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Case Studies in Switzerland

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Earthquake Engineering for Nuclear Facilities - Uncertainties in Seismic Hazard Assessment

“Case Studies in Switzerland”

Trieste, Italy, 14 – 25 February 2005

(Unit 28) - (Dr. Jens-Uwe Klügel)

Contents

Introduction

- Switzerland – 4 NPP sites with 5 reactor units
- PRA up to level 2 for full power and shutdown PRA , both including external events and internal hazards is a regulatory requirement
- PRA is used as a complementary safety analysis tool for BDBA to identify areas for safety upgrades
- All Swiss NPPs have complete PRA, which have to be upgraded at least once in 5 years

Seismic PRA Methodology (used to 2004)

- Based on an extension of the methodology developed for the IPEEE program in the USA
  - Largely based on methods developed by PLG and EQE International (now ABS risk consulting)
- Step 1 :Development of a „PSHA+ for pga (effective ground accelerations) based on seismic hazard maps
- Step 2: Development of a list of safety- important components and structures

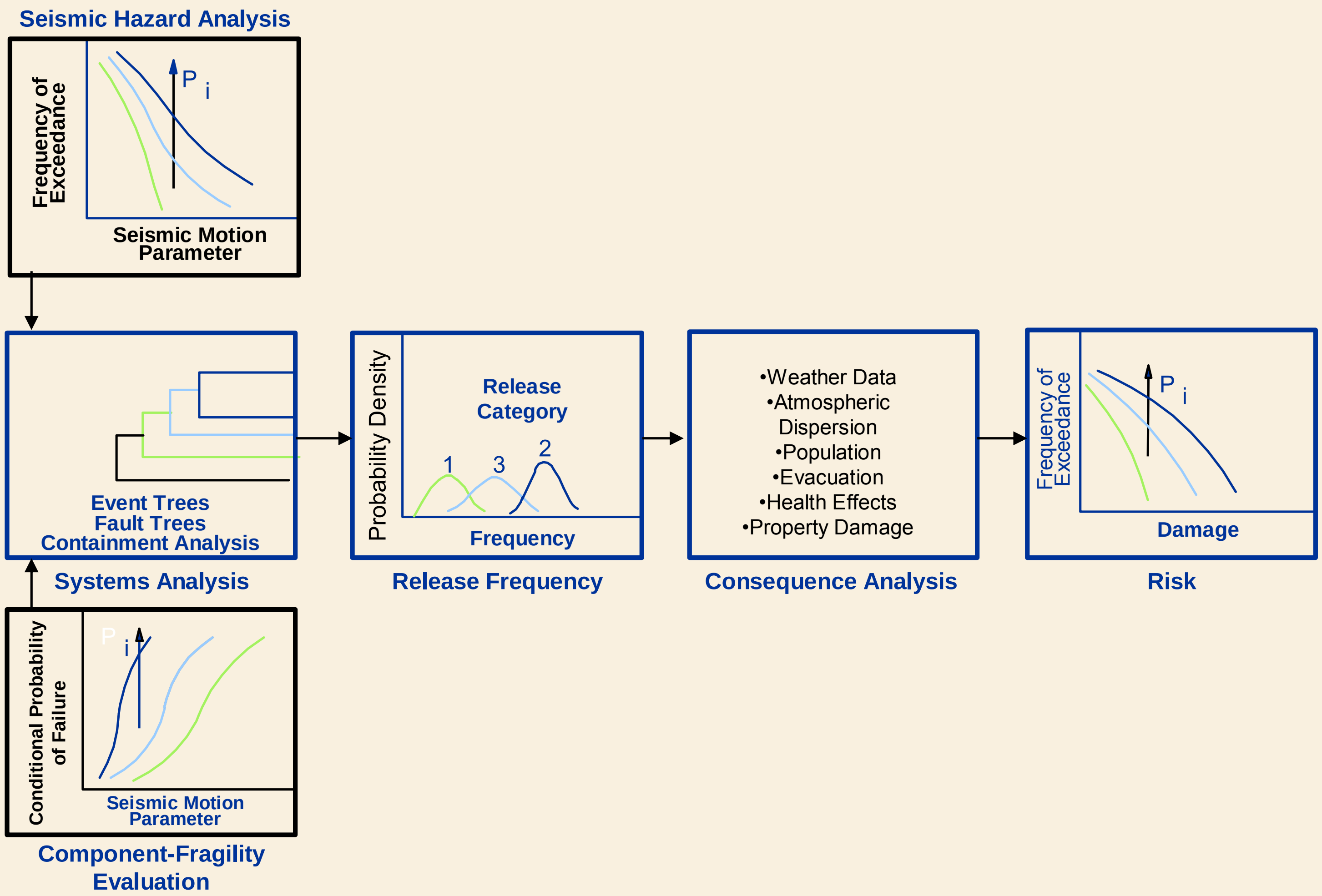
Seismic PRA Methodology (used to 2004)

- Step 3: Fragility calculation
  - Review of plant documentation
  - Walkdown
  - Screening
  - Detailed Fragility-Analysis. partially generic Fragilities (Masonry walls)
  - pga (in the sense of a EGA) as basis parameter

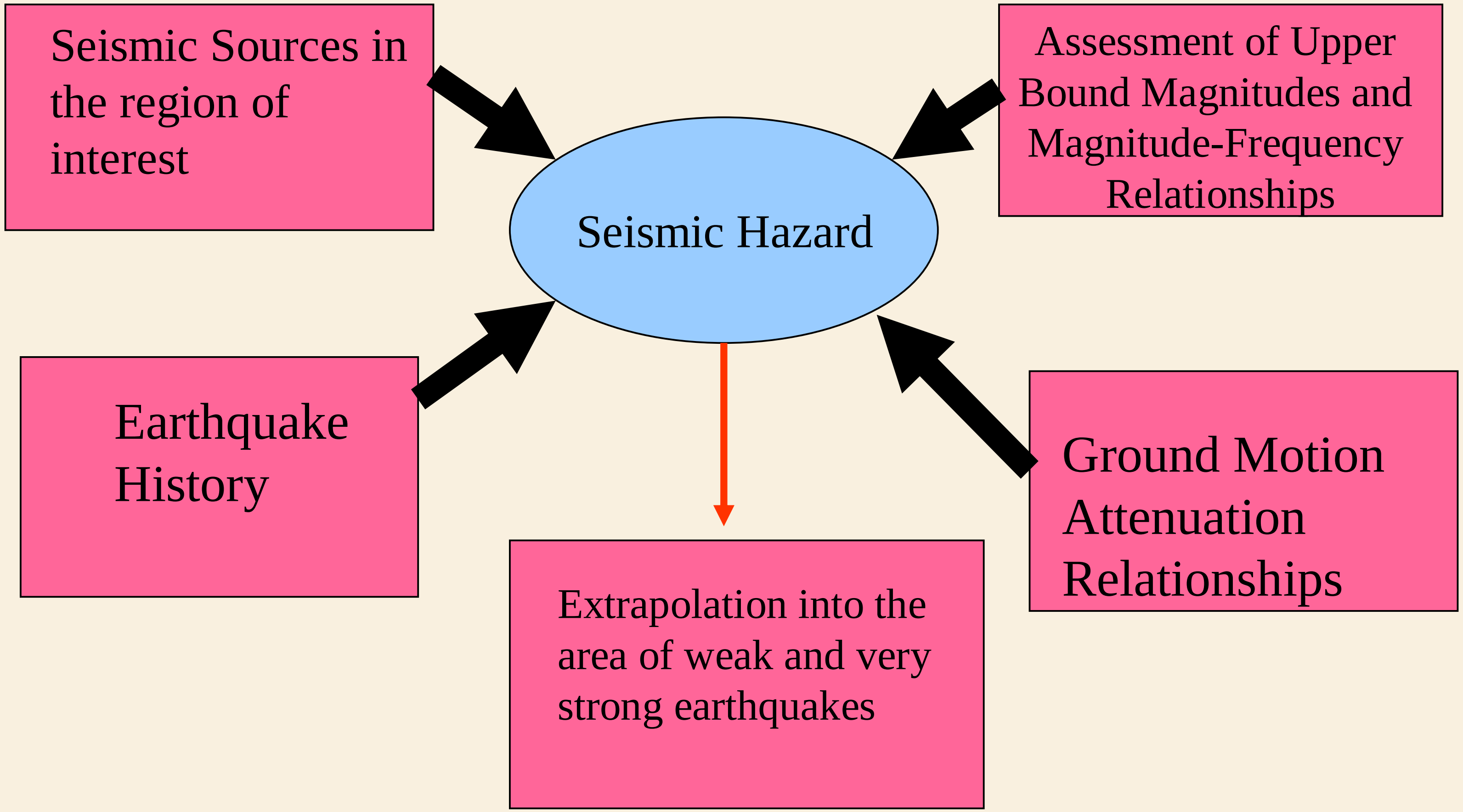
Seismic PRA Methodology (used to 2004)

- Step 4 – Development of a Plant –Logic Model
  - Development of failure models and conditional failure probabilities
  - Seismic PRA model
  - Model Integration
- Step 5: Quantification and Sensitivity studies

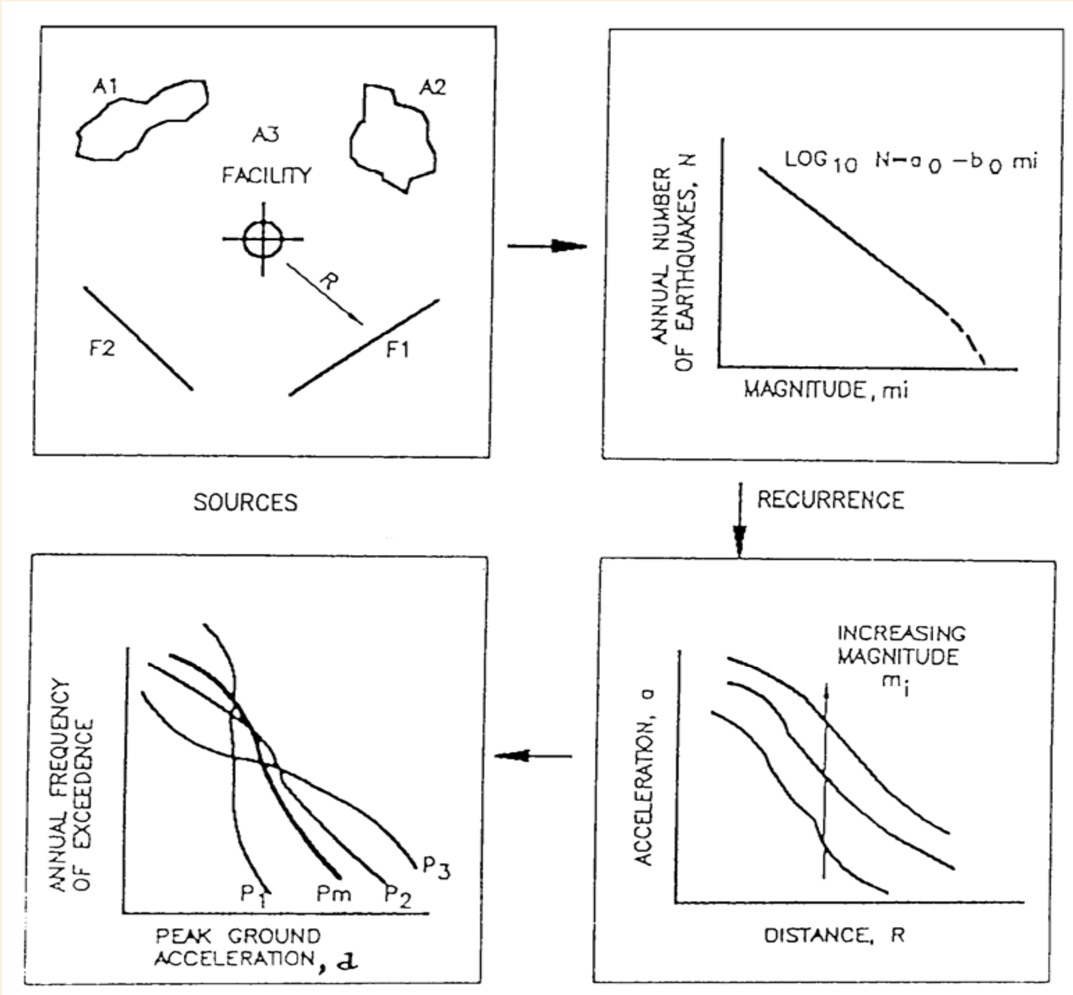
Seismic Probabilistic Risk Assessment



Step 1 - Definition of Site Specific Seismic Hazard



Estimation of Hazard Frequencies



For Goesgen a quadratic recurrence law was used

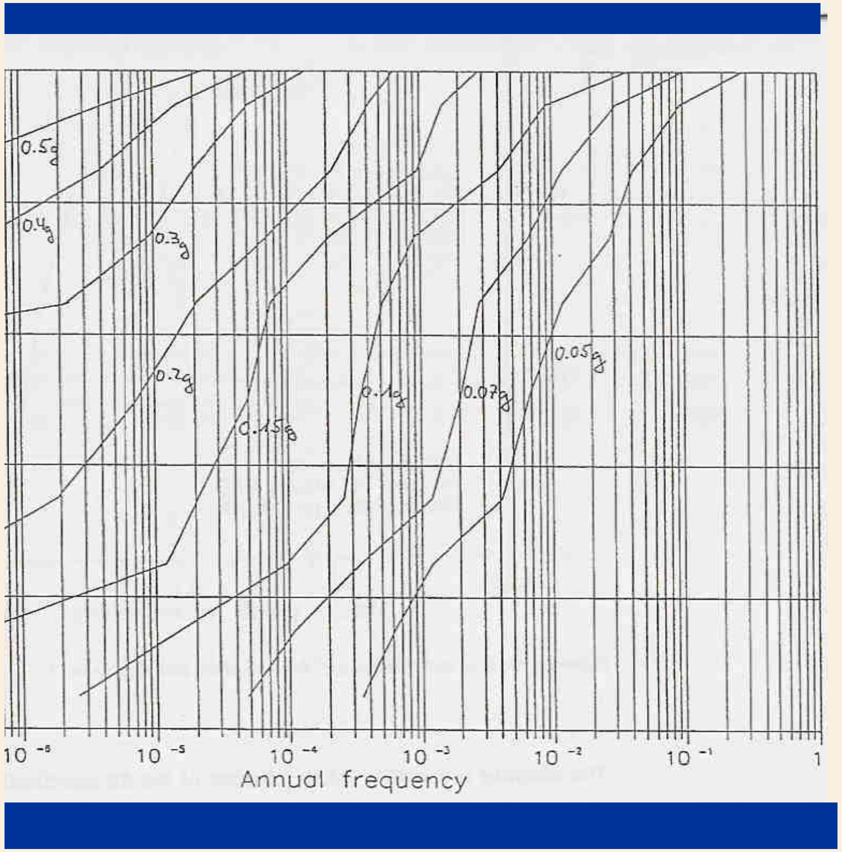
Site Specific Seismic Hazard

- Original Assessment by B&H – Goesgen -1991
  - Basis for Seismic-PRA 1993
  - Result presented as a DPD (108 functions with corresponding weighting factors) in terms of PGA (peak ground acceleration)
- Adjusted for the PRA Update, 2001
  - Extension into the area of weak earthquakes
  - Extrapolation of the hazard functions into the area of very low annual frequencies (< 10^{-8}/a , 10^{-10}/a cutoff value)

Step 1 - PSHA

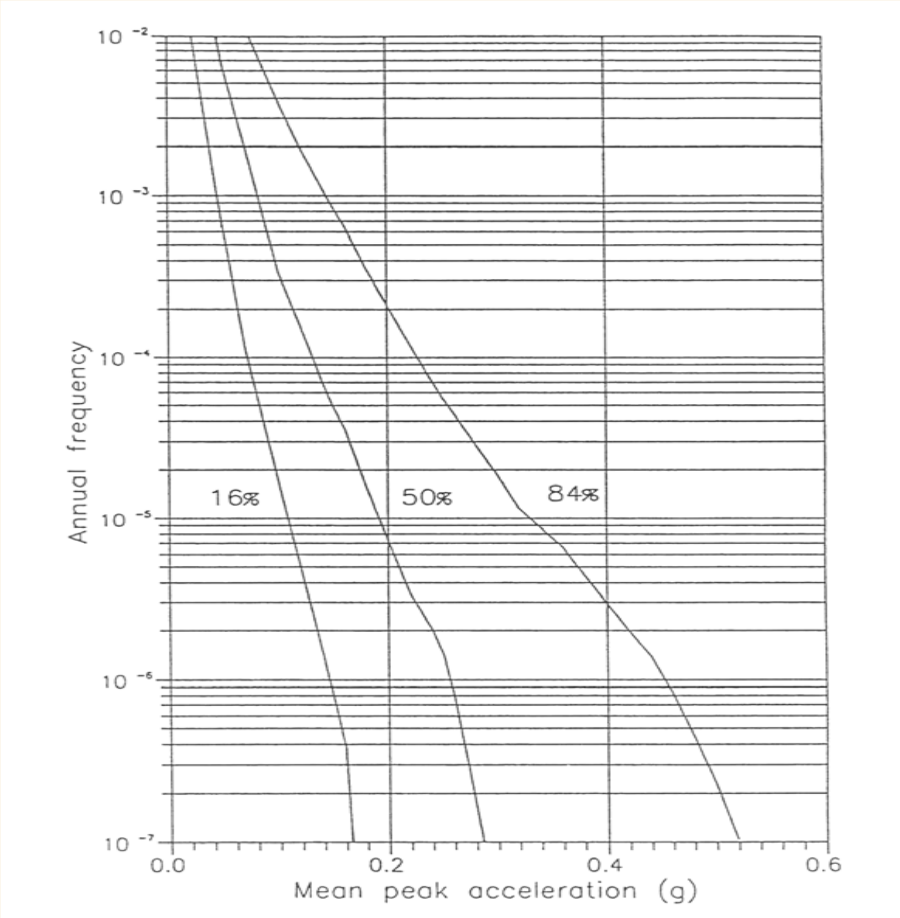
- Based on an extrapolation of existing seismic hazard maps
  - Switzerland is a low to moderate seismic country
  - Moderate activity in the „Wallis“ and in the Basel-area, Ticino
  - No historic macro-seismic events with magnitude >5.5 in any other area
- Two different zonations
- Two different conversion formula from intensity to magnitude
- Two different attenuation laws including azimuthal dependence
- Total uncertainty in the hazard limited to n σ=0.67

Site-Specific Hazard



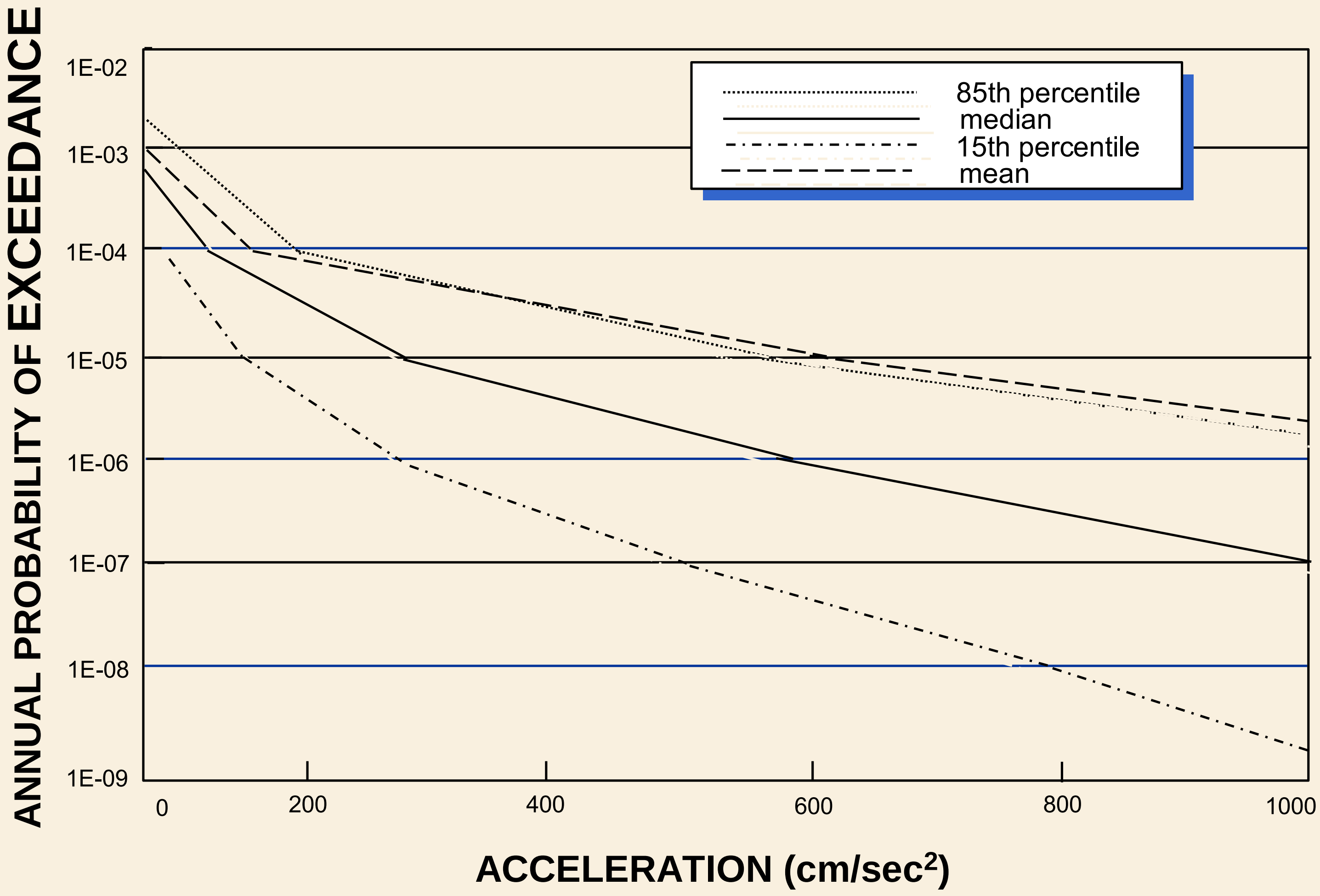
- B&H developed 108 diskrete hazard curves for fixed pga values
- Basis for the development of a cumulative hazard distributions

Site-Specific Seismic Hazard

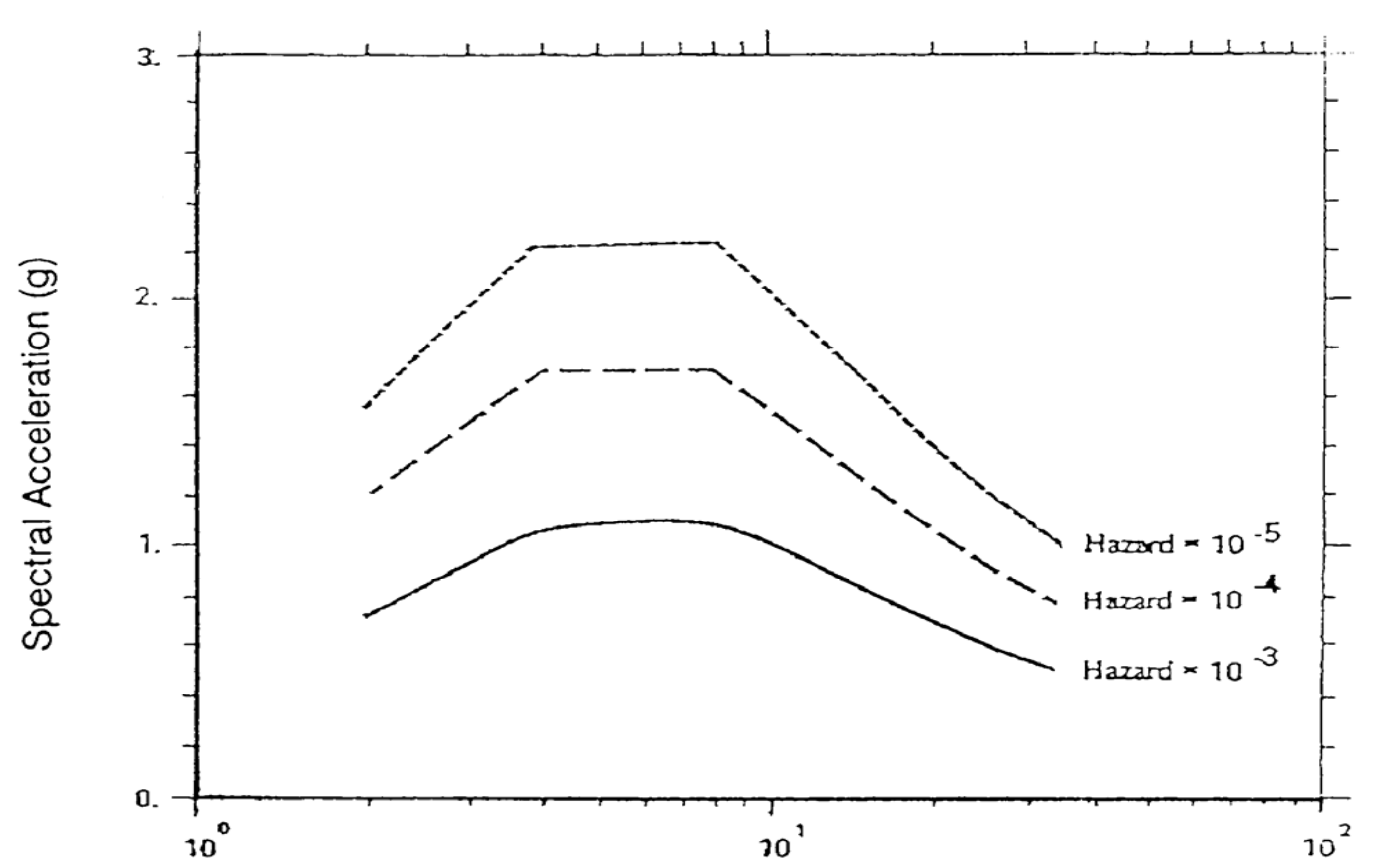


- Low (?)spread of uncertainties was later criticized (by seismologist, engineers criticized the large spread of data and the need of extrapolation)
- Error – common to most PSHA studies, curves based on Uniform seismic hazard spectra, what is meaningless for a PRA
  - A seismic initiator has always ist origin at one source associated with a frequency associated to that source

Seismic Hazard Curves (US plant)



CCF in Seismic PRA- Methodology – the Use of Uniform Hazard Spectra

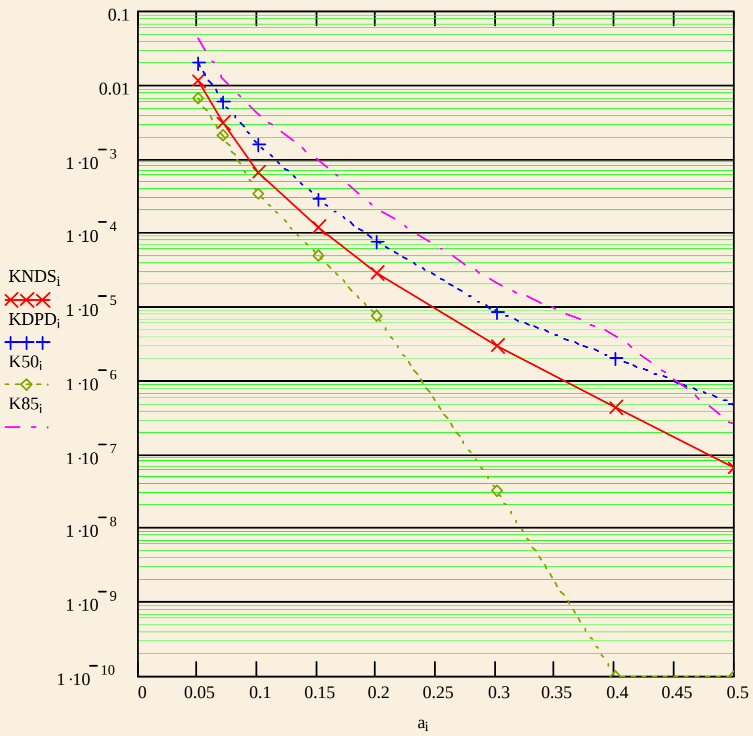


The use of UHS is only justified if the hazard is dominated by the influence of one source

Site Specific Seismic Hazard, Problems

- RISKMAN© seismic module allowed (till 2004) only the use of 9 seismic hazard curves, original 108 curves had to be condensed into 9
- The used ABS(EQE) - DPD-modelling approach in context with the data extrapolation led to a large numerical error
- Alternative approach developed based on data analysis, Model of normally distributed weighting factors

Sensitivity Analysis on Site specific Seismic Hazard,



KNDS - Normalverteilungsmodell,
KDPD - DPD-Modell der EQE/PLG
K50 - Median-Kurve nach Basler&Hofmann
K85 - 85%-Kurve nach Basler und Hofmann

- Sensitivity study on hazard curve integration
  - ABS/DPD-Model intersects the 85%-graph from the original PSHA by B&H (for low seismic areas not to be expected)
  - Model of normally distributed weighting factors fits reasonably between the 50%-and 85%-graph

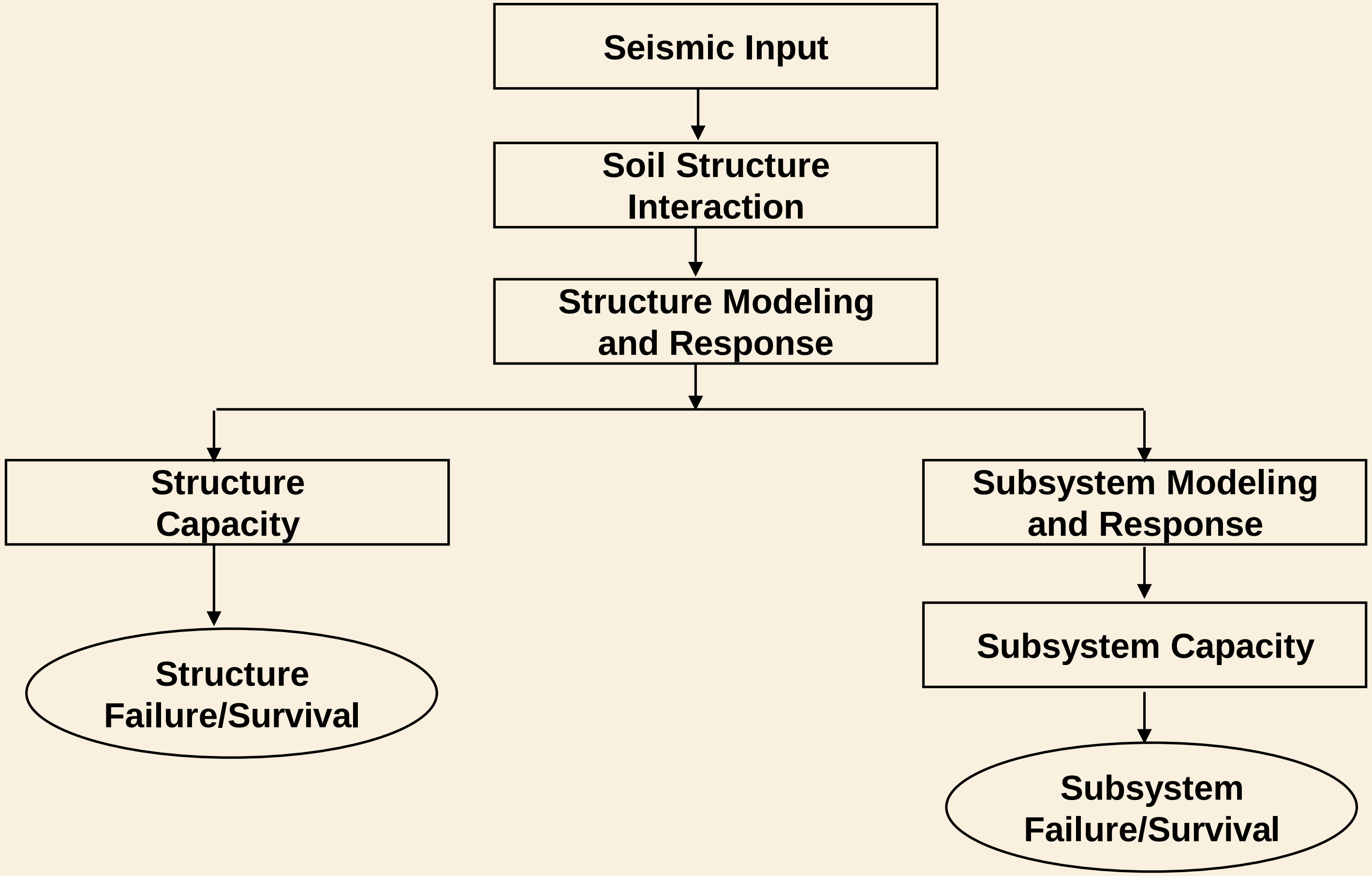
Step 2 – List of safety important components and structures

- Starting list of about 600 items
  - Residual Heat Removal Function
  - Support Functions (electrical equipment)
  - New (different from internal event PRA) Passive components and structures
- List later reduced based on screening, use of super components

Step 3 – Fragility Analysis

- Detailed Review of Plant Documentation
- Walkdown
- Screening – based on generic fragilities, EQE – external events database
- Effort for detailed fragility analysis reduced to less than 100 items, some of them could be summarized to common calculational units

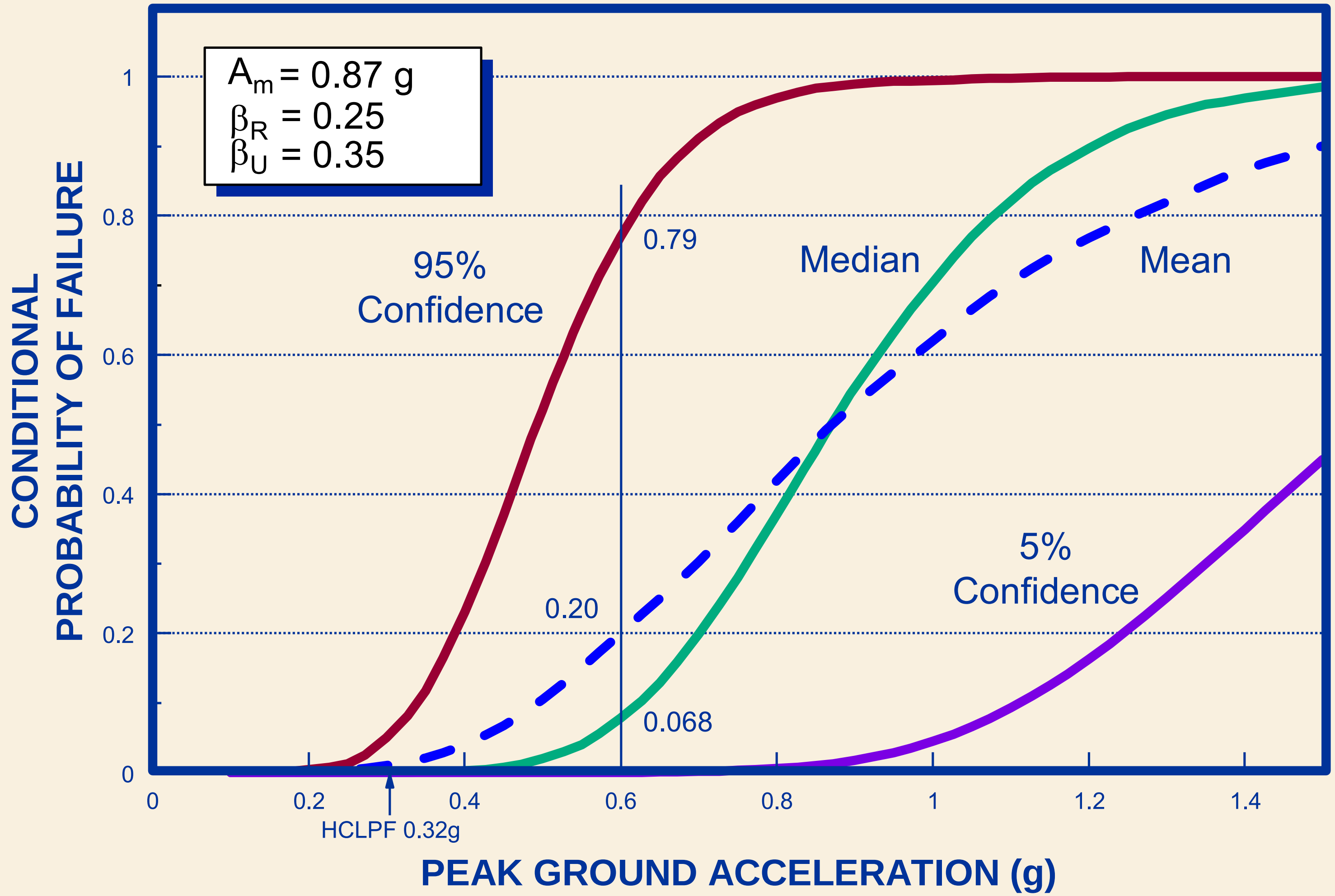
Fragility Analysis Flow Chart



Fragility Derivation

- For GÖSGEN, fragility was extrapolated from design information by quantifying factors of conservatism and variability.
  - $A_m = F_C * F_{RE} * F_{RS} * A_{SSE}$ = median PGA capacity
  - F_C = Capacity Factor (Strength and Ductility Contribute)
  - F_{RE} = Response Factor for Equipment/Block Walls
  - F_{RS} = Response Factor for the Structure
  - HCLPF Capacity = $A_m * e^{-[1.65(\beta_R + \beta_U)]}$

Seismic Fragility Curves



Development of a Plant- Logic Model

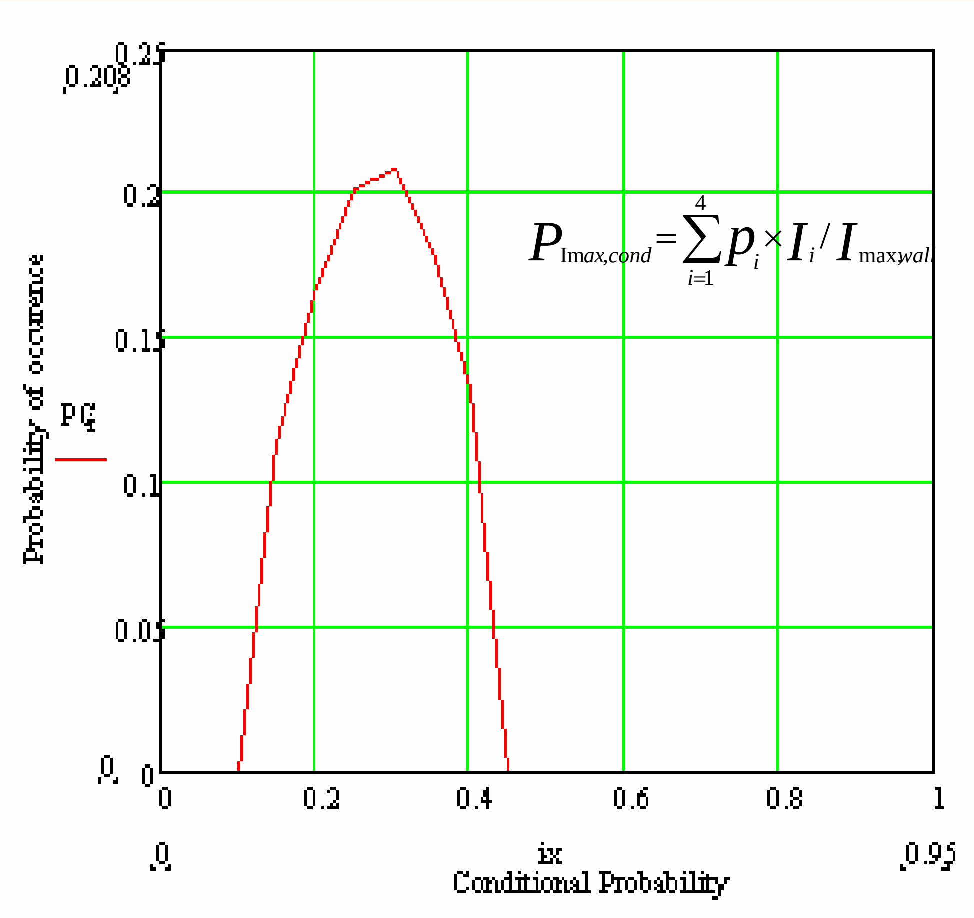
- Definition of failure modes and failure impacts of seismic components on plant safety functions (PSA-components)
- Problem – dependent „secondary“ failure modes, failure of non-structural equipment which can fail plant equipment
  - Example – failure of masonry walls (non-structural)
  - Special expert judgement methodology developed based on a decomposition of the failure modes to potential damage effects
  - Individual assessment of more than 450 masonry walls and wall sections
- Development of the final PRA-model
  - Model size limitations (software)
  - Iterations required, but limited due to regulatory requirements

Expert judgement approach for wall categorization and development of conditional probabilities

Table 6-1 Assignment of masonry walls in the electrical building to the classes.

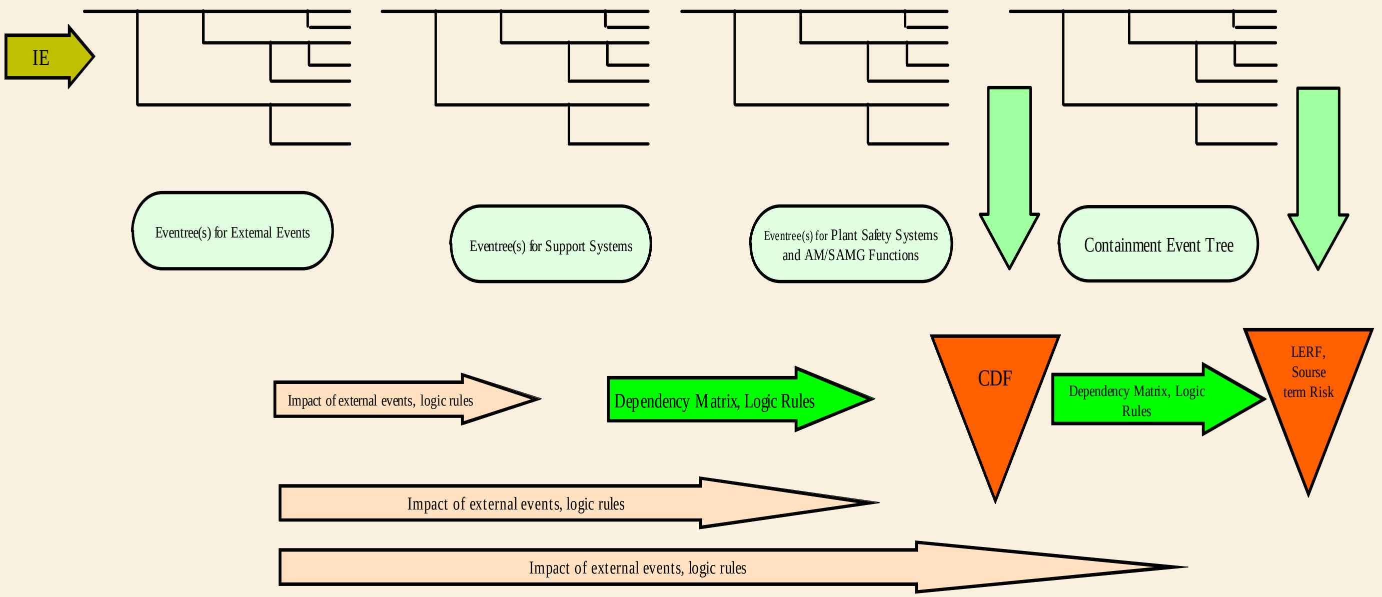
Elevation	Class A/ Conditional Probability		Class B/ Conditional Probability		Class C/ Conditional Probability		Class D/ Conditional Probability		Class E/ Conditional Probability		Class F/ Conditional Probability	
-7.5m	10	0.423	7	0.414	0	0.398	6	0.2915	3	0.226	6	0.1325
-4.2 m	16	0.423	2	0.414	4	0.398	0	0.2915	0	0.226	2	0.1325
0.0 m	6	0.433	14	0.424	6	0.408	9	0.3015	20	0.236	33	0.1425
+4.1 m	4	0.433	13	0.424	24	0.408	8	0.3015	33	0.236	52	0.1425
+7.6 m	3	0.433	11	0.424	24	0.408	1	0.3015	8	0.236	40	0.1425
+10.3 m	0	0.433	2	0.424	7	0.408	0	0.3015	0	0.236	2	0.1425
+12.0 m	0	0.433	2	0.424	27	0.408	1	0.3015	15	0.236	18	0.1425
+14.4 m	0	0.433	0	0.424	6	0.408	0	0.3015	4	0.236	0	0.1425
+19.0m	0	0.433	0	0.414	4	0.398	0	0.2915	0	0.226	0	0.1325
Total Walls in Class	39		51		102		25		83		153	

Conditional Probability for Maximum Wall Failure Impact



- Detailed analysis because seperate modeling of >450 walls is not feasible, large correlation of failure modes
- Adressed were
  - Direct mechanical impact
  - Debris Loads
  - Induced fire damage
  - Dirt/small debris

RISKMAN® Model Linked Level1/Level2 Event Tree Model

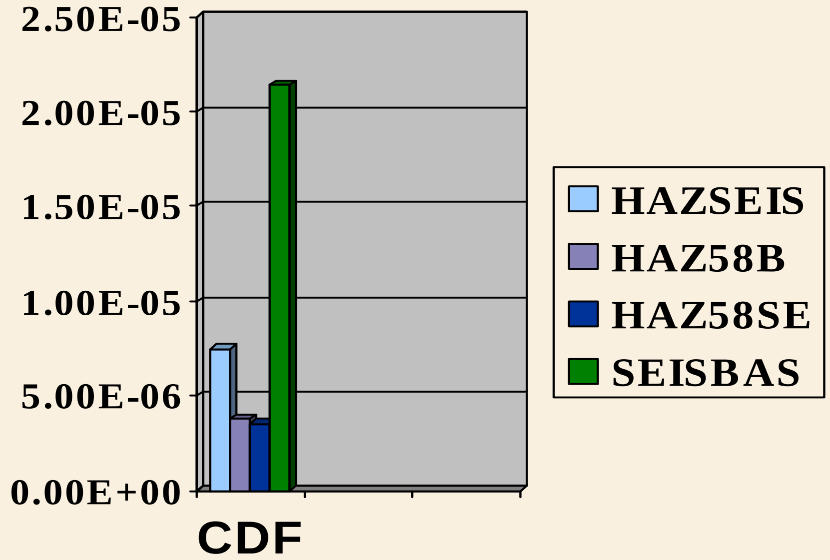


Step 5 Quantification and Sensitivity Studies

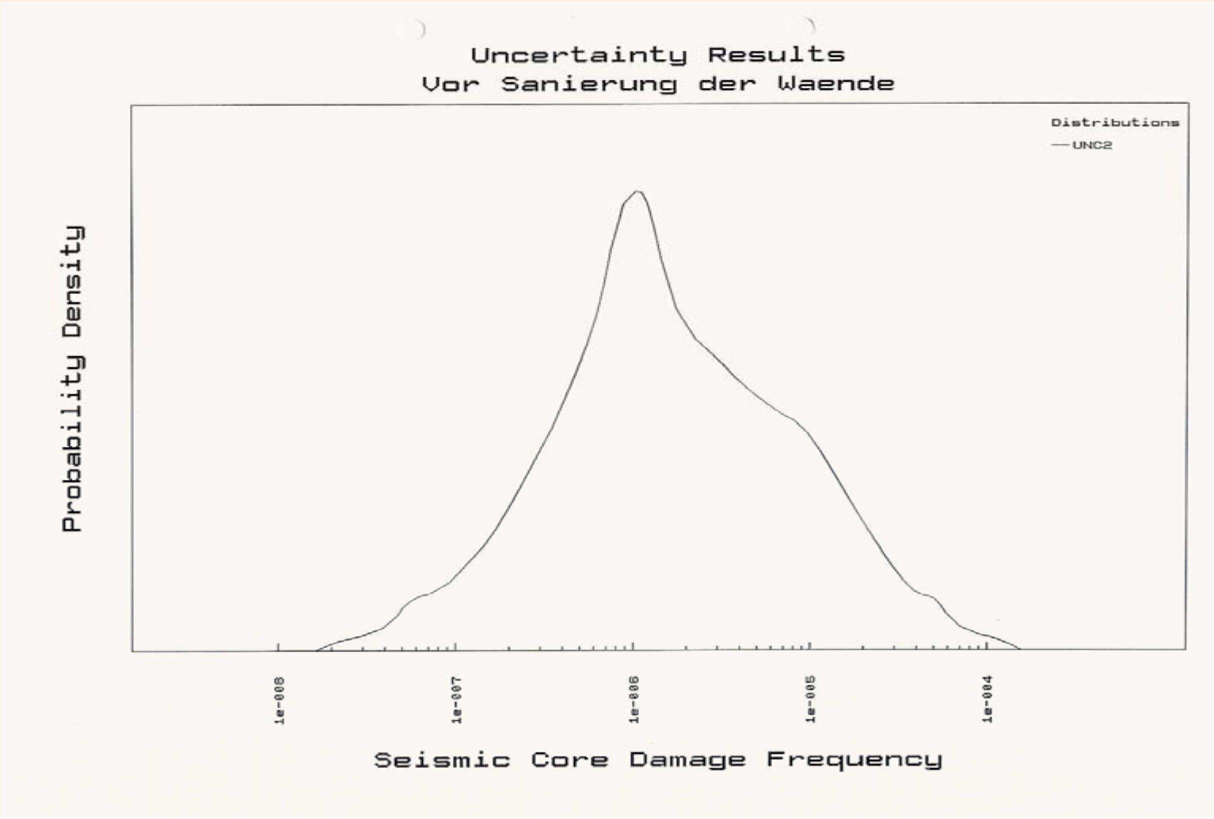
Modell	CDF-mean	CDF-median	95% - Fractile
SEISBAS	1.415E-5/a	1.42E-6/a	7.29E-5/a
HAZSEIS	5.482E-6/a	1.44E-6/a	2.34E-5/a
HAZ58B	1.785E-6/a	8.36E-8/a	7.99E-6/a
HAZ58SE	1.520E-6/a	7.07E-8/a	6.92E-6
HAZ58LF	1.799E-6/a	8.54E-8/a	8.03E-6

Sensitiviy Study – Lessons

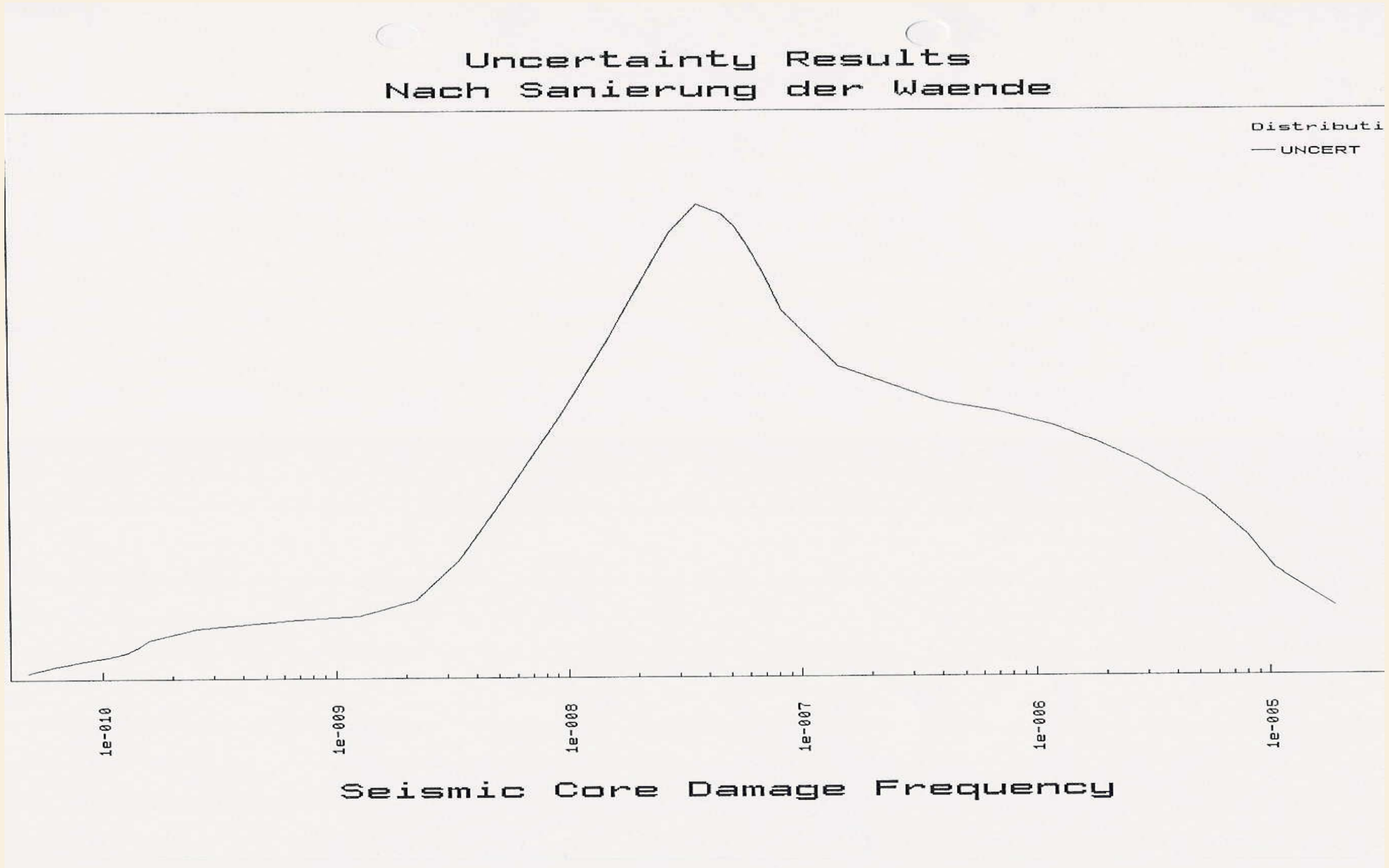
- Reduction of uncertainties in the hazard definition leads to a large reduction of the risk
- Performed seismic upgrade of 58 masonry walls led to a significant reduction of the seismic risk
- Additional possible upgrades do not lead to significant risk reduction



Uncertainty Anaylsis– Before Seismic Upgrade



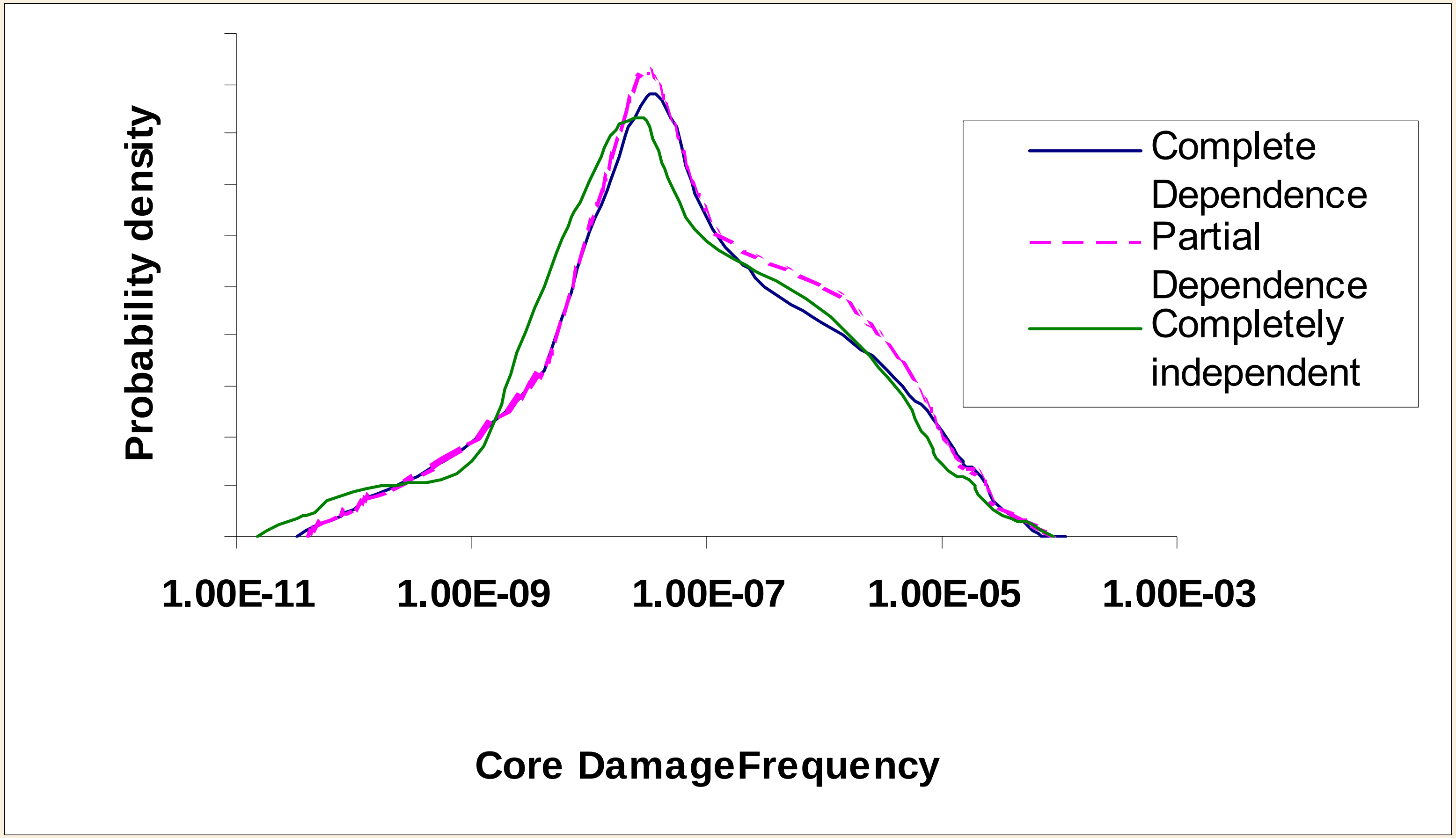
Uncertainty Analysis after Seismic Upgrade of Masonry Walls



Sensitivity studies on coupled dependend failure modes

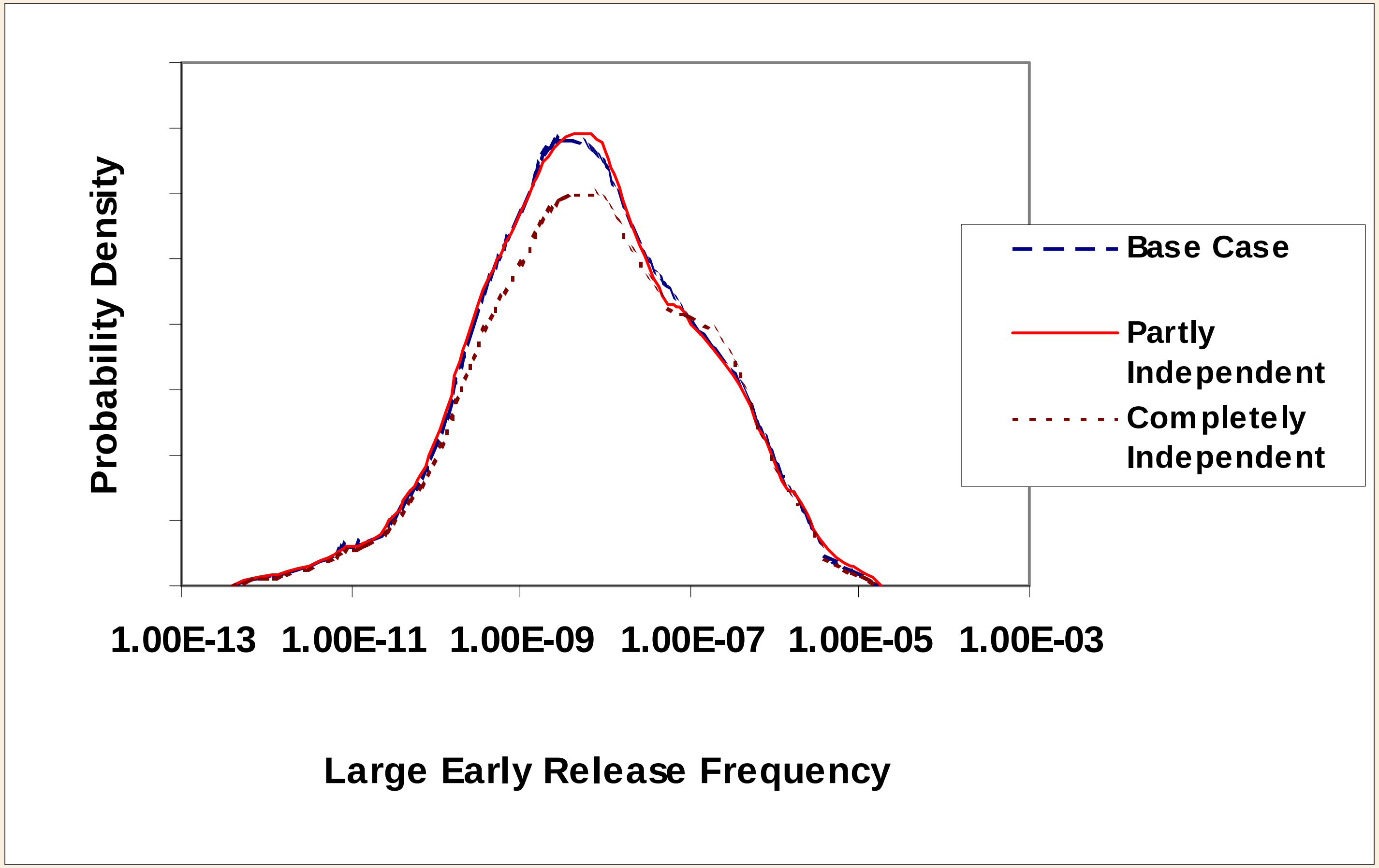
Core Damage Frequency Comparison

380V Switchgear



Large Early Release Frequency Comparison

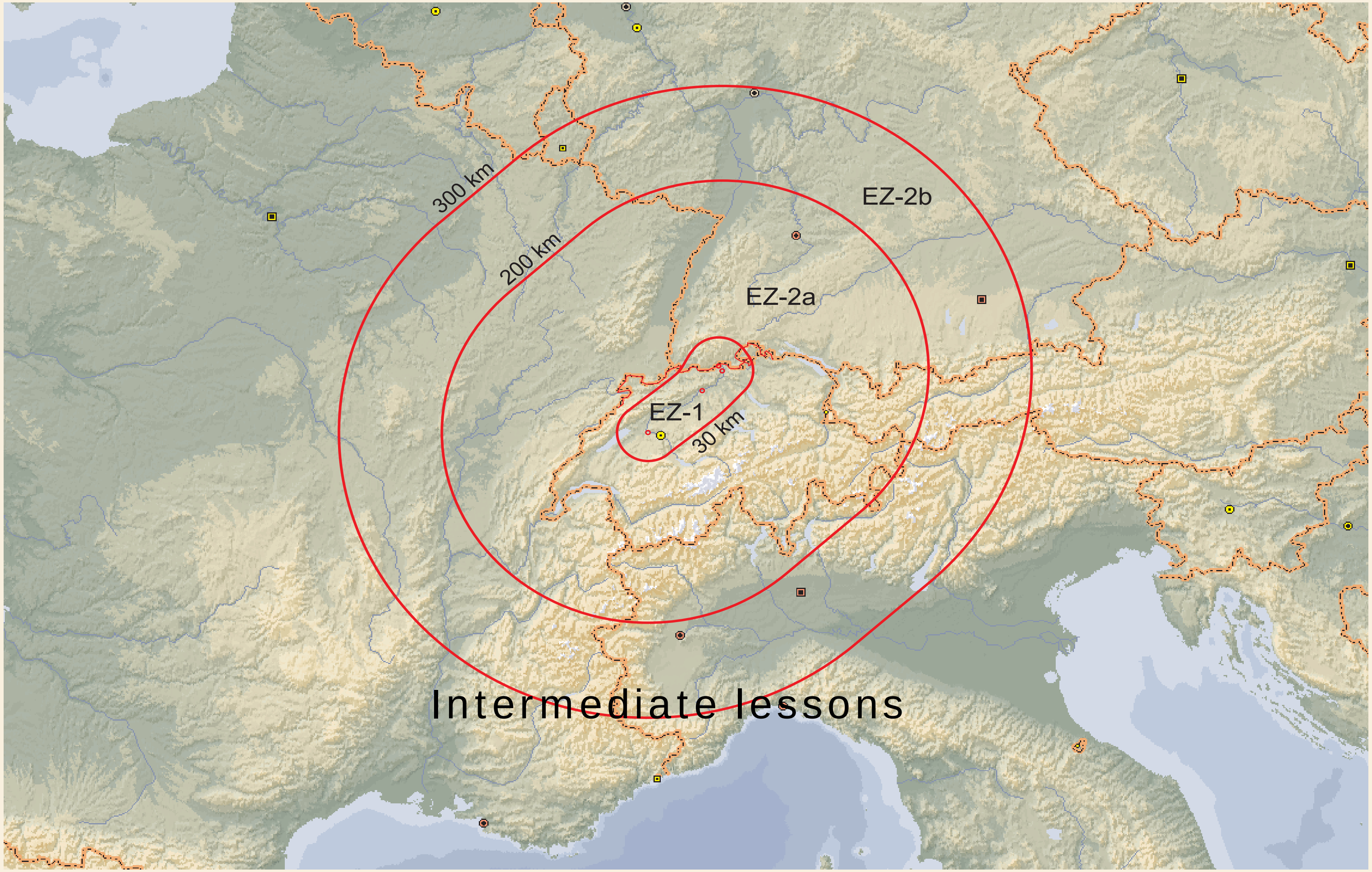
380V Switchgear



Lessons and Conclusions from Swiss PRA-Studies

- Reduction of uncertainties in seismic hazard analysis is the key factor to obtain a meaningful seismic risk profile (error factors shall be smaller than 10)
  - Swiss utilities launched the PEGASOS - project
  - Seismic initiators shall be defined source-specific = Increase in model size, limitations of industrial PRA-codes
  - Fragility calculations shall be modernized – effort and costs can increase by an order of magnitude
    - Nonlinear dynamic coupled soil-structure-component-analysis (?)
      - degree of sophistication (?), buildings of nuclear facilities are more complex than standard buildings and cannot be modelled by simple non-linear SDOF or simple MDOF-systems
    - Alternative – decoupled analysis (will be to pessimistic)

PEGASOS – a first outlook



Intermediate lessons

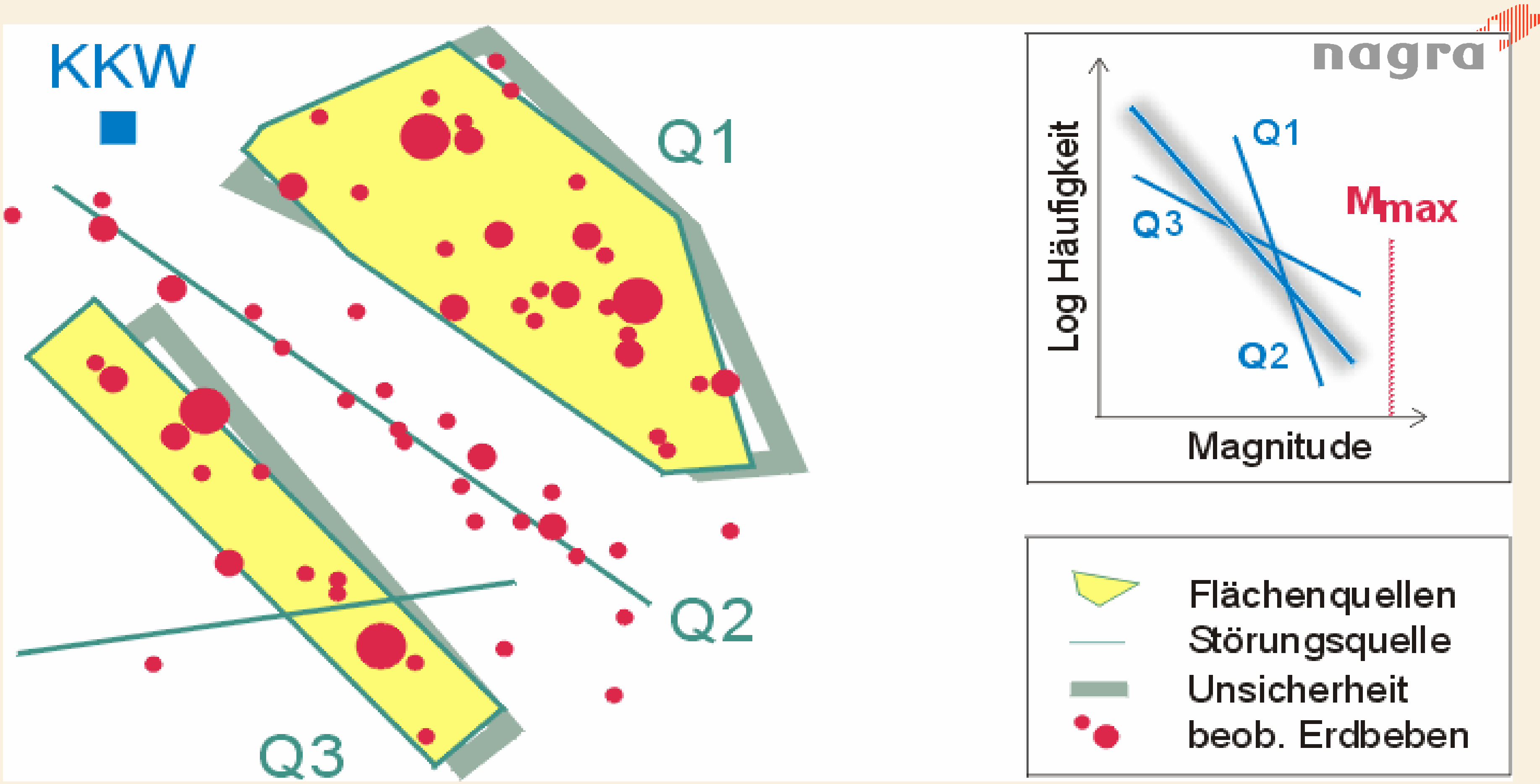
PEGASOS-Project

- GOAL: Probabilistic Seismic Hazard Analysis based on SSHAC Level 4 procedures
- NUREG CR-6372 Recommendation for PSHA: Guidance on Uncertainty and Use of Experts (SSHAC – Senior Seismic Hazard advisory Commitee), 1997
- Research Study
- Seperate treatment of aleatory and epistemic uncertainties according the assumptions in SSHAC, 1997
    - Actually there is no basis for such a seperation, all uncertainties are in the end epistemic, seperation is mathematically not justified

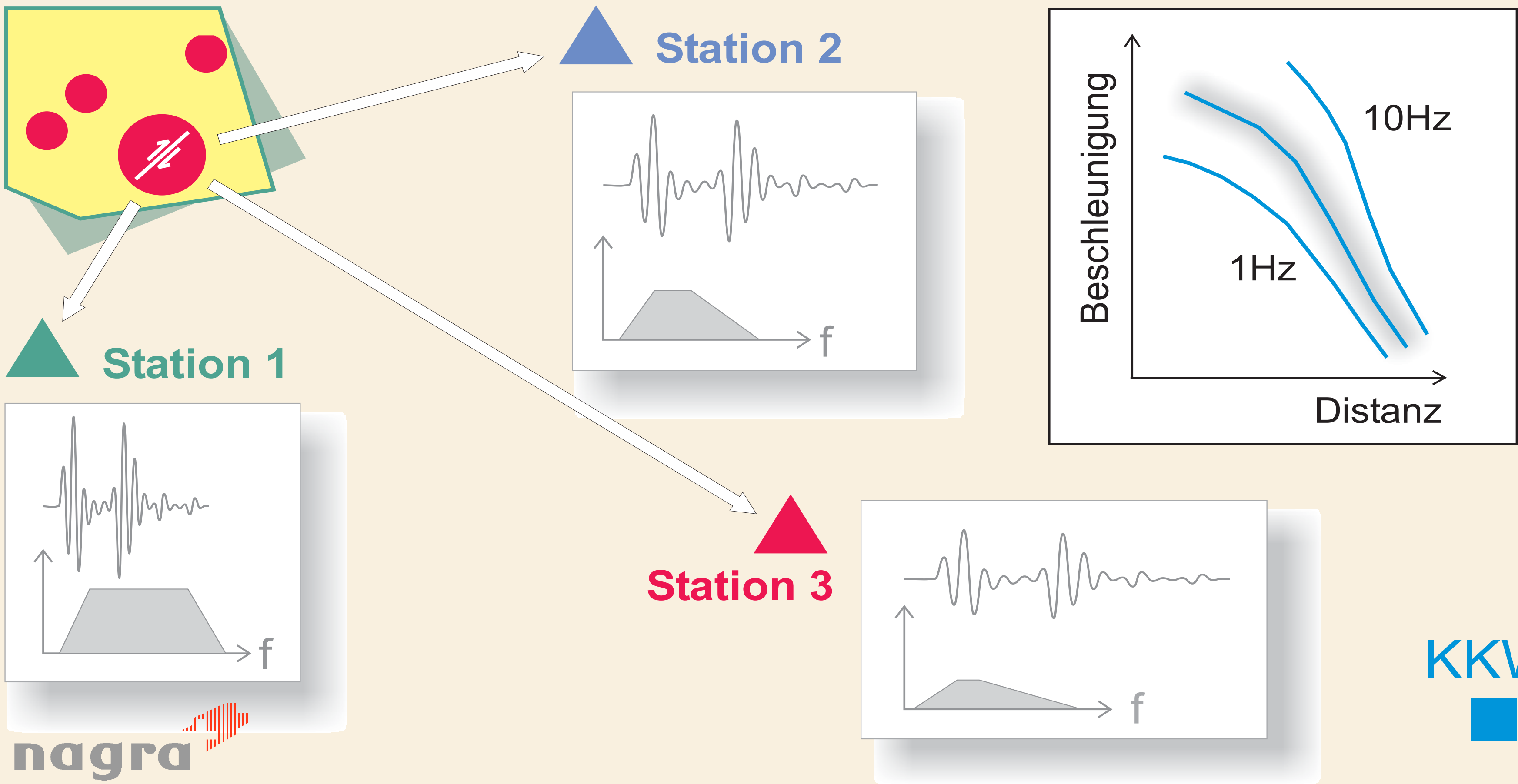
PEGASOS

- 4 Subprojects
  - Seismic Source Characteristics
  - Ground Motion Characteristics
  - Site specifc aspects (site amplification)
  - Quantification of seismic hazard tests
- 21 experts from Europe and the USA and 2 TFI (team facilitators)

Characterisation of seismic sources



Subproject 2 – Ground Motion Characteristics



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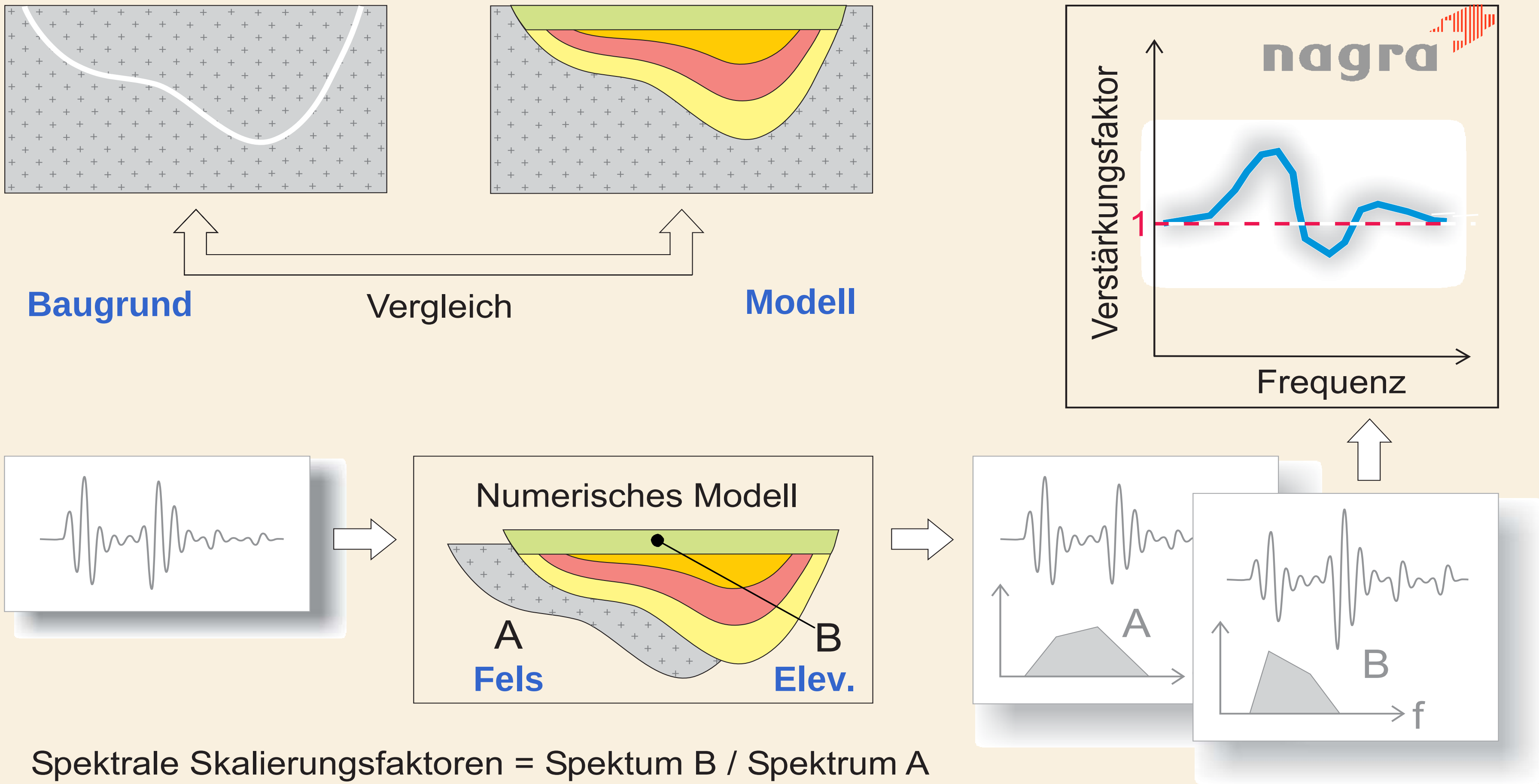
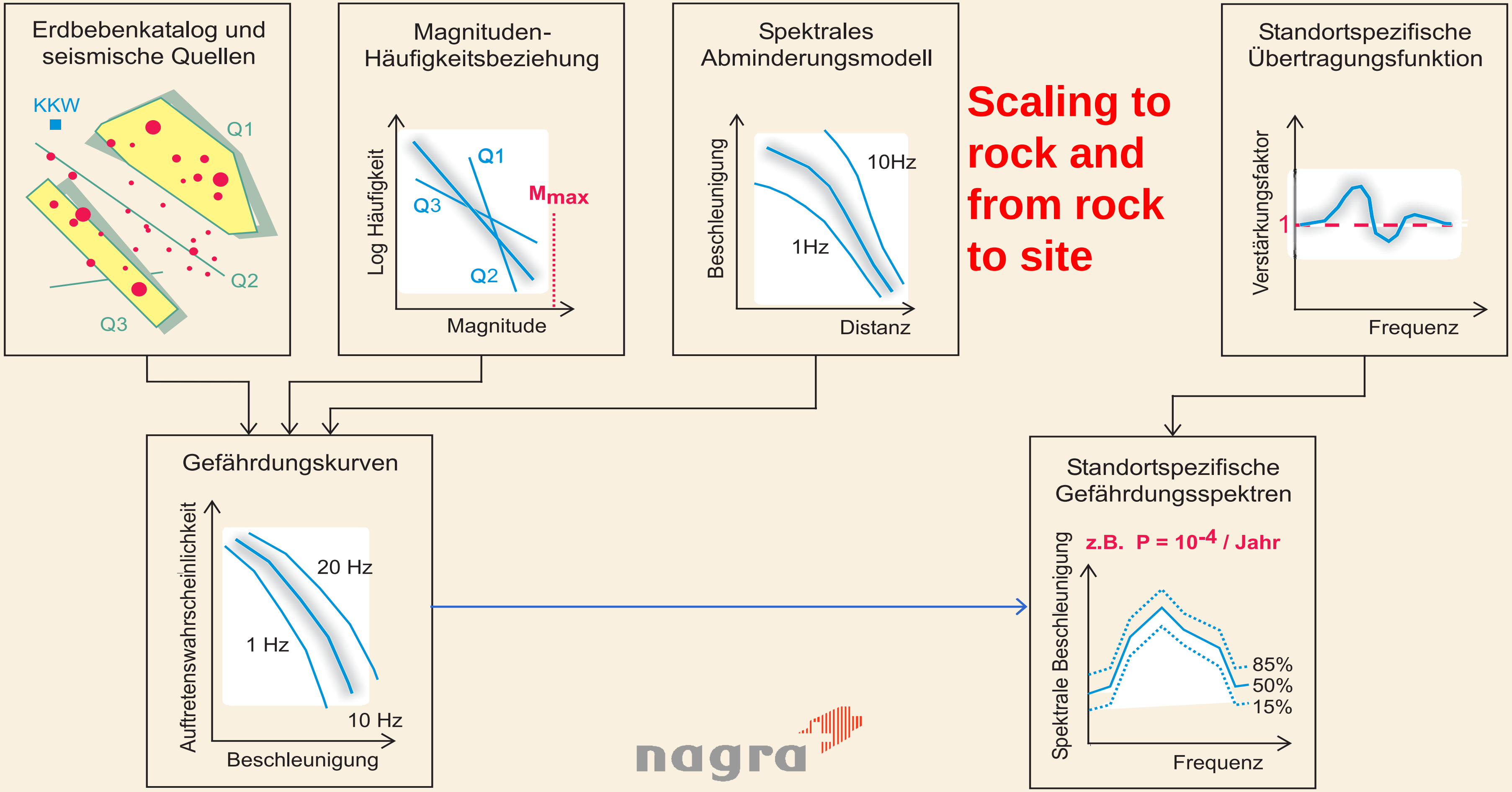
Subproject 3 – Site Effects



Spektrale Skalierungsfaktoren = Spektum B / Spektrum A

PSHA approach in the PEGASOS - Project



Scaling to rock and from rock to site

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Preliminary Results- Deaggregation, Risk is dominated by „hidden undetectable near-site seismic sources“

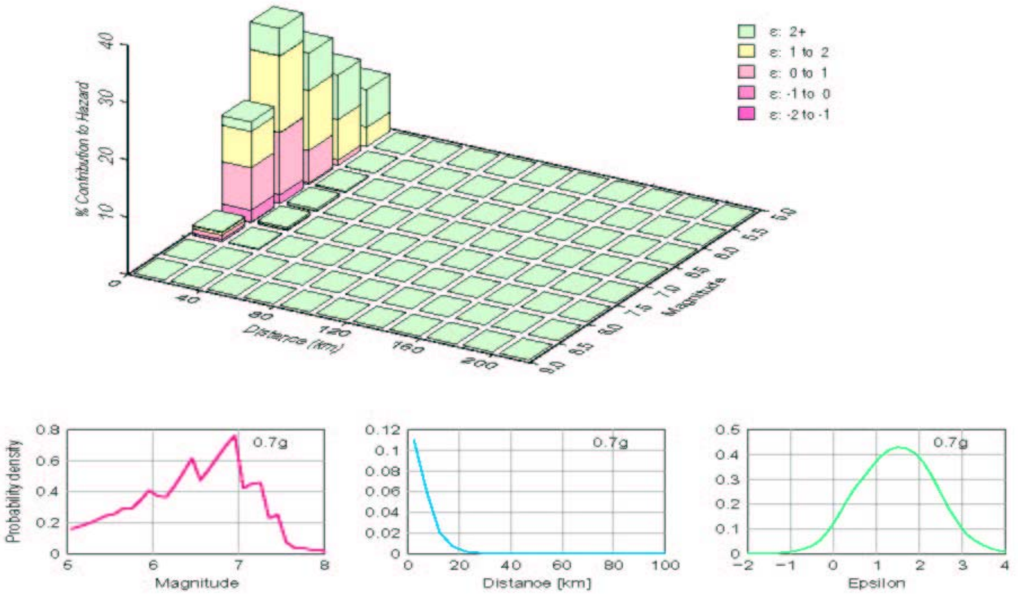

Fig. 3-5.25: Gösgen, horizontal component, rock, surface, hazard deaggregation by magnitude, distance and epsilon for ground motion level 0.7 g, PGA.

Preliminary Lessons of PEGASOS

- Valuable scientific information but still in a form not suitable for practical applications
  - Use of instrumentation pga instead of EGA
- Ongoing project, implementation phase
  - Goal: Development of the final hazard
- Currently review of the results and additional analysis
  - Validation/Benchmarking of results
  - Review of expert judgement procedures of SSHAC
- Long-term working program (?)

Preliminary Lessons of PEGASOS

- Validation tests have shown, that the preliminary results are not realistic
  - Mathematical accumulation of uncertainties due to an incorrect aggregation procedure
  - Not justified use of attenuation laws from the US (where these laws are currently recalibrated to get consistency to the theory of „Precarious rocks“)
  - Unjustified seperation between attenuation and site effects using crude scaling laws from Northern America
  - Possible overestimation of upper magnitude limits

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