

Understanding the Impact of External Hazards on Nuclear Facilities: Severe Weather and Storm Surge

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Working Group on External Events
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Workshop Proceedings -Working Group on External Events (WGEV)

Understanding the Impact of External Hazards on Nuclear Facilities: Severe Weather and Storm Surge

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The Committee focuses primarily on the safety aspects of existing power reactors, other nuclear installations and new power reactors; it also considers the safety implications of scientific and technical developments of future reactor technologies and designs. Further, the scope for the Committee includes human and organisational research activities and technical developments that affect nuclear safety.

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List of abbreviations and acronyms

CEREMA	Le centre d'études et d'expertise sur les risques, l'environnement, la mobilité et l'aménagement
CNSC	Canadian Nuclear Safety Commission
CSNI	Committee on the Safety of Nuclear Installations (NEA)
EDF	Électricité de France
ENSI	Swiss Federal Nuclear Safety Inspectorate
EPZ	Elektricitets Produktiemaatschappij Zuid-Nederland
GRS	Gesellschaft für Anlagen- und Reaktorsicherheit gGmbH (Germany)
INL	Idaho National Laboratory (United States)
IRSN	Radiological Protection and Nuclear Safety Institute (France)
KAERI	Korea Atomic Energy Research Institute
KINS	Korea Institute of Nuclear Safety
NHC	National Hurricane Center (United States)
NPP	Nuclear power plant
NRA	Nuclear Regulation Authority (Japan)
PFHAs	Probabilistic flood hazard assessments
PMSS	Probable maximum storm surge
PNNL	Pacific Northwest National Laboratory (United States)
PRA	Probabilistic risk assessments
PSA	Probabilistic safety assessment
SSC	Systems, structures and components
TGNEV	Task Group on Natural External Events (NEA)
WGEV	Working Group on External Events (NEA)
WGRISK	Working Group on Risk Assessment (NEA)
WMO	World Meteorological Organization

Executive summary

The March 2011 accident at Fukushima Daiichi nuclear power plant triggered discussions about the natural external events that are low-frequency but high-consequence. In order to address these issues and determine which events would benefit from international co-operative work, the Task Group on Natural External Events (TGNEV) was established by the Committee on the Safety of Nuclear Installations (CSNI) at its June 2013 meeting. In June 2014, the CSNI decided to re-organise TGNEV into a Working Group on External Events (WGEV) to improve the understanding and treatment of external hazards that would support the continued safety performance of nuclear installations as well as improve the effectiveness of regulatory practices in NEA member countries. WGEV is composed of a forum of experts for the exchange of information and experience on external events in member countries, thereby promoting co-operation and maintenance of an effective and efficient network of experts.

At its 54th meeting, the CSNI approved the recommended task on severe weather events with a particular focus on high winds and flooding, to be pursued by the TGNEV, the predecessor of WGEV. It was expected that the first activity would be a survey of CSNI members to identify current regulatory practices, research activities and knowledge gaps for severe weather hazards. Then, following an initial assessment of the survey results, a workshop would be planned to involve relevant experts in identifying activities required to address the knowledge gaps. In this context, the workshop, “Severe Weather and Storm Surge” focused on the current national regulatory approaches for the assessment of severe weather events and protection as well as on technical methods for assessing hazards and on the effectiveness of preventive measures.

After convening several preparatory meetings, the WGEV workshop was held at the OECD Conference Centre, 2 rue André Pascal, in Paris, France on 24-26 February 2016. Forty-four participants attended the workshop representing regulators and their technical support organisations, industry and government organisations from 10 countries, as well as international organisations. A total of 17 technical presentations were given in 3 sessions. Full copies of all the workshop presentations are available for download on the Nuclear Energy Agency (NEA) website.

At the end of each session, a panel session was held allowing for more detailed discussions on any of the presentations in that session. On the last day, a general discussion session concluded the workshop.

Based on the discussions, a strong interest for continuing efforts after this WGEV workshop was expressed by the participants of the workshop.

The following issues were highlighted by the participants as topics of concern which needed further consideration:

- Improving the reliability of information and boundary conditions for the performance of hazard evaluation (e.g. how to use a return frequency threshold for the design-basis hazards considerations).
- Risk-informed decisions are an essential approach to regulatory oversight and communication, but data for external hazards is sparse temporally and spatially. Therefore, using simulation and incorporating other data sources (i.e. paleodata) is a key to extending currently available data, but simulations need to be validated with consideration of available data.
- The use of paleodata and historical data is important, but also challenging to interpret and use properly.
- The treatment of uncertainties associated with data and modelling need to be better understood and quantified, and decision makers should be aware of the uncertainties and take them into account in their decision-making processes.
- Developing fragility information is a key knowledge gap that needs to be bridged to support the interface between insights gained from hazards assessment and application of those insights in a probabilistic safety assessment (PSA).
- Climate change is introducing new challenges into the decision-making process that will need to be considered by developing new approaches and models to identify and address these challenges.

It was also noted that it would be beneficial to continue information sharing with several other NEA working groups and in particular with the Working Group on Risk Assessment (WGRISK) on hazard quantification for risk assessments. The workshop demonstrated that it is important for the nuclear and meteorological communities to work together to take advantage of methods, models, data and experiences in the understanding of severe weather phenomenon and impacts to local, national and regional infrastructure. Also, co-operation with subject matter experts is important as well as regional co-operation to share experience and data.

1. Introduction

1.1. Background

The Task Group on Natural External Events (TGNEV) was established at the Committee on the Safety of Nuclear Installations (CSNI) June 2013 meeting in order to address natural external events with low-frequency but high-consequence and to determine which events would benefit from international co-operative work. In June 2014, the CSNI decided to re-organise TGNEV into a Working Group on External Events (WGEV) to improve the understanding and treatment of external hazards that would support the continued safety performance of nuclear installations and improve the effectiveness of regulatory practices in NEA member countries. The WGEV constitutes a forum of experts for exchange of information and experience on external events in member countries, thereby promoting co-operation and maintaining an effective and efficient network of experts.

At its 54th meeting, the CSNI approved the recommended task on severe weather events, with a particular focus on high winds and flooding, to be pursued by the TGNEV (predecessor of WGEV). It was supposed that the first activity would be a survey of CSNI members to identify current regulatory practices, research activities and knowledge gaps for severe weather hazards and coastal flooding. Then, following an initial assessment of the survey results, a workshop was planned to involve relevant experts in identifying activities required to address the knowledge gaps.

To deliver the aim of the task group, it was decided to convene an international workshop on “Severe Weather and Storm Surge” at the OECD Conference Centre in Paris between 24 and 26 February 2016, where specialists from across the world could gather to exchange information and share their own country’s or company’s experiences on the assessment and treatment of specific external hazards associated with high winds and flooding.

1.2. Objectives of the workshop

The main objective of this international workshop was to provide a forum to review and discuss current national regulatory approaches with respect to the assessment of and protection against severe weather events. Further, the workshop provided a forum for discussions on technical methods for assessing impacts to local and regional infrastructure and the effectiveness of preventive and protective measures. Key focus areas were:

- Regulatory requirements and operating experience regarding storm surge and tsunami hazards;
- Severe weather hazard assessment approaches, identification of good practices and knowledge gaps;

- Challenges for regulators regarding the approach to severe weather hazards and tsunamis;
- Information obtained as a result of this workshop should help to understand key regulatory issues related to severe weather events characterisation and assessment, and to determine activities to address knowledge gaps that may warrant further study.

1.3. Organisation of the workshop

The workshop was organised into three technical sessions and an opening and closing session as follows:

- Opening Session
- Session 1: Regulatory Objectives and Approaches to Accomplish Objectives
- Session 2: Severe Weather Assessment & Societal Impact (Protecting People and Infrastructure)
- Session 3: Informing the Nuclear Regulatory Process Through Gap Analysis
- Workshop Closing session

In the closing session, discussions during technical sessions of the workshop were summarised and conclusions and recommendations were developed for possible further CSNI actions. The participation was open to experts from regulatory authorities and their technical support organisations, research organisations, universities, utilities, NPP designers and vendors, industry associations and observers from NEA member countries as well as a small number of experts from non-OECD member countries. A total of 44 participants from 10 countries attended the workshop. The list of participants is provided in Appendix 1. A total of 17 technical presentations were given in the 3 sessions. The detailed workshop agenda is provided in Appendix 2. Full copies of all workshop presentations are available for download on the Nuclear Energy Agency (NEA) website.

1.4. Topics of the workshop

Items addressed in the workshop include:

- Regulatory objectives and research for assessing tsunami hazards;
- Regulatory objectives and research for assessing severe weather and storm surge hazards;
- Case studies on flooding assessment to identify and discuss challenges for the safety of NPPs;
- Countries approaches in severe weather assessment, impact assessment and existing gaps;
- Current research on modelling of storms and storm surges, on statistical methods for data and information analysis, methods to characterise extreme storm surge;
- Long-term weather predictions, statistical and modelling approaches.

2. Summary of the Workshop on Severe Weather and Storm Surge

The workshop consisted of an opening session, three technical sessions with participant presentations followed by short discussions and a closing session summarising the discussions and developing conclusions and recommendations for possible further CSNI actions. The contributions presented were devoted to discussions of national post-Fukushima regulatory programme developments, regulatory objectives in assessing severe weather and storm surge, case studies on flooding and tropical storms assessment, countries' approaches in severe weather characterisation and impact assessment, current research on modelling, statistical methods for data and information analysis, methods to characterise extreme storms, storm surge, and long-term weather predictions, statistical and modelling approaches.

2.1. Opening session

The workshop was opened by the Head of the Nuclear Safety Division of the NEA, Mr. Ho Nieh, who welcomed the participants and gave a brief overview of the post-Fukushima activities undertaken by the agency. The workshop Chair, Mr John A. Nakoski (US Nuclear Regulatory Commission [US NRC]), briefly discussed the background and objectives of the workshop. He reminded the participants that the Fukushima Daiichi accident illustrated that operating NPPs are susceptible to extreme external hazards and that this is an area which had not been thoroughly understood and completely evaluated in every detail. He stated that the purpose of the workshop is to bring together experts in severe weather forecasting, hazards assessment and NPP safety to exchange information to support better and more effective regulatory decision making. A desired outcome of the workshop was to identify and close knowledge gaps by establishing a community and relationships to assess the impact of severe weather on critical infrastructure (including commercial NPPs).

2.2. Session 1 – Regulatory objectives and approaches to accomplish objectives

This session was devoted to the regulatory requirements and current research programmes that many countries have engaged at the national level to strengthen the assessment of storm surge and tsunami impact on NPPs.

The following papers were presented:

- The Regulatory Requirements for Tsunami, Hideharu Sugino (NRA, Japan);
- Current Research on Tsunami Protection, Toru Iijima (NRA, Japan);
- Case Study of Storm Surge and High Wind by Typhoons, Kwanhee Lee (KINS, Korea);

- Research Status of Tsunami Psa, Min Kyu Kim (KAERI, Korea);
- A Licensing Case Study on the Effects of Hurricane Andrew on Turkey Point Nuclear Power Plant (Units 3 And 4), Bruce Mcdowell and Rajiv Prasad (PNNL, USA);
- Its Societal Infrastructure Support and The Operational and Regulatory Lessons Learned from this Event, Bruce Mcdowell and Rajiv Prasad (PNNL, USA);
- The Regulatory Requirement to Severe Weather in Switzerland, Roland Beutler (ENSI, Switzerland);
- Le Blayais Flooding Event and Follow-Up Activities for French NPPs (Reassessment, Guideline Revision), Dr Vincent Rebour (IRSN, France);
- The Case Study on Flooding Assessment to Identify and Discuss Challenges for The Safety of NPP in Netherlands, Hans Te Lintelo and Philip Somers (EPZ, Netherlands);
- CNSC's Regulatory Approaches to Extreme Weather and Flood Hazard Assessment, Dr Shi Zhong Lei (CNSC, Canada).

National regulatory requirements and approaches regarding storm surge and tsunami impacts on NPPs were discussed in this session. Through the presentations, information on regulations, hazards assessment and protective measures against external events were shared among the member states. In many member states, the design basis level is based on annual exceedance frequencies (less than or equal to 10^{-4} per year) for natural events. In other member states design basis level is derived from a deterministic approach (i.e. probable maximum storm surge) and not associated with a probability.

In the aftermath of the Fukushima Daiichi NPP accident, the Nuclear Regulation Authority (NRA) developed a review guideline to specify the design basis tsunami and specify tsunami resistant design criteria. An important lesson learnt from the Fukushima Daiichi NPP accident was that the plant design bases need to be revised based on the results of latest scientific models that employ both conservative analysis methods and assumptions and also assess and characterise uncertainties.

The representative from the Korea Atomic Energy Research Institute (KAERI) reported on the tsunami probabilistic safety assessment (PSA) research that included hazard analysis, fragility analysis and system analysis. It was noted that numerical simulation results significantly underestimated the wave run-up height at each recurrence interval compared to the available historical data which then again contain significant uncertainties.

The representatives from the Canadian Nuclear Safety Commission (CNSC) and the Swiss Federal Nuclear Safety Inspectorate (ENSI) discussed the respective regulatory requirements for extreme weather and flood hazard assessments. CNSC reassessed their requirements and acceptance criteria after the Fukushima Daiichi NPP accident. ENSI requires that earthquakes, extreme winds, tornadoes, external flooding and aircraft crash are analysed and modelled in the PSA. Combinations of external hazards have also to be considered. As a result of ENSI's review of the hazard analyses, it was decided to define where applicable a maximal physical boundary (maximal possible load) for the NPP to be used as a basis for the proof of sufficient protection.

Case studies of impacts of hurricanes, typhoons and flooding events on NPPs, and the flooding event at Le Blayais NPP with follow-up activities for French NPPs were also discussed. It was noted that Hurricane Andrew was one of the most destructive hurricanes in U.S. history and the Turkey Point NPP was directly in its eye. The characteristics of the hurricane, the plant preparation and response as well as the lessons learnt in its aftermath were discussed. The reactor containment and other safety structures at the plant survived the hurricane without major damage, but destruction of non-safety structures resulted in collateral damage to important plant systems.

The "Le Blayais" flooding event took place in December 1999 and was caused by a combination of high tide and storm related high winds generating large (1-2 m) wind waves that exceeded the plant protection and resulted in flooding of buildings containing safety related systems, structures and components (SSCs). It was stated that one of the lessons learnt regarding the characterisation of flooding hazards was that all phenomena which may cause or play a role in flooding of the sites should be identified. As a result of the "Le Blayais" event, the flood protection at all French NPPs was reassessed and new regulatory guidelines were developed to ensure sufficient margins are maintained to account for the combined effects of different phenomena that can contribute to the hazard and uncertainties in the data and models used to determine necessary levels of protection. The specific approach of the Netherlands for the flood protection of the Borssele NPP site, which relies on the national dyke system, was presented. It was noted that a new assessment of the design basis flood for the Borssele NPP had been performed in the frame of the periodic safety review in 2013. The approach is based on PSA and takes into account some important aspects such as dyke failure, breach development, etc.

The representative of the NRA discussed the results of laboratory tests that had been performed to evaluate the influence of the tsunami pressure on the integrity of seawalls as well as to verify the capability of watertight doors against tsunami pressure. The data obtained from these tests are expected to be used for tsunami probabilistic risk assessments (PRA).

It was noted that often a variety of conditions are experienced during severe weather conditions. This creates the potential for damage to on-site infrastructure caused by a combination of such conditions. Differences between national approaches to mitigate the impact of severe weather and other external hazards include the use of on-site hardened facilities to store supplemental emergency equipment and the use of off-site locations, using distance as mitigation to the hazards and to minimise the occurrence of common cause failures.

The presentations and discussion highlighted a number of **commendable practices**. It was noted that experience of non-nuclear organisations can be used to enhance nuclear standards and guidelines. The data received from neighbouring countries can also be used to broaden information on severe weather and other phenomena. A number of presenters were making a concerted effort to characterise and propagate the uncertainties in the assessment of the external hazards so they can be considered in the regulatory decision-making process. New experiments and tests could support the improvement of mitigation measures as well as the verification of computational tools and analytical models.

2.2.1. Challenges and gaps identified:

- Many regulators require the licensee to demonstrate that the design basis is sufficient to ensure safety in case of rare natural external hazards with exceedance

frequencies in the order of 10⁻⁴ per year. An important question raised was how can regulators incorporate this information in their decision-making process given the large uncertainties associated with these estimates for many external hazards?

- There is a broad consensus that addressing the large uncertainties associated with rare events that are of high consequence is particularly challenging and is an important issue that needs to be addressed.
- Climate change is introducing new challenges into the decision-making process that will need to be considered. There will be a need to develop new approaches and models to identify and address these challenges.
- It was noted that there are no historical records that can be used to reliably determine limiting or bounding severe events that are of low return frequencies but with high consequences. The ability to determine such severe events considering physical limits associated to storms and tsunami was also questioned. This also raised the question on how to assess the uncertainties associated with the use of historical records and paleodata to assess potential events that should be considered in the design and operation of NPPs.

2.3. Session 2 – Severe weather assessment and societal impact (protecting people and infrastructure)

This session was devoted to the current research and approaches in severe weather assessment and the possible impact of severe weather on society.

The following papers were presented:

- United States Approach in Severe Weather Assessment, Impact Assessment and Existing Gaps, Dr Richard Knaab (National Hurricane Center, USA)
- Current Methods to Characterise Extreme Storm Surge for NPPS, Claire-Marie Duluc (IRSN, France)
- Current Research on Statistical Methods, Nicolas Roche (EDF, France)
- Current Research on Modelling of Storms and Storm Surges, Amélie Roche (CEREMA, France)
- Long-term Weather Predictions; Statistical and Modelling Approaches, Dr Henk (H.W.) van den Brink (Dutch Meteorological Institute, Netherlands)
- From Weather Assessment to Risk Assessment, Wouter ter Horst (HKV, Netherlands)
- Severe Weather Assessment, Impact Assessment and Existing Gaps, Alice Soares (*World Meteorological Organization*)

The presentations showed that a lot of research is ongoing with respect to severe weather assessment. Recently major steps have been made in the computation and visualisation of extreme weather events. Examples from different countries (e.g. France, the Netherlands and the United States) were presented. It is important to notice that a major part of this research is performed by meteorological institutes. Therefore strong co-operation between the nuclear and meteorological sector is regarded to be of great importance to assure that weather assessments are appropriately taken into account in nuclear facility

siting, design, and operation, as well as in reassessment and emergency planning. The World Meteorological Organization (WMO) is looking at developing a global storm surge model. Whereas the products of the WMO (such as the WMO-TN 170) were not known in much detail by the participants, it was noted that a stronger co-operation with this organisation is recommended.

The presentations and discussions led to a couple of **commendable practices**. It was noted that probabilistic risk assessments (or PSAs) can be used to determine vulnerabilities and possible improvements to nuclear installations. Further, recent developments in storm forecasting, modelling, and visualisation tools can be useful in decision making on a local scale in NPP siting and emergency response.

It was acknowledged that there is a challenge in determining the occurrence frequencies of severe weather events. Weather forecasting and modelling that is developed and used in the meteorological area are typically focused on the short term (days to perhaps weeks) and seasonal conditions. In the nuclear area, there is a need to understand the likelihood of severe weather conditions during the lifetime of the installations (tens of years). It should be noted that historical data are mostly limited to about the last 100 years – however, these data may be used for rare event frequency estimation. Extrapolating these data to calculate extremely low annual exceedance frequencies ($\sim 10^{-4}$ per year) for extreme events involves substantial uncertainties related to the likelihood of missing information. Gathering historical records and looking for other sources of information (e.g., anecdotal evidence from archives and geological records) to account for the uncertainty was seen as an important action that should continue. With respect to the extreme weather event assessment discussions on the use of forecasting and prediction statistical models and tools, it was recommended that consideration should be given to applying these tools by using them to assess maximum credible events based on historical information with additional margins to reflect bounding physical conditions that could be experienced. Insights would be useful from subject matter experts in identifying the maximum credible events that can occur.

The required level of detail of assessment and modelling of severe weather and storm surge was discussed. Detailed analysis at the site level requires a substantial amount of information. It was suggested that in those cases where there are large uncertainties with respect to the available information or within the model, it might not be practical to gather sufficient information to reduce the uncertainty. In these cases it might be more appropriate to add a conservative margin or make conservative assumptions to provide an assessment that supports decision making at the local level. It was also suggested that available information from regional data sources could be used in some instances to reduce the uncertainty of site-specific (local) assessments.

The role of extreme weather-related hazards assessment conducted by other organisations (for example, the National Hurricane Center) for use in decision making in nuclear industry needs to be explored further. For example, these weather-related hazard assessments may play a role in the decision making for the planning phase of event response and weather forecast may play a role in emergency response during an event.

2.3.1. Challenges and gaps identified:

- Determining an appropriate balance among the different elements of the models employed (statistical and physical) to evaluate extreme weather hazards (for example, it makes no sense to develop fine grade hydrodynamic models to resolve

a small uncertainty when there are much larger unresolved uncertainties elsewhere).

- Lack of historical data related to rare events resulting in large uncertainties in both statistical characterisation of these events and the validation of physical modelling of them. How should we interpret the frequency of occurrence of rare events for input to decision making given these uncertainties?
- Additional approaches should be explored to better use limited available data (i.e. regional, historical, paleo, etc.) for application in decision making.

2.4. Session 3 – Informing the nuclear regulatory process through gap analysis

This session consisted of three panel sessions which were devoted to the discussion of the following topics:

- Panel Session on tsunamis (Japan/Korea), Min Kyu Kim (KAERI), Kenta Hibino (NRA), Hideharu Sugino (NRA), Rapporteur - Zdenko Simic (JRC)
- Panel Session on Tropical Storms (United States), Joe Kanney (US NRC), Dr Richard Knaab (US NHC), Bruce McDowell (PNNL), Rapporteur – Stephen Hess (EPRI)
- Panel Session on Extra-Tropical Storms (France/Germany/Netherlands), Dr Vincent Rebour (IRSN), Dr Gernot Thuma (GRS), Wouter ter Horst (HKV), Rapporteur – Wouter VAN LONKHUYZEN (ANVS)

The purpose of this session was to summarise what could be learnt from the first two days of the workshop and how the nuclear regulatory process could be enhanced through gap analysis.

The most significant commendable practices, challenges and gaps identified during the discussions in the panel session on tsunami were the following:

- Knowledge of extreme tsunami conditions and SSC's response are needed as an input to fragility evaluation.
- All the possible sources of information should be considered for tsunami hazard characterisation and in determining the annual exceedance frequency.
- Minority expert opinions should be acknowledged and addressed appropriately.
- Deterministic and probabilistic methods should be used in a complementary manner to evaluate the impact of tsunamis on NPPs.
- The actual conditions at the plant (e.g. degraded equipment, SSCs, maintenance, etc.) should be considered in the evaluation of tsunami effects.

The most significant commendable practices, challenges and gaps identified during the discussions in the panel session on tropical storms were the following:

- The reliability and accuracy of forecasts needs to be understood to support decision making in emergency response.

- Two-way communication between the weather forecasters and the emergency management decision makers is essential for emergency preparedness and effective response.
- The implemented temporary protective measures should be robust and capable of mitigating the anticipated severe weather conditions.
- Integrated effects of correlated hazards (e.g. impact of wind hazard or debris during storm surge events) need to be considered in severe weather analysis.
- The workshop participants acknowledged a strong desire for co-operative research between the nuclear and meteorological communities for the modelling / prediction of severe weather.
- The effects of climate change on extreme weather events are an area that needs to be better understood.

The most significant commendable practices, challenges and gaps identified during the discussions in the panel session on extra-tropical storms were the following:

- In addition to measurement data, historical records, paleo-data and simulations may be a good source of information for assessing rare events. Nevertheless, integration of these data sources is challenging in the context of regulatory decision making.
- There is a challenge in understanding the relationship between physical limits based on empirical data and physical limits developed from theoretical considerations. However, approaches have been established for determining practical criteria to support regulatory decision making for rare events based on maximum credible events such as probable maximum storm surge (PMSS).
- Challenges were identified during the workshop with respect to communication of regulatory decision making related to rare events, such as:
 - contrasting results from different approaches e.g. maximum credible events and statistical methods;
 - communication and collaboration among different governmental agencies.

2.5. Workshop closing session

During the workshop closing session, the participants noted several key points:

- Sharing of information regarding regulations, hazard assessment approaches and protective measures is an important element to successfully understanding the impact of external hazards on nuclear facilities.
 - The sharing of information needs to cross the boundary between the nuclear industry and other organisations that collect and analyse data on external hazards for use in assessing the impact of severe weather on society and its supporting infrastructure. This includes reaching out to organisations responsible for modelling and predicting weather (i.e. national weather services, universities, etc.) and international organisations, such as the World Meteorological Organization to facilitate a more integrated national and international response to severe weather conditions or other natural disasters.

- Given the limited amount of available historical data, further work needs to be done to understand how metrics, such as a selected value for annual exceedance frequency, can be used in regulatory decision making, and clearly communicated to the public.
- It is necessary to augment temporally and spatially sparse historical data with simulations and other information to be able to make decisions associated with rare events.
 - Within this context, how historical and paleodata can be used to understand historical weather conditions in regulatory decision making needs to be improved.
- Probabilistic safety assessment provides an important input for a traceable and reproducible risk-informed regulatory decision-making process, but as highlighted in recent work done by the Working Group on Risk Assessment (WGRISK; e.g. NEA/CSNI/R(2014)9), challenges remain for areas such as fragility analysis for non-seismic hazards, including severe weather and storm surge as discussed during this workshop.
 - Within this context, research related to severe weather phenomena being conducted by universities, regulators, the nuclear power industry, and other organisations should be shared to the extent practical to develop a common data set for use in assessing the impact to the public from severe weather events.

The insights gained during the workshop with engaging discussions among participants have a direct connection to the objectives of regulators that include review of nuclear facility siting, SSC design, licensing decisions and oversight activities. In many countries, deterministic methods such as the stylised, probable maximum events approach are currently used in nuclear facility siting, licensing and regulatory oversight decisions. In other countries, statistical methods are usually used to assess events with annual exceedance frequencies less or equal to 10^{-4} per year. To support the application of risk-informed decision making, research needs to continue to understand the impact of external hazards on nuclear facilities, by, for example: establishing guidelines for probabilistic flood hazard assessments (PFHAs); leveraging data collected and maintained on severe weather and storm surge from organisations outside the nuclear industry; applying modelling and analysis techniques used by organisations inside and outside the nuclear industry that assess the impact of severe weather on local and regional infrastructure; and establishing criteria related to severe weather and coastal flooding (external events) that are based on sound scientific principles with supporting data and analytical techniques for use in risk-informed regulatory decisions. Co-ordination of the work of the Working Group on External Events (WGEV) with other NEA working groups, primarily with WGRISK, is important for understanding how better data and a better understanding of the phenomena associated with external events can be used to better understand the risk to public health and safety from nuclear facilities. Building on the results of this research will support the balance needed in risk-informed decision making between the use of deterministic data and methods and the application of probabilistic methods to extend the applicability of the data for use in PSAs.

3. Conclusions and recommendations

The following conclusions and recommendations are made based on workshop presentations, discussions during particular technical sessions and facilitated discussions:

- Sharing of information between the nuclear industry and non-nuclear organisations regarding regulations, hazard assessment approaches and protective measures is an important element to successfully understanding the impact of external hazards on nuclear facilities. The data received from neighbouring countries can also be used to broaden information on severe weather and other phenomena.
- Given the limited amount of available historical data, further work needs to be done to understand how metrics, such as a selected value for annual exceedance frequency, can be used in regulatory decision making and clearly communicated to the public. It is necessary to augment temporally and spatially sparse historical data with simulations and other information in order to be able to make decisions associated with rare events. Simulation and modelling should be validated with consideration of available empirical data.
- In the treatment of uncertainty, there are two aspects that are important to address. From a scientific perspective, there are uncertainties with data and modelling that need to be better understood and quantified. From a regulatory perspective, decision makers should be aware of the uncertainties in the scientific results and take them appropriately into account in their decision-making process.
- Co-ordination of the work of the Working Group on External Events (WGEV) with other NEA working groups, primarily with the Working Group on Risk Assessment (WGRISK), is important to understand how better data and a better understanding of the phenomena associated with external events can be used to better assess the risk to public health and safety from nuclear facilities. Building on the results of this research will support the balance needed in risk-informed decision making between the use of deterministic and probabilistic methods.
- Climate change is introducing new challenges into the decision-making process that will need to be considered. There will be a need to develop new approaches and models to identify and address these challenges.

*APPENDIX 1: List of participants***BELGIUM**

Mr Joris BLANCKAERT	Belgium	International Marine and Dredging Consultants (IMDC)
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CANADA

Dr Shi Zhong LEI	Canada	Canadian Nuclear Safety Commission
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FRANCE

Mr Marc ANDREWSKY	France	Électricité de France (EDF)
Dr Ekaterina ANTOSHCHENKOVA	France	Institut de Radioprotection et de Sûreté Nucléaire (IRSN)
Mr Amine BEN DAOUED	France	Institut de Radioprotection et de Sûreté Nucléaire (IRSN)
Ms Nathalie BERTRAND	France	Institut de Radioprotection et de Sûreté Nucléaire (IRSN)
Ms Claire-Marie DULUC	France	Institut de Radioprotection et de Sûreté Nucléaire (IRSN)
Mr Yasser HAMDI	France	Institut de Radioprotection et de Sûreté Nucléaire (IRSN)
Mr Erik LECLERC	France	Institut de Radioprotection et de Sûreté Nucléaire (IRSN)
Ms Veronique LHOMME	France	Institut de Radioprotection et de Sûreté Nucléaire (IRSN)
Dr Vincent REBOUR	France	Institut de Radioprotection et de Sûreté Nucléaire (IRSN)
Ms Amélie ROCHE	France	CEREMA
Mr Nicolas ROCHE	France	Électricité de France (EDF)

GERMANY

Dr Gernot THUMA	Germany	Gesellschaft für Anlagen- und Reaktorsicherheit mbH (GRS)
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JAPAN

Mr Kenta HIBINO	Japan	Nuclear Regulation Authority (NRA)
Mr Toru IJIMA	Japan	Nuclear Regulation Authority (NRA)
Mr Hideharu SUGINO	Japan	Nuclear Regulation Authority (NRA)

KOREA

Dr Min Kyu KIM	Korea	Korea Atomic Energy Research Institute (KAERI)
Mr Kwanhee LEE	Korea	Korea Institute of Nuclear Safety (KINS)

NETHERLANDS

Mr Philip SOMERS	Netherlands	NV EPZ
Mr Hans TE LINTELO	Netherlands	NV EPZ
Mr Wouter TER HORST	Netherlands	HKV
Dr Henk VAN DEN BRINK	Netherlands	KNMI
Mr Wouter VAN LONKHUYZEN	Netherlands	ANVS

SWEDEN

Mr Lars BENNEMO	Sweden	Swedish Radiation Safety Authority (SSM)
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SWITZERLAND

Mr Roland BEUTLER	Switzerland	Swiss Federal Nuclear Safety Inspectorate (ENSI)
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UNITED STATES OF AMERICA

Mr John NAKOSKI	USA	United States Nuclear Regulatory Commission (US NRC)
Dr Joseph KANNEY	USA	United States Nuclear Regulatory Commission (US NRC)
Dr Richard KNABB	USA	National Hurricane Center (NOAA)
Mr Pierre MACHERET	USA	JENSEN HUGHES
Mr Leo SHANLEY	USA	JENSEN HUGHES
Mr Bruce MCDOWELL	USA	Pacific Northwest National Laboratory (PNNL)

Dr Rajiv PRASAD	USA	Pacific Northwest National Laboratory (PNNL)
Dr Jeffrey A. MELBY	USA	US Army Corps of Engineers
Dr Norberto C. NADAL-CARABALLO	USA	US Army Corps of Engineers
Dr Curtis L. SMITH	USA	Idaho National Laboratory (INL)
Prof. Stephen M. HESS	USA	Electric Power Research Institute

INTERNATIONAL ORGANISATIONS

European Commission

Dr Zdenko SIMIC	Joint Research Centre (JRC)
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WMO

Ms Alice SOARES	World Meteorological Organization
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NEA

Dr Victor NERETIN	Nuclear Energy Agency
Mr Ho NIEH	Nuclear Energy Agency
Mr Andrew WHITE	Nuclear Energy Agency

APPENDIX 2: Workshop programme

WEDNESDAY, 24 FEBRUARY 2016

8:30-9:00 Registration of the participants

9:00-9:30 **OPENING SESSION**

Session chaired by *Mr John A. NAKOSKI – Workshop Chair (US NRC, USA)*

09:00 **NEA WELCOME AND REMARKS**
Ho Nieh, Head of Nuclear Safety Technology and Regulation Division (NEA)

09:10 **WELCOME AND WORKSHOP BACKGROUND, OBJECTIVES, SCOPE, GOALS**
John Nakoski, Chief, Performance and Reliability Branch, Office of Nuclear Regulatory Research (US NRC)

09:20 **WORKSHOP ORGANISATION & LOGISTICS**
NEA Secretariat

Session 1 REGULATORY OBJECTIVES AND APPROACHES TO ACCOMPLISH OBJECTIVES

9:30 – 18:00 Session chaired by *Mr Toru IIJIMA (NRA, Japan)*

9:30 – 10:30 **REGULATORY REQUIREMENTS AND RESEARCH FOR TSUNAMI IN JAPAN**

THE REGULATORY REQUIREMENTS FOR TSUNAMI
Hideharu Sugino (*NRA, Japan*)

CURRENT RESEARCH ON TSUNAMI PROTECTION
Toru Iijima (*NRA, Japan*)

10:30 – 11:00 *Coffee Break*

11:00 – 12:00 **INSIGHTS ON THE KOREAN REGULATORY OBJECTIVES IN ASSESSING SEVERE WEATHER AND STORM SURGE (RESEARCH STATUS OF TSUNAMI PSA)**

CASE STUDY OF STORM SURGE AND HIGH WIND BY TYPHOONS
Kwanhee Lee (*KINS, Korea*)

RESEARCH STATUS OF TSUNAMI PSA
Min Kyu Kim (*KAERI, Korea*)

12:00 *Lunch Break*

Session 1 REGULATORY OBJECTIVES AND APPROACHES TO ACCOMPLISH OBJECTIVES (cont'd)

13:00 – 14:00 **NRC OBJECTIVES IN ASSESSING SEVERE WEATHER AND STORM SURGE**

A LICENSING CASE STUDY ON THE EFFECTS OF HURRICANE ANDREW ON TURKEY POINT NUCLEAR POWER PLANT (UNITS 3 AND 4)
Bruce McDowell and Rajiv Prasad (*PNNL, USA*)

ITS SOCIETAL INFRASTRUCTURE SUPPORT, AND THE OPERATIONAL AND REGULATORY LESSONS LEARNED FROM THIS EVENT
Bruce McDowell and Rajiv Prasad (*PNNL, USA*)

14:00 – 14:30 **THE REGULATORY REQUIREMENT TO SEVERE WEATHER IN SWITZERLAND**
Roland Beutler (*ENSI, Switzerland*)

14:30 – 15:00 *Coffee Break*

15:00 – 15:30 **LE BLAYAIS FLOODING EVENT AND FOLLOW-UP ACTIVITIES FOR FRENCH NPPS (REASSESSMENT, GUIDELINE REVISION)**
Dr Vincent Rebour (*IRSN, France*)

15:30 – 16:30 **THE CASE STUDY ON FLOODING ASSESSMENT TO IDENTIFY AND DISCUSS CHALLENGES FOR THE SAFETY OF NPP IN NETHERLANDS**
Hans te Lintelo and Philip Somers (*EPZ, Netherlands*)

16:30 – 17:00 **CNSC'S REGULATORY APPROACHES TO EXTREME WEATHER AND FLOOD HAZARD ASSESSMENT**
Dr Shi Zhong Lei (*CNSC, Canada*)

17:00 – 18:00 **PANEL SESSION 1**

Open discussion from the floor with all the presenters in the Session 1

THURSDAY, 25 FEBRUARY 2016

Session 2 SEVERE WEATHER ASSESSMENT & SOCIETAL IMPACT (PROTECTING PEOPLE AND INFRASTRUCTURE)

9:00-15:30 Chaired by *Dr Vincent REBOUR (IRSN, France)*

9:00 – 10:00 **US APPROACH IN SEVERE WEATHER ASSESSMENT, IMPACT ASSESSMENT AND EXISTING GAPS**

Dr Richard Knaab (*National Hurricane Center, USA*)

10:00 – 11:00 **FRENCH APPROACH IN SEVERE WEATHER ASSESSMENT, IMPACT ASSESSMENT AND EXISTING GAPS**

CURRENT METHODS TO CHARACTERIZE EXTREME STORM SURGE FOR NPPs

Claire-Marie Duluc (*IRSN, France*)

CURRENT RESEARCH ON STATISTICAL METHODS

Nicolas Roche (*EDF, France*)

CURRENT RESEARCH ON MODELLING OF STORMS AND STORM SURGES

Amélie Roche (*CEREMA, France*)

11:00 – 11:30 *Coffee Break*

11:30 – 14:30 **NETHERLANDS APPROACH IN SEVERE WEATHER ASSESSMENT, IMPACT ASSESSMENT AND EXISTING GAPS**

LONG-TERM WEATHER PREDICTIONS; STATISTICAL AND MODELLING APPROACHES

dr. Henk (H.W.) van den Brink (*Dutch Meteorological Institute, Netherlands*)

12:30 *Lunch Break*

FROM WEATHER ASSESSMENT TO RISK ASSESSMENT

Wouter ter Horst (*HKV, Netherlands*)

14:30 – 15:30 **SEVERE WEATHER ASSESSMENT, IMPACT ASSESSMENT AND EXISTING GAPS**

Alice Soares (*World Meteorological Organization*)

15:30 – 16:00 *Coffee Break*

16:00 – 17:00 **PANEL SESSION 2**

Open discussion from the floor with all the presenters in the Session 2

Session 3 INFORMING THE NUCLEAR REGULATORY PROCESS THROUGH GAP ANALYSIS

17:00-18:30 Chaired by *Mr John A. NAKOSKI (NRC, USA)*

17:00-18:30 **PANEL SESSION ON TSUNAMIS (JAPAN / KOREA)**
 Min Kyu Kim (*KAERI*), Kenta Hibino (*NRA*), Hideharu Sugino (*NRA*), Rapporteur - Zdenko Simic (*JRC*)

FRIDAY, 26 FEBRUARY 2016

Session 3 INFORMING THE NUCLEAR REGULATORY PROCESS THROUGH GAP ANALYSIS (contd.)

9:00-10:30 **PANEL SESSION ON TROPICAL STORMS (USA)**
 Joe Kanney (*US NRC*), Dr Richard Knaab (*US NHC*), Bruce McDowell (*PNNL*), Rapporteur - Stephen Hess (*EPRI*)

10:30 – 11:00 *Coffee Break*

11:00-12:30 **PANEL SESSION ON EXTRA-TROPICAL STORMS (FRANCE / NETHERLANDS)**
 Dr Vincent Rebour (*IRSN*), Dr Gernot Thuma (*GRS*), Wouter ter Horst (*HKV*), Rapporteur - Wouter van Lonkhuyzen (*ANVS*)

12:30 *Lunch Break*

13:30 – 14:30 **PANEL SESSION 3**
 Open discussion from the floor with all the presenters in the Session 3

14:30 – 15:00 *Coffee Break*

15:00-16:00 CLOSING SESSION PANEL

Session chaired by *Mr John A. NAKOSKI (NRC, USA) – Workshop Chair (IRSN, France)* and panel members *Mr Toru IJIMA (NRA, Japan), Joe Kanney (US NRC) and Dr Vincent REBOUR (IRSN, France)*

FINDINGS AND CONCLUSIONS
RECOMMENDATIONS FOR FURTHER WORK

16:00 **CLOSING REMARKS – Mr John A. NAKOSKI, Workshop Chair (US NRC, USA)**