turbine missiles is $P \leq$ 1.0E-07 1/year.

The orientation of Ignalina NPP turbines is such that the rotor rotation axis is perpendicular to a reactor direction. Thus, the product of the probability of missiles striking a barrier which encloses the safety system and the probability of unacceptable damage to the system, in case that one or more missiles strike the barrier, can reach the size 1.0E-02 1/year. Besides, as the periodic in-service inspections of turbines are carried out, at the conservative approach and using statistical estimation it is possible to assume, that the probability of turbine failure leading to missile generation is equal to 1.0E-04 1/year. And finally, the probability of serious damage from turbine missiles can be estimated as 1.0E-06 1/year and it is possible to consider that influence of such event on safety of Ignalina NPP is negligible.

2.4 External Flooding

External flooding can be caused by extremely high water level in lake Druksiai, which serves as a coolant for service water system (SWS) of the Ignalina NPP. Lake Druksiai is 42 km^2 size and contains 3.26E+08 m^3 water. In case of flooding pump station of the SWS, which is situated nearest to the lake, will be affected first. High water level can damage SWS pumps and electrical installations resulting in immediate reactor shutdown.

Nominal lake Druksiai water level elevation is 141.6 meters. Critical elevation for the SWS pump station is 144.1 meters. The main buildings of the Ignalina NPP are situated higher than 148-149 meters elevation. Mathematical model was created to estimate probability of high flood resulting in SWS damage. For this purpose historical data (see Figure 1) for the period 1950-1985 were analysed and extreme values were predicted from normal distribution.

1- the highest elevation changes; 2 - the lowest elevation changes.

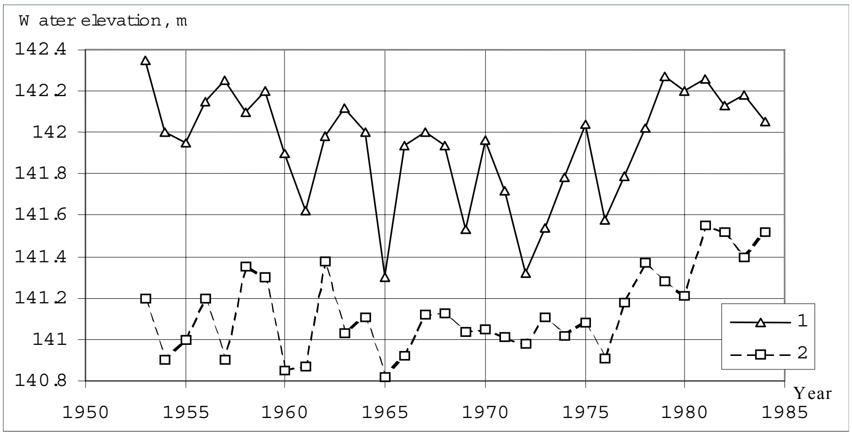

Figure 1: Elevation changes in lake Druksiai year 1950-1985

Calculated probabilities for different water elevations are shown in Table 4. The results prove the conclusion that extremely high external flooding, which could threaten a safe operation of the Ignalina NPP is incredible.

Table 4: Flood elevation probabilities

Elevation, m	Elevation from nominal level 141.6	Probability / year
142.0	0.4	0.41
142.5	0.9	1.8E-02
142.8	1.2	6.2E-04
143.0	1.4	8.6E-05
143.2	1.6	3.2E-06

To evaluate probability of extremely high precipitation the observation data in Lithuania and eastern regions were analysed. With the probability of 10^{-6} the precipitation level, which was reached less than in 12 hours, was calculated to be 279.7 mm. This cannot significantly influence the safety level of SWS.

2.5 Extreme Winds and Hurricanes

Extreme winds, hurricanes or tornadoes can have significant impact on structural integrity of the Ignalina NPP buildings and equipment. Therefore a statistical analysis was performed of available meteorological data in order to estimate hurricane and extreme wind probabilities.

Table 5: Extreme winds probabilities

Wind speed, m/s	**Probability /year**
40	6.8E-03
50	1.1E-03
60	1.9E-04
70	3.2E-05
80	5.3E-06

Meteorological data were available for the period 1961-1995. Extreme winds probabilities are shown in Table 5. In fact wind speed of 40-60 m/s cannot have a significant impact on the safety of the Ignalina NPP and probabilities of higher speed are negligible. F2-F3 class by Fujitsu scale hurricane probability in 1 km^2 around the Ignalina NPP was estimated to be 4.4E-06 per year. Therefore risk of this event can also be considered as non-significant.

2.6 Forest fire

Forest fire was found to be one of the most probable external events to occur. Although it cannot have direct impact on Ignalina NPP safety, but the smokescreen can disturb an operation. This can also cause some difficulties for the personnel as a venting system takes fresh air from the outside and has no protecting sensors for the outside smoke.

There are about 2000 hectares of forests in 10 kilometres diameter circle around the Ignalina NPP. The shortest distance from the NPP territory to forest is less than 0.5 km. A forest fire probability in the NPP surroundings was calculated directly from statistical data on forest fires in Lithuania for the period of 1993-1997 (see Table 6).

Table 6: Number of fires in different areas during 1993-1997

Fire area in hectares	Number of fires
<5	3161
5-10	4
10-20	8
20-50	2
>50	1

The forest fire probability in 20 hectares area was calculated to be 1.5E-03 per year and in 50 hectares area - 1.5E-04 per year (see Figure 2). A probability of 100 hectares area forest fire is estimated to be 2.8E-06 per year.

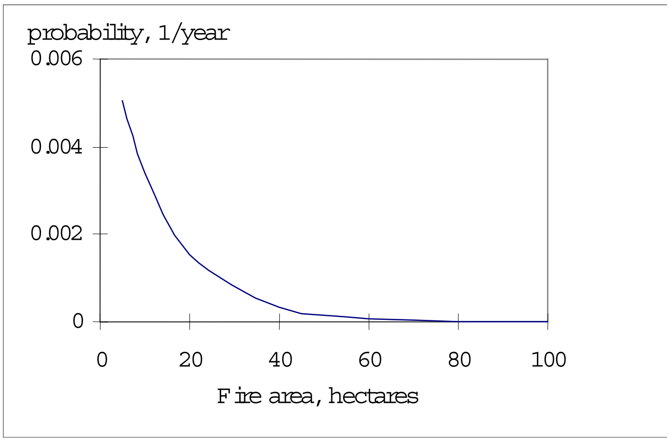

Figure 2: Different area fire frequencies in 2000 hectares of forests

The forest fire was indicated as an external event with the highest probability. However, its impact on safety level of the Ignalina NPP is limited, and therefore no additional protective actions are required.

3 SIMULATION AND SENSITIVITY ANALYSIS

3.1 The analytical approach

The approach suggested for uncertainty and sensitivity analysis, and illustrated in this paper by an application of SUSA (GRS Software System for Uncertainty and Sensitivity Analyses), is based on well-established concepts and tools from probability calculus and statistics. It requires identification of the potentially important contributors to the uncertainty of the model results and the quantification of the respective state of knowledge by subjective probability distributions [3]. Such a distribution expresses how well an uncertain parameter of the model application is known. The aim of sensitivity analysis is to identify the main contributors to the possible variations of results. Sensitivity analysis is often performed in connection with uncertainty analysis in order to see the combined influence of all the potentially important uncertainties on the result.

3.1.1 Sampling and uncertainty measures

The quantitative uncertainty analysis results can be expressed as quantiles (as example 5% and 95%) of the result distribution. They could be obtained easily if result distribution was known. In practice these quantiles are estimated using parameters subjective probability distributions and Monte Carlo simulations. The quantitative uncertainties of model parameters can be expressed by the parameters distribution with mean and standard deviation values. Standard deviation in normal distribution case can be assumed as a value, which is three times less than the interval between maximum and minimum values. If distribution is untruncated, then the probability, that parameter value belongs to this interval, is 0.866. Otherwise, if distribution is truncated, then it is one. The simulations are performed for each sample set (all random parameters varied simultaneously). For this purpose, the special software using Visual Basic programming language was created. It was also integrated into SUSA, so that the desired quantiles can be estimated from this sample by standard statistical techniques.

In addition, it is needed to quantify the possible impact of the sampling error. Usually this can be done by the computing (u, v) statistical tolerance limits. Where *v* is the confident level that maximum model result will not be exceeded with the probability *u* (or % quantile, which reflects the amount of combined influence of all quantified uncertainties) of the corresponding output distribution, which is to be compared to the acceptance criterion. The confidence statement quantifies the possible influence of the fact that only a limited (frequently small) number of model runs have been performed. For example, according Wilks' formula, 93 runs are sufficient to have two sided (0.95, 0.95) statistical tolerance limits. The required number n_1 of runs for one-sided tolerance limits and correspondingly the number n_2 for two-sided statistical tolerance intervals can be expressed as following:

$$n_1 \geq \ln(1-v)/\ln(u); \tag{3}$$

$$n_2 \geq (\ln(1-v) - \ln((n_2/u) + 1 - n_2))/\ln(u). \tag{4}$$

The minimum number of model runs needed for these limits is independent of the number of uncertain quantities taken into account and depends only on the two probabilities u and v given above. The amount of runs is a result from nonparametric statistics. Its advantage is that this amount is completely independent of the number of uncertainties taken into account and does not assume any particular type of underlying distribution. The distribution event does not need to be continuous [3].

An element of modelled sample is called a parameter vector and is composed of one value for each of the uncertain quantities. The model is run with each parameter vector in the sample, and the alterative sets of the obtained output values constitute again a random sample. Using this sample and applying statistical concepts and methods in SUSA it can be derived quantitative uncertainty statements. For this paper we chose simple random sampling as the sampling strategy. Another well-known strategy is the so-called Latin hypercube sampling [4]. Quantile estimates from Latin Hypercube sample (LHS) can be expected to show less variability from sample to sample, however statistical tolerance limits cannot be computed from LHS [3].

3.1.2 Sensitivity measures

Results from applications of models are subject to uncertainty. An uncertainties analysis can provide a statement about the combined influence of potentially important uncertainties on the results. Often more important, it provides quantitative sensitivity statements that rank the uncertainties with respect to their contribution to the model output uncertainty [5].

The results from the model runs, together with the respective parameter vector of the sample, are subsequently used to derive global sensitivity measures. They account both the differential sensitivity of the model result with respect to the uncertain parameter and the parameter uncertainty. Thus they are suited to rank uncertainties according to their contribution to model output uncertainty.

From the many measures available, standardized regression coefficients (SRCs) are chosen here. They are capable of indicating the direction of the contribution (negative means inverse proportion). Additionally, the correlation ratios are computed. The correlation ratio is the square root of the quotient of the variance of the conditional mean value of the model result (conditioned on the uncertain parameter) divided by the total variance of the model result due to all uncertainties taken into account. So it serves as a measure, how one model uncertainty was quantified through a set of alternative model formulations.

In case the numbers of uncertainties are large and sample size is small, spurious correlations can play a non-negligible role. The effect of spurious correlations on sensitivity measures may be avoided if the estimates of correlation coefficients and standardized regression coefficient are compared [3]. However, the correlation ratio and SRCs usually are the main sensitivity measures. The correlation ratio quantifies degrees of parameters and results relationship. SRCs can be obtained from stepwise regression. A standardized regression coefficient is supposed to tell by how many standard deviations the model result will change if the uncertain parameter is changed by one standard deviation. How well this is achieved in practice depends on the degree of linearity between the model result and the uncertain parameter. In the case of strong nonlinearities, rank transformation of parameter values and model results in the sample generally helps to improve the quality of the measure, especially in the case of monotonicity [4].

From the above-presented explanation, it becomes evident that the analytical results can only be as good as the input to the analysis. Care in the identification of the potentially important uncertainties, in the quantification of the respective state of knowledge, and also in the selection of measures for uncertainty and sensitivity are rewarded by new modelling possibilities and informative uncertainty and sensitivity statements. The options described above and chosen for this illustration of the approach are, together with others of potential use, part of the software system SUSA [4].

3.2 An example aircraft impact model

As an example model for sensitivity analysis the probabilistic model of the aircraft accident is used. In the above section a total aircraft impact probability on the Ignalina NPP was estimated using the conservative assumptions and the following model:

$$P = \frac{N_c P_l r^2 g}{8} \int_{-50}^{50} \frac{e^{-g\sqrt{x^2+100}}}{\sqrt{x^2+100}} dx \; ; \qquad (5)$$

Where P is aircraft impact probability/year, P_l is aircraft impact frequency per flight kilometre and N_c is flight number per year.

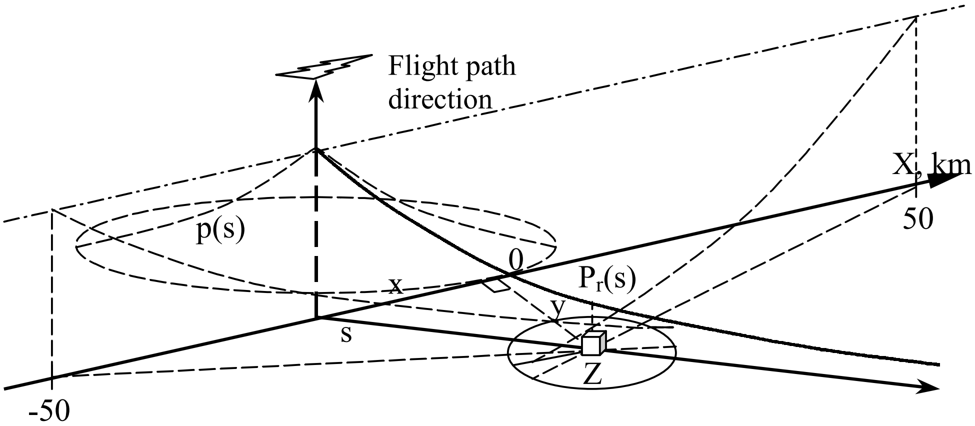

Figure 3: Aircraft impact probability per year on the circle with radius **r**

In example case for sensitivity analysis the improved assumptions and model of aircraft impact (see Figure 3) were used. An aircraft impact probability $P_r(s)$ on the NPP area Z (circle with radius **r)** can be computed from:

$$P_r(s) = \iint_Z p(s) \cong \frac{r^2 \cdot g^2 \cdot e^{-g \cdot s}}{2} \text{, where } \frac{\pi}{g} \cdot p(s) = \frac{g}{2} \cdot e^{-gs} ; \int_0^{2\pi} \int_{-\infty}^{\infty} p(s) ds d\varphi = 1 , \qquad (6)$$

if accident starts in distance **s** from the NPP.

The ircraft distance **s** to the NPP under above described assumptions is obtained from:

$$s = \sqrt{x^2 + y^2} \text{ , and } y = 10, x \in]-50, 50[; \qquad (7)$$

Therefore total aircraft impact probability on the Ignalina NPP is estimated from:

$$P = \frac{N_c P_l r^2 g^2}{2} \int_{-50}^{50} e^{-g\sqrt{x^2+100}} dx \; . \qquad (8)$$

Deviation coefficient **g** in the model was assumed to be g = 0.23. This means that probability of the plane to deviate 10 kilometres aside its initial trajectory during the accident is 10 times less than to crash on it. This number was also used in some references, e.g. [1].

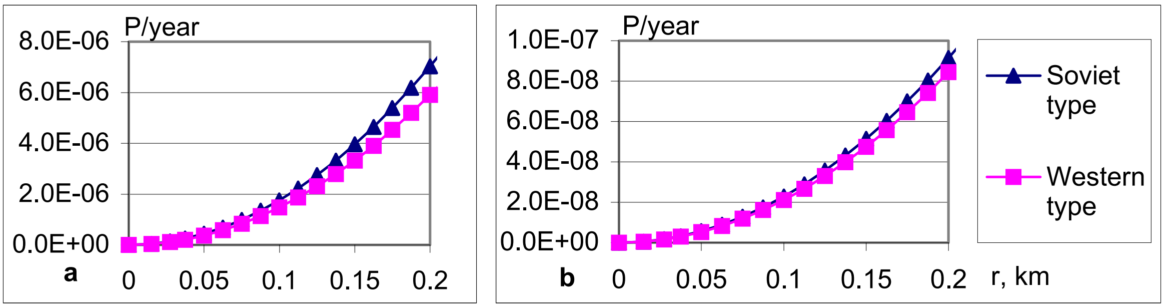

Figure 4: The frequencies of light (a) and heavy (b) aircraft impact on various radius zones

In presented model it was conservatively estimated that total amount of flights through the zone of 50 km radius around Ignalina NPP in average is 35000 flights annually. The graph of frequencies of light aircraft (the mass below 5700 kg) and frequencies of heavy aircraft (the mass above 5700 kg) impact versus different radius zones (r from 0 up to 0.20 km) are presented in Figure 4. It is necessary to note, that the frequency of accidents for aircraft with take-off weight up to 5700 kg is much more, than with take-off weight more than 5700 kg. However, the majority of flights of planes with take-off weight up to 5700 kg is carried out near airport, and potentially has small influence on Ignalina NPP safety.

A part of the state of knowledge quantification is presented in Table 7. The main parameters, which may impact the calculation uncertainty, can be divided into two main groups related to the initial conditions and to the model parameters.

Table 7: Selection of parameters, which may impact the uncertainty of calculation results

#	**Parameter**	**Ranges**		**Reference (mean m)**	**Standard deviation**	**Distribution**	**Explanation**
		Min.	**Max.**				
Initial conditions							
1	$P_{l,}$ aircraft impact frequency per 1 km	1.2E-09	1.0E-07	5.1E-08	3.29E-08	Normal, truncated	Data uncertainty
2	$N_{c,}$ flight number per 1 year	20000	50000	35000	10000	Normal, truncated	Data uncertainty
Model parameter							
3	r, aircraft impact radius, km	0.010	0.020	0.015	0.003	Normal, truncated	Modelling variations
4	g, aircraft impact deviation coefficient	0	0.46	0.23	0.15	Normal, truncated	Modelling variations

This analytical input clearly does require an expert judgment to varying degrees. It is the only instance where a subjective enters the analysis. The uncertainties identified as potentially important and the subjective probability distributions together with their parameters specified for illustrative application in this paper are presented in Table 7.

3.3 Results of simulation analysis

The total number of 100 (sample size) of aircraft impact model calculations was performed. For each sample set the four random parameters varied simultaneously (e.g. model output versus parameter 1 and 4 are presented in Figure 5).

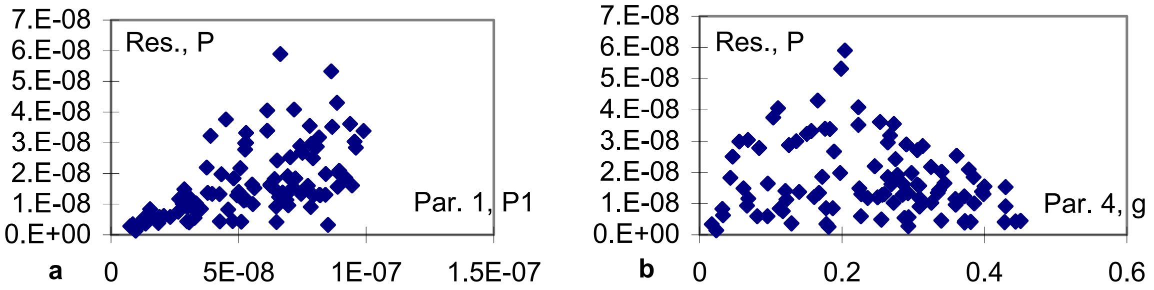

Figure 5: Simultaneous variation of model output versus parameter 1 (a) and parameter 4 (b)

For quantitative uncertainty measures two-sided statistical tolerance limits (with given probability u=0.95 and confidence v=0.95) were chosen for each of the model results of interest. These limits contain at least 95% of the combined influence of all quantified uncertainties at a classical statistical confidence level of at least 95% (resulting v=0.9629). Two sided tolerance limits (see Figure 6) formed by sample extremes are 1.4E-09 and 5.9E-08. The empirical distribution function is presented together with fitted Gamma distribution, which can be used as quite good approximation of model output.

Table 8: Main statistical characteristics of aircraft impact model output sample

#	**Result with (0.95, 0.95) tolerance limits**	**Min.**	**Max.**	**Mean**	**Standard deviation**	**Best fitted distribution**	**Confidence limits (5%, 95%)**
1	P, aircraft impact probability per year	1.4E-09	5.9E-08	1.7E-08	1.2E-08	Gamma	Lower: 3.4E-09 Upper: 3.8E-08

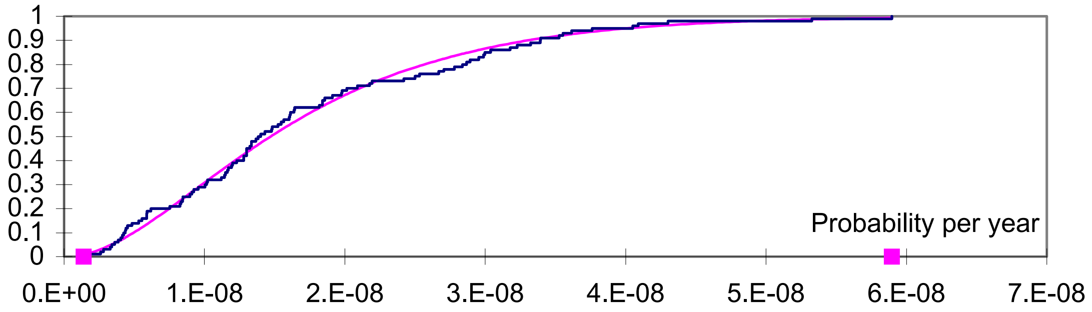

Figure 6: Empirical Distribution Function with two-sided tolerance limits

The minimum, maximum, mean, standard deviation and other characteristics of the model output sample are presented in Table 8. The lower and upper confidence limits are 5% and 95% quantiles derived from suitable observations by classical statistics. The 95% quantile, for instance says that the appropriate result value is below this quantile value with the 95% degree of belief.

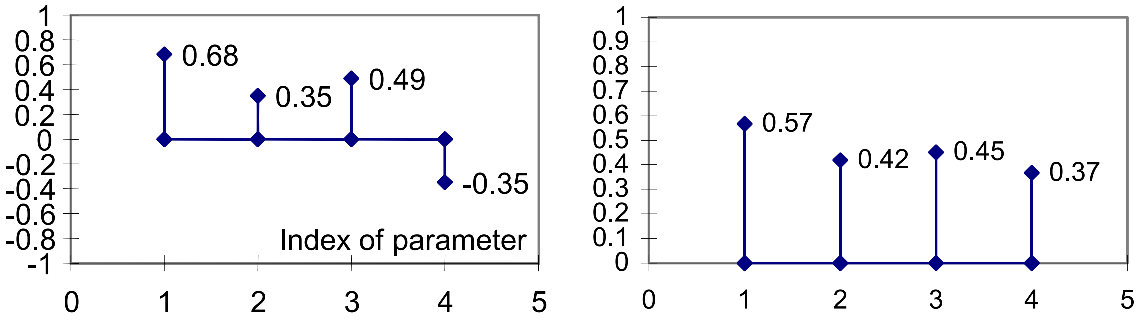

Figure 7: Standard Regression Coefficients (a) and Empirical Correlation Ratios (b)

The sensitivity factors (see Figure 7), which are a by-product of the probabilistic analysis, tell the analyst which sources of uncertainty are contributing most to the uncertainty in the predicted performance. It is possible that sensitivity measure SRC explain too small a fraction of the variability of the model output values if coefficient of determination (the correlation coefficient between the computer model output and the corresponding output from the multiple regression model) $R^2 < 0.5$, for instance. However, for analysed sample the coefficient of determination $R^2 = 0.7$. Thus, the analyst can determine which variables (model parameters) should be regulated and controlled better in order to decrease unfavourable event occurrence. Alternatively, the analyst can determine which tolerances could be relaxed without substantially affecting system risk.

4 CONCLUSIONS

In this paper the external events having impact on safety of the Ignalina NPP were analysed. Analysis excluded seismic events and some more events, which could be classified as area events. The most detailed model was performed for the aircraft catastrophe analysis. Besides this external flooding, extreme winds, hurricanes, forest fire and flying parts of turbine were included in the bounding analysis. The results of performed analysis are summarised in the Table 9.

Table 9: Estimated probabilities of the external events occurrence

External event (remarks)		**Probability per year**
Aircraft catastrophe (Bounding analysis)	zone with 85 m radius (main building)	1.64E-07
	200 m radius (reactor buildings in site)	9.1E-07
Aircraft impact simulation, an example model output sample mean		1.7E-08
Turbine missiles (expert judgement, conservative assumptions)		1.0E-06
External flooding (even for not critical level)		<3.2E-06
Extreme winds and hurricanes (F2-F3 class by Fujitsu scale)		5.3E-06
Forest fire (impact on safety level is non-significant)		1.5E-03

As evident from Table 9, the external events have either negligible probabilities or their impact on safety level is non-significant. Except for the probability of forest fire, the probabilities of analysed external events are smaller than Core Damage Frequency (5.9E-06).

The predicted probabilities of events are necessarily approximate; however, the probabilistic approach will still provide very useful information, especially in the form of sensitivity factors. As boundary analysis takes into account the safety features provided by the design to cope with these events, the sensitivity analysis can take into account the uncertainty features raised by external event and its model. The external event analysis with additional consequence analysis and more detail sensitivity and uncertainty analysis can be incorporated in probabilistic safety assessment. However it is reasonable to perform recalculations in case if external events data change in the future. At present, the probabilistic and deterministic calculations can show that external events cannot significantly influence the safety level of the Ignalina NPP operation, however the events occurrence and propagation can be sufficiently uncertain. Even in case when the external events analysis show rather limited external events occurrence probability, the sensitivity analysis can determine the highest risk contributors, which possible variations can be significant for safety level and risk based decisions making.

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