Consideration of Long-Lasting External Flooding Within PSA – Modelling Supplementary Emergency Measures

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Introduction (1)

- Operating experience has demonstrated the relevance of some long-lasting event sequences - mainly from single or combined hazards for probabilistic safety assessment (PSA)

➢ Development of a methodological approach for considering long-lasting event sequences within Level 1 PSA

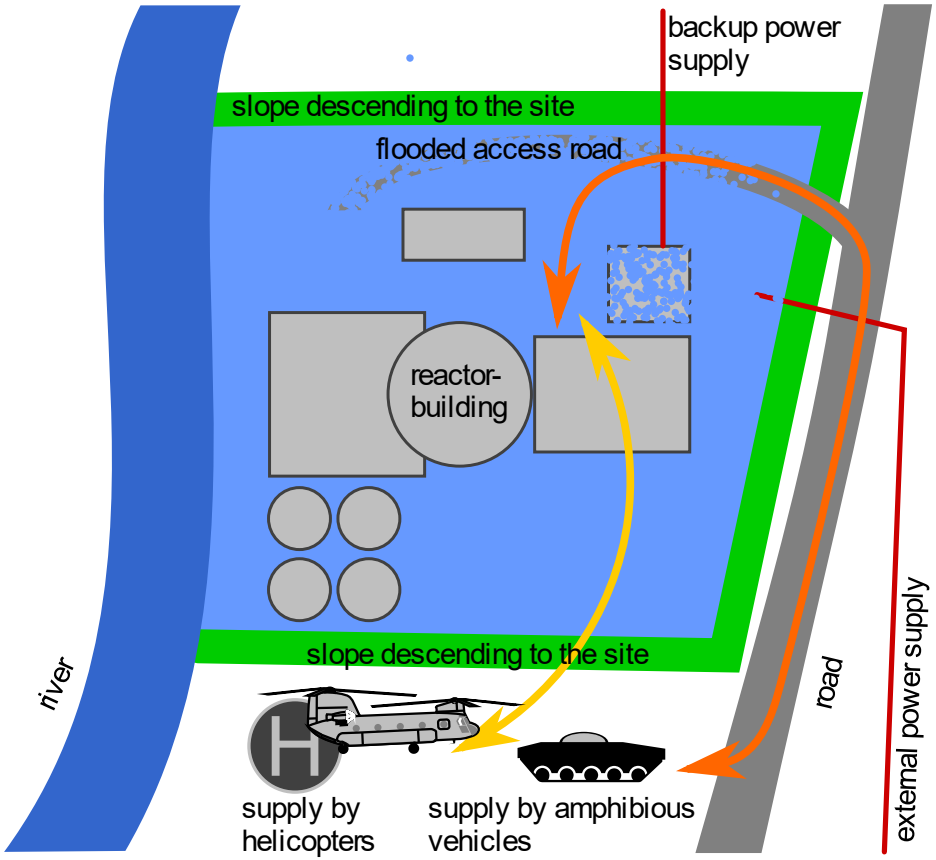
- In general, long-lasting event sequences can impair NPP safety in different ways
  - Increase of failure rates due to prolonged demanded time for certain items important to safety, e.g. emergency diesel generators (EDGs)
  - Increase of recovery possibilities of system functions with more time available
  - Short-term measures established to prevent harm from the NPP, not planned in advance, may be carried out because of sufficient time available
  - Only the first two aspects are typically considered within PSA

Introduction (2)

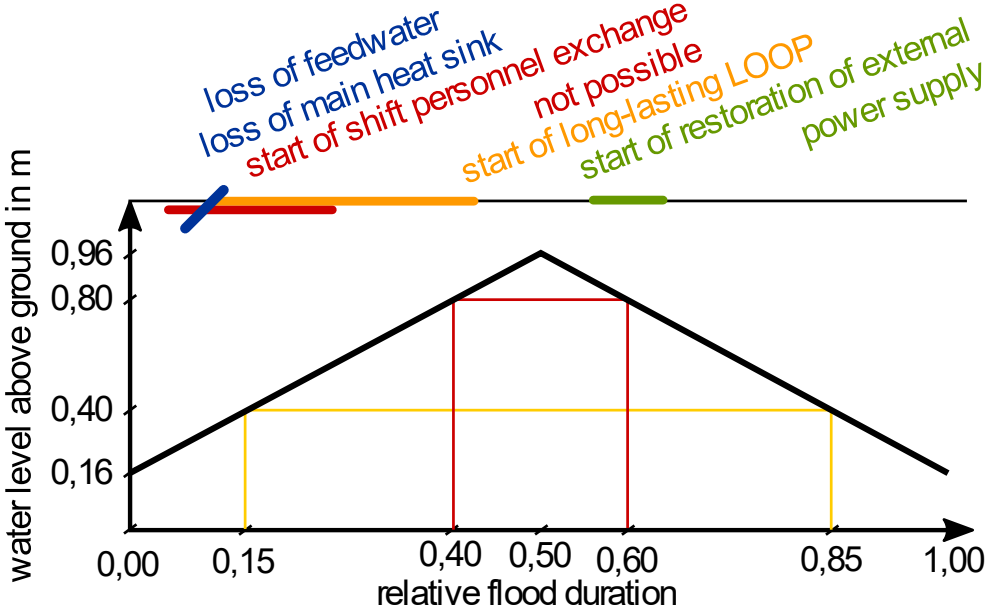
- Need for focusing on so-called ‘supplementary emergency measures’ (SEMs) during long-lasting event sequences in PSA
  - Identification of possible single or combined hazards with long-lasting event sequences for a German NPP site applying the GRS Hazards Screening Tool HST
  - Development of an approach for considering SEMs in such long-lasting scenarios
    - One possible scenario analyzed: a long-lasting external flooding scenario with loss of offsite power (LOOP)
    - Implementation of the SEMs identified in the already existing Level 1 PSA plant model of the NPP
    - SEMs based on two principles:
      - Long-lasting events allow for planning of additional measures
      - SEMs are more or less generic and applicable to NPP sites with similarities

Flooding Scenario Analyzed

- NPP site under consideration
  - Riverine multi-unit, multi-source NPP site
  - One PWR in commercial operation
  - Design with permanent protection against E-03 /a frequency flooding
  - Plant operating state (POS) assumed for the scenario: ‘subcritical, hot’
  - Power supply provided by double connection to external grid via 400 kV switchyard
- Long-lasting flooding scenario
  - Flood duration up to 18 days
  - Entire region affected



Flooding Scenario Characteristics



$$\text{relative flood duration} = \frac{\text{time passed since submergence}}{\text{probabilistic overall flood duration}}$$

- Phase 1 – water level increase: loss of offsite power (LOOP)
- Phase 2 – peak water: water nearly reaches protection line of buildings important to safety
- Phase 3 – water level decrease: full accessibility of site possible again, start of restoration work of external power supply

Consequences of Long-Lasting Flooding Scenarios

- Shift personnel exchange no longer possible
  - Approx. 135 persons needed on-site per shift
  - Extended shift duration: of 12 – 48 h (assumption)
  - ➢ Increase of human error probability (HEP) by factor 5 (SPAR-H)
- Diesel fuel of emergency power supply EPS 1 (providing power supply in case of flooding and LOOP) completely consumed
  - 2 of 4 diesel generators are taken out of operation early
  - EPS 1 requires 4 t / h of diesel fuel
  - EPS 2 fuel can be used
  - ➢ EPS 1 can be operated up to 7 days before station blackout (SBO)

Supplementary Emergency Measures (1)

- Long-lasting flooding affects larger region
- Use of military means as supplementary emergency measures (SEMs)
  - German emergency services cope with incidents in regions affected by extreme, long-lasting flooding
  - High priority is supposed for the NPP under consideration
  - Military means are available for the NPP

➢ Realization of two supply routes

- Support by military on demand by the crisis team
- Supply routes for
  - ❖ Shift personnel exchange (135 persons every 12 h)
  - ❖ Repeated diesel fuel supply (4 t / h)

Supplementary Emergency Measures (2)

https://www.bundeswehr.de/de/ausruestung-technik-bundeswehr/seesysteme-bundeswehr/schwimmschnellbruecke-amphibie-m3

https://www.bundeswehr.de/de/ausruestung-technik-bundeswehr/luftsysteme-bundeswehr/sikorsky-ch-53

	Amphibious Vehicle M3	Transport Helicopter CH-53
Number available at base	5 – 10 out of 30	5 – 20 out of 60
Passengers	60	30
Load	20 t	7 t

Supplementary Emergency Measures – Supply Routes

Item	Air Transport	Ferry Service
Shift personnel exchange every 12 h	2 CH-53	1 M3
Repeated fuel supply	1 CH-53	1 M3 (+ 1 backup)
Total means required at site	3 CH-53	2 M3 (+ 1 backup)
Number present at military base	5 to 20	5 to 10
Availability of one vehicle	0.22	0.25
Time to reach NPP site	12 – 36 h	19 – 48 h

- Supply routes successfully established if
  - Required number of means available at base **and**
  - Means available on-site before shift personnel exchange / fuel needed (required) **or**
  - Shift personnel exchange and fuel supply can be realized via normal access in time (sufficiently early flood decrease)

Supplementary Emergency Measures – Failure Causes

Failure Cause	Description
‘Base availability’	Means are not available at the military base (e.g. due to their use somewhere else), or are not ready for use
‘Time availability’	Means are not available at the site in time when the shift personnel exchange or the fuel supply are required
‘Means applicability’	Means cannot be applied at the site (e.g., due to environmental reasons or other random technical failures)
‘Site accessibility’	Site cannot be reached by the means (e.g., due to obstructions on route from the military base)

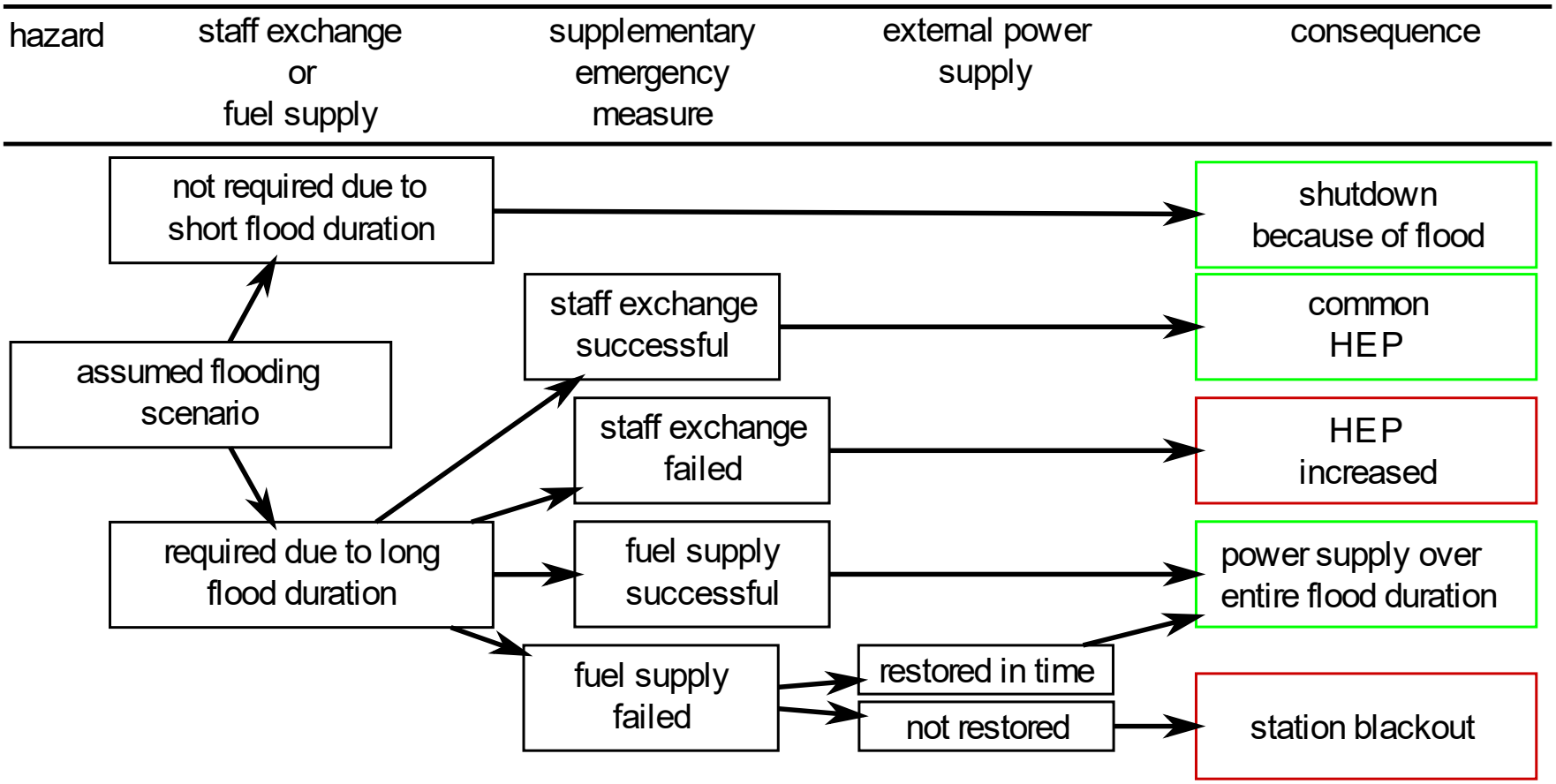
- **‘Base unavailability’** depending on number available at military base
- **‘Time unavailability’** depending on time of initiation, period to reach site, time when fuel / personnel exchange required
- **‘Means non-applicability’** not considered due to repair teams
- **‘Site non-accessibility’** not considered due to design and purpose of M3 and CH-53

Supplementary Emergency Measures – Failure Probabilities

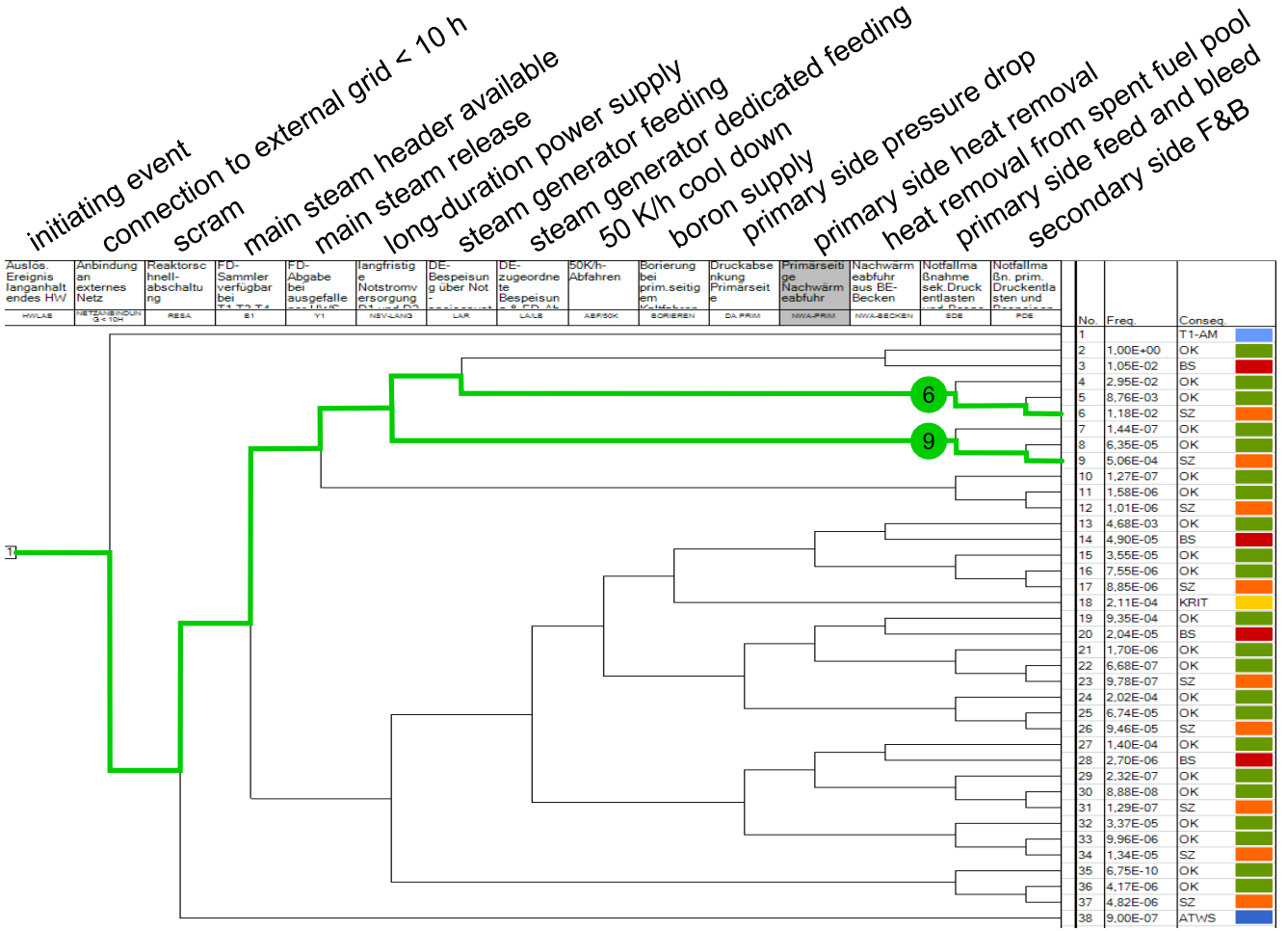
Item	Total	Ferry Service	Air Transport	Normal Access
Shift personnel exchange	4.6 E-01	8.7 E-01	6.5 E-01	8.3 E-01
Fuel supply	2.3 E-03	4.6 E-01	9.0 E-02	5..5 E-02
Restoration of external power supply	1.4 E-01	---	---	---
Early external power supply	nearly 1	---	---	---

- Sensitivity analysis demonstrates strong effect of flood duration and initiation time of SEMs
- Correlation between failures of both supply routes over flood duration
- Fuel supply more reliable (demand up to 7 days after LOOP) compared to shift personnel exchange (demand 48 h after submergence)
- Timely restoration of external power supply more likely than fuel supply
- Early external power supply (< 10 h) unlikely due to assumed flood durations

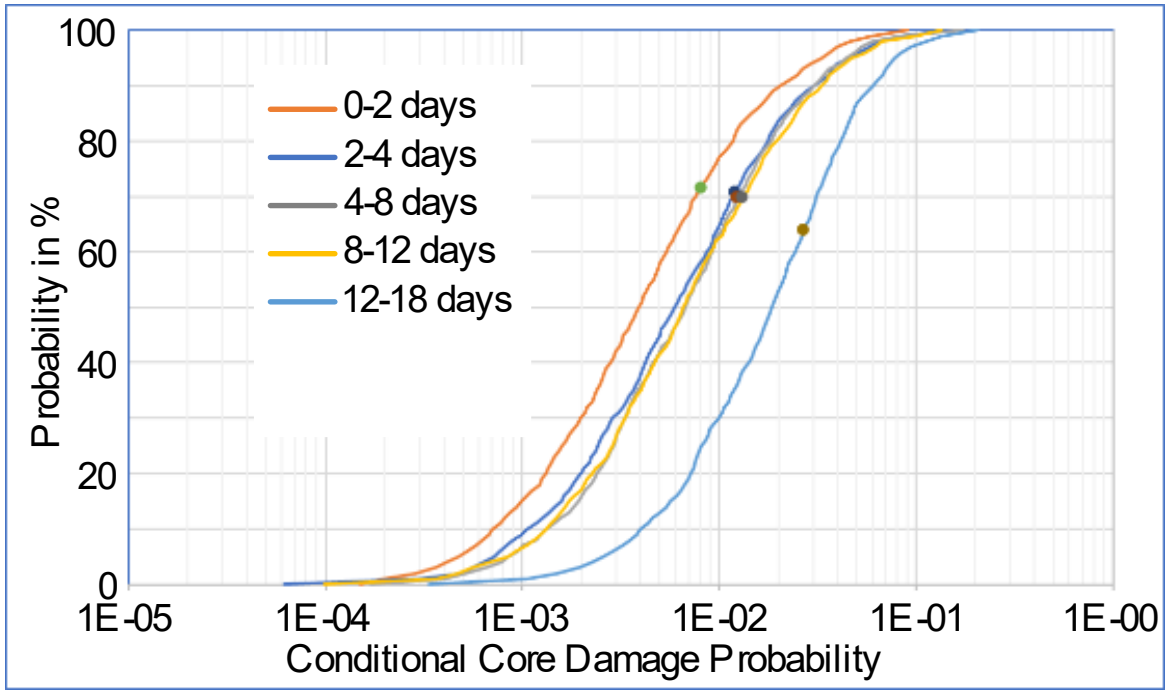
Potential Consequences of the Long-Lasting Scenario



Implementation in the Level 1 PSA Plant Model



Estimation of the Conditional Core Damage Probability (CCDP)



- Hazard occurrence frequency not considered (R&D study):
  => determination od CCDP only
- Failure probability of supply routes depends on flood duration
  - After 2 days: increase of shift personnel exchange failure probability
  - After 12 days: increase of fuel supply failure probability

Results

- Dominating event sequences:
  - For flood durations < 12 d: steam generator feeding via emergency feedwater system in combination with failed primary and secondary feed and bleed with increased HEPs due to failed shift personnel exchange
  - For flood durations between 12 and 18 d: fuel supply failure, failure of external power supply restoration, and the failures of primary and secondary feed and bleed in combination with failed shift personnel exchange
  - For all flood durations, the basic events for exchange of shift personnel as well as primary and secondary feed and bleed provide highest contribution to core damage

➢ In long-lasting external flooding events ensuring shift personnel exchange provides a significantly higher contribution to the success of the mitigation measures than ensuring fuel supply

Conclusions

- A regular exchange of shift personnel will significantly affect the success of mitigation measures in case of long-lasting event sequences
- Aspects of long-lasting scenarios not considered
  - SSC reliability data are typically based on shorter mission times
    - ❖ Few Diesel generator tests over 24 h do not show significant differences compared to tests over 24 h
    - ➢ Study was based on commonly available failure rates for 24 h
  - Long-lasting events may increase the possibilities to recover failed SSC
    - ❖ Major contribution to core damage from operator actions
    - ➢ No large effect of repair on the CCDP expected
    - ➢ No consideration of repair possibilities
- SEMs require sufficient time available for their planning during the event scenario

Outlook

- SEMs are more or less generic and therefore applicable to various NPP sites
- SEMs reduce the risk estimates from long-lasting event sequences within PSA
- SEMs should therefore be
  - Realistic but still conservative
  - Simple to be carried out
  - Related to existing emergency procedures
- Alternatives to the above mentioned SEMs (e.g. on-site quartering of relevant personnel) already exercised at some nuclear sites) need to be considered as well
- Time dependent changes in the event sequence and success paths could and should be modelled in more detail by methods of dynamic PSA reducing modelling uncertainties

Thank you for your attention!

For further questions, please contact

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