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Probabilistic analysis of hazardous events and safety of the Ignalina NPP

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Objective and Content

The main objective of the considered work was to present the approach and analysis of the probabilistic modeling of the aircraft crash as well as results of the probabilistic modeling of aircraft crash impact on the main building of Ignalina nuclear power plant in Lithuania.

Outline of presentation:

- Introduction and considered issues;
- Methodology for the probabilistic analysis of external events ;
- Data for probabilistic model for the aircraft crash;
- Probabilistic model of the aircraft crash;
- Methodology for the Uncertainty and Sensitivity Analysis;
- Simulation and uncertainty analysis approach;
- Summary and Conclusions.

Introduction

The review of Probabilistic Safety Assessment (PSA) of the Ignalina NPP clearly indicated the need of continued attention to the risk analysis and safety improvements.

Reflect a part of methodology for the probabilistic analysis of external events, which have an influence on safety of the Ignalina NPP.

The methodology was established for screening out external events, which impact on Ignalina NPP safety is not significant.

In order to estimate probabilities of external events occurrences the statistical data were collected, mathematical models were constructed and probabilities of these events occurrences were determined.

For risk estimation, the following external events were studied: forest fires, external floods, aircraft crash, seismic events, extreme winds, fall of frequency in electricity network and loss of an external electricity supply.

Mathematical models of probability estimation of the aircraft crash and NPP impact were developed and examined in detail.

The aircraft crash probability estimation model is improved considering uncertain data.

Analysis of initial events

The considered initial events are events, which generates sequences of events in the nuclear power plant potentially resulting in damage of the core.

The analysis of initial events consists of eight tasks:

1. Selection of initiating events;
2. Parameter definition for each initiator;
3. Approximate screening by impact;
4. Detailed screening by frequency;
5. Detailed parameterization of each initiator;
6. Hazard analysis;
7. Sensitivity analysis;
8. Documentation.

External events

Usually initial list of external events is divided into two groups - natural events and the external events connected to the human being activities.

Natural external events are:

- extreme conditions of a nature;
- earthquakes;
- external flooding.

External events caused by the human being activities are:

- aviation accidents;
- dangers related to transportation and industrial activity.

For revealing those external events which influence on safety is insignificant, the criteria used in procedures of performance PSA may be used.

Important external events

In technical project of Risk Safety Assessment it is determined, that for the Ignalina NPP it is necessary to consider the following external events:

- aircraft crash;
- extreme winds;
- external fire;
- turbine missiles;
- external flooding and extreme showers;
- fall of frequency in a network and loss of an external electricity supply.

Description of aircraft crash event

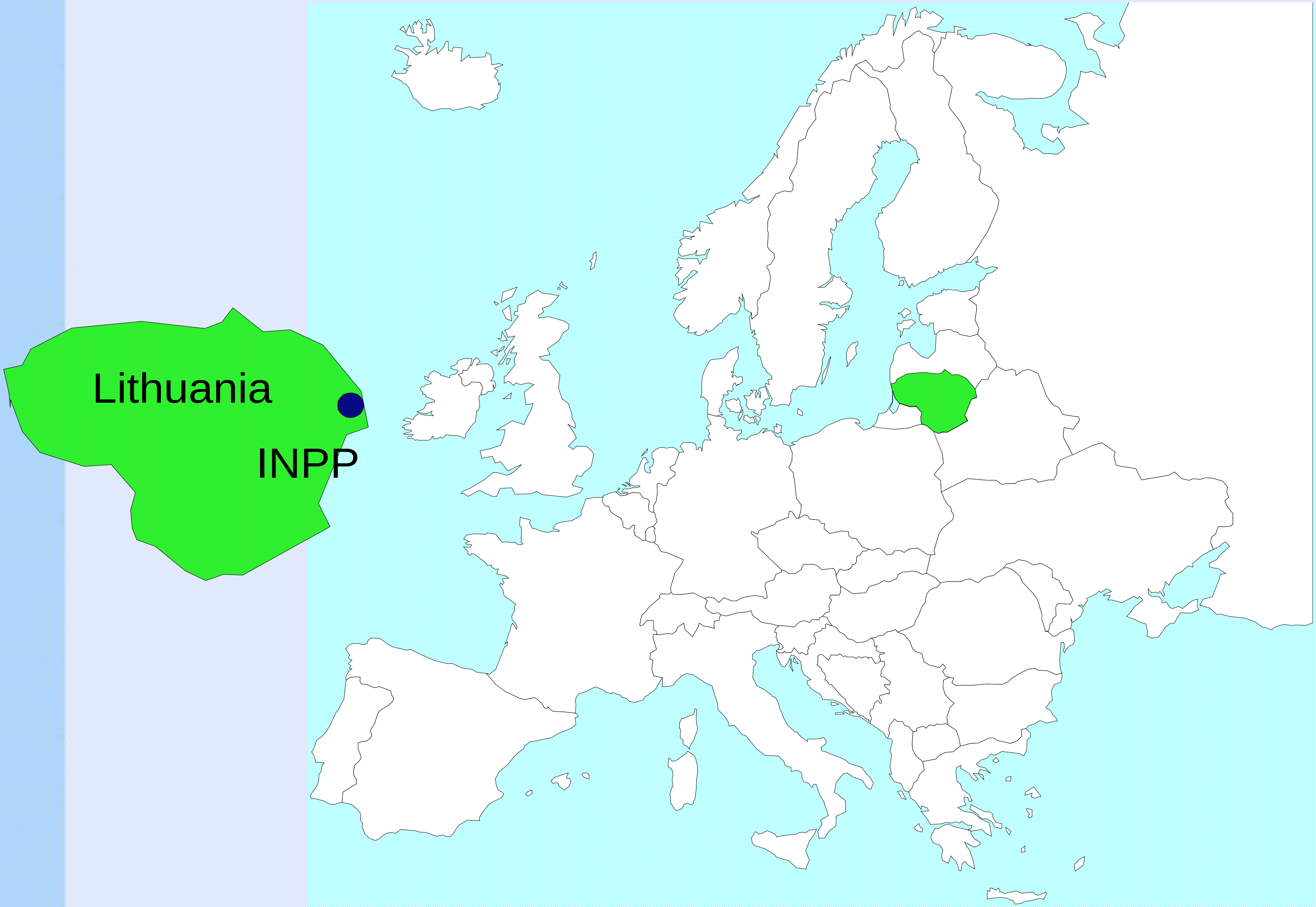
Within the analysis of an aircraft crash, terrorist actions or other non-ordinary human activities in this project are excluded.

The analyzed frequency of aircraft crashes depends on the intensity of flights near the target object, the technical condition of the aircrafts, the experience of crew, the meteorological conditions and other factors.

Usually a probabilistic model of aircraft crash frequency depends on the distance between the NPP and the closest airports.

There are no large airports nearby Ignalina NPP – the largest airport is in Vilnius (Republic of Lithuania), approximately 130 km away from Ignalina NPP.

INPP Location

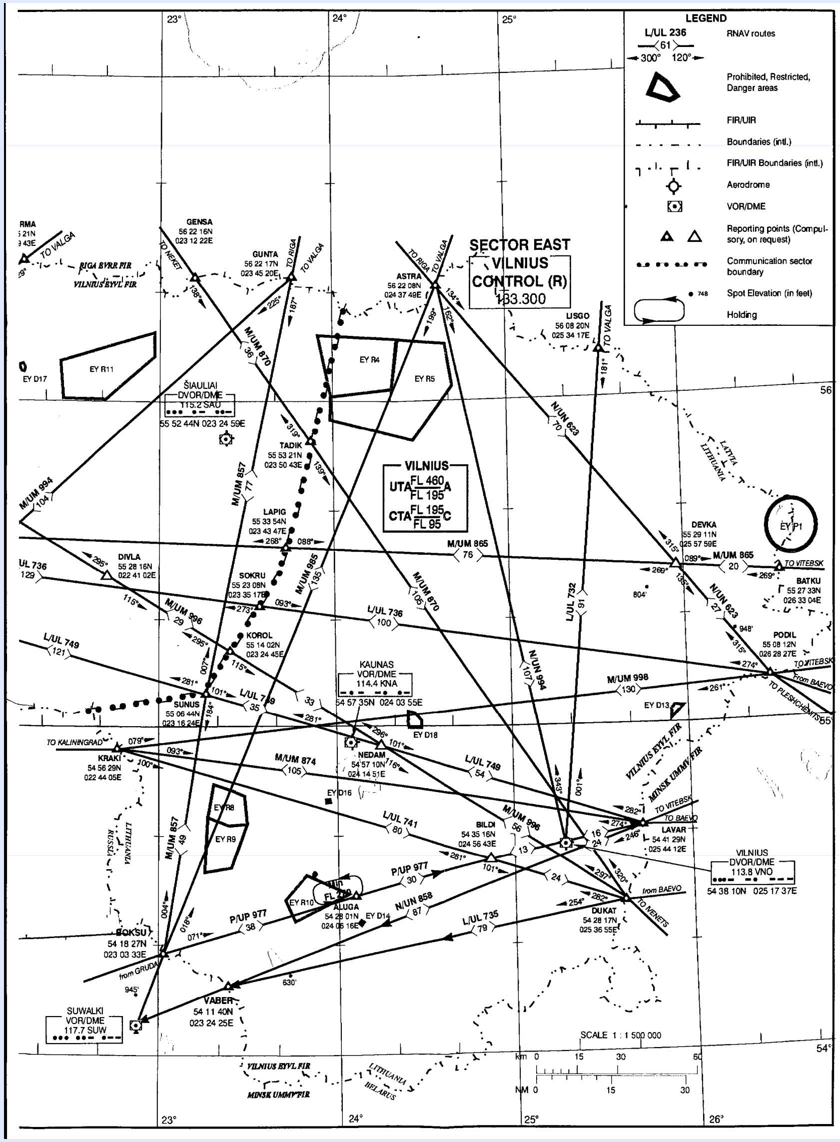


Air Routes Near Ignalina NPP

The decision of the Government of the Lithuanian Republic on January, 22, 1997, No. 39 “About the statement of structure of Lithuanian Republic airspace", establishes the following prohibited zone of airspace around the Ignalina NPP:

• vertical the top border – flight level 195 (FL 195), the bottom border - a terrestrial surface (GND);

• the horizontal border is established as a circle, with radius of 5.4 nautical miles concerning a point 5536.0N02634.0E (Ignalina NPP).



Data studies (1/2)

The initial data for the estimation of the aircraft crash probability:

- Ignalina NPP distance from the civil or military airports;
- arrangement of air transport corridors in the eastern part of Lithuania;
- intensity of flights in the air transport corridors of Lithuanian airspace;
- distribution of aircrafts by their type;
- generalized world statistics of aircraft crashes by their weight and type;
- statistical data on serious aircraft incidents.

Data studies (2/2)

- All air corridors pass on a significant distance from the Ignalina NPP. Only three of them are within the 50 kilometer zone around NPP.

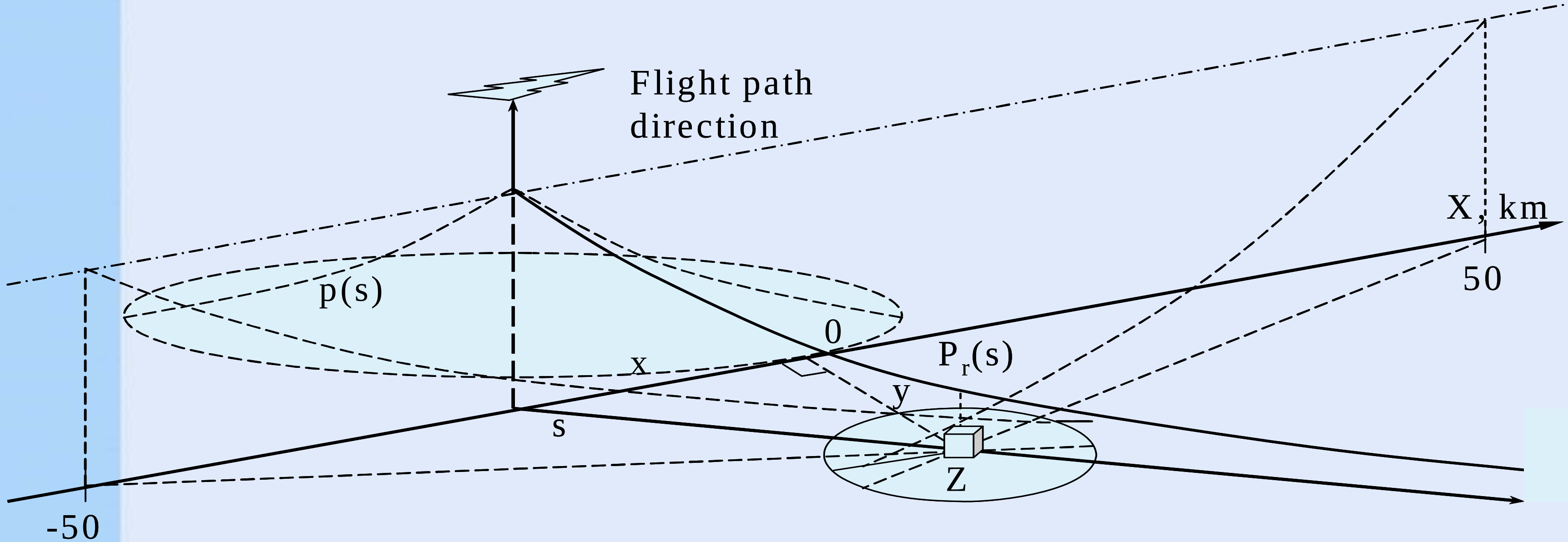
- The calculation of aircraft crash probability per one year uses approximate flight numbers from 40000 (approximate flight number in Vilnius airport during 2007 year) to 160000 (approximate flight number in Vilnius airspace during 2010 year).

Relatively new and old aircraft crash frequencies

Aviation Catastrophe Frequency / year	Relatively new aircrafts		Relatively old aircrafts	
	Weight up to 5700 kg	Weight over 5700 kg	Weight up to 5700 kg	Weight over 5700 kg
For 1 flying hour	$2.1 \cdot 10^{-5}$	$9.0 \cdot 10^{-7}$	$2.5 \cdot 10^{-5}$	$1.0 \cdot 10^{-6}$
For 1 flying km	$8.4 \cdot 10^{-8}$	$1.2 \cdot 10^{-9}$	$1.0 \cdot 10^{-7}$	$1.3 \cdot 10^{-9}$

Probabilistic model (aircraft crash)

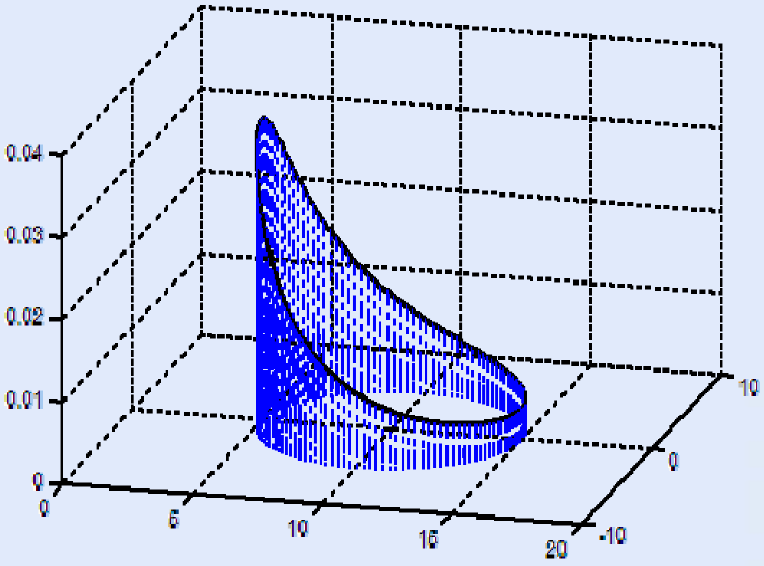
Conservatively, it was assumed that all flights from 50 km radius zone, take place at the periphery of 10 km radius zone. Because in the 10 kilometer radius zone around the Ignalina NPP flights below 5950 meters are non-flying zone.



The model of aircraft crash calculation on territory of NPP with radius *r*

Probabilistic analysis

Aircraft crash probability onto r radius zone Z with condition if plane loses control and start to fall in distance s from the zone centre is expressed by:



$$P_r(s) = V_{cylinder} = \pi r^2 h = \pi r^2 \cdot p(s) = \frac{r^2 \cdot g^2 \cdot e^{-gs}}{2},$$

where:

$$p(s) = \frac{g^2}{2\pi} \cdot e^{-gs} \quad \text{such, that} \quad \int_0^{2\pi}\int_0^{\infty} s \cdot p(s)\, ds\, d\varphi = 1.$$

where g - a constant dependent on type of planes and describing likelihood of close crash (for military g = 0.63, for passenger g = 0.23 and for transport g = 1.00).

Model and analysis results

If the aircraft flies 100 km route through corridor touching 10 km radius zone around the Ignalina NPP, then the distance to the analyzed zone centre is expressed by:

$$s = \sqrt{x^2 + y^2},$$

where y = 10, x∈(-50, 50).

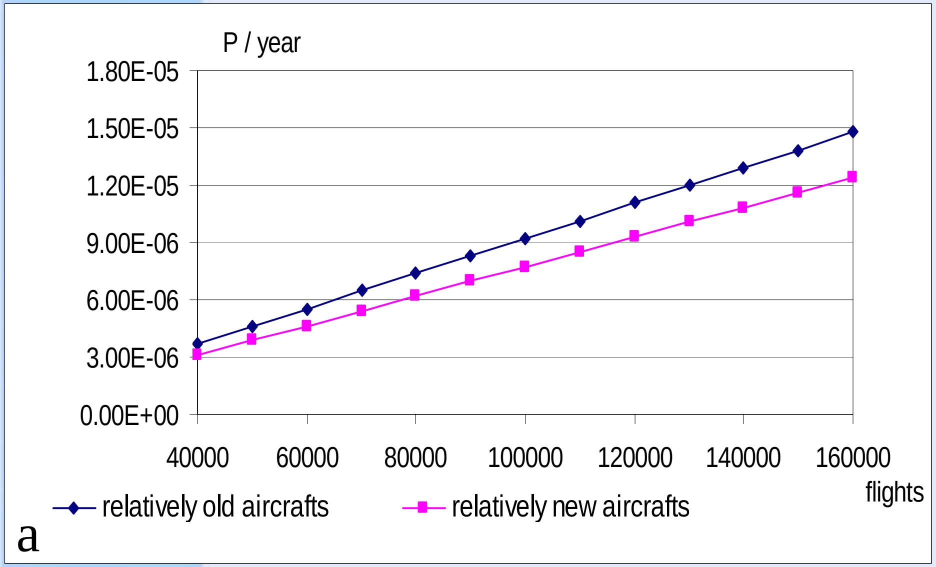
Therefore general aircraft crash probability per year on 10 km radius territory is expressed by the following formula:

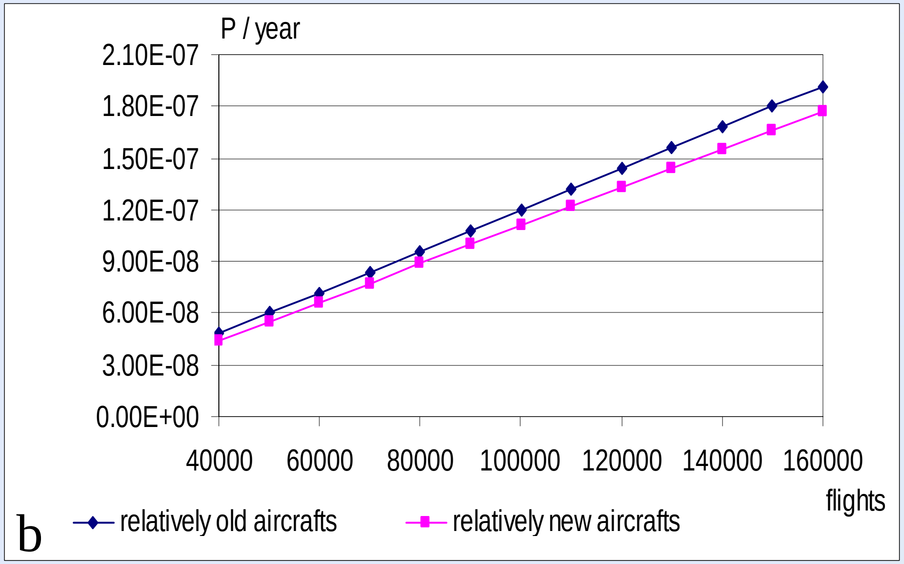
$$P = \frac{N_c P_l r^2 g^2}{2} \int_{-D}^{D} e^{-g\sqrt{x^2+100}}\, d\sqrt{x^2+100} = N_c P_l r^2 g \left(e^{-10g} - e^{-g\sqrt{D^2+100}} \right),$$

where $D = 50$, P - aircraft impact probability/year, P_l - aircraft impact frequency per flight kilometre, N_c - flight number per year.

Model and analysis results

Using statistical data of year 2007 in the formula above with the mentioned assumptions, the aircraft crash probability (per one year) into 0.2 km radius territory when flight numbers are varying from 40000 to 160000 has been calculated.

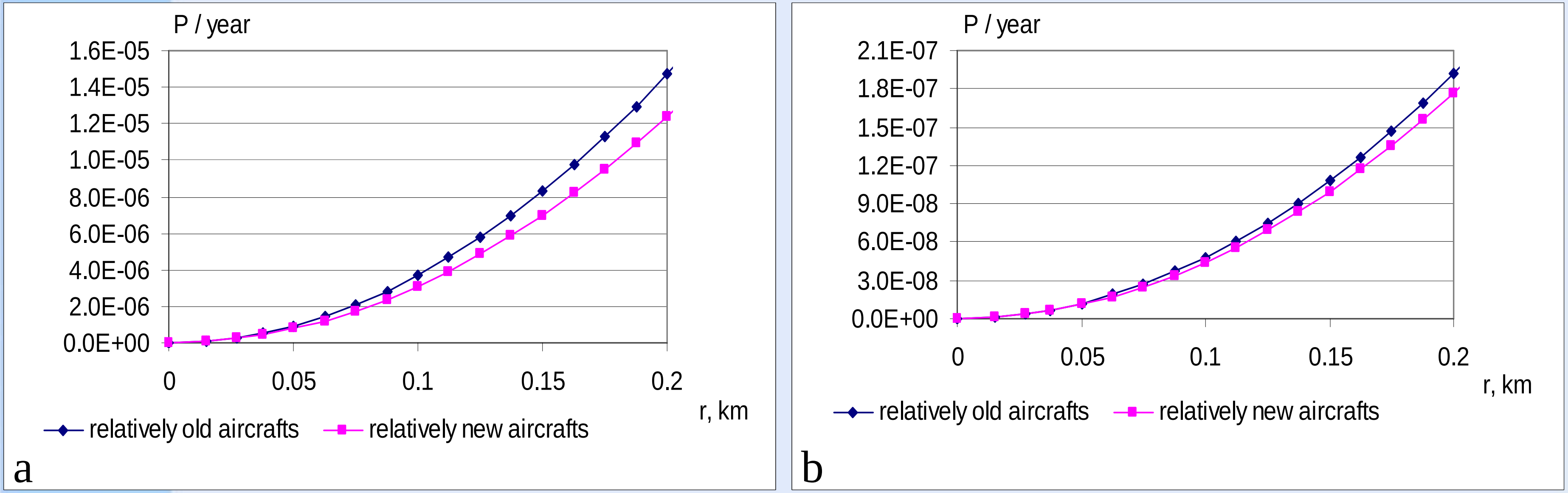




Light (a) and heavy (b) aircraft crash frequencies dependence on flight number

Model and analysis results

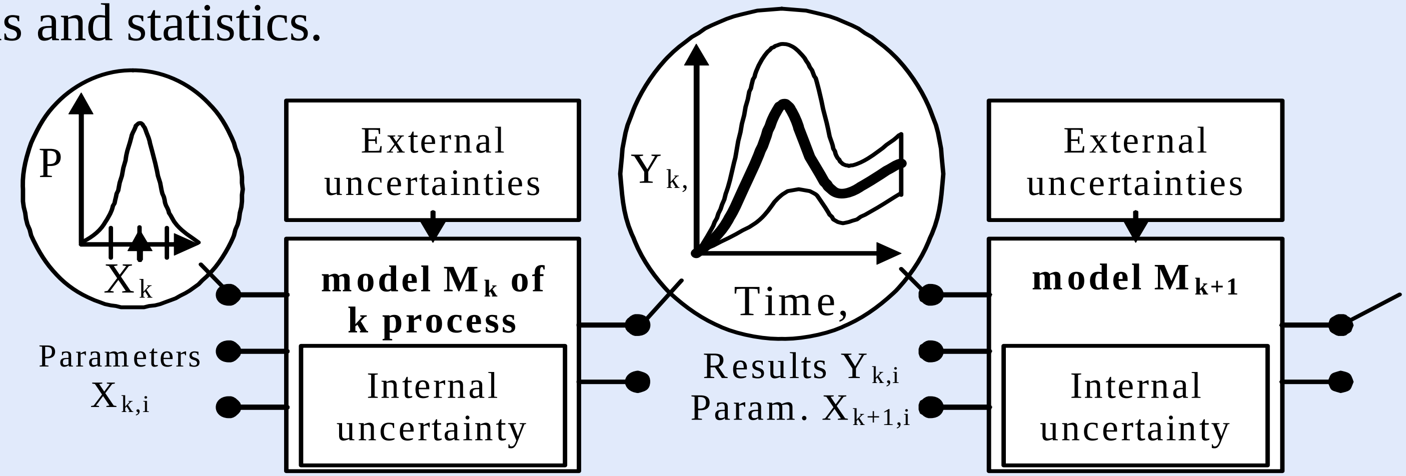
In order to determine the dependencies of results on the radius *r* the calculations were performed (changing *r* values and flight quantities for different types of aircrafts).



Light (a) and heavy (b) aircraft crash frequencies with 160000 flights

Simulation & uncertainty analysis

The approach suggested for uncertainty and sensitivity analysis, and illustrated by an application of SUSA (Software System for Uncertainty and Sensitivity Analyses), is based on well-established concepts and tools from probability calculus and statistics.



System process parameters distribution evaluation

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. Such a distribution expresses how well an uncertain parameter of the model application is known.

Simulation results (1/2)

Values of model parameters for the uncertainty analysis

#	Para-meter	Margins		Reference (mean)	Standard deviation	Distribution
		Min	Max			
Initial conditions						
1	P_l	1.2E-09	1.0E-07	5.1E-08	3.29E-08	Normal, truncated
2	N_c	40000	160000	100000	40000	Normal, truncated
Model parameters						
3	r	0.1	0.3	0.2	0.067	Normal, truncated
4	g	0	0.46	0.23	0.15	Normal, truncated

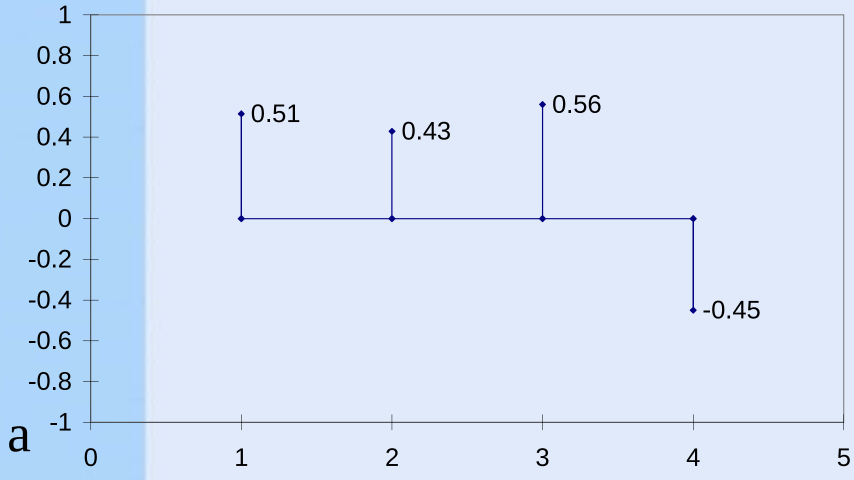
Parameter:

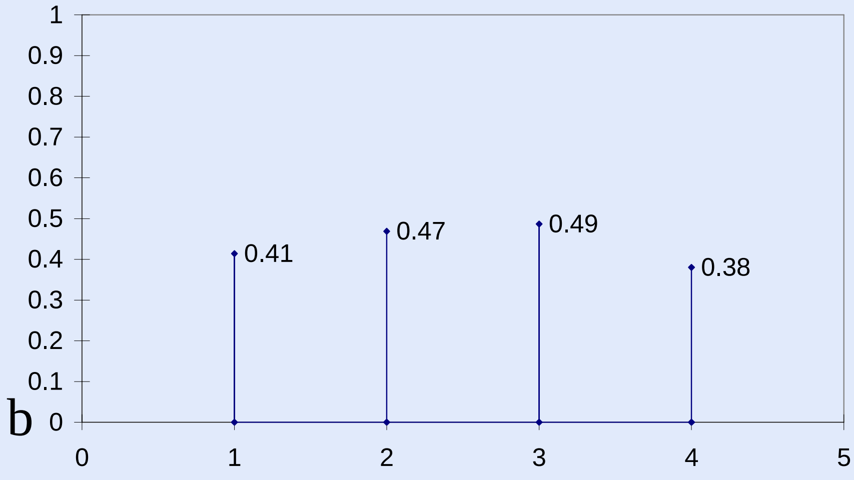
1) *Pl* - aircraft impact frequency per flight kilometre,
2) *Nc* - flight number per year,
3) *r* - which is the radius of aircraft crash zone around Ignalina NPP,
4) *g* - a constant dependent on type of planes and describing likelihood of close crash.

Simulation results (2/2)

Main statistical characteristics of aircraft impact model output sample

Model analysis results with defined tolerance limits	Min.	Max.	Mean (best est.)	Standard deviation	Confidence limits (5%, 95%)
P aircraft impact probability per year	$2.43 \cdot 10^{-7}$	$1.44 \cdot 10^{-5}$	$2.77 \cdot 10^{-6}$	$2.52 \cdot 10^{-6}$	Lower: $2.18 \cdot 10^{-7}$ Upper: $7.76 \cdot 10^{-6}$





Standard regression coefficients (a), empirical correlation coefficients (b)

Summary and Conclusions

- The sensitivity analysis shows that the most influencing parameter is *r*, which is the radius of aircraft crash zone around Ignalina NPP.
- Calculations show that the maximal and minimal values of aircraft crash per year probability are equal to 1.44E-05 and 2.43E-07, respectively. The average value of the aircraft crash per year probability is equal to 2.77E-06, and the standard deviation is equal to 2.52E-06.
- It is more probable that aircrafts would crash into the lake of Druksciai, into the forest or onto the electricity lines, because they take up much larger area..

Thank you for attention! Questions?

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