Screening Approach for Systematically Considering Hazards and Hazard Combinations in PRA for a Nuclear Power Plant Site

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Introduction (1)

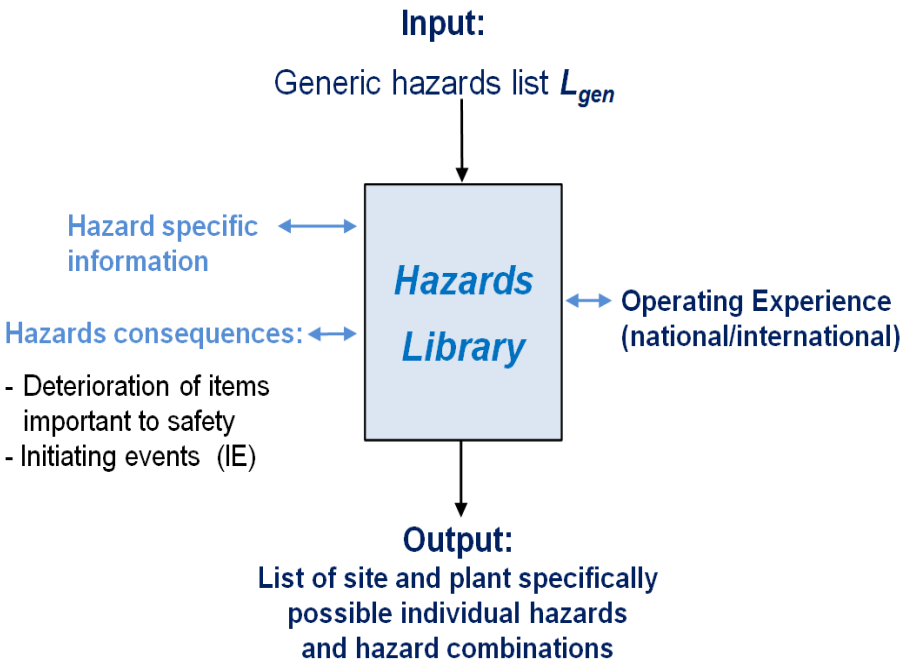
- Post-Fukushima investigations have indicated that the entire risk resulting from external and internal hazards, including event combinations involving hazards, need to be addressed systematically and comprehensively within PRA
  - Need for methods to analyze the broad spectrum of hazards
- In principle, high number of individual hazards and hazard combinations
  - Need for a screening approach to reduce number of hazards and hazard combinations to be modelled in detail in PRA significantly, but systematically considering all those ones which site and plant specifically may contribute to the PRA result
- Screening starts with an identification of those hazards which may occur at the site being analyzed
- Based on this compilation of generic hazards $\boldsymbol{L_{gen}}$ a qualitative and quantitative screening is carried out

Introduction (2)

- Those hazards to be considered for the NPP site under investigation have to be categorized with respect to the level of detail needed for the probabilistic analyses to be carried out
  - L_0 : Hazards with a negligible contribution to the overall risk
  - L_{rough}: Hazards with a risk contribution low enough that a rough quantitative assessment is sufficient
  - L_{detail}: Hazards that need in-depth probabilistic analysis
- Identification of hazard combinations starts from those individual initial hazards not screened out on a site and plant specific basis in order to reduce the effort for screening of hazard combinations
- Probabilistic analyses can be systematically carried out for all hazards and hazard combinations remaining after screening based on the Level 1 PRA model for internal events

Hazards Library – An Analytical Tool for Hazards PRA Screening

- GRS has developed the tool *Hazards Library* for systematically considering the variety of external and internal hazards in safety assessment
  - Compilation of as much as possible generic information for each individual hazard
  - Detailed information characterizing hazard and impact consequences
  - Complete information on all types of hazard combinations
  - Consideration of insights from operating experience worldwide as far as possible
  - Library contains some criteria for hazards screening (partly automated, by pre-formatted queries, keyword searches, etc.)



Hazards Library – Information on Individual Hazards

- Hazard ID
- Nomenclature 1 to n
- Short title of the hazard
- Detailed hazard title
- Hazard characterization
  - Hazard duration (minutes, hours, days, longer)
  - Protection against the hazard possible? (U: unpredictable; P: predictable, protection is possible before the event starts)
  - Event progression possible? (R: progressing rapidly; G: progressing gradually, protection is possible during the event sequence)
- Detailed remarks
- References concerning the hazard
- Link to operating experience
- Link to site parameters

Hazards Library - Overview on Different Hazard Classes

I. External hazards		
1. Natural hazards:		
Class A:	**Seism tectonic hazards**	6
Class B:	**Flooding and other hydrological hazards**	17
Class C:	**Meteorological hazards**	27
Class D:	**Extraterrestrial hazards**	2
Class E:	**Biological hazards**	7
Class F:	**Geological hazards**	12
Class H:	**Natural fires**	1
2. Man-made hazards (Class Z)		29
II. Internal hazards (Class I)		14

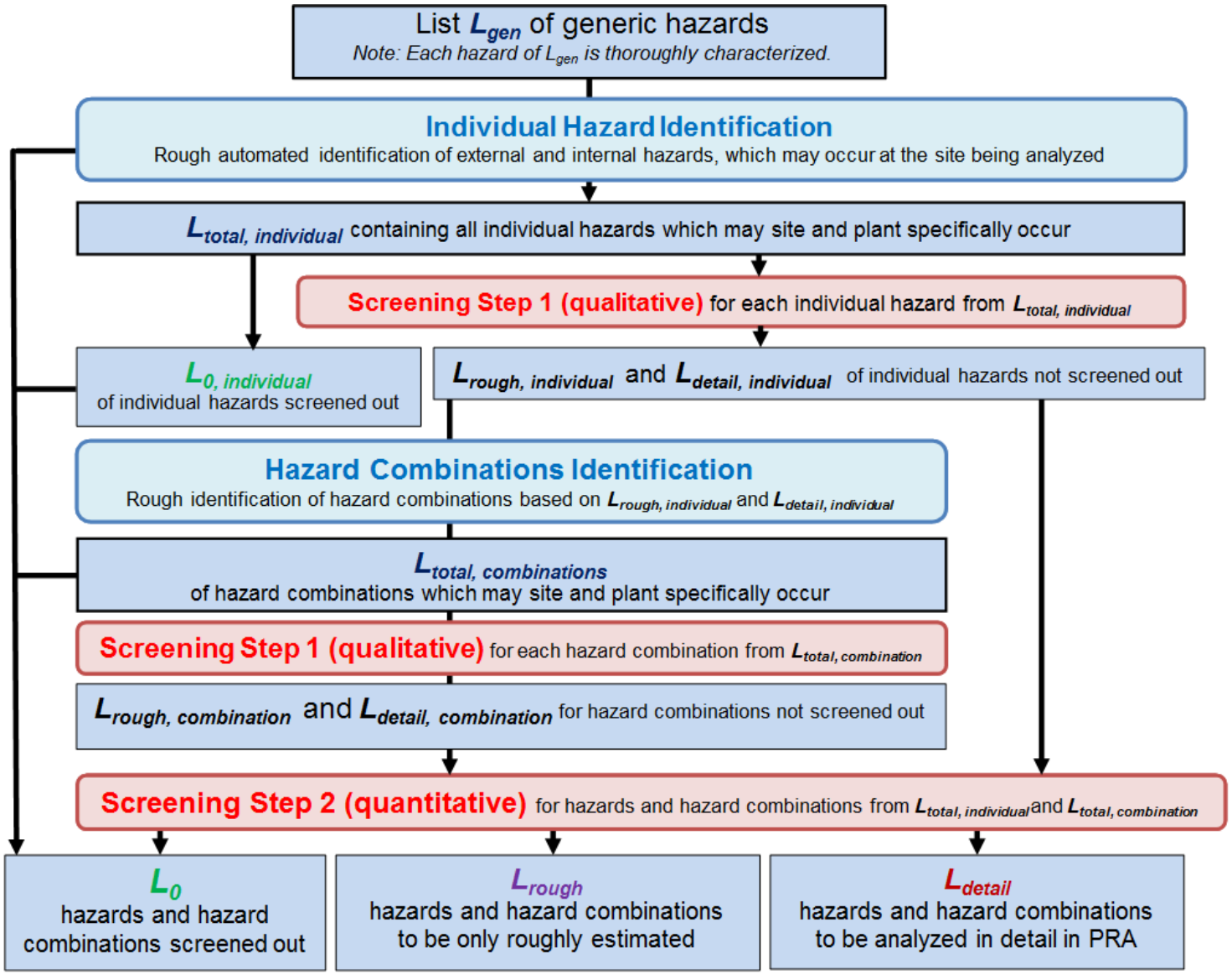
Hazards Library – Information on Hazard Combinations (1)

- Causally related events (hazards subsequent or consequential to other hazards), such as:
  - External hazard (e.g., earthquake) inducing another external hazard (e.g., Tsunami)
  - External hazard (e.g., aircraft crash) inducing internal hazard (e.g., fire)
  - Internal hazard (e.g., fire) inducing another internal hazard (e.g., flooding)
- Event chains of hazards such as:
  - External hazard (e.g., earthquake) inducing another external hazard (e.g., high water level with wave formation due to failure of water control or retention systems inducing one or more internal hazards (e.g., flooding, fire)
  - External hazard (e.g., flash flood by extreme local precipitation) inducing internal hazard (e.g., internal flooding) inducing one or more further internal hazards (e.g., explosion, flooding)
  - Internal hazard (e.g., explosion) inducing another internal hazard (e.g., fire) inducing one or more further internal hazards (e.g., flooding, explosion)

Hazards Library – Information on Hazard Combinations (2)

- Correlated events:
  A common initial event (including external hazards) results in one or more hazards, which even may with a certain probability occur simultaneously, such as:
  - Loss of offsite power (LOOP) or station black-out (SBO) resulting in one or more internal hazards (e.g., fire, missiles) and perhaps an internal event at the same time
  - External hazard (e.g., Tsunami, earthquake) resulting simultaneously in more than one other external and/or internal hazards (e.g., external flooding, internal flooding, fire, explosion)
- Unrelated events:
  Initiatial event (including hazards) occurring independently from, but simultaneously to a hazard
  (typical examples: longer duration flooding and independent fire or explosion, seismic and fire, LOOP and fire or explosion)

Screening of Hazards and Hazard Combinations



Qualitative Screening of Individual Hazards (1)

- Identification of those individual hazards from $L_{gen,}$ in principle possible to occur at the plant and site under investigation ➔ $L_{total,individual}$
- Qualitative screening of individual hazards, see example for Class B "*flooding and other hydrological hazards*"

Hazard	Type of Individual Hazard
B1	Tsunami
B2	Flash flood by local extreme precipitation
B3	Flooding by melting snow
B4	Flooding by extreme precipitation outside the plant boundary
B5	Extreme groundwater increase
B6	
a	High water level due to obstructions in the course of the river
b	Low water level due to obstructions in the course of the river
B7	
a	High water level by natural changes in the course of the river
b	Low water level by natural changes in the course of the river
B8	Flooding by high fresh water waves due to volcanism, landslide or snow slide

Hazard	Type of Individual Hazard
B9	
a	High water level with wave formation due to failure of water control or retention systems (e.g., damns, dykes, etc.)
b	Low water level with wave formation due to failure of water control or retention systems (e.g., damns, dykes, etc.)
B10	Seiche
B11	Tidal bore (running extremely river-up)
B12	Tidal high water, spring tide
B13	Storm induced waves and monster waves
B14	Storm surge
B15	Corrosion resulting from contact with salt water
B16	Instability of coastal areas (of rivers, lakes, oceans) by erosion due to strong water flows or sedimentation
B17	Water flotsam (mud, debris, etc.)

Qualitative Screening of Individual Hazards (2)

- NPP site under investigation: riverine site
  - B1, B10, B11, B12, B14, B15 screened out
- Analysis only of hazards with flooding potential
  - B6b, B7b, B9b, B17 screened out
- Site specific information of hazard analysis (Periodic Safety Review)
  - B5, B7a screened out
- Individual class B hazards remaining after qualitative screening: B2 (flash flood) and B3, B4, B6a, B8, B9a (riverine flooding due to different reasons)

Quantitative Screening of Individual Hazards

- Definition of quantitative screening criteria (either by national or international guidance)
  - Occurrence frequency (e.g., < E-06 /ry)
  - Core and/or fuel element damage frequency (e.g., << E-08 /ry)

➢ Class B hydrological hazards with flooding potential remaining after quantitative screening for the reference plant site:
  - B2 (flash flood by local extreme precipitation)
  - B3 (flooding by melting snow)
  - B4 (flooding by extreme precipitation outside the plant boundary)

Screening of Hazard Combinations

- Qualitative screening
  - Screening of hazard combinations starts from all individual hazards remaining after qualitative screening
    - Category I: Causally related (consequential) hazards
    - Category II: Correlated hazards
    - Category III: Independently, but simultaneously occurring hazards
  - Screening of first order combinations
  - Identification of potential event chains (higher order combinations)
  - Screening of higher order combinations
- Quantitative screening
  - Application of same criteria as for individual hazards
  - Iterative quantitative screening of higher order combinations identified

Example of Hazard Combinations Screening (1)

		B2	B3	B4	B6a	B8	B9a	I2
	B: Flooding and Other Hydrological Hazards							
B2	Flash flood by local extreme precipitation							↗
B3	Flooding by melting snow							↗
B4	Flooding by extreme precipitation outside plant boundary	↙						↗
B6a	High water level due to obstructions in the river							
B8	Flooding by high fresh water waves							
B9a	High water level with wave formation due to failure of water retention systems	↙	↙	↙	↙	↙		
	I: Internal Hazards							
I1	Internal fire	↙	↙	↙	↙	↙	↙	↗
I2	Internal flodding	↙	↙	↙	↙	↙	↙	
I3	Component failure (including high energetic)	↙	↙	↙	↙	↙	↙	↗
I4	Pipe failure (pipe whip, breaks, etc.)	↙	↙	↙	↙	↙	↙	↗
I5a	Drop of heavy laods	↙	↙	↙	↙	↙	↙	↗
I5b	Collapse of structural elements	↙	↙	↙	↙	↙	↙	↗
I6	Collision of vehicles onsite	↙	↙	↙	↙	↙	↙	
I7	Internal explosion	↙	↙	↙	↙	↙	↙	↗
I8	Multi-unit impact	↙	↙	↙	↙	↙	↙	
I9	Electromagnetic interference (EMI)	↙	↙	↙	↙	↙	↙	
I10	Missiles							
I11	Releases of dangerous substances	↙						↙
I12	Onsite excavation and construction work							↗
I23	High voltage eddy currents into ground (onsite sources)							

		B2	B3	B4	B6a	B8	B9a
	B: Flooding and other Hydrological Hazards						
B2	Flash flood by local extreme precipitation						
B3	Flooding by melting snow						
B4	Flooding by extreme precipitation outside plant boundary						
B5	Extreme groundwater increase						
	C: Meteorological Hazards						
C1	Precipitation (rain or snow)						
C2a	High ambient temperature						
C3a	High ground temperature						
C3b	Low ground temperature						
C4a	High water temperature						
C4b	Low water temperature						
C5a	High humidity						
C6	Extreme air pressure						
C10	Icing						
C12	Hail						
C14	Recurring soil frost						
C15	Lightning (incl. electromagnetic interference (EMI))						
C16	High wind						
C17	Tornado						
C18	Water spout						
C19	Snow storm						
C24	Frazil ice						
	E: Biological Hazards						
E6	Biological flotsam						

orange: combinations of external hazards

consequential events:
A can induce B

A can induce B and
B can induce A

B can induce A

correlated events:
A and B are induced by
common cause

blue: combinations with internal hazards

consequential events:
A can induce B

A can induce B and
B can induce A

B can induce A

correlated events:
A and B are induced by
common cause

Example of Hazard Combinations Screening – Results (2)

			B2	B3	B4	B6a	B8	B9a		I2
	B: Flooding and Other Hydrological Hazards									
B3	Flooding by melting snow									
B4	Flooding by extreme precipitation outside plant boundary									
	C. Meteorological hazards									
C1	Precipitation (rain or snow)									
	E: Biological Hazards									
E6	Biological flotsam		↙	↙	↙	⇙	↙	↙		⇙
	F: Geological Hazards									
F1	Slope instability									
	I: Internal Hazards									
I1	Internal fire									⇙
I2	Internal flooding									
I3	Component failure (including high energetic)									⇙
I5a	Drop of heavy laods									↙
I5b	Collapse of structural elements									
I7	Internal explosion									⇙

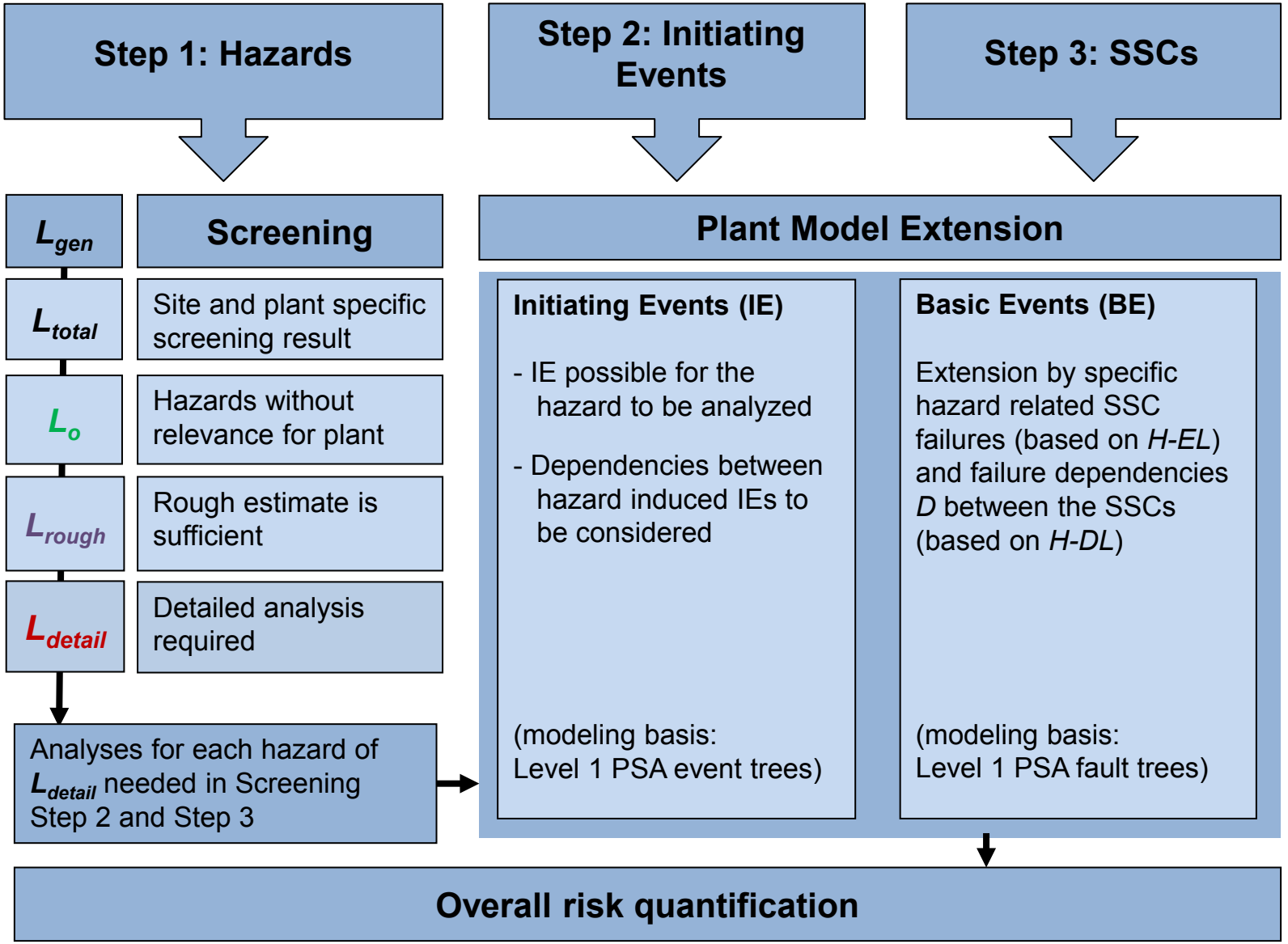
orange: combinations of external hazards

- consequential events: A can induce B
- A can induce B and B can induce A
- B can induce A
- correlated events: A and B are induced by common cause

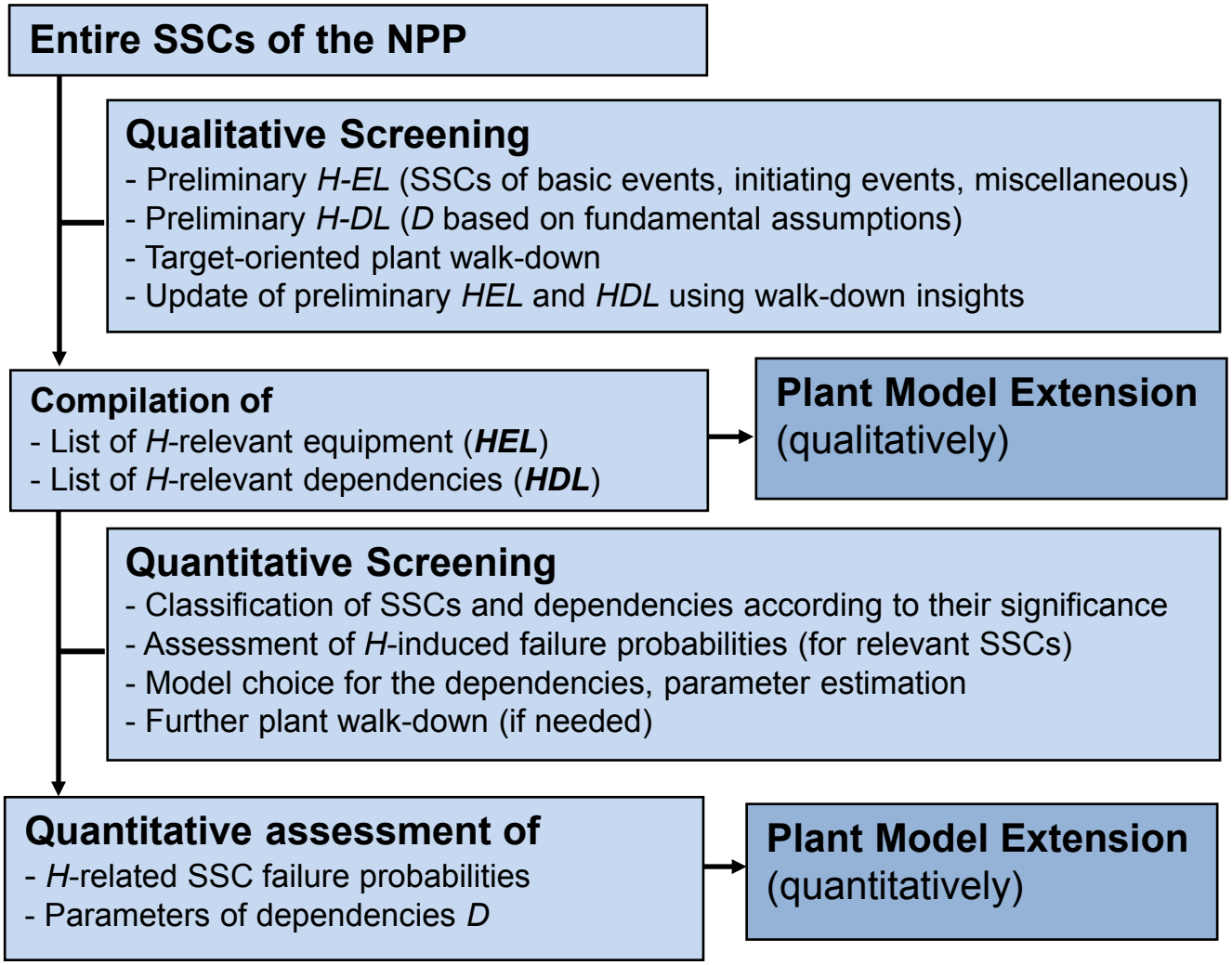
blue: combinations with internal hazards

- consequential events: A can induce B
- A can induce B and B can induce A
- B can induce A
- correlated events: A and B are induced by common cause

Generation of Hazard Equipment List and Hazard Dependencies List (1)



Generation of Hazard Equipment List and Hazard Dependencies List (2)



Hazard Equipment List (*HEL*)

- The SSCs screening for generating hazard equipment lists *HEL* starts with compilation of such a list for each hazard and hazard combination remaining after hazards screening
- The hazard equipment list for an individual hazard H_k covering the entire number *j* of SSCs $H_kEL = \{SSC_1, \ldots, SSC_m\}_{Hk}$ has the following characteristics:
  - For a given H_i the corresponding H_kEL contains those $j = 1, \ldots, m$ SSCs being vulnerable to the impact of H_k
  - In addition, the failure or unavailability of any such SSC_j should contribute to the hazard induced risk
- First, a preliminary rough *HEL* is generated covering those SSCs related to the basic events (BE)
- Based on a target oriented plant walk-down the list is updated
- Result of the qualitative screening is a compilation of the final hazard equipment list *HEL* applicable for extending the plant model

Hazard Equipment List (*HEL*) – Example for B2 (2)

Component ID	Description	System	Building / Area
ALARM_.1	Alarm chain failure	Cf.	MCR
ALARM_.2	Alarm chain failure	Cf.	MCR
ALARM_.3	Alarm chain failure	Cf.	MCR
DIAGNOSIS_.1	Hazard diagnosis failed	Cf.	MCR
DIAGNOSIS_.2	Hazard diagnosis failed	Cf.	MCR
DIAGNOSIS_.3	Hazard diagnosis failed	Cf.	MCR
DP_FTR_A.	Drainage pump A fails to run	Cf.	EDG building
DP_FTR_B.	Drainage pump B fails to run	Cf.	EDG building
...	…	...	...
MDP_FTO_A.2	Mobile drainage pump A not in service in time	Cf.	EDG building
...	…	...	...
MDP_FTO_D.3	Mobile drainage pump D not in service in time	Cf.	EDG building
MDP_FTR_A.	Mobile pump fails to run	Cf.	EDG building
...	…	...	...
MDP_FTS_D.	Mobile pump fails to start	Cf.	EDG building

Component ID	Description	System	Building / Area
PBH_FL_D.3	Permanent bulkhead D flooded (height dep.)	Cf.	EDG building
PBH_NR_A.2	Permanent bulkhead A not replaced after detected damage (time dep.)	Cf.	EDG building
...	…	...	...
PBH_NR_D.3	PBH D not replaced after detected damage (time dep.)	Cf.	EDG building
SBH_FCM_A.	Slewing bulkhead A fails to close	Cf.	EDG building
...	…	...	...
SBH_FL_A.2	Slewing bulkhead A flooded (height dep.)	Cf.	EDG building
...	…	...	...
SBH_FL_D.3	Slewing bulkhead D flooded (height dep.)	Cf.	EDG building
SBH_NC_.1	Slewing bulkhead 4oo4 closing omitted	Cf.	EDG building
...	…	...	...
SBH_UT_A.2	Slewing bulkhead A not tight	Cf.	EDG building
...	…	...	...
SBH_UT_D.3	Slewing bulkhead D not tight	Cf.	EDG building

Hazard Dependencies List (*HDL*)

- As part of the Hazards PRA steps 2 and 3 for each hazard and hazard combination not screened out, a hazard dependencies list H_kDL needs to be compiled $H_kDL = \{D_1, \ldots, D_n\}_{Hk}$ with $D_k = \{A_k, S_k, c_k\}$, characterized as follows:
  - For a given H_k the corresponding H_kDL contains dependencies among the hazard induced failure behavior of SSCs needed to be considered
  - Generally, dependency D can be characterized as a triple of:
    - Set of dependent SSCs S_k,
    - Common characteristics of the elements of S (e.g., the water level as cause for a hydrological hazard H_k induced dependency) A_k, and
    - Correlation factor c_k representing the strength of the dependency

Conclusions

- A partly automated systematic and as far as possible comprehensive site and plant specific screening approach has been developed for all types of internal and external hazards including different types of event combinations with hazards
  - First step:
    Extended and enhanced screening of individual hazards followed by hazard combinations screening
  - Second step:
    Screening of SSCs to be accounted for within PRA resulting in hazard equipment lists *HEL* and hazard dependencies lists *HDL* for each hazard and hazard combination remaining for further analysis after hazards screening
- Approach has been successfully applied for selected classes of hazards and resulting hazard combinations for a German reference plant

Outlook

- Activities for further enhancing and extending the approach, in particular for a more automated screening of hazard combinations, are ongoing
  - Additional generic and site specific information for a variety of sites and NPP types will be included in the corresponding *Hazards Library* to enable more analysts to apply this screening approach
  - Special issues intended to be addressed within an enhanced screening approach are related to multi-unit and multi-source aspects

Thank you for your attention!