

Consideration of Combined Hazards Within PSA – A WGEV and WGRISK Perspective

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Abstract: After the Fukushima reactor accidents, combinations of hazards have gained more and more attention. As a result, the importance of adequate consideration of hazard combinations involving external hazards in safety assessments of nuclear installations was recognized. National and international activities are ongoing regarding hazard combinations. One of these is the joint task “Combinations of External Hazards – Hazard and Impact Assessment and Probabilistic Safety Analysis (PSA) for Nuclear Installations” of the OECD Nuclear Energy Agency (NEA) Working Groups on Risk Assessment (WGRISK) and on External Events (WGEV).

The first phase of this activity covered a survey from members of both Working Groups for developing an informed understanding of the regulatory requirements and the technical approaches in member countries regarding the treatment of combined external hazards and integrated hazard impacts.

The survey included questions on regulatory requirements for consideration of combined external hazards in safety analyses, the specific approaches to assessing hazard combinations in the framework of siting and licensing new installations and possible differences compared to operating ones, the use of specific PSA guidance for hazard combinations and its applications to support risk-informed decision-making (RIDM). PSA needs were also considered including the underlying methodologies for identifying, interpreting, and screening combined external hazards and performing probabilistic hazard assessment suitable for use in PSA.

In the second task phase, an expert workshop will be held to involve a broader range of experts in this field to address key issues and identify technology gaps. The insights from the first phase will be discussed, with a specific focus on risk assessment for accidents induced by combinations of hazards in different plant operational states. The discussions will help better identify and characterize important hazard combinations and understand the state-of-the-art in assessing the integrated impact of combined external hazards and in developing PSA for these hazards.

1. INTRODUCTION

After the Fukushima Dai-ichi reactor accidents, combinations of hazards have gained more and more attention. As a result, the importance of adequate consideration of hazard combinations, particularly involving external hazards, within all types of safety assessments of nuclear installations has been recognized by the experts involved.

Various national as well as international activities are ongoing with respect to combinations of hazards including the extension of IAEA Safety Guides to better cover combined hazards and a currently ongoing activity conducted jointly by the OECD Nuclear Energy Agency (NEA) Working Groups on Risk Assessment (WGRISK) and on External Events (WGEV). The NEA task entitled

“Combinations of External Hazards – Hazard and Impact Assessment and Probabilistic Safety Analysis (PSA) for Nuclear Installations” was initiated in 2020 [1] addressing the state-of-the-art practices in member countries in considering combinations of external hazards in the design, operation, and safety assessment of nuclear installations.

This task comprises two phases. In the first phase of the activity a survey of members from both Working Groups was conducted for developing an informed understanding of the regulatory requirements and the technical approaches in WGEV and WGRISK member countries with regards to the treatment of combined external hazards and characterizing integrated hazard impacts.

After completion of the corresponding report, an expert workshop is planned for the second task phase to gain more detailed insights on the topic and to draw conclusions based on the presentations and facilitated discussions.

This paper presents the status of this international activity and some intermediate results with a focus on PSA for combined external hazards.

2. TASK SCOPE AND OBJECTIVES

One main objective of this joint WGRISK and WGEV task is the collection of information on current regulatory practices as well as technical approaches and methods applied in hazard assessments for nuclear installations with respect to combinations of external hazards and integrated hazard impacts, i.e. the loads and conditions resulting directly or indirectly from a single hazard or from a combination of hazards. Based on the evaluation of this information, key issues of interest are being identified.

Event combinations of external hazards are categorized into three types: (1) combinations of causally related, so-called consequential (or subsequent) hazards or other events (hazard and consequential hazard or event), (2) combinations of correlated hazards (two or more hazards correlated by a common cause initiator), and (3) combinations of two or more independently (randomly), but simultaneously occurring hazards.

Integrated hazard impacts are considered as an aggregate of different impacts on a nuclear installation caused by one or more external events.

A further objective of the task is to provide an overview of the current state-of-the-art with respect to risk analysis of event combinations of external hazards and to review the methods applied for these analyses in order to provide a basis for advances in this area.

The scope the task covers in the first task phase was a survey that was conducted to develop an informed understanding of the regulatory requirements and the technical approaches in WGEV and WGRISK member countries for dealing with combinations of external hazards and integrated hazard impacts. Besides the corresponding regulatory requirements, the survey addressed the methodology for identifying possible combinations of hazards and relevant aspects of hazard assessment (e.g., availability of data, deterministic/statistical/probabilistic criteria and approaches for the selection of combinations of different hazards) and for determining the resulting integrated impacts on nuclear installations. The needs of PSA were also considered in the survey concerning methodologies for identification, interpretation, selection and screening of combinations of external hazards for probabilistic hazard assessment.

In addition to hazards screening and assessment for combinations of external hazards, the scope covered methodologies for plant response and fragility analysis, development of event sequence models including the role of plant personnel, and risk quantification along with the treatment of uncertainties. PSA modelling of plant internal events and hazards (internal or external) consequential to external hazards or combinations of external hazards were also addressed in the survey. Risk assessment for

accidents that can be induced by combinations of hazards at full power as well as in low power and shutdown states are in the scope of the activity.

Following the evaluation of the survey, a workshop is planned for the second task phase that will involve a broader range of engineers, scientists, risk analysts and other experts in this subject to address key issues and identify technology gaps. The discussions will help to identify and characterize important hazard combinations; understand the state-of-the-art in assessing the integrated impacts of hazard combinations as well as in developing PSA for hazard combinations; specify further needs for research and development (R&D); and potential improvements in assessing external hazards during the design and in the safety assessment of nuclear installations specifically including probabilistic safety assessment and risk-informed decision-making.

3. FIRST TASK PHASE: WGRISK AND WGEV MEMBER SURVEY

As an initial part of the first task phase, the questionnaire for the international survey on combined external hazards was developed as a cooperative effort of the core group members of the task from both WGEV and WGRISK. Concerted actions of the two groups were necessary to properly incorporate the technical issues that were in the interests of the different experts. Since these interests were manifold due to the complexity of task objectives and scope, it appeared highly challenging to come to agreement on the structure of the survey as well as on the number and depth of the questions that could be formulated with the hope of obtaining reasonably meaningful answers from the member states.

Efforts were made to reach consensus in the core group in its pursuit of satisfying all these, often conflicting needs. Moreover, the elaboration of the questionnaire was the first instance when the representatives of the two groups of the Committee on the Safety of Nuclear Installations (CSNI) were actually working jointly. Most importantly, the working methods had to be harmonized and a basic minimum level of common understanding of the various technical issues within the domain of the task had to be developed in the core group. Finally, it should be highlighted that the schedule for the first phase of the task has so far been in a much unfortunate coincidence with the unfolding of the Covid-19 pandemic worldwide. This fact adversely affected the progress that could be made up to date. Despite these difficulties, the core group members have made considerable efforts to date in order to advance in phase 1 of the task.

Overall, the survey questions were classified into 8 technical and scientific areas (hereinafter referred to as *technical areas*). 42 questions were prepared in these technical areas in total. Table 1 provides a summary of the technical areas and the number of questions included in the questionnaire for the different technical areas.

Table 1: A Top-Level Overview of Survey Questions

Technical Area		Number of Questions
No.	Description	
1	Regulatory Environment Related to Assessing Combinations of External Hazards	11
2	Definitions and Terminology Used for Classifying Combinations of External Hazards	2
3	Selection of Combined External Hazards (Identification and Screening)	9
4	Hazard Assessment for Combinations of External Hazards	4
5	Plant Response and Fragility Analysis in Support of PSA	5
6	Modelling of Accident Sequences in PSA	5
7	Risk Quantification	5
8	Ongoing Efforts (Research and Development)	1
Total		42

Most of the questions were not merely “yes” or “no” type questions but the respondents were encouraged to share their views on the different issues rather than just providing factual information. Although it was expected that the use of this approach might increase the level of subjectivism in the answers and make the evaluation of the survey more demanding, this choice appeared justifiable and it was considered beneficial, as safety assessment for combinations of external hazards is generally viewed as an evolving discipline with a spectrum of challenges and less than fully resolved issues. To illustrate the composition of survey questions, Table 2 lists the questions raised in relation to technical area no. 3, i.e. selection of hazards.

Table 2: Survey Questions Related to the Selection of Combined External Hazards

Question ID	Description
3a	Do you use an initial list of single external hazards as a basis for defining hazard combinations? If yes, please briefly discuss how you substantiate this list?
3b	Have you performed screening of the initial list of single external hazards before using it for defining hazard combinations relevant to your nuclear power plants / sites? If yes, please briefly describe the screening criteria applied. If you have not yet performed such analyses, but you are ready to share your views, what would you consider as an appropriate approach to addressing these technical issues? Please briefly describe.
3c	Please provide the screening criteria that you applied for screening of combined external hazards. If you have not yet specified such criteria, but you are ready to share your views, what would you consider as an appropriate approach to addressing this technical issue? Please briefly describe.
3d	What is the method used to evaluate the dependence between the different external hazards in order to identify combinations of external hazards? Did you use a formalized procedure and / or supporting tool, e.g., a cross-correlation chart in support of the analysis? If yes, please briefly describe. If you have not yet performed such analyses, but you are ready to share your views, what would you consider as an appropriate approach to addressing these technical issues? Please briefly describe.
3e	Did you consider combinations of independent external hazards during hazard selection? What was the rationale for excluding or including this kind of hazard combination? If you have not yet performed such analyses, but you are ready to share your views, what would you consider as an appropriate approach to addressing these technical issues? Please briefly describe.
3f	Did you consider combinations of more than two external hazards during hazard selection? What was the rationale for including more than two external hazards during hazard selection? If you have not yet addressed this issue, but you are ready to share your views, do you consider that combinations of more than two external hazards should be assessed?
3g	Please provide the list of hazard combinations you have selected for detailed assessment after screening.
3h	Are combinations of external hazards listed in response to question 3g explicitly modeled in your existing PSA models, so that risk results are produced for these combinations?
3i	Are there national regulatory guidance documents or any other methodology documents in place for selection and screening of hazard combinations? If yes, please specify.

The questionnaire was distributed to the NEA member states together with a set of example responses provided by one country represented in the core group of the task. Multiple institutions or organizations were invited to provide answers to the questions from a member state to, preferably, represent regulatory as well as the utility positions. As the answers of different institutions to a question could be different, member states had the opportunity to provide more than one answer to a question if it was seen necessary. However, it was required that each member state fills in and returns a single questionnaire only, so that a completed questionnaire from a member state would reflect

differences in opinions concerning the answers given to a specific question. Despite some concerns, the experience from the questionnaire responses suggests that this arrangement worked reasonably well.

Sixteen member states provided responses to the survey questionnaire that provide a solid basis for evaluating the answers and for yielding insights useful for the purposes of the second task phase. The evaluation of survey responses is currently ongoing. After a top-level review of the responses, the structure of a survey task report was outlined. The report structure is in good agreement with that of the survey questionnaire in the sense that a dedicated report section is assigned to each technical area addressed in the survey and covered by the responses. These report sections are meant to be the central part of the report. Overall conclusions are planned to be drawn on the basis of evaluating the state-of-practices in each technical area, as witnessed by the answers provided by the member states.

The development of the survey task report is a truly joint activity of the two groups, especially because multiple authors and co-authors, selected typically from both WGRISK and WGEV, are responsible for each key report section. The interpretation of survey responses was found to be a demanding task. In a few instances, the respondents were consulted for clarification and for additional information in order to enable a meaningful review of the survey results.

Country responses are the drivers of the survey evaluation. Accordingly, the survey task report is to reflect the contents of the country responses rather than any other methodological documents, guidelines, or the subjective opinions of the authors. Also, efforts are being made to ensure that the findings and conclusions are clearly derived from the evaluation of the members' answers in each technical area that is in the focus of the survey. Numerous important, preliminary conclusions have already been drawn. These conclusions will be subject to discussions within the core group of the task and the consent of all the task group members will be necessary before making them publicly available to a wider scientific community. The final draft of the survey task report is planned to be developed and distributed to WGIRSK and WGEV members for their review by the end of 2022.

4. PHASE 2: TASK WORKSHOP

The interim results obtained from the first phase of the task can usefully support the technical workshop to be organized in the second phase. Understanding state-of-practices throughout the member states concerning regulatory requirements for as well as regulatory and utility approaches to assessing combinations of external hazards is of particular importance for the workshop.

Planning for the workshop is ongoing. Tentatively the workshop will be held in the fall of 2023. The plans for this workshop are to invite subject matter experts on both hazards analysis and on probabilistic safety assessment. Participation by experts from national, international, and multi-national organizations will be sought out to share their knowledge and experiences on hazards analysis and assessment of risks at nuclear installations and other critical infrastructures (e.g., water supply installations, electrical energy distribution networks). During the workshop these subject matter experts will give presentations and participate in panel discussions on topics such as the phenomenological aspects of combined hazards and the potential impact of these hazards on critical infrastructure, such as nuclear installations; discussions on the impacts from these combined hazards on nuclear installations and how these impacts can be assessed using probabilistic and statistical approaches within state-of-practice PSA tools. Plans are to have an in-person workshop over three to four days, with sessions on each of the topical areas of the survey sent to the WGRISK and WGEV members. The outcome from the workshop will be workshop proceedings that will integrate the insights from the technical note prepared following the survey with the additional insights gained through the presentations and discussions during the workshop. These workshop proceedings will be made available to the workshop participants and the public by the OECD NEA.

5. CONCLUSIONS AND OUTLOOK

There is a multi-year task in place of the CSNI at the OECD NEA on the safety assessment for combinations of external hazards. The task is a joint activity of the Working Group on Risk Assessment and the Working Group on External Events of the CSNI. The task is broken down into two phases. A survey questionnaire is in the focus of the first task phase. A comprehensive questionnaire was prepared and distributed to the OECD NEA member states to collect information on (1) regulatory requirements for considering combined external hazards in safety analyses, (2) the specific approaches followed when assessing hazard combinations in the framework of siting and licensing new installations and possible differences compared to operating ones, (3) the use of specific PSA guidance for hazard combinations and its applications to support risk-informed decision-making. PSA needs were also considered including the underlying methodologies for identifying, interpreting, and screening combined external hazards and performing probabilistic hazard assessment suitable for use in PSA. Sixteen OECD NEA member states have provided answers to the questionnaire in eight pre-selected technical areas of particular interest in the safety assessment for combinations of external hazards. The evaluation of survey responses is ongoing, and a survey task report is being prepared to summarize the most important findings from the survey.

In the second task phase, an expert workshop will be held in the fall of 2023 that will involve a broader range of experts in these fields to address key issues and identify technology gaps. Insights from the first phase will be discussed, with a specific focus on phenomenological aspects of the combined hazards, the impact of these hazards on critical infrastructure such as nuclear installations, and on the risk assessment for accidents induced by combinations of hazards in different plant operational states. The discussions will help to better identify and characterize important hazard combinations and understand the state-of-the-practice in assessing the integrated impact of combined external hazards that support developing particularly PSA for these hazards. The outcome from the workshop will be workshop proceedings that will integrate the insights from the technical note prepared following the survey with the additional insights gained through the presentations and discussions during the workshop.

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References

[1] Organisation for Economic Co-operation and Development (OECD) Nuclear Energy Agency (NEA), Committee on the Safety of Nuclear Installations (CSNI), Working Group on External Events (WGEV) and Working Group on Risk Assessment (WGRISK). “*Combinations of External Hazards – Hazard and Impact Assessment and Probabilistic Safety Analysis (PSA) for Nuclear Installations*”, Common Activity Proposal Sheet (CAPS), 2019(2), Paris, France, (2019).