NUBIKI NUCLEAR SAFETY RESEARCH INSTITUTE

A Preparatory Study on Systematically Considering Combinations of External Events in the Design Basis and the PSA of NPP Paks

Tamas Siklossy, Attila Bareith, Barnabas Toth

siklossyt@nubiki.hu

PSA2019

Charleston, SC, USA, April 28 – May 4, 2019

Content

- Introduction
- Regulations and recommendations related to hazard combinations
- A critical review of current Hungarian practices
- Overview of the publically available literature
- Proposed technical tasks in details considering hazard combinations in the design basis and PSA
- Conclusions

Introduction

- Mostly single external hazards have been considered in the definition of the design basis for the Paks NPP in Hungary
- Motivation of assessing the impact of hazard combinations on NPP safety
  - Hungarian Nuclear Safety Codes and international recommendations
  - Lessons learnt from the Fukusima Dai-ichi accident
  - International/national R&D programs
- According to a corrective measure of the PSR of the Paks NPP in 2017: a systematic survey and assessment should be performed to:
  - identify and characterize external hazard combinations
  - assess the effects of hazard combinations on NPP safety:
    - the adequacy of protection against hazard combinations to be included in the design basis has to be justified
    - the residual risk due to beyond design basis load combinations has to be quantified
- The technical tasks and the schedule thereof had to be worked out first.

Hungarian Regulations

- Nuclear Safety Codes – generic level
  - all realistic combinations of the individual events shall be considered during design, which may lead to DBC4 or to DEC
  - all such events and event combinations shall be taken into account in the selection of events leading to DEC1, whose probability of occurrence cannot be proven with high confidence to be low and may lead to conditions that have not been included in the design basis
  - several other relevant NSC requirements
  - no direct requirements or guidance concerning methodologies for analyzing and evaluating hazard combinations
- Regulatory guide no. 7.1 (site investigation and evaluation) highlights the importance of considering different hazards jointly in the design basis:
  - meteorological hazards
  - the effects of meteorological conditions on the availability of ultimate heat sink, radioactive releases, etc.

International Recommendations

- WENRA reference levels (2007) (NSC in conformity):
  - 2014: new reference levels in Issue T on natural hazards
    - T3.1: care shall be taken not to exclude hazards, which, in combination with other hazards, have the potential to pose a threat to the nuclear facility
  - 2015-2016: guidance document + 3 hazard specific appendices in support of reference levels in issue T
    - terminology on categorization of hazard combinations
    - list several potential hazard combinations that should be looked at
- IAEA documents:
  - Development and Application of Level 1 Probabilistic Safety Assessment for Nuclear Power Plants. SSG-3
  - External Events Excluding Earthquakes in the Design of Nuclear Power Plant. NS-G-1.5
  - Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations. SSG-18

Use has been made of the methodological recommendations given in these safety guides

A Critical Review of Current Hungarian Practices – Design Basis

NUBIKI

1. FSAR – targeted assessment in 2002:
   - no need to consider any hazard combination in the design basis
   - not a state-of-the-art analysis (simplistic, have not been updated)
2. Assessments of single hazards incorporate potential hazard combinations
   - man-made hazards – no correlation, except for meteorological conditions
   - meteorology – no correlation, except for wind&snow loads on structures
   - Danube contamination endangering the water intake system – combination considered in the identification of relevant event sequences
   - hydrology – possible combinations of single hydrological events
   - geosciences – all seismological hazards are assessed in conjunction with geotechnical, geological and tectonic conditions and hazards

   The combination among the different scientific areas was not assessed
3. Site investigation and evaluation program (Paks 2016-2018) – targeted assessment of hazard combinations
   - the results cannot be applied directly and decisively to the existing NPP units
   - the assessment has some inherent limitations too, e.g. no input data to PSA
   - need to revise and supplement quite a few analysis assumptions and evaluations

A Critical Review of Current Hungarian Practices – PSA

NUBIKI

- No dedicated PSA for hazard combinations for the Paks NPP
- PSA for single hazards incorporate potential hazard combinations
  - full correlation for instantaneous, daily average and weekly average air temperature and cooling water temperature
  - hydraulic load assessment for the canalization system – extreme precipitation & LOOP (cooling water of diesel generators)
  - potential snow induced blockage of air intake systems (wind&snow)
  - fragility of the grid due to extreme temperature (all relevant grid related events that may occur)
  - vulnerability of the power transmission lines to the combination of extreme wind, frost and ice formation, and high/low air temperatures
  - partial correlation between earthquake and soil liquefaction

Overview of the Publically Available Literature

NUBIKI

- Swedish Nuclear Inspectorate: SKI Report 02:27 (2003)
- EPRI: Identification of External Hazards for Analysis in Probabilistic Risk Assessment (Update 2015)
- Documents of the ASAMPSA_E project
- WGRISK questionnaire on external hazards PSA (2007)
- Technical articles on national assessments:
  - GRS on screening of hazard combinations
  - Hanhikivi external hazard combination PSA
- Methodological documents on multivariate distribution functions

Types of External Hazard Combinations

NUBIKI

- Combination of dependent hazards – causal connection
  - Consequential hazards – cause-effect relation:
    - A may cause B (e.g. explosion – forest fire)
    - A is a prerequisite of B (e.g. earthquake – soil liquefaction)
  - Non-consequential connected hazards (correlated hazards) – common root cause
    (e.g. a meteorological condition triggers many hazards)
- Combination of independent hazards – no causal connection
  - independent events have a high occurrence frequency,
  - at least one of the events is long-lasting and usually rare.

Proposed Technical Tasks

PSA:

I. Selection of external hazard combinations
II. Screening of external hazard combinations
III. Detailed assessment of screened-in events:
   i. Probabilistic hazard assessment
   ii. Plant response and fragility analysis
   iii. Event logic modeling and risk quantification

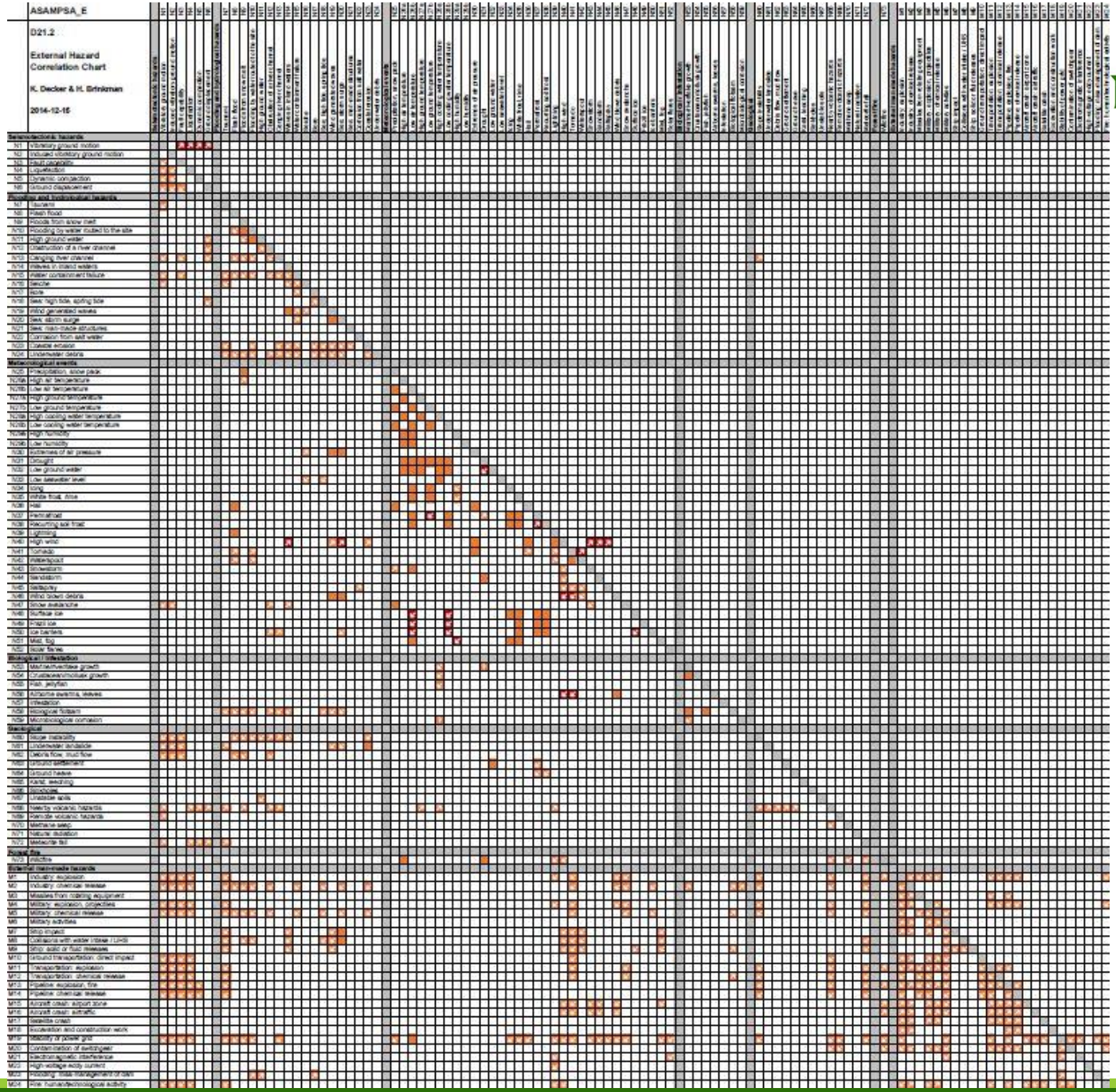
Design basis (identification and justification of protection):

I. Selection of external hazard combinations
II. Screening of external hazard combinations
III. Definition of design basis load combinations
IV. Evaluation of plant protection and specification of protective measures

Selection of External Hazard Combinations

NUBIKI

- Development of a comprehensive list of potential single external hazards
- Screening of single hazards with respect to hazard combinations
  - screening by relevance (cannot occur at the site)
  - frequency based screening (Hungary: 10^{-7}/a for existing NPP)
- Evaluation of the dependence among the hazards
  - a table („matrix”) form – cross-correlation chart
  - for all the possible hazard combinations, the possible relation type has to be identified and marked with a predefined symbol
  - further considerations are needed to identify hazard combinations including 3 or more hazards


ASAMPSA_E
D21.2
External Hazard Correlation Chart
K. Decker & H. Brinkman
2014-12-15

NUBIKI

Screening of External Hazard Combinations

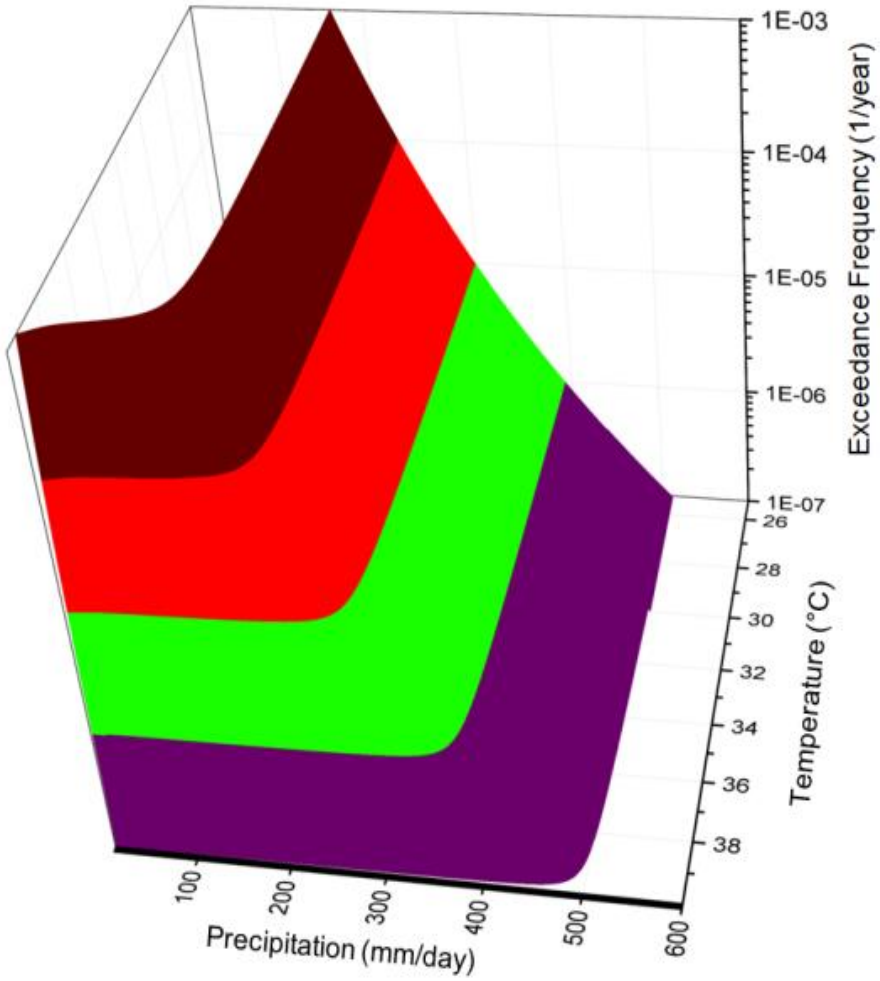
NUBIKI

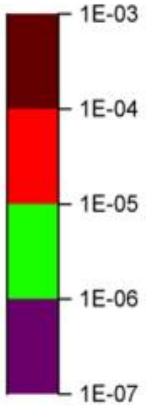
- In general, the same screening criteria as for single hazards
- Relation between the impact mechanisms of the single hazards:
  - similar or the same (e.g. wind & snow to structures):
    - hazards affect the same SSCs amplifying one another's effects
    - resistance against the combined load has to be assessed
  - different (e.g. wind & high temperature)
    - hazards do not affect the same SSCs or not with the same mechanisms
- Hazard combination specific screening criteria:
  - hazards are mutually exclusive
  - definition of a single hazard incorporates the other single hazard
  - the impact of the hazard combination is not more severe than the effect of the more powerful hazard

Probabilistic Hazard Assessment

Frequency-
combinatio

- combinat
  - consec
  - correla
    - ha
      me
    - cu
      co
- combinat
  event)
    - λ_i occ
    - t_i dur
    - N dur





ad

rmined

ue theory for

d intensity

long-lasting

= P

ously [year]

Plant Response and Fragility Analysis Event Logic Modeling, Risk Quantification

NUBIKI

- Plant response and fragility analysis
  - which SSCs are challenged and how characterize the vulnerability
  - ideally: probability of failure for different levels of load combinations by means of fragility surfaces
  - current practice: fragility for predefined load intensity combinations
  - relation between the impact mechanisms of the single hazards is decisive
- Event logic modeling and risk quantification
  - similar fashion as it is done in the single hazards PSA
  - assessment of plant transients and mitigation system degradation induced by hazard combination
  - random SSC failures and human failure events considered too

Conclusions

As a preparatory step to systematically identify and assess the combinations of external hazards for the Paks NPP:

- the regulations and recommendations have been looked at
- the available methodologies have been studied and evaluated
- analysis practices applied in Hungary have been reviewed
- a proposal has been developed for the technical tasks and the schedule thereof to identify combinations of external hazards and assess the effects of such hazards on NPP safety

The assessment of external hazard combinations is to be started in 2019 and is planned to be finished in 2022.

NUBIKI

Thank you for your attention!