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Application of FIRE PSA in case of modifications for post-operational shutdown states

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Introduction I

- German PSA Guideline and its technical document on PSA methods require PSA for NPP safety reviews
- Since 2005, this also covers detailed probabilistic analyses for the following (internal and external) hazards:
  - Internal fire
  - Internal flooding
  - Aircraft crash
  - Explosion pressure (blast) wave
  - External flooding
  - Earthquake.
- For these hazards, specifications and methodological approaches are provided in the German PSA Guideline

Introduction II

- Risk contributions of other hazards have to be only roughly assessed, e.g.:
  - Toxic (gas) clouds
  - External fires
  - Ship collisions with intake structures
  - Extreme weather conditions
    (e.g. lightning, storm, snow, ice and combinations of these)
  - Biological phenomena

Concept of a comprehensive site-specific Hazards PSA

- The reactor accidents at Fukushima Dai-ichi in March 2011 gave reason and indication to check the modelling for calculating plant specific risk of hazards
- A standardized approach for performing a comprehensive site specific Hazards PSA is being developed for all kinds of internal and external hazards

Main ideas of the Hazards PSA concept I

- Screening of site specific hazards:
  Decision, which hazards or which combinations of hazards have to be assessed and in which level of detail
- Systematic discussion of all potential dependencies to be considered in the plant risk model
  - Impact dependencies of different hazards
  - Dependencies of safety functions needed to control the consequences of hazard induced initiating events
  - Dependencies of hazard induced failures of SSC

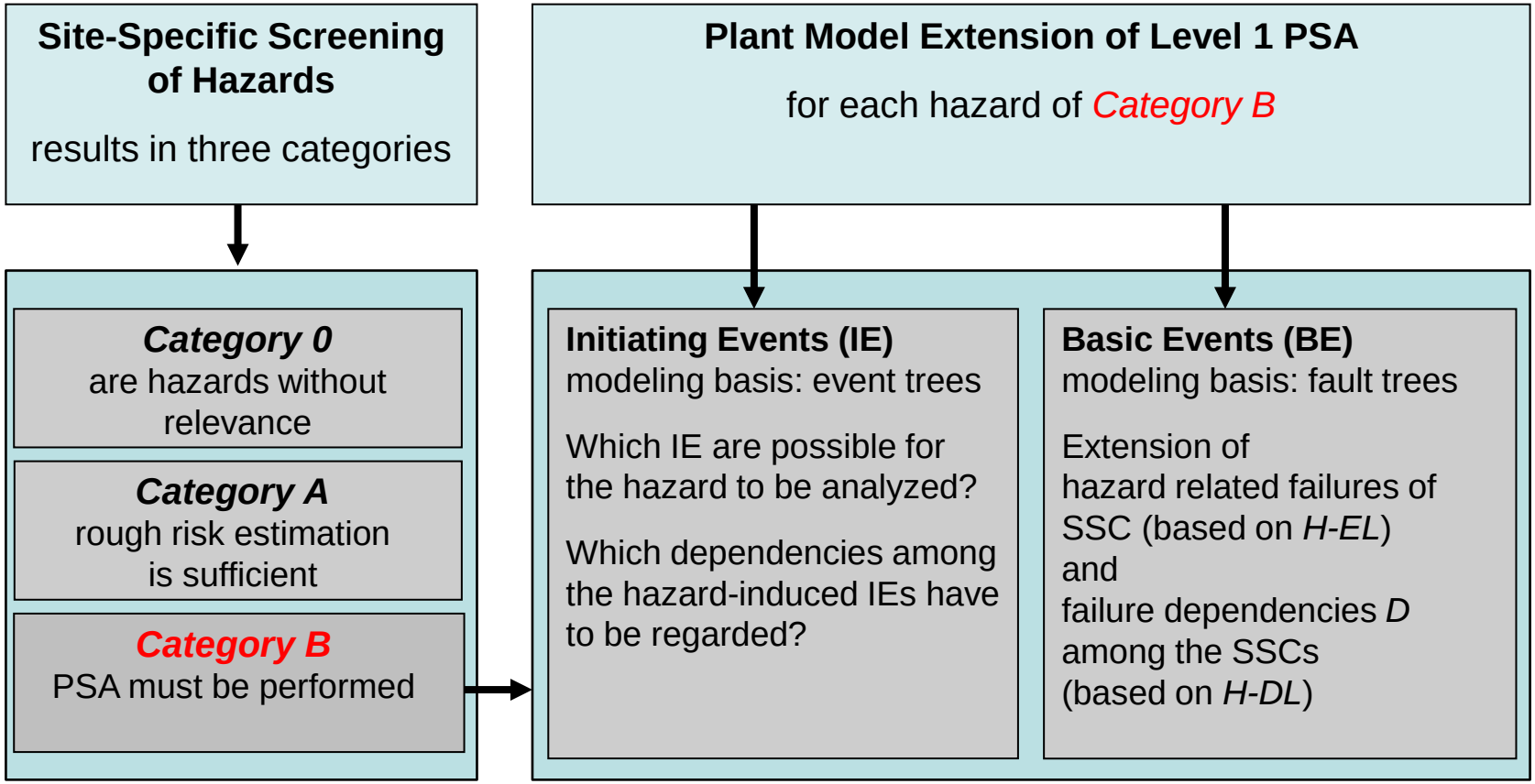
Main ideas of the Hazards PSA concept II

- Standardized methodology for all hazards, which must be probabilistically analyzed in detail
  - Generation and compilation of
    Hazard Equipment Lists (*H-EL*) and
    Hazard Dependency Lists (*H-DL*)
  - Systematic (and partly automatic) extension
    of the given Level 1 plant risk model using *H-EL* and *H-DL*

First applications of the HAZARDS PSA concept

- Meanwhile, essential parts of the approach have been tested in practice:
  - **Seismic PSA**:
    A database has been prepared to support the equipment screening and the compilation of the Seismic Equipment List (*S-EL*) with all relevant SSC
  - **Fire PSA:**
    Systematic and automatic extension of the plant risk model (fault trees) using the Fire Equipment List (*F-EL*) containing a compartment assignment for all relevant components including cables (compartment inventory)

Performing a Hazards PSA – Overview I



Performing a Hazards PSA – Overview II

Site-specific hazard selection and categorization

Selection: Identification of hazards or hazard combinations that could occur at the site.
Categorization: Which hazards are relevant, i.e. lead to a measureable risk contribution, or which can be neglected?

Which Initiating Events (IE) are triggered by an identified relevant hazard?

Which initiating events occur (nearly) simultaneously due to a hazard (hazard-induced IEs)?
What are the conditional occurrence probabilities of the initiating events?

- Identification of possible IE
- Investigation of dependencies
- Consideration in plant risk model

Plant model extension (hazard-induced failures of SSC)

Compilation of *H-EL* and *H-DL* (using screening procedures and plant walkdowns)

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

$$HEL = \{SSC_1, SSC_2, ..., SSC_n\}_H$$

- For a given hazard *H*
  the corresponding Hazard Equipment List *H-EL* contains all SSC, which are vulnerable by the impact of hazard *H*
- Additionally, the failure or unavailability of such a SSC should contribute to the *H*-induced risk
- The process of compiling and applying such an equipment list is well known from Seismic PSA with the Seismic Equipment List *S-EL*

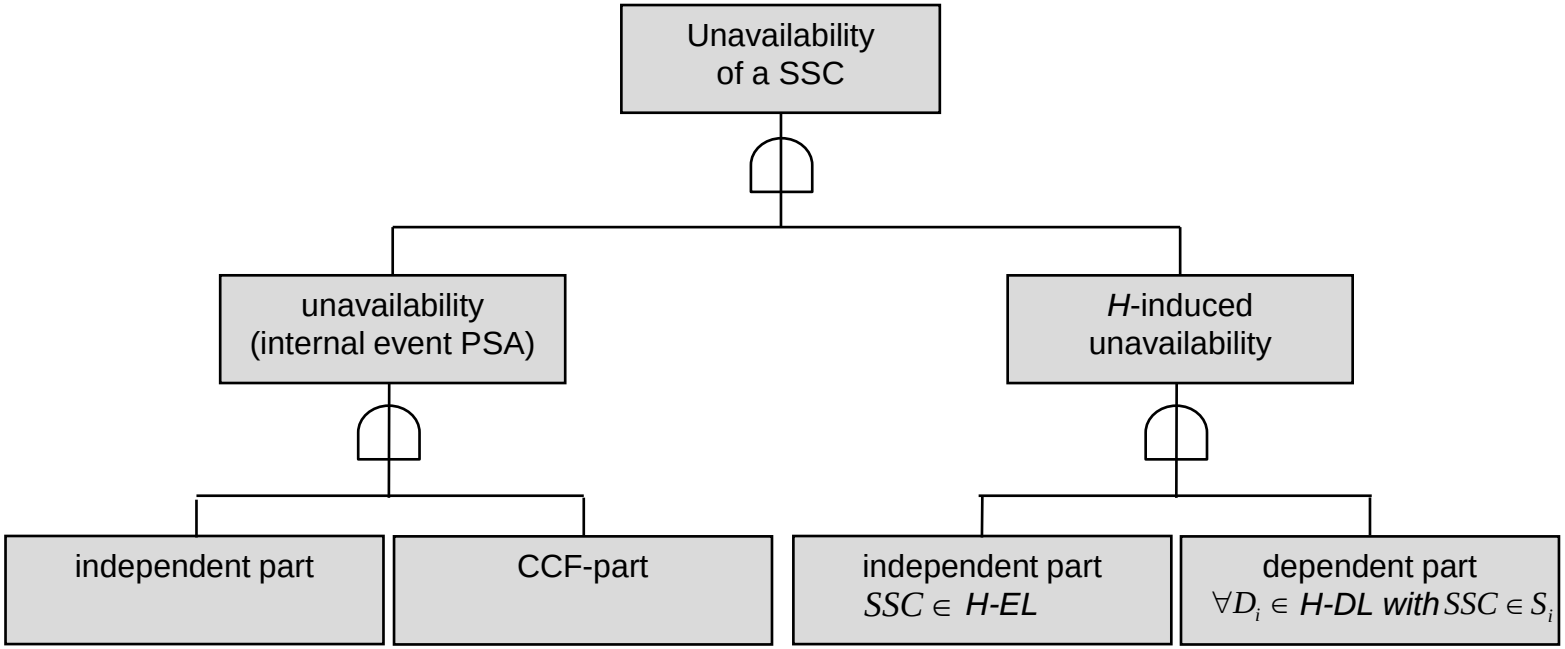
What is a Hazard Dependency List (*H-DL*)?

$$HDL = \{D_1, D_2, ..., D_m\}_H \quad \text{mit} \quad D_i = \{A_i, S_i, c_i\}$$

- For a given hazard *H*
  the corresponding Hazard Dependency List *H-DL* contains all dependencies among the H-induced failure behaviour of SSC, which should be considered
- Generally, a dependency *D* can be described with a triple

  S is the set of dependent *SSC*
  A is the common property of the elements of *S* (reason for hazard-induced dependency)
  c is the strength of dependency (correlation factor)

Fault tree extension using *H-EL and H-DL*



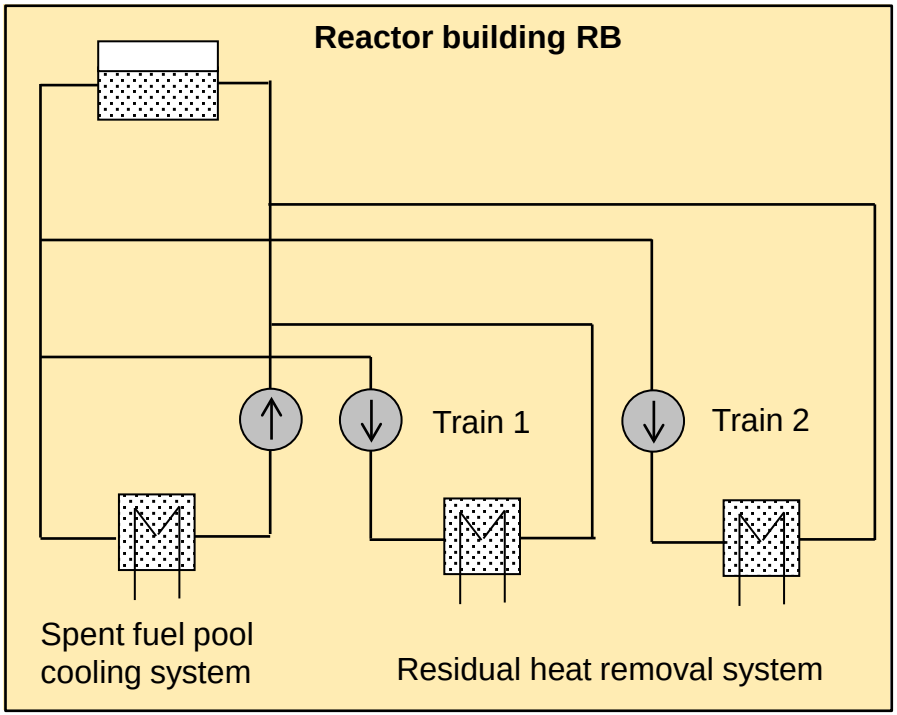
$$H\text{-}EL = \{SSC_1, SSC_2, ..., SSC_n\}$$

$$D\text{-}EL = \{D_1, D_2, ..., D_m\}\_with\_D_i = (A_i, S_i, c_i)\_i = 1, ..., m$$

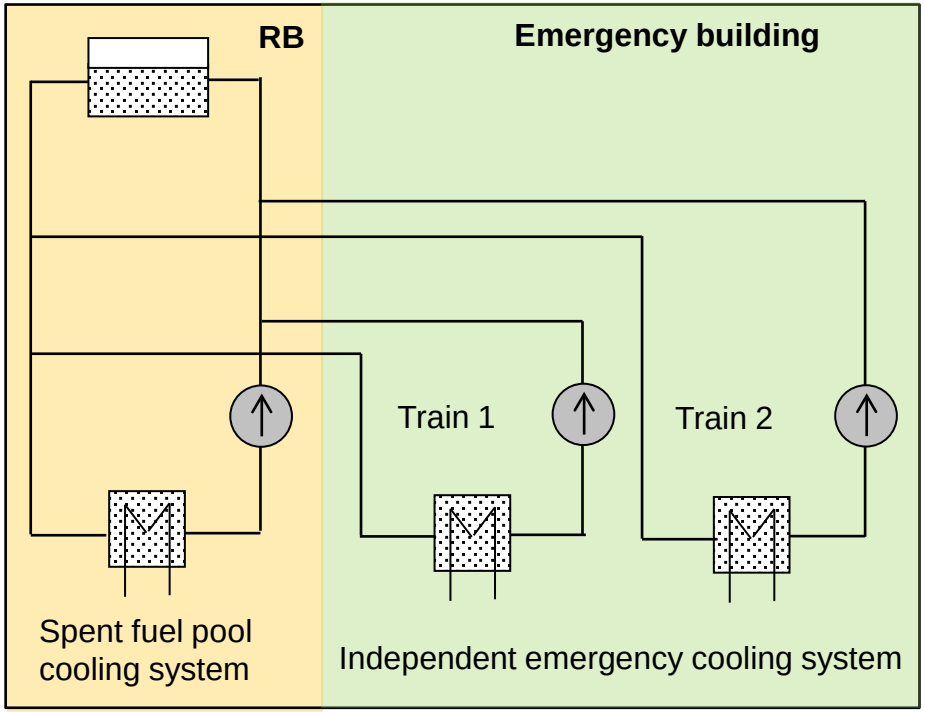
Application to Fire PSA for a NPP in post-commercial shutdown operation

- A licensee plans a plant modification regarding the cooling of the spent fuel pool for the post operation.

Alternative 1:
Original plant design



Alternative 2:
Plant modification



Alternatives of spent fuel pool cooling

- **Original plant design** (alternative 1)
  Cooling of the spent fuel pool by SFPC system in normal operation
  - If SFPC system fails or is in outage, RHR system takes over with two redundant trains
- **Intended plant modification** (alternative 2)
  Spent fuel pool cooling function of the RHR system shall be replaced by the two redundant trains of the IEC system
  - IEC system has two independent ultimate heat sinks
  - IEC-system is located within the emergency building and therefore protected against external hazards

Fire PSA for the SFP cooling alternatives

- PSA carried out by NPP licensee to compare the FDF for both alternatives
- Consideration of the following initiating events:
  - Loss of offsite power
  - Spent fuel pool RHR failure
  - Loss of water from spent fuel pool
  - Flooding of IES building (only for alternative 2)
- Task:
  Comparative Fire PSA based on the above PSA plant model and data derived from plant specific FP Fire PSA

Performing a FIRE PSA

- Depth of investigation:
  Partitioning of the relevant buildings into compartments
- Compartment failure:
  Functional unavailability of the total inventory of the compartment (components, cables).
- Compartment failure frequency:
  Fire induced failure frequency to be estimated for each compartment; this is the product of
  - Compartment specific fire occurrence frequency and
  - Conditional fire extinguishing failure probability
- Component failure:
  Component or its cables belong to the fire induced failed compartment

Fire Equipment List

- Fire Equipment List *F-EL*
  - *F-EL* contains a component/cable-compartment assignment
  - Fire induced compartment failure frequency estimated for each compartment
  - Basis of compilation:
    - Inventory database including cables
    - Fire PSA database for power operation

Fire Dependency List

- Fire dependency list *F-DL*
  - *F-DL* contains the compartments directly adjacent to each room (‘neighbouring compartments’)
  - Conditional fire propagation probability is given for each couple of compartments
  - Basis of compilation:
    - Fire PSA for power operation including information on fire barriers between compartments

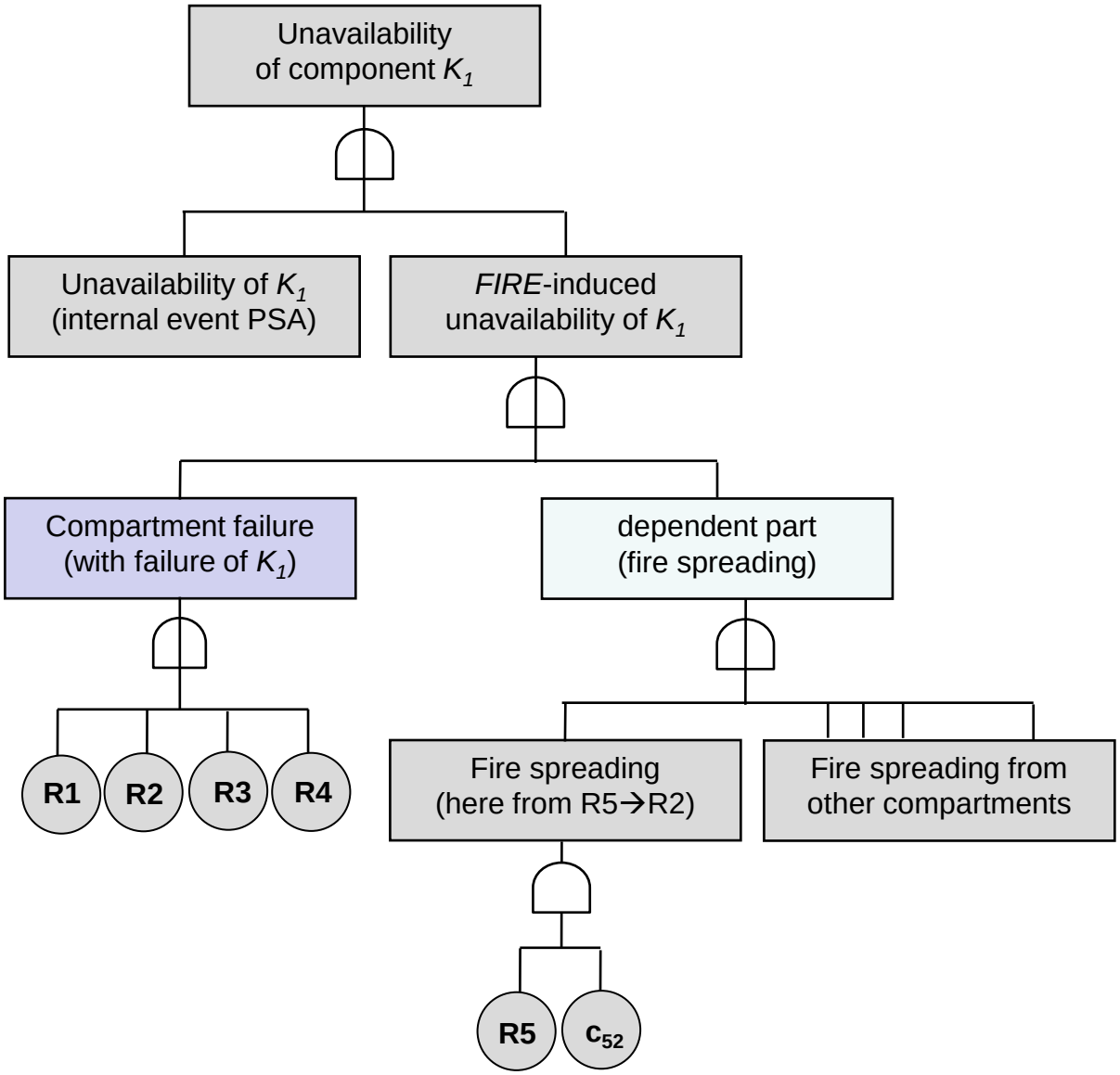
Fault tree extension by fire induced failures

Excerpt from **Fire Equipment List *F-EL***

component	room	remark
K_1	R1	Component itself (e.g. motor valve)
K_1	R2	power cable
K_1	R3	control cable
K_1	R4	control cable
K_1	…	…
…	…	…
K_n	…	…

Excerpt from **Fire Dependency List *F-DL***

fire compartment	adjacent compartment	c_{ij}
…	…	…
R5	R2	c_{52}
…	…	…
…	…	…



Results

- Fire PSA could effectively be performed for two alternatives of spent fuel pool cooling based on FP Fire PSA and a comparative PSA for post-commercial shutdown states
- Fire PSA result: risk of the new alternative of spent fuel pool cooling is lower than that of original design
- Restrictions:
  - Results are applicable for comparison only
  - For post-commercial shutdown Fire PSA, need for additional analyses
    - Development of fault trees for fire induced IE
    - Fire specific investigations to consider particular conditions of post-commercial shutdown states

Conclusions

- A conceptual approach for a comprehensive site specific Hazards PSA has been developed
- The concept is being validated and implemented step by step
- Part of this concept is the systematic extension of Level 1 PSA quantification models (fault trees) supported by Hazard Equipment Lists *H-EL* and Hazard Dependency Lists *H-DL*
- Fire PSA could effectively be carried out for two alternatives of spent fuel pool cooling within the conceptual approach for a comprehensive site specific Hazards PSA