Recent Research on Hazards PSA

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Introduction

- German PSA Guideline and its technical document on PSA methods require PSA for safety reviews (SR) of NPPs
- This also covers probabilistic analyses for the following hazards:
  - Internal hazards (IH):
    - Internal fire
    - Internal flooding
  - External hazards (EH):
    - Aircraft crash
    - Explosion pressure wave
    - External flooding
    - Earthquake
- For these hazards, specifications and methodological approaches are provided in the technical guidance document on PSA methods
- Risk contributions of other hazards such as gas clouds (e.g. toxic, corrosive), external fires, ship collisions with intake structures, extreme weather conditions (e.g. lightning, storm, snow, ice and combinations of these), and biological phenomena have to be assessed only roughly

Approach for a Comprehensive Site-specific Hazards PSA (1)

- The reactor accidents at the Fukushima Dai-ichi NPP site gave reason and indications to check modeling for calculating plant specific risk from hazards
- A standardized approach for performing a comprehensive site-specific **Hazards PSA** has been developed for all kinds of internal and external hazards, all plant operational states covering also spent fuel pool

Main ideas

- Screening of site-specific hazards:
  Decision which hazards have to be assessed in which level of detail
- Standardized methodology for all hazards to be analyzed probabilistically in detail
  - Generation of Hazard Equipment Lists ***H-EL*** and Hazard Dependency Lists ***H-DL***
  - Systematic (partly automatic) extension of the given plant quantification model using *H-EL* and *H-DL*

Approach for a Comprehensive Site-specific Hazards PSA (2)

Main ideas (contd.)

- Systematic consideration of all potential dependencies caused by hazards
  - Impact dependencies of different hazards
  - Dependencies of safety functions needed for control of the consequences of hazard induced initiating events
  - Dependencies of hazard induced failures of SSC
- Some essential parts of the approach have already been tested successfully:
  - **Seismic PSA**: A database has been developed to support equipment screening and compilation of relevant SSC for the Seismic Equipment List ***S-EL***
  - **Fire PSA**: Automatic extension of the plant quantification model (fault trees) using the Fire Equipment List ***F-EL*** containing an equipment-room-mapping for all relevant components and cables

What is a Hazard Equipment List (*H-EL*)?

$$H\text{-}EL = \{SSC_1, SSC_2, \ldots, SSC_n\}_H$$

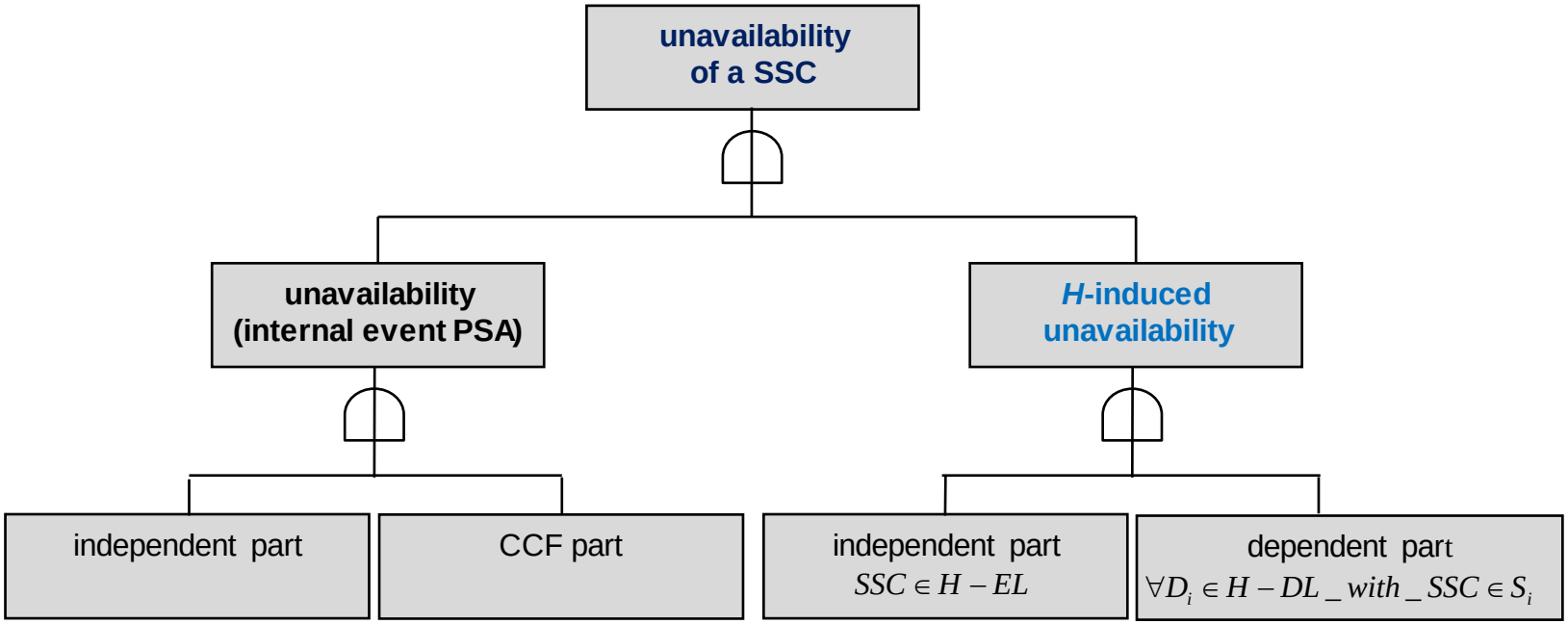
- For a given hazard ***H*** the corresponding Hazard Equipment List ***H-EL*** contains all structures, systems and components (SSC) vulnerable to the impact from *H*
- Additionally, the failure or unavailability of such SSC should contribute to the *H*-induced risk
- *H-EL* is used to extend the plant quantification model systematically
- For each SSC of *H-EL* the corresponding failure gate(s) in the fault trees of the plant model must be completed with *H*-induced failure of the SSC
- This procedure of using such an equipment list is well known from Seismic PSA with the Seismic Equipment List *S-EL*

What is a Hazard Dependency List (*H-DL*)?

$$H\text{-}DL = \{D_1, D_2, \ldots, D_m\}_H$$

- For a given hazard ***H*** the corresponding Hazard Dependency List ***H-DL*** contains all dependencies among the *H*-induced failure behavior of SSC, which should be considered
- Dependency *D* is described by a triple ***D* = {A, S, c}**:
  - ***S*** set of dependent *SSC*
  - ***A*** common property of the elements of *S* (reason for *H*-induced dependency)
  - ***c*** strength of dependency (correlation/link factor)
- With this triple model all kinds of *H*-induced dependencies can be described
- *H-DL* is used to extend the plant quantification model systematically with respect to dependencies
- For each *D* of *H-DL* the corresponding failure gate(s) in the fault trees of the plant model must be completed with *H*-induced dependencies

Extension of the Fault Tree Models Applying *H-EL* and *H-DL*



H-EL **= {SSC$_1$, SSC$_2$, …, SSC}**

H-DL **= {D$_1$, D$_2$, …, D$_m$} with D$_i$ ={A, S, c} and i = 1, …, m**

Compilation of *H-EL* and *H-DL*

All
Structures, Systems and Components (SSC)
of a nuclear power plant

Qualitative Screening

- Preliminary H-EL (SSC of basic events, initiating events, miscellaneous)
- Preliminary H-DL (*D* based on basic assumptions)
- Target-oriented plant walkdown
- Correction of preliminary H-EL and H-DL using walkdown experiences

Compilation of
- List of H relevant equipment (H-EL)
- List of H relevant dependencies (H-DL)

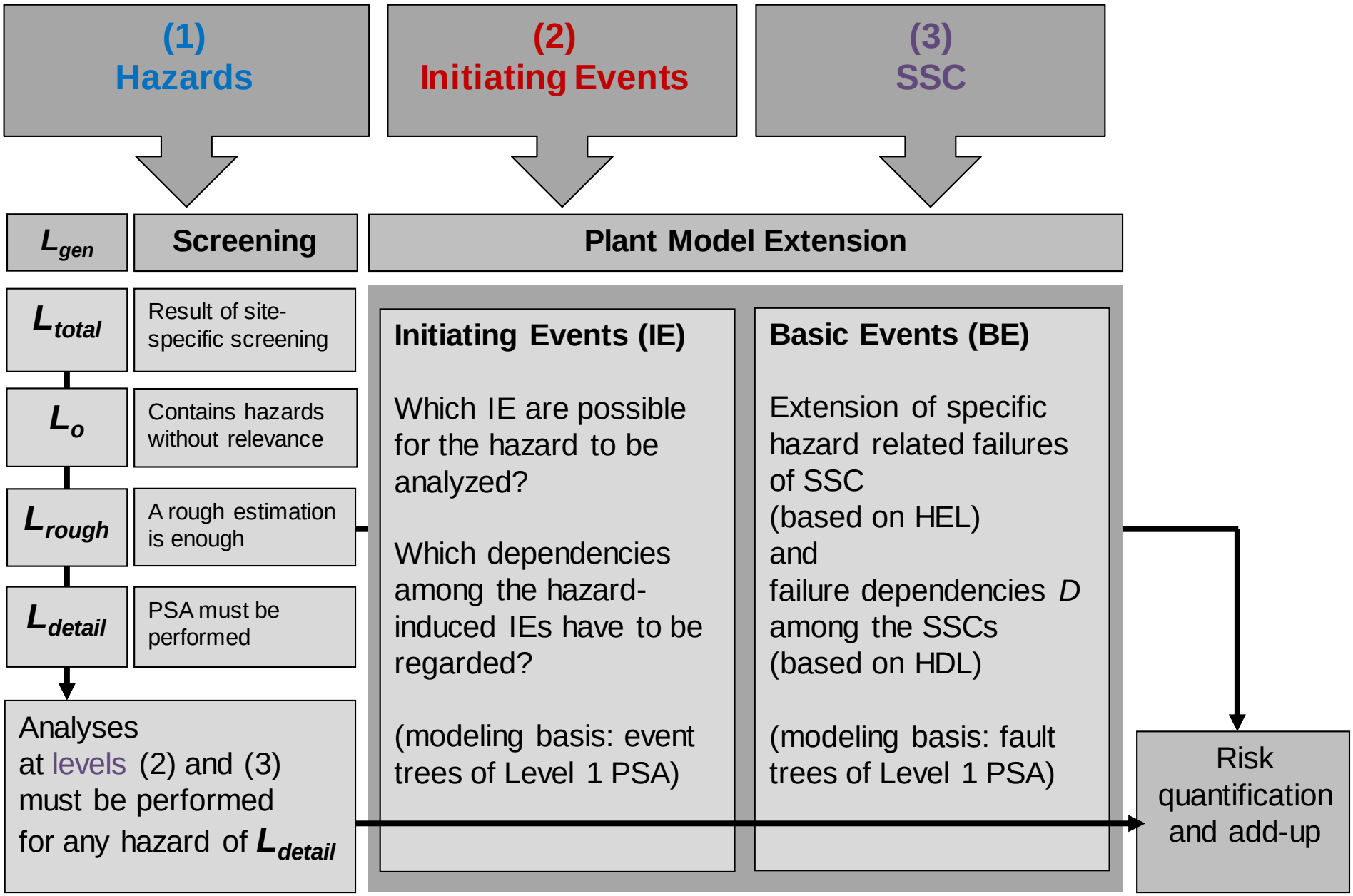
→ **Plant Model Extension** (qualitative) according to previous slide

Quantitative Screening

- Classification of SSC and dependencies *D* according to their importance
- Assessment of *H* induced failure probabilities (for the important SSC)
- Model choice for the dependencies, parameter estimation
- Anew plant walkdown (if necessary)

Quantitative determination and assessment of
- *H* related SSC failure probabilities
- Parameters of dependencies *D*

→ **Plant Model Extension** (quantitative)


(1)
Hazards
(2)
Initiating Events
(3)
SSC
L_{gen}
Screening
Plant Model Extension
L_{total}
Result of site-specific screening
L_o
Contains hazards without relevance
L_{rough}
A rough estimation is enough
L_{detail}
PSA must be performed
Analyses at levels (2) and (3) must be performed for any hazard of L_{detail}
Initiating Events (IE)
Which IE are possible for the hazard to be analyzed?
Which dependencies among the hazard-induced IEs have to be regarded?
(modeling basis: event trees of Level 1 PSA)
Basic Events (BE)
Extension of specific hazard related failures of SSC (based on HEL) and failure dependencies D among the SSCs (based on HDL)
(modeling basis: fault trees of Level 1 PSA)
Risk quantification and add-up

Systematic Consideration of Initiating Events from EH (1)

Operating experience

- Three databases compiling international as well as national NPP operating experience have been analyzed with respect initiating events from external hazards:
  - International Reporting System (IRS) by IAEA
  - VERA Database on reportable events from German NPP by GRS
  - TRANS Database by GRS compiling non-reportable events with transients from German NPP
- Three events have been identified with concurrent loss of the main heat sink and loss of offsite power (LOOP)

Event Date	Plant Type	Event Title
1980	GCR	Cooling water pump house flooding
1987	GCR	Partial blockage of the water intake of one unit, and loss of offsite power to the twin during cold weather
1999	PWR	Partial loss of safeguard systems as a result of external flooding

Systematic Consideration of Initiating Events from EH (2)

Categories of impacts from EH identified from the operating experience

- EH resulting in a loss of the main heat sink
  - K1: Flooding with water impact on systems and components
  - K2: Cold weather with ice formation
  - K3: Ingress of jellyfish, mussels, shrimps or swarms of little fish
  - K4: Flooding or heavy precipitation with ingress of sediments or debris
  - K5: Strong wind with ingress of vegetable materials
  - K6: Low water level with high concentration of dirt/soil
- EH resulting in a LOOP
  - N1: heavy storm with impact on transmission lines
  - N2: Lightning strike in transmission line or switchyard
  - N3: Large fire in the surrounding of transmission lines
  - N4: Cold weather and rain precipitation with ice formation on transmission lines
  - N5: Strong wind with salt precipitation in the switchyard
  - N6: High ambient air temperatures with impact on main or auxiliary transformers

Systematic Consideration of Internal and External Hazards (1)

Concept of a hazards database

L_{gen}

generic list of hazards

Consequences of hazards

Combinations of hazards
Maloperation of safety systems
Initiating events

International operating experience

Which event?
Where?
In which POS?

Systematic Consideration of Internal and External Hazards (2)

- **External hazards (EH)**
  - **Natural hazards**
    - Seismo-tectonic
    - Hydrological
    - Meteorological
    - Extraterrestrial
    - Biological
    - Geological
  - **Man-made hazards**
    - External fire
    - Aircraft crash
    - External explosion, blast wave
    - Ingress of dangerous materials (i.e. gaseous or liquid)
    - External electromagnetic interference (EMI)

Systematic Consideration of Internal and External Hazards (3)

- **Internal hazards (IH)**
  - Internal fire
  - Internal explosion
  - Internal flooding
  - Component faults (mechanic as well as electric) including high energy faults with potential impact on items important to safety
  - Pipe whip / jet impact
  - Drop or collapse of loads
  - Internal missiles
  - Internal electromagnetic interference (EMI)
  - Collisions of vehicles onsite
  - Multi-unit impacts

Systematic Consideration of Internal and External Hazards (4)

- **Combinations of hazards**
  - Causal relation
    - EH resulting in EH (e.g. extreme weather resulting in external flooding)
    - EH resulting in IH (e.g. earthquake resulting in fire)
    - IH resulting in IH (e.g. explosion resulting in fire)
  - Hazards occurring independently of each other during the mission time of one of these
    - EH and EH (e.g. earthquake occurring during flooding)
    - EH and IH (e.g. fire occurring during flooding)
    - IH and IH (e.g. drop of loads occurring during fire)
- **Approach for consideration of combinations**
  - First qualitative screening step:
    physical exclusion of individual hazards and hazard combinations
  - Second quantitative step: site-specific screening by frequency
    - Individual hazards
    - Hazard combinations including those of more than two hazards via application of matrix automatically created from hazards database with site-specific occurrence frequencies

Summary and Conclusions (1)

- A methodology for a comprehensive site-specific Hazards PSA has been developed
- The conceptual approach is being validated and stepwise implemented
- A systematic extension of the Level 1 PSA quantification models (fault trees) supported by Hazard Equipment Lists *H-EL* and Hazard Dependency Lists *H-DL* is part of the systematic approach
- Internal and external hazards as well as their impact combinations are being systematically considered
- For this purpose, the international NPP operating experience is being analysed

Summary and Conclusions (2)

- The general approach has already been successfully applied for extending Level 1 PSA for the IH “fire” and its combinations with site-specific EH to the spent fuel pool (SFP) for the post-commercial safe shutdown phase
- In the near future, it will be possible to perform a comprehensive site-specific Level 1 Hazards PSA for all plant operational states and all radioactive sources
- Methods for consideration of human response in case of hazards have already been developed; the approach needs implementation and validation for practical applications
- In the longer term, an extension to Level 2 Hazards PSA including the need for risk metrics for multi-unit sites on an international basis seems to be valuable

Thank you for your attention!

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