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PSA on Extreme Weather Phenomena for NPP Paks

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WGRISK Technical Discussion on PSA Related to Weather-Induced Hazards

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Background

- Level 1 Seismic PSA for Paks NPP – 2002
- Periodic Safety Review – 2009
  - PSA for external hazards other than earthquake
- Hungarian nuclear safety regulations (for existing units):
  - design basis for natural hazards: 10^{-4}/a freq.
  - risk assessment for external hazards beyond the design basis, at least 10^{-7}÷10^{-4}/a freq.
  - PSA screening criteria for external hazards: 10^{-7}/a
- High importance of risk assessment for external hazards after Fukushima and Targeted Safety Reassessment

Level 1 External Events PSA for Paks NPP – 2012
Follow-on analyses – 2013-2018

Objectives

Overall objectives:

- Quantify (to the extent feasible) the level of risk induced by natural & man-made external hazards
- Identify the main risk contributors
- Analyze accidents in full power and in LPSD states

Further objectives of the original assessment (till 2012):

- Identify analysis areas to be further dealt with:
  - unresolved issues and necessary follow-on analyses
- Identify apparently important safety concerns

Further objectives of the follow-on analyses (since 2013):

- Develop a full scope external events PSA
- Reduce uncertainties and conservatism

Major Analysis Steps

1. Selection of external hazards
2. Screening of external hazards
3. Detailed analysis of screened-in external hazards:
   - hazard assessment (strength-frequency correlation)
   - plant response analysis (failure probability of SSCs for different levels of load)
   - development and quantification of plant risk model
     - identification of event sequences leading to CD
     - CDF quantification
     - uncertainty and sensitivity analyses

External Hazards Subject to Detailed Analysis

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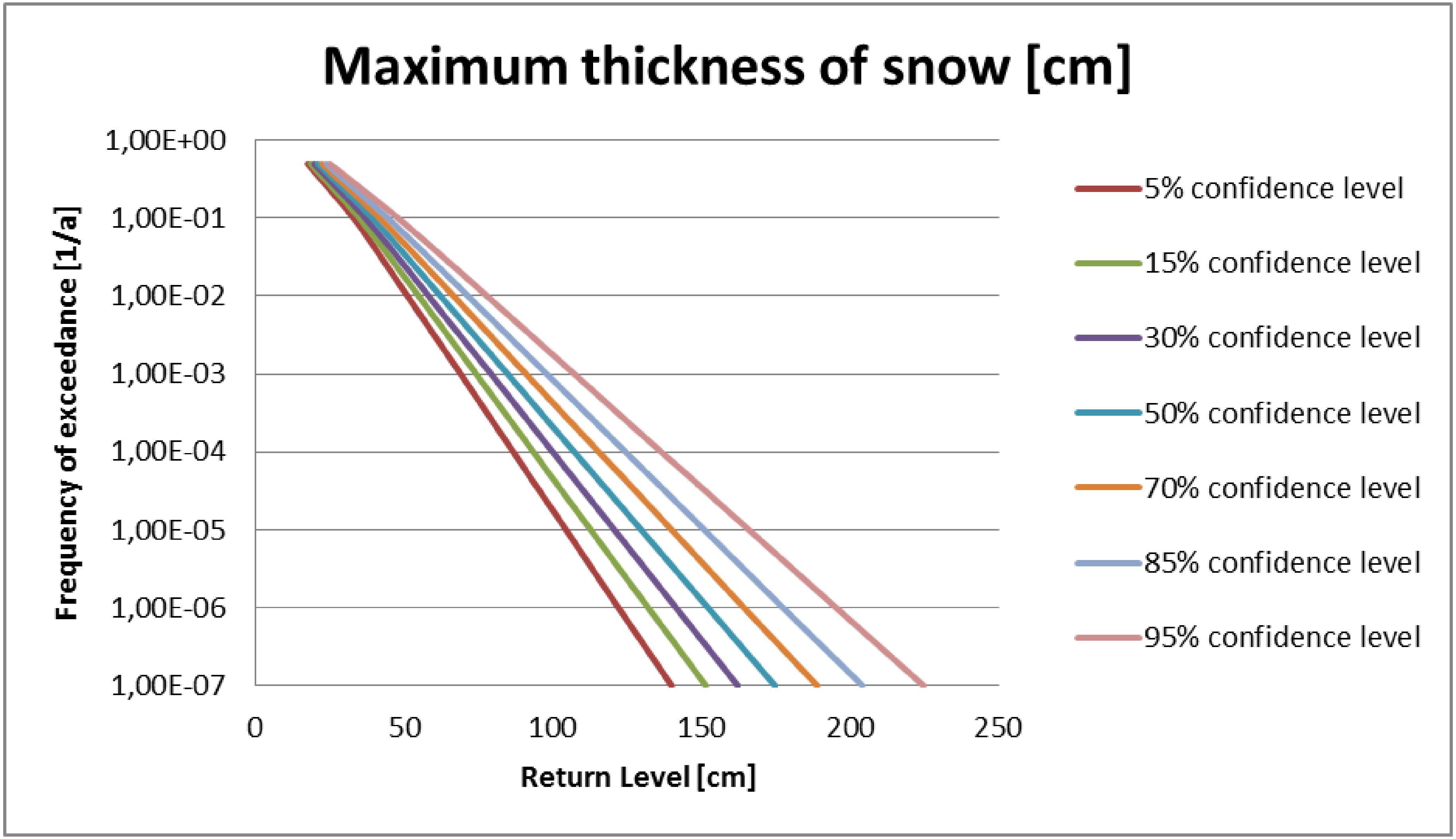
Screened-in (natural and human induced) external hazards:

- earthquake (not subject of this analysis)
- extreme wind
- extreme rainfall
- extreme snow
- extremely high and low air temperature
- extreme frost and ice formation
- lightning
- tornado
- blockage of water intake filters (not a weather-induced hazard)

Hazard Assessment – Extreme Value Theory



Hazard Assessment – Individual Approaches

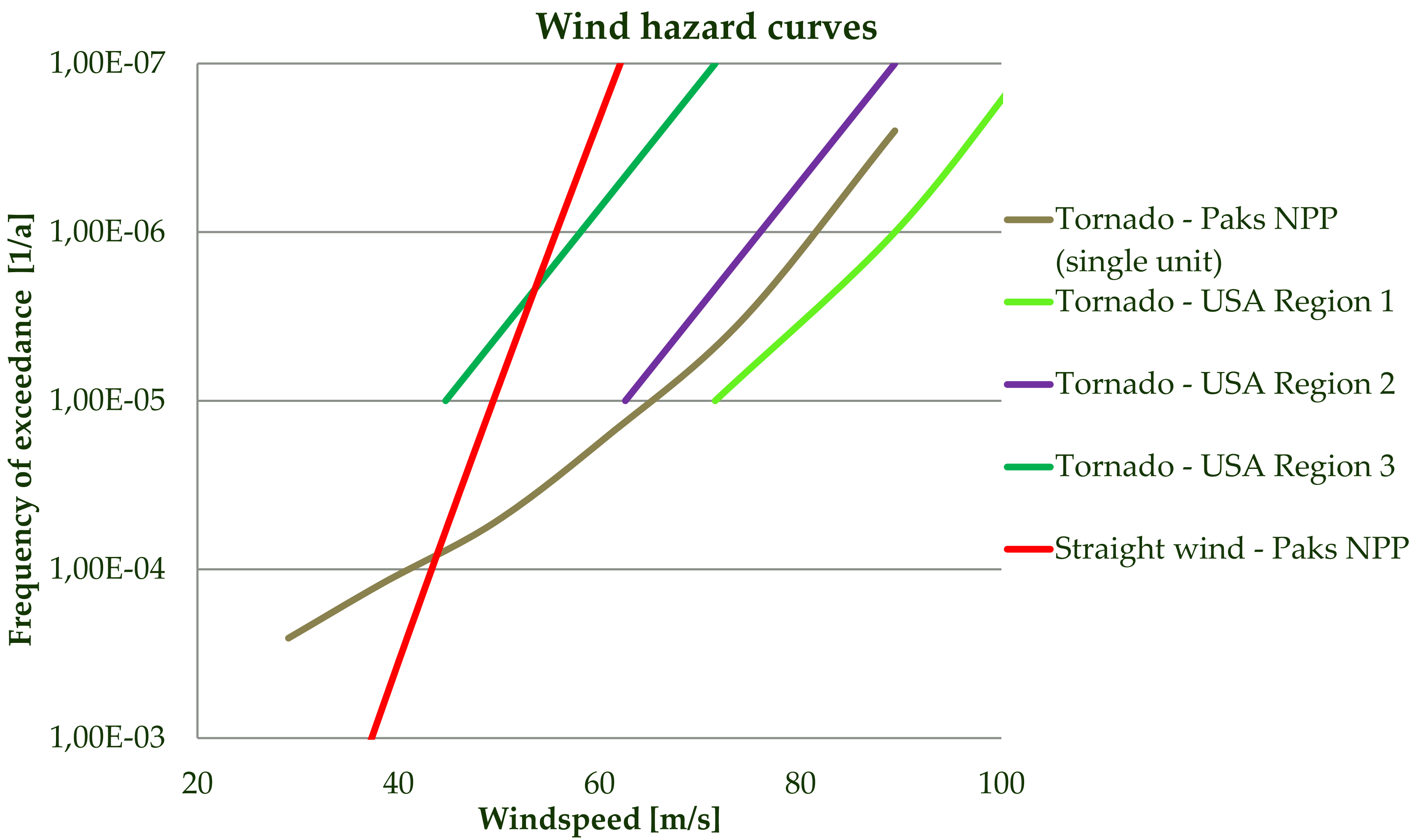
Lightning:

- several relevant physical properties of lightning
- not necessarily the most extreme ones are the most hazardous ones
- lighting strike frequency ($5/km^2/a$) & conditional failure probability of SSCs (based on lightning protection standard)

Tornado:

- review of the tornado hazard assessment in FSR
- applied methodology based on NUREG/CR-4461 (Tornado Climatology of the Contiguous United States)
- input data assessment: national or general (e.g. NUREG)
- quantification: point estimate, sensitivity & uncertainty studies

Hazard Assessment – Tornado and Straight Wind



Plant Response and Fragility Analysis

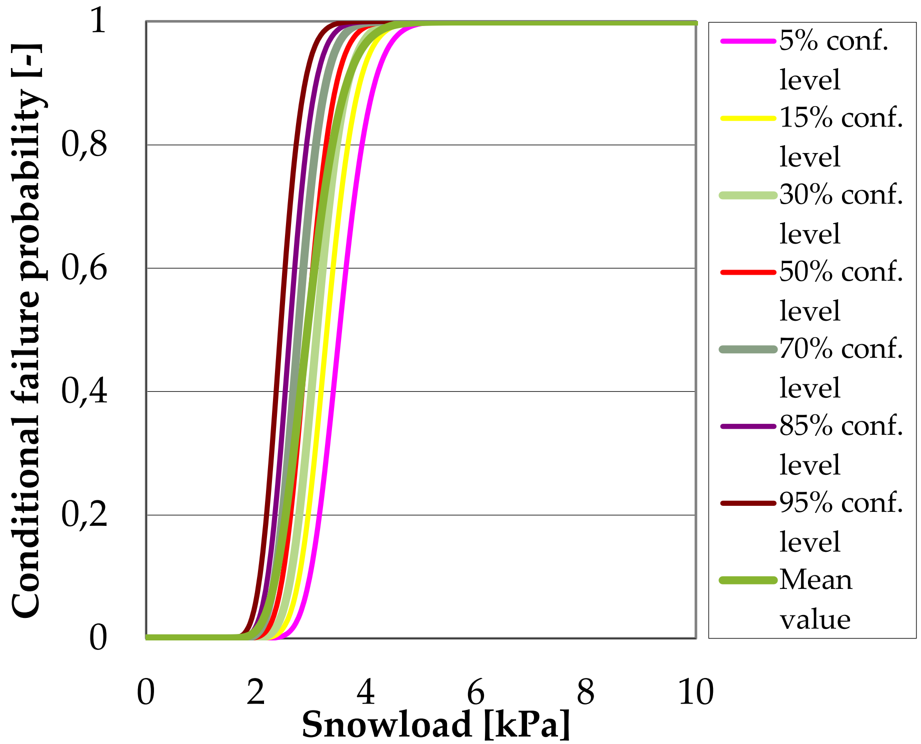
Wind & snow – structures and outdoor facilities

Frost/glaze ice – power transmission lines

- Till 2012: methodology development to establish fragility curves based on:
  - design data
  - safety margins ensured by relevant standards
  - structural re-analysis of safety related buildings
- Since 2013: review of the methodology and the fragility characteristics of all safety related buildings
  - refined methodology based on structural reliability analysis
  - higher level model for critical structural elements
  - empirical fragility curves (not in a closed mathematical form)

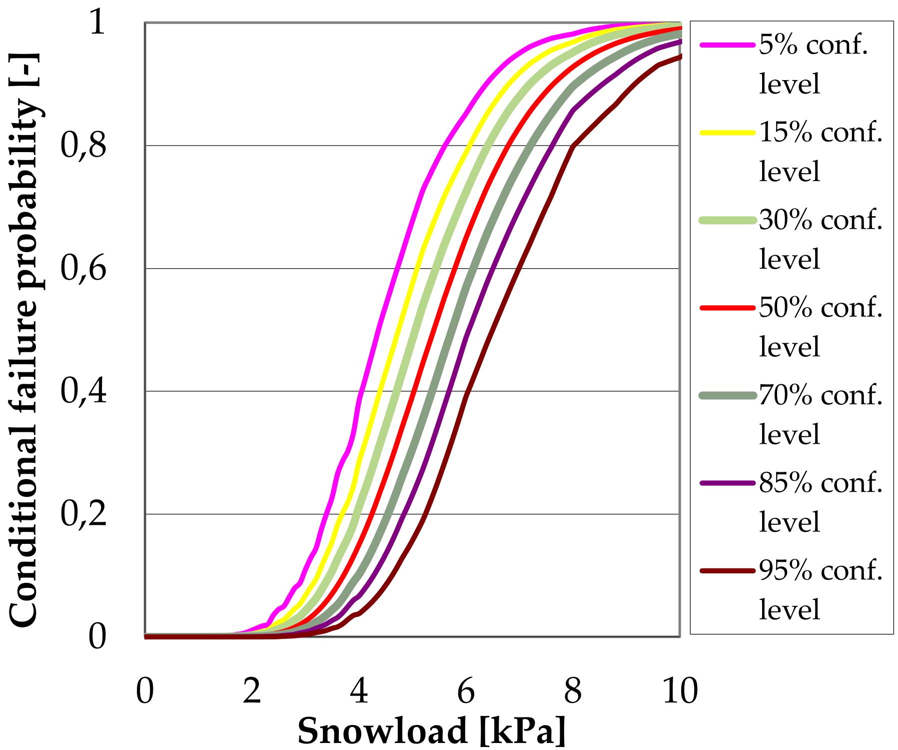
ORIGINAL METHODOLOGY

$P_f = 4{,}47 \cdot 10^{-5}$



REFINED METHODOLOGY

$P_f = 5{,}39 \cdot 10^{-6}$



Snow fragility curves for the reactor hall

Plant Response and Fragility Analysis

Plant Response and Fragility Analysis

Beyond fragility curves for wind, snow and frost:

- Snow – blockage of air intake systems / inlets
- Rain – canalization system (hydraulic load assessment)
- Lightning – lightning protection system (adequacy to the applicable standards and evaluation of system-effectiveness)
- High and low temperatures – all safety related components (temperature resistance vs. expected air temperature at the location of the component), fragility of off-site power
- Tornado – structures and outdoor facilities (ongoing)

Expert panel to help plant response analysis

PSA Model Development

Wind-, Snow-, Frost-PSA models
utilizing PSA models for internal events and seismic hazards

- Initiating event (EH) ➡ fragility groups ➡ transient initiating failures and additional SSC failures
- Mitigation of multiple transient initiating failures: the union of the safety functions for single transient initiating failures
- Generic event tree for every POS - event tree headers:
  - potential hazard induced transients (lower branch: occurrence of the given transient initiating failure)
  - combination of all core damage event sequences from all the single transient initiating failures that may occur (setting the boundary conditions sets on each event sequence)

Risk Quantification

- Data assessment: family of continuous hazard and fragility curves and random equipment failures
- MCSs det.: Risk Spectrum; freq. calc.: stand-alone code
- Occurrence frequency of a minimal cutset (MCS):

$$f(MCS) = FP(NEBE_1) \cdot \cdots \cdot FP(NEBE_{NE}) \cdot \sum_{i=1}^{160} (FF_i(EBE_1) \cdot \cdots \cdot FF_i(EBE_E) \cdot h_i)$$

- The conditional probability of core damage in relation to a minimal cutset: $CCDP(MCS) = \dfrac{f(MCS)}{\sum_{i=1}^{160} \mathrm{h}_i}$
- The CDF induced by an external hazard:

$$CDF = \left(1 - \prod_{n=1}^{N_{MCS}} \left(1 - CCDP(MCS_n)\right)\right) \cdot \sum_{i=1}^{160} \mathrm{h}_i$$

Interpretation of Results

- Point estimates
  - CDF and CDP for every hazard in each POS
  - cumulative plant risk (annual CDP) by hazards
- Dominant MCS to plant risk (identify and interpret)
- Importance & sensitivity analyses - fragility groups:
  - FC, RDF
  - $S_{U/L}$ - assuming a higher and a lower value of HCLPF for the group (one order of magnitude change in the hazard occurrence frequency)
  - risk reduction if the HCLPF is at least the design basis
- Uncertainty analysis – Monte Carlo Simulation (hazard & fragility curves and random failures)

Findings – Core Damage Risk

- Risk induced by extreme rainfall and lightning was found insignificant
- No solid assessment for extremely high and low air temperature due to uncertainties in:
  - operational strategy under harsh weather conditions
  - hazard assessment
  - temperature related fragility assessment
- Risk assessment for tornado is still ongoing (till the end of 2018)
- Annual CDP induced by wind, snow and frost:
  - $1{,}24 \cdot 10^{-5}$ from extreme wind
  - $5{,}20 \cdot 10^{-6}$ from extreme snow
  - $2{,}78 \cdot 10^{-6}$ from extreme frost

  Results are relevant to the basic assessment. Re-quantification in light of the results of follow-on analyses is expected by the end of 2018.

Findings – Unresolved Issues (1/2)

Follow-on analyses & corrective actions proposed to:

- screen out hazards considered negligible from risk point of view (e.g. lightning, extreme rainfall)
- enable risk assessment for hazards not characterized quantitatively yet (e.g. temperature)
- reduce uncertainties and conservatism for hazards already quantified (wind, snow, frost)

Set-up a detailed operational and transient mitigation strategy to follow in case of extreme meteorological conditions

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Findings – Unresolved Issues (2/2)

- Wind: enhance the reliability of establishing plant operation in island-mode
- Snow: modify procedure on snow removal from the roofs
- Rain: hydraulic load reassessment on the canalization system
- Lightning: review of risk figures on I&C components
- Tornado: plant response and fragility assessment, development and quantification of plant risk model
- High and low air temperatures
  - effectiveness and reliability of the plant HVAC systems
  - freezing of fluids in safety related pipes
  - failure of bearings due to not sufficient cooling
  - safe stable plant conditions in case of LOOP etc.

Conclusions

- External events PSA for the Paks NPP – 2012
  + follow on analyses (2013-2018)
- Core damage risk induced by external hazards was quantified to the extent seen feasible:
  - wind, frost, snow - point estimate, sensitivity, importance and uncertainty analyses
  - extreme rainfall and lightning – insignificant
  - tornado, extreme temperatures – no PSA model developed yet
- Unresolved issues and necessary follow-on analyses were identified and proposed (2012)
- At present follow-on analyses are on-going according to the action plan developed earlier

Thank you for your kind attention!