Some Results of the Low Power and Shutdown Seismic Risk Assessment for the Paks NPP

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Paks Nuclear Power Plant

Four VVER-440/V213 units each with 460-500 MW electrical capacity

Started in the years: 1983, 1984, 1986 and 1987

Outline

- Introduction
- Seismic safety program
- Seismic PSA – steps
  - PSH computation
  - Seismic acceleration ranges
  - Failure modes and fragility
  - Baseline LPSD seismic PSA model
- Quantification
- Evaluation of Selected Seismic Upgrades
- Conclusions

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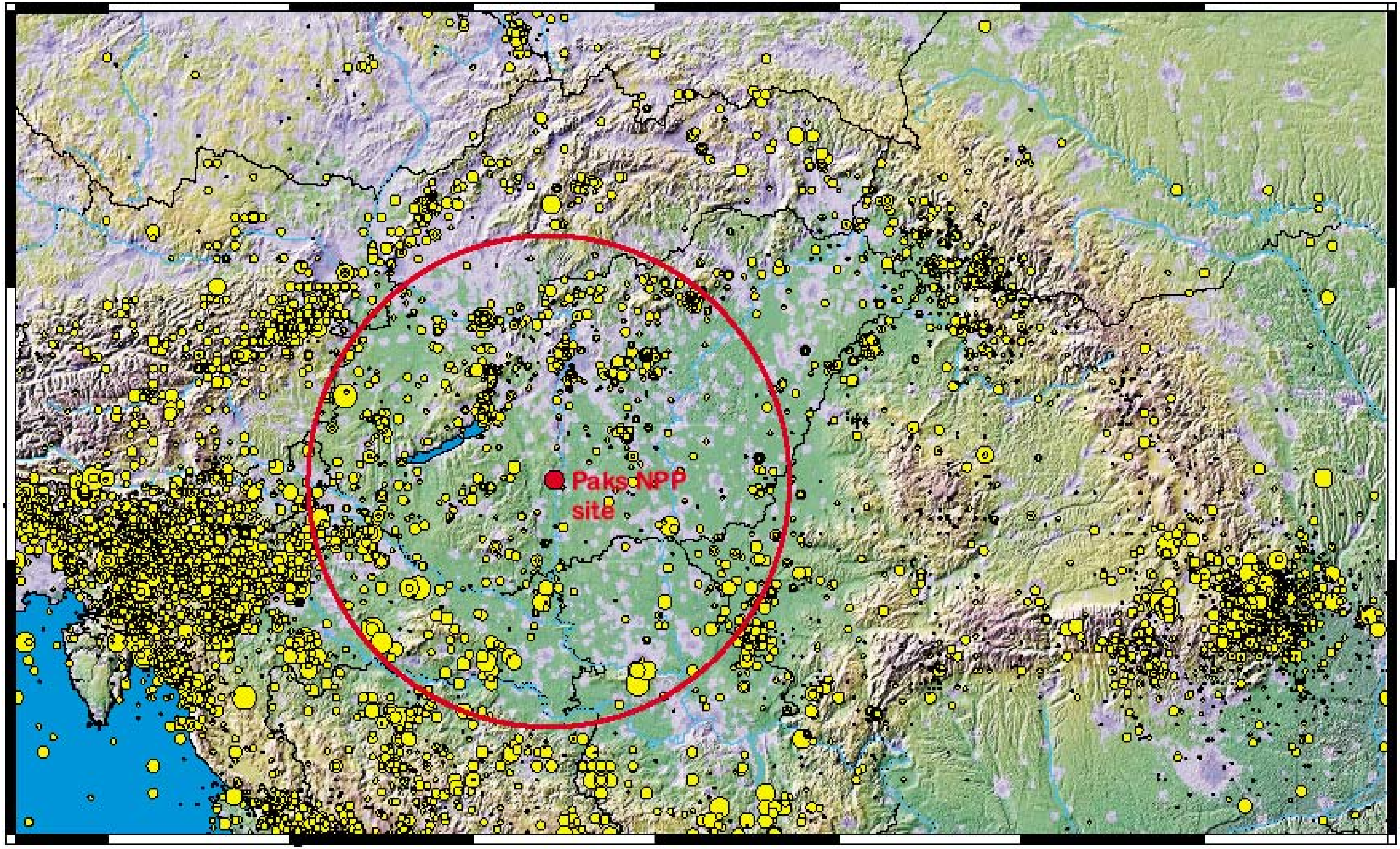
Status of level 1 PSA studies

year	activity
1994 1997	First comprehensive level 1 PSA for internal initiators Unit specific level 1 PSA for internal initiators for all units
1997	Level 1 PSA for low power and shutdown status, internal initiators
1998-2001 2007	Unit specific fire and flood level 1 PSA for all units (full power) Fire and flood level 1 PSA for one unit (low power and shutdown)
2002-2004	Level 1 PSA for spent fuel pool, internal initiators, fire and floods, all operational modes
2001-2004 2006	Seismic PSA level 1 plus containment (full power) Seismic level 1 PSA (low power and shutdown)

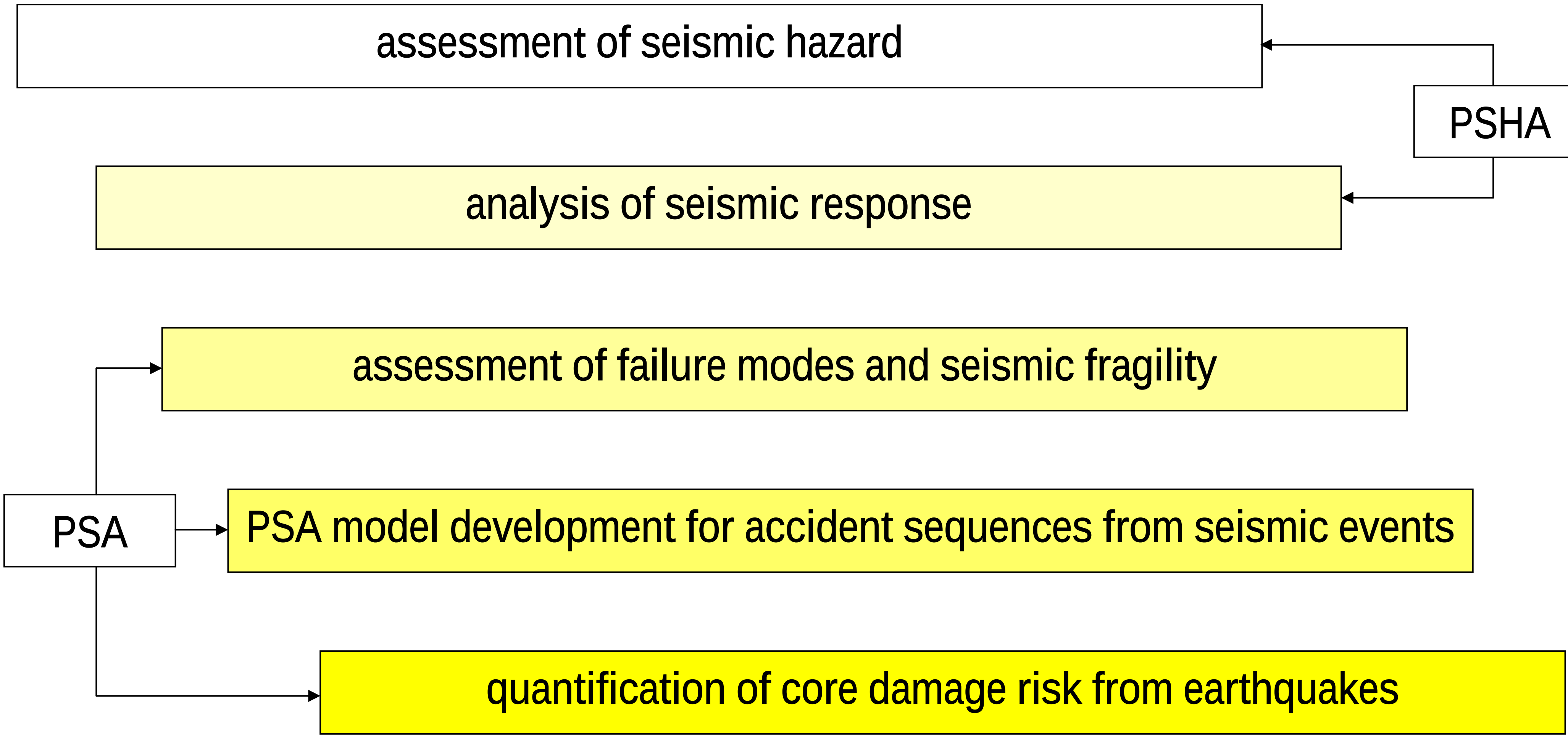
Introduction

- During the design of VVER plants the seismic hazard of the sites was underestimated and safety aspects related to the external events were neglected
- The Paks site seismic hazard was also underestimated
- Units of the Paks NPP were not designed for any earthquake loads
- At the end of 1980s it was clear that seismic hazard of the site can be much greater, than it was assumed during the design
- We launched a comprehensive program for seismic assessment and upgrading of the plant years ago; the approach followed in the upgrade program was a combination of seismic margin assessment and the use of experience-based methods
- Preparation of the seismic PSA for the units was an integral and final part of the program
- The objective of the PSA study was to
  - determine the remaining risk of core damage due to seismic events
  - identify the upgraded plant vulnerabilities to a strong seismic motion
  - provide feedback to further seismic upgrades of the plant, if necessary
- Quantitatively show the current level of plant safety with respect to the seismic hazard representative for the Paks site

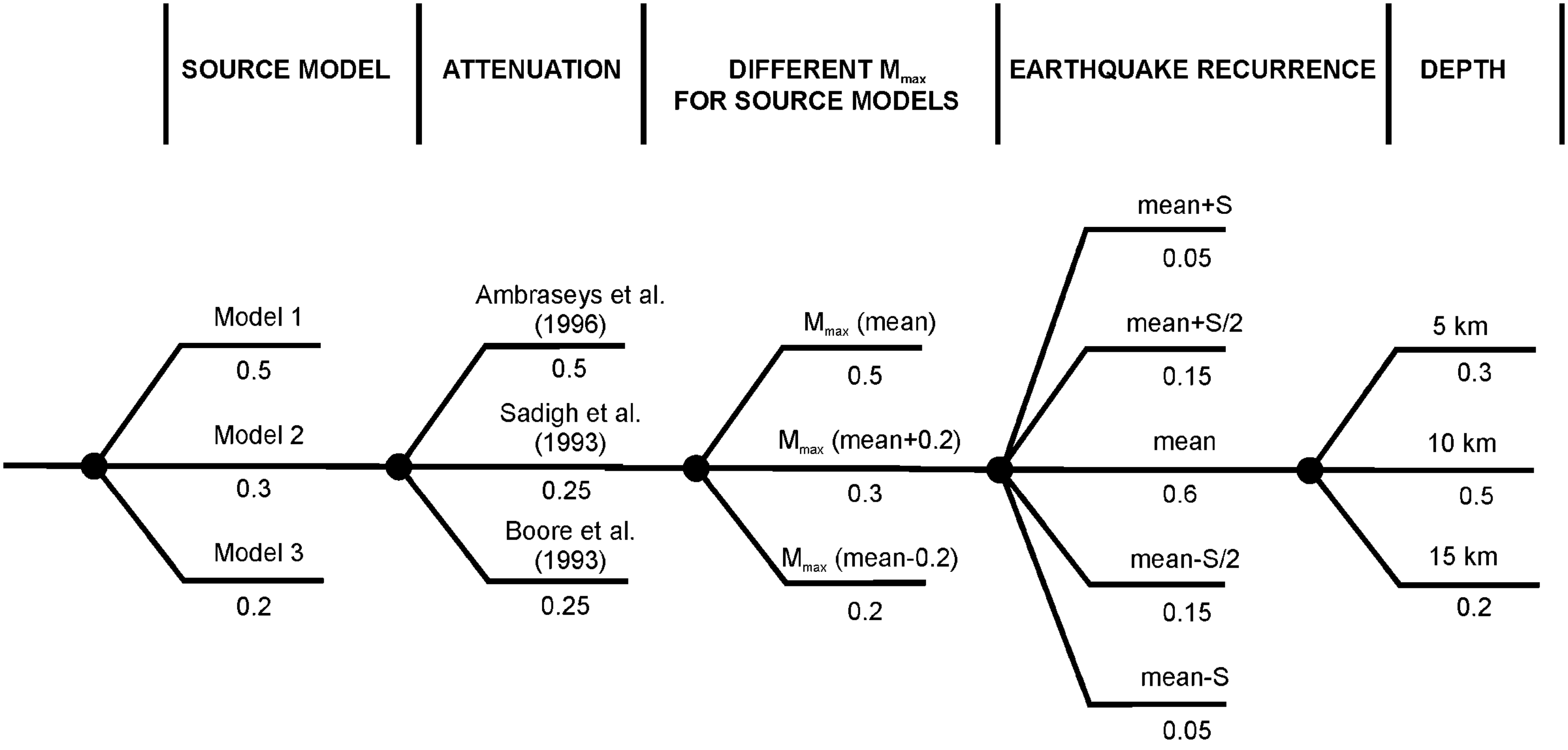
Seismicity of the Pannonian region



Seismic PSA - steps



Simplified logic tree for PSH computation



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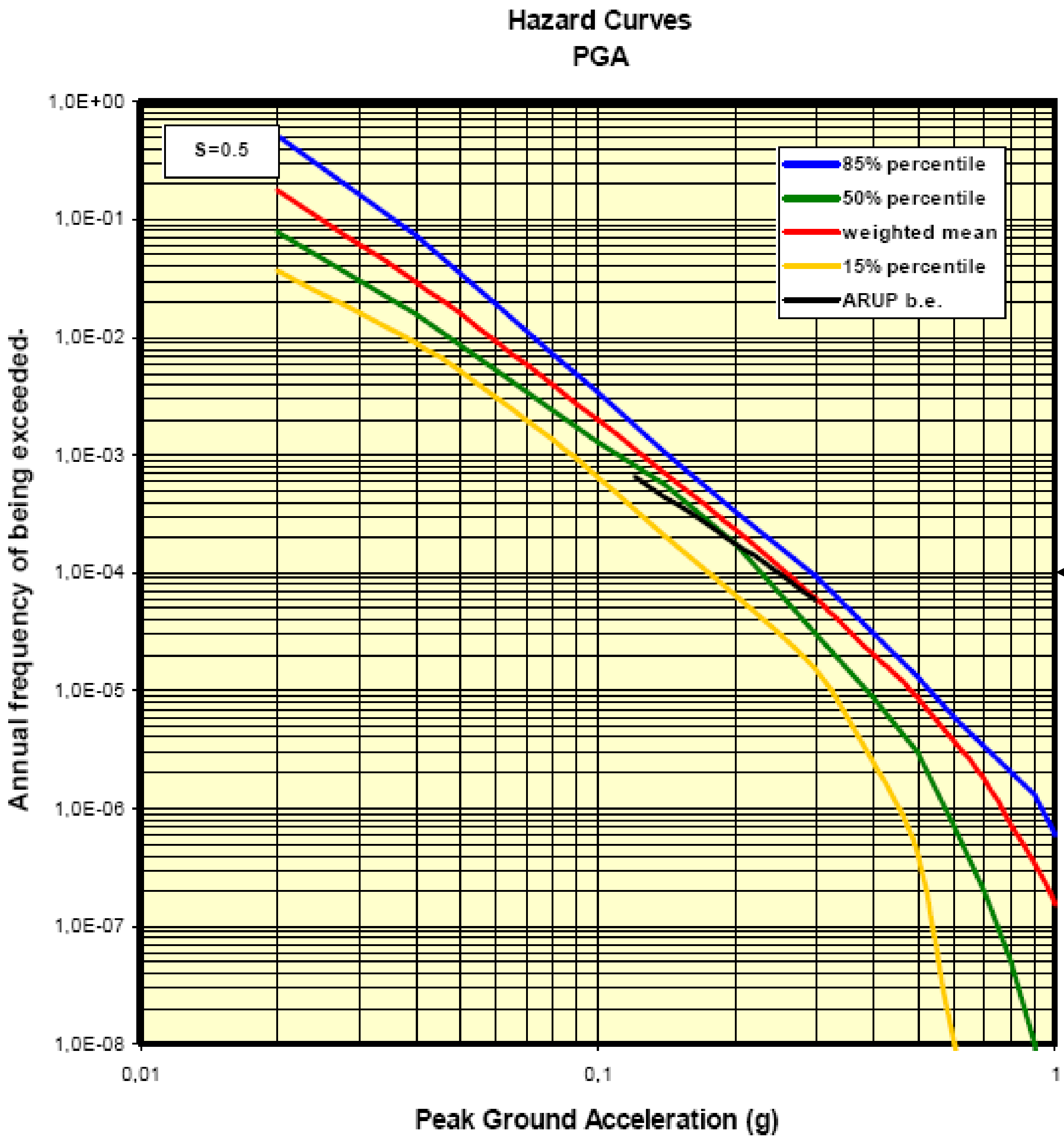
Hazard curves



10.000 years

0.25 g

Picture is taken from GeoRisk 2000.

Seismic acceleration ranges

- It was not practical to quantify the PSA models using continuous families of seismic hazard curves and associated equipment fragility distributions
- Seven acceleration ranges were selected to define seismic initiating events
- Lower bound corresponds to the lowest seismic capacity for all structures and equipment
- Upper bound is the highest acceleration evaluated in the seismic hazard analysis

Initiating Event	Acceleration Range (g)	IE Frequency (event/year)
SEIS1	0.07 – 0.10	$2.69 \cdot 10^{-3}$
SEIS2	0.10 – 0.15	$1.08 \cdot 10^{-3}$
SEIS3	0.15 – 0.22	$3.16 \cdot 10^{-4}$
SEIS4	0.22 – 0.32	$8.71 \cdot 10^{-5}$
SEIS5	0.32 – 0.48	$2.35 \cdot 10^{-5}$
SEIS6	0.48 – 0.70	$4.76 \cdot 10^{-6}$
SEIS7	0.70 – 1.0	$8.99 \cdot 10^{-7}$

Failure modes and fragility

- Most fragilities were developed during the full power seismic PSA
- Extended for the LPSD study: a limited number of mechanical and I&C components, structures (e.g. cranes and support structures)
- Fragilities determination: standard separation of variables approach, based on existing deterministic analyses conducted during seismic upgrades
- It was not practical to perform fragility calculations or tests on all components modelled in PSA
- Screening was applied, and generic fragilities were developed (used as surrogate elements) according to the criteria evolved in US IPEEE
  - high screen level HCLPF= 0.41g pga
  - low screen level HCLPF= 0.27g pga
- The analysis of seismic response based on the results of finite element evaluations of structures and floor response spectra were calculated for practically all levels of interest within the buildings of safe shutdown components
- Focus on consequences of liquefaction, non-ductile failure modes of steel structures and spatial systems interactions identified during plant walk-down

Baseline LPSD seismic PSA model

- Selection and grouping of equipment failures that can be caused by an earthquake
- Identification of transient initiating failures and additional system, system train and component level failures and degradations in each POS that can be caused by equipment failures within a seismic failure group
- Development of functional event trees for single transient initiating failures
- Development of a generic event tree in each POS for modelling plant responses to an earthquake with combinations of single and multiple transient initiating failures

- Quantification of post-initiator human errors were revised to take an account of mental and physiological factors associated with a seismic event
- Operator failure definitions and probabilities of the internal event PSA were used up to an acceleration level of 0.3 g unless operator intervention was assumed physically affected (hindered) by seismic failures
- No credit was given to successful post-initiator action above this acceleration level

Quantification

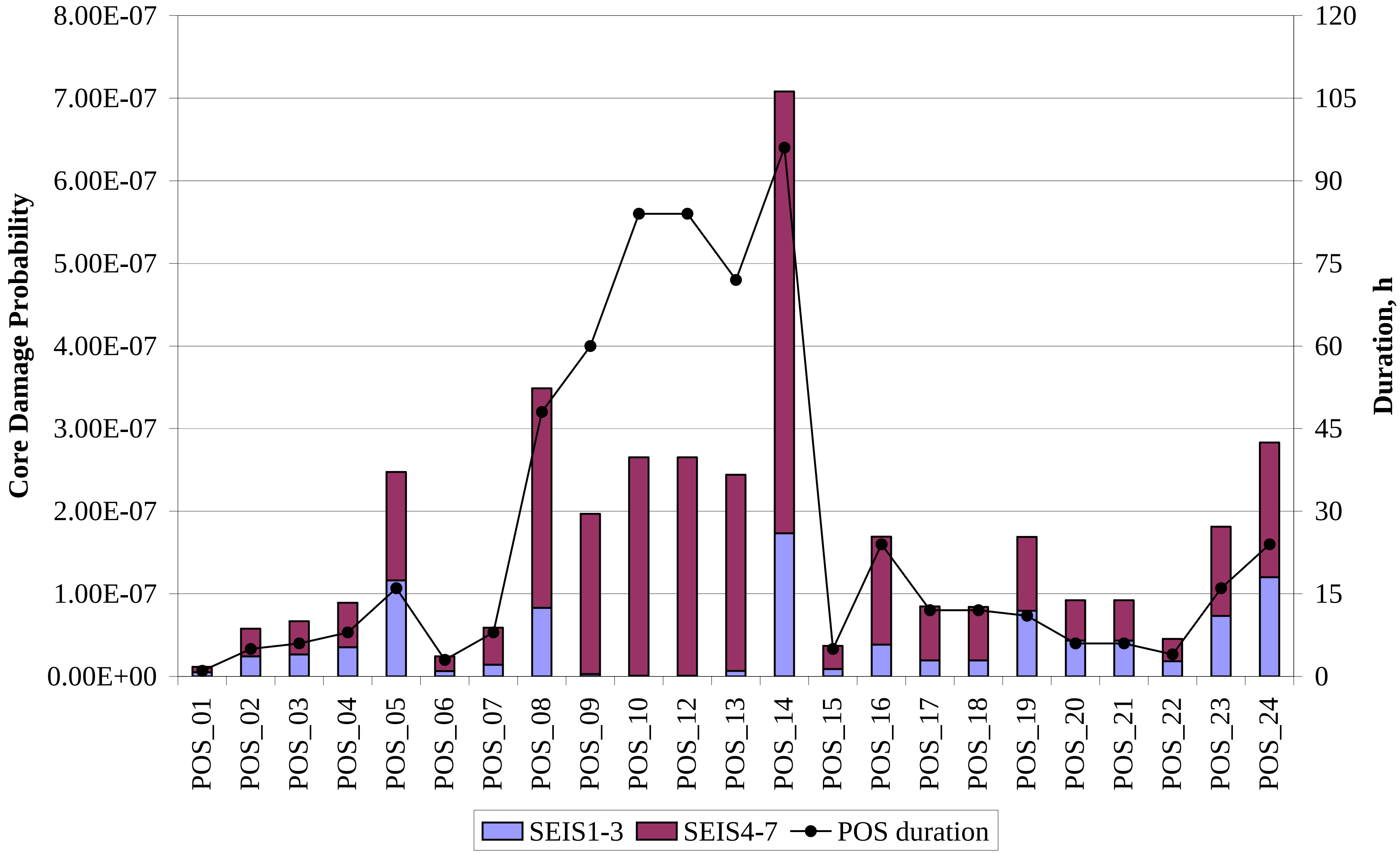
- Model was developed using the Risk Spectrum PSA Professional computer code
- For convoluting seismic hazard and seismic fragility curves a separate code was developed and used
- Calculations performed by Risk Spectrum required a new type of calculation as compared to the internal event PSA: the conditional core damage probability was computed where the rare event approximation does not apply

- The annual core damage probability from seismic initiating events that can occur during any of the low power and shutdown states is

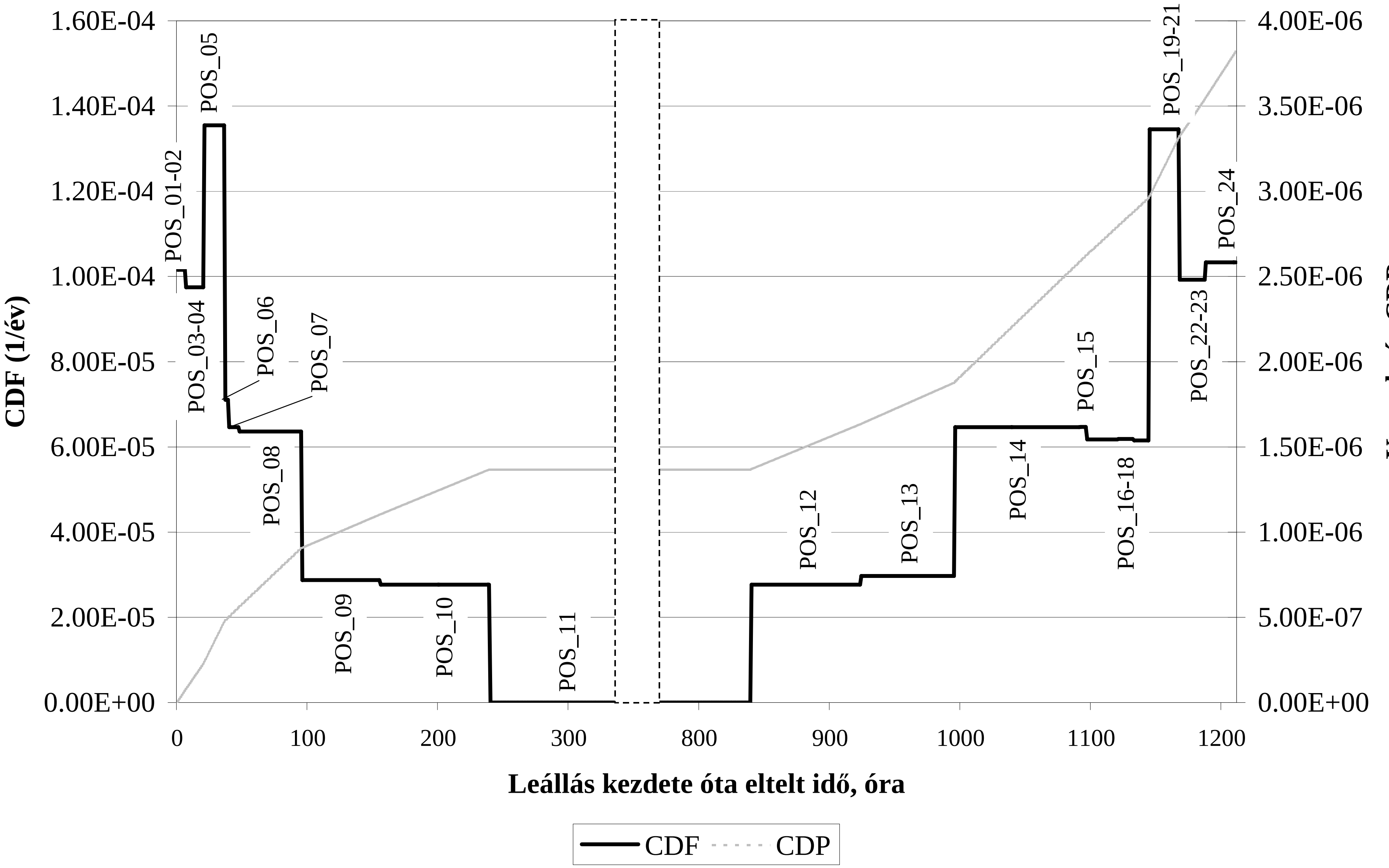
$$3.82 \cdot \mathbf{10}^{-06}$$

- Results are dominated by failures of untested (seismically non qualified) relays and cabinets (both electrical and I&C) and failure of the air compressor building paks nuclear power plant

Distribution of Core Damage Risk between POSs



Distribution of CDF between POSs



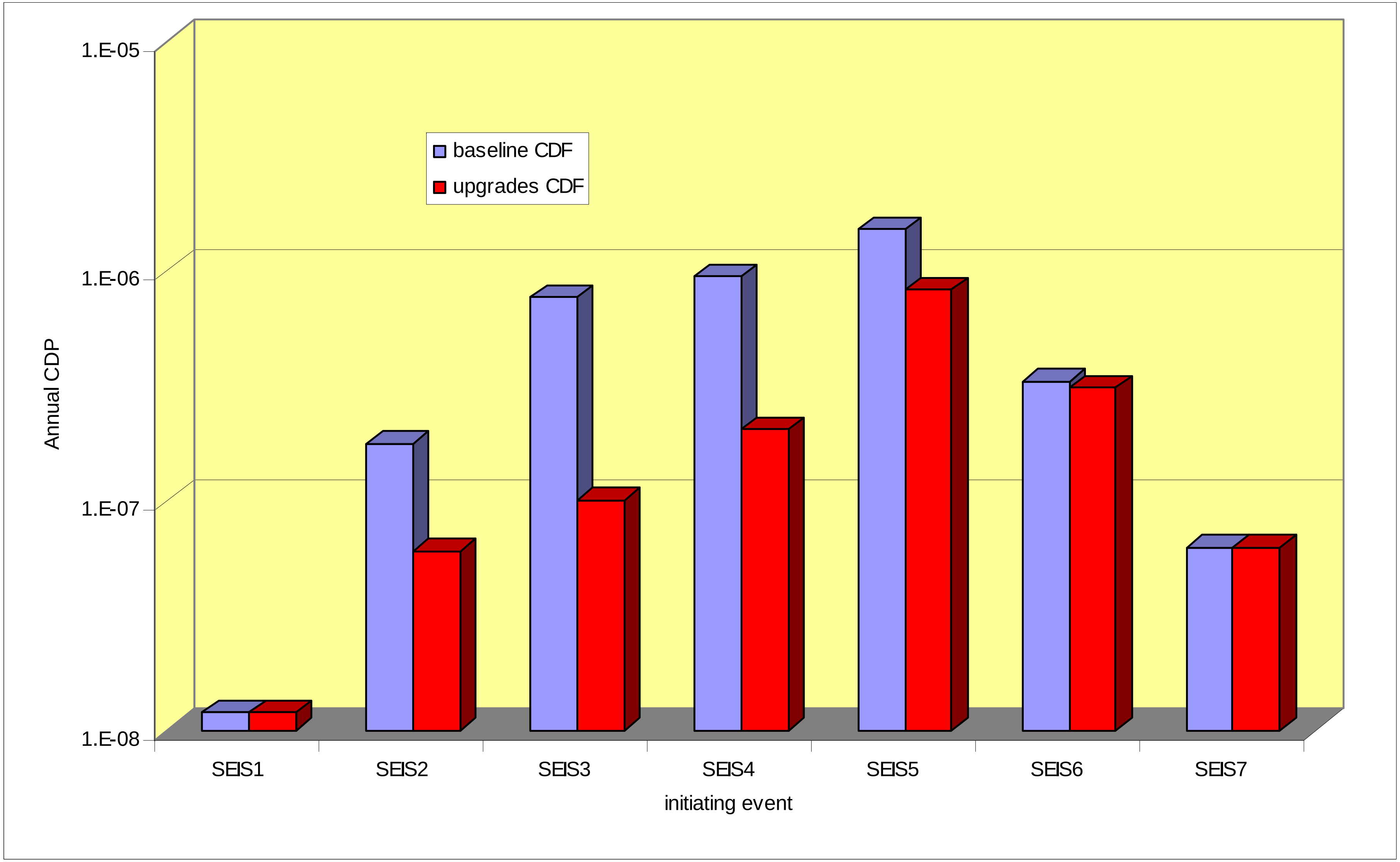
CDP for „baseline” PSA

Initiating Event	Acceleration Range (g)	IE Frequency (event/year)	Annual CDP $\Sigma\ 3.82 \cdot 10^{-06}$
SEIS1	0.07 – 0.10	2.66E-3	1.20E-08
SEIS2	0.10 – 0.15	1.08E-3	1.78E-07
SEIS3	0.15 – 0.22	3.16E-4	7.69E-07
SEIS4	0.22 – 0.32	8.71E-5	9.47E-07
SEIS5	0.32 – 0.48	2.35E-5	1.52E-06
SEIS6	0.48 – 0.70	4.76E-6	3.31E-07
SEIS7	0.70 – 1.00	8.99E-7	6.27E-08

Evaluation of Selected Seismic Upgrades

- Progressive risk improvements evaluated that may be achieved from implementation of two potential seismic upgrades
- Upgrade 1: untested relays and cabinets
  - Increase the seismic capacities for untested relays, electrical and I&C cabinets that affect any equipment in the PSA models to at least the lower screening capacity
  - Correlated failures of all the untested relays and cabinets are assumed in the baseline PSA and a single element is used in the model to describe these correlated failures
  - To avoid simultaneous failure of untested relays and cabinets that would cause loss of offsite power, inadvertent closure of all steam generator isolation valves, inadvertent opening of all steam generator safety valves and failure of all feedwater systems as well as failure of emergency core cooling systems
- Upgrade 2: air compressor building
  - Increase the structural capacity of the air compressor building
  - To avoid loss of high-pressure air that causes the steam generator isolation valves and the main steam header sectioning valves to close
  - Enable more reliable closed loop secondary side heat removal
- According to parametric studies significant risk reduction can be achieved by implementing these upgrades

CDP for different initiating events



Conclusions

- Probabilistic safety assessment for seismic events has been carried out in the last stages of a comprehensive program on enhancing the seismic safety of the four VVER-440, type 213 reactors of the Paks NPP in Hungary
- The seismic PSA was concerned with the quantification of core damage risk and with an evaluation of the effectiveness of the previously performed seismic upgrade.
- The initial analysis covered seismic events at full power operation and followed by a low power and shutdown seismic PSA.
- The analysis followed the traditional steps of a seismic PSA including: assessment of seismic hazard, development of seismic fragilities for safety related systems, structures and components, development of accident sequence models for seismic-induced plant transients, and computation of core damage risk.
- The results of the Paks LPSD seismic PSA show that earthquakes are an important contribution to LPSD core damage risk.
- Based on these results two upgrades have been conceptualized.
- According to parametric studies, significant risk reduction can be achieved by implementing these upgrades.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