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Riverine Flooding: Hazard Assessment and Protection of Nuclear Installations

Workshop Proceedings
21-23 March 2018
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COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

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The mission of the NEA is:

– to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally sound and economical use of nuclear energy for peaceful purposes;

– to provide authoritative assessments and to forge common understandings on key issues as input to government decisions on nuclear energy policy and to broader OECD analyses in areas such as energy and the sustainable development of low-carbon economies.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management and decommissioning, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

The Committee on the Safety of Nuclear Installations (CSNI) is responsible for the Nuclear Energy Agency (NEA) programmes and activities that support maintaining and advancing the scientific and technical knowledge base of the safety of nuclear installations.

The Committee constitutes a forum for the exchange of technical information and for collaboration between organisations, which can contribute, from their respective backgrounds in research, development and engineering, to its activities. It has regard to the exchange of information between member countries and safety R&D programmes of various sizes in order to keep all member countries involved in and abreast of developments in technical safety matters.

The Committee reviews the state of knowledge on important topics of nuclear safety science and techniques and of safety assessments, and ensures that operating experience is appropriately accounted for in its activities. It initiates and conducts programmes identified by these reviews and assessments in order to confirm safety, overcome discrepancies, develop improvements and reach consensus on technical issues of common interest. It promotes the co-ordination of work in different member countries that serve to maintain and enhance competence in nuclear safety matters, including the establishment of joint undertakings (e.g. joint research and data projects), and assists in the feedback of the results to participating organisations. The Committee ensures that valuable end-products of the technical reviews and analyses are provided to members in a timely manner, and made publicly available when appropriate, to support broader nuclear safety.

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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The members of the Nuclear Energy Agency (NEA) Working Group on External Events (WGEV) wish to acknowledge the significant contributions of those individuals who had a key role in the preparation of the "Technical Note on Riverine Flooding: Hazard Assessment and Protection of Nuclear Installations" (NEA, 2018[1]), and those who had a leadership role in the conduct and success of the NEA International Workshop "Riverine Flooding: Hazard Assessment and Protection of Nuclear Installations". Additional thanks are extended to Abir Maalouf, NEA Assistant, in support of the workshop and the preparation of these proceedings.

Preparation of the WGEV technical note on riverine flooding

Gernot Thuma	Gesellschaft für Anlagen- und Reaktorsicherheit gGmbH (GRS), Germany
Shi Zhong Lei	Canadian Nuclear Safety Commission (CNSC), Canada
Roland Beutler	Swiss Federal Nuclear Safety Inspectorate (ENSI), Switzerland
Vincent Rebour	Radiological Protection and Nuclear Safety Institute (IRSN), France
Wouter van Lonkhuyzen	Authority for Nuclear Safety and Radiation Protection (ANVS), Netherlands
John A. Nakoski	Nuclear Regulatory Commission (NRC), United States
Curtis Smith	Idaho National Laboratory (INL), United States
Victor Neretin	Nuclear Energy Agency (NEA)

Presenters and panel members at the workshop

Gernot Thuma	GRS, Germany - Workshop and Closing Session Chair
John A. Nakoski	NRC, United States – Session 1 Chair
Vincent Rebour	IRSN, France – Session 2 Chair
Dries Gryffroy	Bel V (Belgian institute of nuclear expertise), Belgium – Session 3 Chair
Joey Zhaoliang Wang	CNSC, Canada
John Perdikaris	Ontario Power Generation, Canada
Zdenko Simic	Joint Research Centre-Petten, European Commission
Claire-Marie Duluc	IRSN, France
Denis Jautzy	Electricité de France (EDF), France
Sylvain Saviot	EDF, France
Christian Strack	GRS, Germany
Saskia van Vuren	Rijkswaterstaat, Netherlands
Rainer Hausherr	ENSI, Switzerland

[1] Document available online at: www.oecd-nea.org/nsd/workshops/wgev2018/docs/wgev_technical_note.pdf.

Vinh Dang	Paul Scherrer Institute, Switzerland
Carlo Scapozza	Federal Office for the Environment, Switzerland
Christopher Cook	NRC, United States
Roger Kay	US Army Corps of Engineers, United States
Michelle Bensi	University of Maryland, United States
Yoshimitsu Fukushima	International Atomic Energy Agency
Yuri Simonov	World Meteorological Organization

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List of abbreviations and acronyms

AEP	Annual exceedance probability
ANVS	Autoriteit Nucleaire Veiligheid en Stralingsbescherming (Authority for Nuclear Safety and Radiation Protection, Netherlands)
ASN	Autorité de Sûreté Nucléaire (Nuclear Safety Authority, France)
AUM	Additional ultimate means
BDBF	Beyond design basis flood
Bel V	Institut belge d'expertise nucléaire (Belgian institute of nuclear expertise)
CGB	Crue de grand bassin versant (large watershed flooding)
CNSC	Canadian Nuclear Safety Commission
CSNI	Committee on the Safety of Nuclear Installations (NEA)
DBF	Design basis flood
DEC	Design extension conditions
EDF	Électricité de France
EESS-EBP	External Events Safety Section-Extrabudgetary Programme (IAEA)
ENSI	Swiss Federal Nuclear Safety Inspectorate
GRS	Gesellschaft für Anlagen- und Reaktorsicherheit gGmbH (Germany)
HEC	Hydrologic Engineering Center (US Army Corps of Engineers)
IAEA	International Atomic Energy Agency
IRS	International Reporting System
IRSN	Radiological Protection and Nuclear Safety Institute (France)
JRC	Joint Research Centre (European Commission)
LIP	Local intense precipitation
NEA	Nuclear Energy Agency
NI	Nuclear installation
NPP	Nuclear power plant
NRC	Nuclear Regulation Commission (United States)
NUREG	NRC Technical Report Designation
OECD	Organisation for Economic Co-operation and Development
OPG	Ontario Power Generation (Canada)
PFHA	Probabilistic flood hazard assessment
PMF	Probable maximum flood
PMP	Probable maximum precipitation
PRA	Probabilistic risk assessments
PSA	Probabilistic safety assessment

PSR	Periodic safety review
RFS	Reference flooding situation
ROR	Rupture d'ouvrage de retenue (failure of water-retaining structure)
RWS	Rijkswaterstaat (Directorate-General for Public Works and Water Management of the Netherlands)
SSC	Systems, structures and components
TGNEV	Task Group on Natural External Events (NEA/CSNI)
WGEV	Working Group on External Events (NEA/CSNI)
WGRISK	Working Group on Risk Assessment (NEA/CSNI)
WMO	World Meteorological Organization
XFPRA	External Flood Probabilistic Risk Assessment

Executive summary

The March 2011 accident at the Fukushima Daiichi nuclear power plant (NPP) triggered discussions about natural external events that are low frequency but high consequence. In order to address these issues and determine which events would benefit most from international co-operative work, the Nuclear Energy Agency (NEA) established the Task Group on Natural External Events (TGNEV) under the Committee on the Safety of Nuclear Installations (CSNI). The CSNI then decided in 2014 to reorganise the TGNEV, which became the Working Group on External Events (WGEV) and would have the objective of improving understanding and treatment of external hazards that would support the continued safety performance of nuclear installations, as well as of improving the effectiveness of regulatory practices in NEA member countries. The WGEV is composed of a forum of experts who exchange information and experience on external events in their respective member countries, thereby promoting co-operation and maintenance of an effective and efficient network of experts.

The WGEV "Riverine Flooding – Hazard Assessment and Protection of NPPs" task was designed to share regulatory practices and technical approaches for riverine flood hazard assessment (both deterministic and probabilistic) and for flood protection of NPPs. The first activity involved in this task was to survey CSNI members so that they could share information on such regulatory practices and technical approaches. The results of this survey are available in the "Technical Note on Riverine Flooding: Hazard Assessment and Protection of Nuclear Installations" (NEA, 2018). Following an initial assessment of the survey results, an international workshop was organised to involve relevant experts in identifying the activities required to address knowledge gaps. In this context, the international workshop on "Riverine Flooding: Hazard Assessment and Protection of Nuclear Installations" focused on current national regulatory approaches and operating experience, technical methods for the assessment of riverine flooding events, protection of nuclear installations against river floods and promotion of the effectiveness of preventative measures.

The workshop was held at the Organisation for Economic Co-operation and Development (OECD) Conference Centre on 21-23 March 2018, with 37 participants representing regulators and their technical support organisations, industry, universities and government organisations from 9 countries, as well as representatives from international organisations. A total of 20 technical presentations were given in 3 sessions. All workshop presentations are available for download on the NEA website.

At the end of each technical session, a panel session was held allowing more detailed discussions on the presentations in that session, with a general discussion session concluding the workshop. During these discussions, participants expressed a strong interest to continue such efforts after the NEA international workshop.

Some of the issues that were highlighted by the participants include:

- Bridging the gap between hydrologists dealing with the science-based aspects of flooding and decision making in a regulatory framework is a challenge.
- Correct and reliable weather forecasts in relation to flooding are needed.
- While the use of historic information, paleodata and simulations can supplement instrumental data, it is difficult to incorporate them into the existing hazard assessment framework. Treating uncertainties can also be very challenging.
- When assessing the impact on a facility, it may be necessary to consider other factors (associated affects) in addition to the maximum probable flood level.
- A more rigorous understanding of the fragility of facilities is needed to strengthen the technical basis for establishing appropriate protective measures.
- Maintaining the public's trust in protective measures for critical infrastructures will require proactive approaches, and not only in terms of communication.
- The key challenges associated with probabilistic safety analysis (PSA) for NPPs and other nuclear installations are the nature of flooding hazards and plant impacts from flooding hazards.
- The main technical challenges of the probabilistic flood hazard assessment (PFHA) methodology are time-consuming calculations, characterisation of probability distributions for each input parameter and dealing with dependent input parameters.
- A balance is needed between the appropriate consideration of the spectrum of associated effects from flooding and the information necessary to support decision making for adequately protecting the facility from realistic external floods.
- The concept of a "dry site" needs to be reconsidered. Even sites that were designed with the "dry site" concept need to consider flooding effects.

Based on the results of the international workshop, the NEA proposes the following conclusions and recommendations:

- It is important to share information between the nuclear industry and non-nuclear organisations, as well as between neighbouring countries.
- It is necessary to augment temporally and spatially sparse historical data with simulations and other information. 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.
- Uncertainties with data and modelling need to be better understood and quantified and decision makers should be aware of the uncertainties in the scientific results and appropriately take them into account.
- Co-ordination of work between NEA working groups is a key factor.
- New approaches and models need to be developed to identify and address the challenges introduced by climate change.

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 flooding hazards and impacts to local, national and regional infrastructure. Additionally, co-operation among subject matter experts, including non-nuclear experts, will be key, as well as regional co-operation to share experience and data. The NEA will use insights gained from this workshop and the supporting survey, along with insights from other activities, to identify potential future work that will address the areas recommended for follow-up.

1. Introduction

1.1. Background

The Task Group on Natural External Events (TGNEV) was established by the Nuclear Energy Agency (NEA) Committee on the Safety of Nuclear Installations (CSNI) in 2013 so as 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 reorganise the TGNEV into a Working Group on External Events (WGEV) with the objective of improving understanding and treatment of external hazards that would support the continued safety performance of nuclear installations, and improving the effectiveness of regulatory practices in NEA member countries. The WGEV constitutes a forum of experts who exchange information and experience on external events in member countries, thereby promoting co-operation and maintaining an effective and efficient network of experts.

At its 58th meeting, the CSNI approved the recommended task on riverine flooding – hazard assessment and protection of nuclear power plants (NPPs) to be pursued by the WGEV. It was proposed that the first activity would be a survey of CSNI members to share regulatory practices and technical approaches for riverine flood hazard assessment (both deterministic and probabilistic) and flood protection of NPPs. The result of this survey is available as the "Technical Note on Riverine Flooding: Hazard Assessment and Protection of Nuclear Installations" (NEA, 2018). 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 achieve the aim of the working group, it was decided to convene an international workshop on "Riverine Flooding: Hazard Assessment and Protection of Nuclear Installations" at the OECD Conference Centre in Paris between 21 and 23 March 2018, where specialists from across the world could gather to exchange information and share their own country's or company's experiences on riverine flood hazard assessment and protection of nuclear installations against 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 and operating experience, technical methods for the assessment of riverine flooding events, protection of nuclear installations (NIs) against river floods and to promote the effectiveness of preventative measures. Key focus areas were:

- Regulatory requirements and operating experience with regard to riverine flooding.
- Technical methods for hazard assessment, identification of good practices and knowledge gaps.

- Protection of NIs against river floods and the effectiveness of preventative measures.

Information obtained as a result of this workshop should help to provide an understanding of key regulatory issues related to the characterisation and assessment of riverine flooding events, flood protection and the determination of activities to address knowledge gaps.

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 Approaches and Operating Experience
- Session 2: Technical Methods for Hazard Assessment
- Session 3: Protection of NIs Against River Floods
- 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, operating organisations, industry associations and observers from NEA member countries as well as a small number of experts from non-NEA member countries. Thirty-seven representatives from nine countries as well as the International Atomic Energy Agency (IAEA), the European Commission (EC) and the World Meteorological Organization representatives attended the workshop. The list of participants is provided in Appendix 1. A total of 20 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 NEA website.

1.4. Topics of the workshop

Items addressed in the workshop include:

- Regulatory considerations and guidance for flood hazard assessment and flood protection of NIs;
- Operating experience with flood protection measures;
- Riverine flood hazard assessment in member countries;
- Riverine flood hazard assessment based on probable maximum precipitation and probable maximum flood;
- Probabilistic flood hazard assessment for rivers and probabilistic risk assessments (PRA) standards;
- Data collection, and advances in modelling river floods and risk management;
- Protection of NIs against river floods in member countries.

2. Summary of the Workshop on Riverine Flooding: Hazard Assessment and Protection of Nuclear Installations

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 Nuclear Energy Agency (NEA) Committee on the Safety of Nuclear Installations (CSNI) actions. The contributions presented were devoted to discussions of international guidance for flood hazard assessment and flood protection at nuclear installation (NI) sites, national regulatory framework in assessing flood hazard and flood protection of NIs, case studies on flooding and hazard assessment, countries' approaches in riverine flood hazard assessment, statistical and probabilistic methods for riverine flood hazard assessment, data collection and advances in modelling river floods, advances in flood risk management, operating experience with flood protection measures.

2.1. Opening session

The workshop was opened by the Acting Head of the Nuclear Safety Division of the NEA, Mr Andrew White, who welcomed the participants, gave a brief overview of the recent Agency activities and wished a very productive and fruitful workshop. The workshop Chair, Dr Gernot Thuma (Gesellschaft für Anlagen- und Reaktorsicherheit gGmbH [GRS]), briefly discussed the background and objectives of the workshop. He stated that the objectives are to review and discuss current national regulatory approaches and operating experience, technical methods for the assessment of riverine flooding events, protection of NIs against river floods and to promote the effectiveness of preventative measures. He also mentioned the main priorities and challenges of this workshop such as understanding of key regulatory issues related to the characterisation and assessment of riverine flooding events, identification of knowledge gaps and research needs to address knowledge gaps by establishing a community and relationships to enhance the assessment of riverine flooding hazard and protection of NIs against river floods.

2.2. Session 1 – Regulatory approaches and operating experience

This session was devoted to the regulatory approaches and operating experience that many countries have implemented at the national level to strengthen the assessment of riverine flooding hazard and protection of NIs.

The following presentations were made:

- IAEA guidance for flood hazard assessment and flood protection at NI sites, Yoshimitsu Fukushima (IAEA);
- Regulatory considerations for flood hazard assessment and flood protection of NIs in the United States, Christopher Cook (NRC, United States);

- Regulatory requirements for flood hazard assessment and flood protection of NIs in France, Vincent Rebour (IRSN, France);
- Undertaking vulnerability assessments of critical water resources infrastructure, John Perdikaris (Ontario Power Generation, Canada);
- Operating experience at Fort Calhoun, Roger Kay (US Army Corps of Engineers, United States);
- Riverine flood hazard assessment in Germany, Christian Strack (GRS, Germany).

National regulatory requirements and approaches as well as international guidance regarding flood hazard assessment and protection of NIs against river floods were discussed in this session. Through the presentations, information on regulations, hazards assessment and protective measures against river floods were shared among the member states. In many member states, the design basis level is based on annual exceedance frequency (e.g. 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 precipitation (PMP) and probable maximum flood (PMF)) and not associated with a probability.

Mr Fukushima (IAEA) presented the IAEA guidance for flood hazard assessment and flood protection at NI sites. He informed that IAEA Safety Guide SSG-18 provides guidance to establish design basis parameters for meteorological and hydrological phenomena, measures for site protection and strategies for monitoring nuclear installations located on a coastal or a river site or an estuary site. It was noted that the results of probabilistic methods should be checked for consistency with the results of a simplified deterministic analysis and, in all cases (deterministic, statistical and probabilistic approach), quantitative estimate of the uncertainties should be determined. He stated that climate change adds further uncertainty to the meteorological and hydrological analyses and should be considered. Such approaches as paleoflood analysis of the site area should also be considered. He underlined that in deriving the design basis flood for an NI site, combined events should be considered as well as single events and the annual exceedance frequency for each combination should be estimated. The measures for site protection such as dry site concept and permanent external barriers were discussed. He said the EESS-EBP drafted the "Safety Report: Assessment of External Flooding (Excluding Tsunami) and High Wind Hazards in Site Evaluation for Nuclear Installations". 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 the latest scientific models that employ both conservative analysis methods and assumptions and also assess and characterise uncertainties.

The US NRC representatives discussed the regulatory considerations for flood hazard assessment and flood protection of NIs in the United States. Dr Cook informed on the post-Fukushima flood walkdowns undertaken to verify that procedures or activities can be executed as specified within the allocated time frame, and to understand cliff-edge effects. As a result, many licensees have enhanced procedures, practices and training programmes, and identified better locations to store flood protection equipment. It was noted that post-Fukushima hazard reevaluations showed that the majority of the exceedances was associated with the local intense precipitation hazard (LIP>85%), which was not part of the original design basis. He presented the update of NUREG-0800 Standard Review Plan related to hydrology and flooding hazards assessment. He also mentioned that flood inundation maps are the US government standard for communication of flood hazard information (warning time, inundation depth/duration, etc.), which should be shared with

NPPs, and he spoke of how the flood hazard analysis results could feed into the probabilistic risk assessment (PRA) models to derive the safety goals.

The representatives from IRSN discussed the regulatory requirements for flood hazard assessment and flood protection of NIs in France. Dr Rebour mentioned that a guide on protection of nuclear installations against external flooding was published in 2013 taking into account the «Le Blayais» flooding event (December 1999) and the «Fukushima» flooding accident. The definition of "Reference Flooding Situation" (RFS) was introduced in this guide as well as methods for the characterisation of the RFSs and principles for protection of NIs. According to this guide, it is needed to consider a set of 11 RFSs to define design basis floods (DBF). It recommends taking into account all situations likely to be encountered on the basis of relevant past experience (e.g. historical evidence) by applying statistical and deterministic methods. The general aim is to derive RFSs with frequency of exceedance of 10^{-4} per year and to cover associated uncertainties. The evolution of the hazard with time should be also considered. Regarding flood protection, he noted that measures requiring neither human intervention nor energy supplies should be preferred. It is also recommended to consider a beyond design basis flood/design extension conditions (BDBF/DEC) scenario as DBF scenario plus margin, which is specific to each flooding scenario. Lastly, he said the follow-up activities in the domain should include the development of probabilistic flood hazard assessment to support the current deterministic/statistical flood risk assessment.

Dr Perdikaris (Ontario Power Generation) discussed the vulnerability assessment of critical water resources infrastructure. He said that the assessment and ranking of the vulnerability of affected groups should serve as the starting point in defining priorities and means of remedial interventions He presented how OPG evaluates flood risk by looking at the watershed itself and then following a systematic assessment approach. He also spoke of looking at the population exposure to the flooding event and taking life safety into the flood risk assessment. He stated that climate change needs to be incorporated into the overall vulnerability index quantification method. In addition, given the level of uncertainty associated with climate change, several future climate scenarios need to be examined in order to quantify their risk and impact. The knowledge gaps and future research needs on this matter were also discussed.

The representatives from the US Army Corps of Engineers presented the operating experience related to 2011 Missouri river flood at Fort Calhoun NPP. Dr Kay noted that reservoir regulation during extreme events requires flexibility to be built into mainstream reservoir systems, as well as consideration of changing conditions on the ground and changing climate. He stated that unprecedented runoff occurred in the Missouri River Basin above Sioux City (Iowa) during May-July 2011, which was higher than the total annual runoff in 102 of 113 years in the period of record. It was mentioned that some local levees raised by farmers made the situation even worse at the NPP site. The nuclear reactor had been shut down and defueled in April 2011 for scheduled refuelling. The Fort Calhoun plant had taken a number of protective measures (e.g. makeshift barriers), which helped to keep the water away from safety related buildings.

The representative of the GRS discussed the regulatory requirements and methodology for riverine flood hazard assessment in Germany. Mr Strack informed that according to nuclear safety standard KTA 2207 at river sites the design basis water level is based on the flood runoff from the catchment basin of the river with an exceedance frequency of 10^{-4} per year. For the derivation of this design basis runoff, all relevant parameters (e.g. condition and characteristics of the drainage area and overflow/failure of dikes/embankments) have to be taken into account. He noted the assessment of flood runoffs is based on the statistical evaluation and extrapolation of gauge measurements. The peak runoff of the 10^{-2} per year flood event is derived from representative gauge measurements using standard statistical procedures. The peak runoff of the 10^{-4} per year flood event is extrapolated from the peak runoff of a flood event with an exceedance frequency of 10^{-2} per year by using the Pearson Type III probability distribution with a conservative skewness coefficient. Finally, the 10^{-4} per year flood runoff is converted to a design basis water level using a suitable hydraulic model (applying the information on the slope of water surface). It was underlined that the conservative approach described in KTA 2207 is not binding and other approaches may also be used.

The presentations and discussions highlighted a number of **commendable practices**. It was noted as a commendable practice that the design basis is based on an annual exceedance frequency less than or equal to 10^{-4} per year for riverine flooding. Associated effects, such as debris, hydrostatic pressure, which happen at lower than design basis flood levels, could impact the plant safety and they should be taken into account. The resilience of the facility against external flooding hazards needs to be demonstrated in a systematic way for the safety case. Reliable forecasting is far more important for plants that tend to use temporary measures for flood protection versus those using permanently installed measures. The operators of NIs should establish a strong relationship with forecasting organisations so that they can effectively implement their strategies to protect their facility from flood events.

Challenges and gaps identified:

- There seems to be a gap between hydrologists dealing with the science-based phenomenon of flooding and decision making in a risk-informed regulatory framework. Bridging this gap is a challenge.
- Data extrapolation for low probability flooding events is a commendable practice, but it is challenging to do.
- Weather forecast data related to flooding (LIP, etc.) should be correct and reliable, which is a challenge.

2.3. Session 2 – Technical methods for hazard assessment

This session was devoted to the technical methods in modelling river floods and hazard assessment.

The following presentations were made:

- Riverine flood hazard assessment based on Probable Maximum Precipitation and Probable Maximum Flood, Yuri Simonov (WMO expert, Hydro-meteorological Research Centre of Russia);
- PMP and PMF under a changing climate, John Perdikaris (Ontario Power Generation, Canada);
- Probabilistic flood hazard assessment for rivers and updates on the PRA standard, Michelle Bensi (University of Maryland, United States);
- Global sensitivity analyses applied to hydraulic modelling, Claire-Marie Duluc (IRSN, France);

- Illustrative example - nuclear plant along the Rhône River, Sylvain Saviot (EDF, France);
- Riverine flood hazard assessment in Switzerland, Carlo Scapozza (Federal Office for the Environment) and Vinh Dang (Paul Scherrer Institute, Switzerland);
- Data collection, and advances in modelling river floods, Roger Kay (US Army Corps of Engineers, United States).

Dr Simonov, the expert of the World Meteorological Organization (WMO), provided the presentation on riverine flood hazard assessment based on probable maximum precipitation (PMP) and probable maximum flood (PMF). He noted that there are two groups of methods for deriving design flood parameters: probabilistic approach (flood frequency analysis) and deterministic approach (estimation of the so-called PMP and PMF). He stated that methods of statistical extreme analysis are widely used in hydrology and considered appropriate for return periods of up to 10^3 or 10^4 years. He said that PMP/PMF events are considered to be at least two orders of magnitude greater (10^4 to 10^6 years) and they cannot be considered as having a specific return period. He gave the definitions of PMP and PMF, and discussed the considerations, methods/models currently used for PMP/PMF estimation, data requirements and some other issues (maximisation, transposition, enveloping, accuracy, plausibility etc.). It was underlined that close co-operation of meteorological and hydrological specialist is needed in this area. He also mentioned that factors of climate change need to be considered in PMP/PMF estimation. Lastly, he said that some examples of PMP/PMF estimates for different climate/orographic conditions are given in the "Manual on estimation of Probable Maximum Precipitation" (WMO-No. 1045), 2009.

Dr Perdikaris (Ontario Power Generation) discussed the PMP and PMF under a changing climate. He presented the history of PMP development, approaches to PMP estimation and noted that there is no universally accepted methodology for deriving the annual exceedance probability (AEP) for the PMP. He mentioned the statistical approach to evaluating extreme precipitation events as well as its advantages and disadvantages. Methods for estimating PMP and steps of the most commonly used PMP estimate such as moisture maximisation have been discussed. He noted the accuracy of PMP/PMF estimation rests on the quantity and quality of data on extraordinary storms and floods and the depth of analysis and study. There are no methods to quantitatively assess the accuracy of PMP and PMF, and it is most important to analyse, compare and harmonise results of PMP/PMF from multiple perspectives. He also discussed the development of the PMF hydrograph and incorporation of climate change for determining PMF, which was illustrated on case study of Canadian basins. It was noted there is no big change (±5%) in PMP/PMF in Ontario region with climate change between two different time periods (1971 to 2000 and 2041 to 2070). Lastly, he shared his opinion on existing knowledge gaps and future research needs in the areas of uncertainty in climate change projection, a systematic approach to risk management, and proactively maintaining public trust.

Dr Bensi (University of Maryland) discussed the probabilistic flood hazard assessment for rivers and provided updates on the US PRA standard. She informed that ASME/ANS RA-S standard (Part 8 addresses external flooding) describes the technical elements required for performing a PRA (Level I, At-power) in support of nuclear plant safety and risk-informed applications. She said that significant effort being undertaken to revise the current version of Part 8 (XFPRA) of the ASME/ANS RA-S standard with the aim to reflect recent lessons learnt and identified flood-specific challenges. It was noted that key challenges associated with XFPRA for NPPs are the nature of flooding hazards (diverse flooding hazards and diverse characteristics of flooding events) and plant impacts from flooding hazards (diverse ways in which they may affect a plant, and diverse strategies to protect against or mitigate). She stated that the revision of Part 8 of the standard is performed using many non-prescriptive requirements, providing significant flexibility in addressing requirements and developing extensive non-mandatory appendices with commentary, clarifications, and insights. She discussed the key technical elements of revising Part 8 of ASME/ANS RA-S such as hazard analysis, fragility and plant response.

Mr Saviot from EDF presented an illustrative example of applying the ASN guide n°13 for riverine flood hazard assessment of NPP site along the Rhône River. He noted that according to the guide n°13, two «Reference Flood Situation» (RFS) should in particular be considered in flood hazard assessment for sites at the Rhône River: large watershed flooding (CGB) and failure of a water-retaining structure (ROR). He discussed the examples of flood hazard assessment for failure of the Vouglans dam with a height more than 100 m (ROR case) and a 1 000-year return period flood (taking the upper bound of the 70% confidence interval) plus 15% increase (CGB case). It was mentioned that TELEMAC-MASCARET system was used for numerical modelling of a hydraulic structure (hydraulic dam, waterways, hydroelectric power station). The numerical results of the base case and the most unfavourable case were presented.

Ms Duluc form IRSN presented the global sensitivity analyses applied to hydraulic modelling. She noted the objective of this activity was to develop a rigorous and objective methodology to define the most influencing parameters for hydraulic modelling with the associated uncertainties. She discussed the main steps of an uncertainty propagation study and the role of IRSN's computational environment PROMETHEE in a global sensitivity analysis. The application of this methodology to hydraulic studies were presented for a 1D hydraulic model of the Rhône River; a 2D hydraulic model for flooding and levee breach studies on La Garonne river; and 2D hydraulic model for the study of tsunamigenic potential of the Azores-Gibraltar Fracture Zone (AGFZ). It was mentioned that global sensitivity analysis allows identifying the most influencing parameters in a rigorous way as well as some rare combinations of critical flooding situation, which would not have been identified solely based on expert opinion. She also noted the main challenges of this methodology such as time-consuming calculations, characterisation of probability distributions for each input parameter and dealing with dependent input parameters.

Mr Scapozza from the Federal Office for the Environment provided an overview of flood protection measures used in Switzerland as well as lessons learnt from extreme events and climate changes. He informed that average damages from flood amount to CHF 350 million per year and investments in flood protection is approximately 1/3 of all public investments. He mentioned the climate in Switzerland is warming and therefore extreme events will occur more often. He discussed the project EXAR whose goals are to establish a common base for the risk and damage potential of extreme flooding events along the Aare and Rhine River, based on existing studies, and to derive hazard scenarios for events of different probability levels, especially for extremely rare events (down to annual exceedance frequency of 10^{-7} per year). He gave an example of modelling the catchment area of the Aare River and expected results of peak runoff on observation-area. Mr Dang (Paul Scherrer Institute) provided more details on the project EXAR. He briefly described the PFHA methodology, decomposition into subsystems, meteorological and weather scenarios, hydraulics, structures and natural processes as well as flood scenario event tree modelling and synthesis. Lastly, he noted the challenges of this project including selection of representative hydrographs, verification and plausibility of hydrographs and their frequencies, identification of key sites (whose behaviour have an impact on total system), and uncertainty and sensitivity analysis in multi-level analysis.

Dr Kay (US Army Corps of Engineers) discussed the data collection and advances in modelling river floods. He noted that data by itself is facts and statistics collected together for reference or analysis, but when put in certain context becomes information useful for decision making. He said the long-term monitoring of hydrologic systems (precipitation, streamflow etc.) is essential for understanding system behaviour and is a basis for predictive modelling and thus risk management. Data gathering need to be pooled, quality-controlled and archived, and archives then need to be maintained, updated and should ideally be made accessible to everyone. It may well be one of the greatest future challenges to decide who pays for the costs of ensuring longevity and continuity of data gathering, monitoring and archiving. He mentioned that different methods can be used for data collection such as aerial photogrammetry, laser scanning, multipurpose remote survey boat etc. He also informed that Hydrologic Engineering Center (HEC) has been developing computer software for hydrologic engineering and planning analysis procedures since its inception in 1964. He provided a list of software developed by HEC, and discussed the area of application of some codes in modelling river floods. It was noted that some of HEC software are available for download on their website and may be used by individuals outside of the Corps of Engineers.

The presentations and discussions led to a number of **commendable practices**. Assessment methods used for evaluating the hazards from riverine flooding vary widely. It was noted that the results of the models developed using these various methods should not be taken as the definitive answer, but should be cross checked when feasible using other models or methods. This approach will help to understand better the uncertainty and the effects of assumptions on the results of the analysis so that the results can be put into context in support of decision making. The development of probabilistic flood hazard assessment methodologies for combining hazards (dependent and independent) and building a complete probabilistic approach, including uncertainty propagation was noted as a commendable practice.

It was underlined that close co-operation of meteorological and hydrological specialist is needed in this area. It was also mentioned that factors of climate change need to be considered in PMP/PMF estimation.

Challenges and gaps identified:

- The lack of data to go to very low-frequency events creates a significant challenge. While the use of historic information and paleodata can supplement instrumental data, this is not sufficient and other sources of information should be used. It was suggested that supplemental data could be generated using simulations based on phenomenological modelling of riverine systems. However, it was also recognised that there are many dimensions to data that makes it difficult to incorporate data from other sources into the existing hazard assessment framework. It was further noted that treating the uncertainty in data and modelling can be very challenging.
- It was concluded that it may not be sufficient to just identify the flood level, but there are other factors (associated affects) that should be considered when assessing the impact on a facility. For example, hydrodynamic loads, sediment transport, duration of the flood, debris in the floodwater, erosion, etc. should be considered. The challenge is to determine how to integrate their impacts in support of decision making on appropriate protective measures.

- A more rigorous understanding of the fragility of facilities for integrated flooding impacts would strengthen the technical basis for establishing appropriate protective measures.
- Maintaining the public's trust in protective measures for critical infrastructures will require proactive approaches not only in communication, but should include further research into areas such as: current and emerging risks; development of better DBF estimates; and implementing a credible and diverse portfolio of initiatives to mitigate risk.
- It was noted the key challenges associated with PSA for NPPs and other NIs are the nature of flooding hazards (diverse flooding hazards and diverse characteristics of flooding events) and plant impacts from flooding hazards (diverse effects and diverse strategies to protect against or mitigate).
- The main technical challenges of the PFHA methodology were identified as time-consuming calculations, characterisation of probability distributions for each input parameter and dealing with dependent input parameters.

2.4. Session 3 – Protection of nuclear installations against river floods

This session was devoted to the technical means and methods for protection of NPPs and other NIs against river floods.

The following presentations were made:

- Protection of NIs against river floods in Belgium, Dries Gryffroy (BelV, Belgium);
- Protection of NIs against river floods in France, Denis Jautzy (EDF, France);
- Protection of NIs against river floods in Germany, Gernot Thuma (GRS, Germany);
- Protection of NIs against river floods in Switzerland, Rainer Hausherr (ENSI, Switzerland);
- Operating experience with flood protection measures, Zdenko Simic (JRC, EC);
- Advances in flood risk management in The Netherlands - dike failure & solutions, Saskia van Vuren (RWS, the Netherlands).

Dr Gryffroy (BelV) provided the example of flood protection measures used at Tihange NPP site in the Meuse river valley. He mentioned that the original design basis flood (DBF) was taken as the historical flood of 1926 plus 20% with a water level at 69.80 m and the site platform at 71.50 m (based on "dry site" concept). He informed that reassessment of DBF was performed during PSR based on combination of potential flooding phenomena (high river flow rates + wind waves + impact of mobile dam (Ampsin) downstream of Tihange NPP) and using a 2D-hydrodynamic model of the Meuse river floods. The revised DBF is a 1 000-year flood (confidence interval 70%) increased by 15% with resulting water levels between 73.20 m (west) and 72.65 m (east), which leads to complete flooding of the site platform. He said that the flooding protection concept for the Tihange NPP includes two layers of protection: peripheral protection for the whole site (DBF + 40 cm margin) and additional ultimate means (AUM) for protection of each unit against BDBF or DEC (DBF + 1 m). He discussed the new site protection against the revised DBF including peripheral site protection, upstream dike, isolation structure at entrance of water intake channel, isolation structure in discharge channels, and pumping stations to evacuate sewage water. It was noted that dedicated flooding alert procedure (onset of "pre-alert phase", "alert phase" and shutdown of all units) and flood protection procedures (at site level or per unit) were developed. The second layer of protection (AUM) includes for each unit 1 ultimate diesel generator (6 kV) in a dedicated bunkered building, redundant pumps and (mostly) fixed piping for water makeup and associated flooding procedures. Long-term flooding management strategy and combinations of hazards/events (causally or non-causally linked) were identified as challenges.

Mr Jautzy from EDF informed about the flood protection measures and warning system used in France. He discussed the external flood risk management including its purpose, risks taken into account (site isolation, platform flooding, loss of off-site power, loss of ultimate heat sink) and three types of sites considered (river, sea shore and estuary). He said that organisational measures for each site include definition of equipment protections and operational actions to be implemented based on design basis assessment for each risk, as well as equipment monitoring and maintenance programmes, and operations particular rules (actions required and justifications). The protection measures – both internal (permanent and temporary protections) and external (to ensure that local infrastructure does not increase risks) – were presented. It was noted that the warning system is common to all types of external flooding events and includes four levels of monitoring and actions, i.e. watch (regular operations), vigilance (strengthened monitoring), pre-alert (increase surveillance and checks) and alert (anticipate NPP shutdown). Lastly, he provided a couple of examples of application of the event management (warning system) for Belleville NPP (dam break warning) and for Chinon NPP (flooding).

Dr Thuma from GRS informed on the flood protection measures against river floods used in Germany. He presented the German safety requirements for NPPs according to which all safety systems have to be functional during and after design basis natural events including design basis floods. He noted that DBF is defined in the pertinent nuclear safety standard KTA 2207 as a flood event with an exceedance frequency of 10-4 per year. It was mentioned that loads resulting from DBF have to be combined with classical civil engineering loads (dead loads, live loads, etc.), loads due to potential consequential events of the flood and seismic loads. KTA 2207 defines different types of sites. The type of site has consequences for the parameters that need to be taken into account in the hazard assessment. The protection measures against flooding can be subdivided into two categories: structural measures and administrative measures. KTA 2207 requires the compilation of a comprehensive plant-specific concept demonstrating the appropriateness of the combination of the individual protection measures. He mentioned that preferred protection measures are permanent structural measures such as adequate site elevation, dikes and waterproofing of buildings etc. It was stated that temporary flood protection measures may be applied only for water level between the 10-2 per year flood event and the 10-4 per year flood event. He noted that flood protection measures shall be subject to regular in-service inspections or, alternatively, be designed such that the required protection is ensured during the planned service life. Structural flood protection measures shall be supplemented by organisational and administrative measures, such as ensuring the accessibility of the plant, provision of necessary equipment, integration in flood warning systems, and specification of a water level for a precautionary shutdown.

Mr Hausherr from ENSI discussed the protection of NPPs and other NIs against river floods in Switzerland. He said that older plants were designed against a break of upstream dams or against a flood with exceedance frequency of 10-3 per year. ENSI required the existing NPPs to reassess flood protection against the new flood hazards that were finished in 2010 (before the Fukushima Daiichi accident) and to assess the margins. It was mentioned that safety cases regarding flooding are usually done by detailed 2D hydraulic calculations using up to date software. In the course of this reassessment, one «dry site» became «wet» and additional short-term, medium-term and long-term protective measures had been implemented. After the Fukushima Daiichi accident, ENSI requested operators to develop new safety cases related to flooding, including blockage of river water intake structures, and its harmonisation with sediment transport modelled using fractioned grain size. One safety case showed that clogging of the water intake structure of the bunkered system could not be ruled out. This led to additional measures to prevent clogging of water intake structures of the bunkered system (periscope pipes) and for component cooling of the bunkered system. Another safety case showed possibilities to increase the safety margins by minor modifications to the groundwater wells (stronger manhole lid, backfitting of a check valve). For mobile accident management equipment either local storage or external storage was foreseen.

Dr Simic from JRC (European Commission) discussed the results of a statistical and engineering analysis of flooding and flooding protection related events in the nuclear power plants from 4 databases (French, German, US and the IAEA/NEA International Reporting System (IRS)) during the last 20 years. He noted this topical study has been conducted to review the recent worldwide operating experience related to flooding events and flooding protection, in order to formulate lessons learnt. In total, 263 event reports were analysed with real and potential flooding events (i.e. when flooding protection deficiency was discovered without flooding). He said that the events were analysed and classified considering 13 categories in order to create statistical analysis and assess its possible insights. It was mentioned that most of the events are occurring during power operation, but events frequency is higher during outage for all databases. The events were analysed based on categorisation related to three groups: event conditions (i.e. root causes and causal factors), event consequences and corrective actions. He stated that valves and passive components are the main reasons for floods in all databases, while seals and drainage are also important cause for the IRS and US databases. Training, qualification and procedures with design configuration and analysis are the most important root causes and causal factors in all databases, where maintenance activity is also important for the IRS and the equipment performance for the French database. He noted that it is important to have a holistic view on maintenance, inspection and analysis of flood hazard and protection measures (especially for non-safety systems interaction, drainage system, fire protection systems, major cooling systems and all infrastructural barriers preventing water propagation). Configuration management, flood protection engineering programme, communication and training are all important elements for reducing flood risk.

Ms Van Vuren from RWS gave a presentation on advances in flood risk management in the Netherlands - dyke failure and solutions. The presentation focused on dike and coastal protection systems, rather than nuclear installations. It was mentioned that the flood protection scheme in the Netherlands has a length of 3 760 km and includes closuring of estuaries by building storm surge barriers. She noted that the Netherlands recently adapted new flood safety standards and performed assessments of all protection systems. She said the study strived to set standards that balance risks across geographic regions. The goal of the new flood safety standards is to provide protection for everyone at the level of risk less than 10-5 per year by 2050. Both the probability of flooding and the consequences of flooding are considered in the risk calculations. Several mechanisms of dikes and structures failure were taken into account such as overflow/overtopping, erosion of outer/inner slope, piping, dune retreat, non-closure and instability of construction. Dominant failure mechanisms are uplifting and piping (for dikes) and non-closure of constructions (for structures). She stated that the maximum acceptable failure probabilities of dikes and structures were established in the new safety standards for Petten NPP as 3×10-4 per year, for Delft NPP as 1×10-5 per year and for Borssele NPP as 1×10-6 per year. It was noted that the study is currently available on a public website along with related data.

The presentations and discussions led to a number of commendable practices. It was noted that applying the concepts of defence-in-depth (in the sense of multiple barriers against flooding) is important to establish appropriate protective measures for flood prevention and mitigation. This practice can be used to account for uncertainties in the analyses and for the effectiveness of barriers (engineered features) and supports the development of emergency measures in the event of a barrier breach. A commendable practice noted was also the use of both prevention and mitigation when developing protective measures against flooding. It was suggested that a third line of defence against flooding would be to harden components against the effects of flooding. It was noted as a commendable practice to also assess the impact of the protective measures on other hazard protective features and event prevention or mitigation features when assessing the effectiveness of protective measures. Consideration should be given to all potential hazards when developing protective measures. When establishing the criteria for protective measures to assure their effectiveness, it is important to also consider how the equipment or feature could be credited in other situations.

A commendable practice identified was to verify on a periodic basis that the protective measures against flooding remain in good working order during the life of the plant. This should include periodic walkdowns to make sure the protective features have not degraded and remain consistent with the assumptions made in the hazard assessment. The use of precursor events and other operating experience to inform flood hazard assessments and assure the effectiveness of protective measures was identified as a commendable practice. Another commendable practice identified was to demonstrate the resilience of the facility against flooding considering the protective measure that will be used during a flooding event. It was suggested that analysis and evaluation alone were not sufficient, and that to the extent practical the effectiveness of the protective measures should be demonstrated.

There was acknowledgement that forecasting of conditions that contribute to riverine flooding is important to flooding protection. With this recognition, it was also noted there should be stronger relationships between those organisations that forecast these conditions and those organisations that need to act to protect vital infrastructure, including nuclear installations. This relationship is particularly important for those facilities that rely on temporary protective measures (i.e. sand bags). Also, it was noted that nuclear installations should have strong relationships with those organisations that manage the water control structures that could affect the nuclear installation. This is important to provide co-ordination and warnings in the event the water control structure is used to mitigate or prevent impacts on other critical infrastructure or to the public. It was noted that awareness of flood impacts on infrastructure, including nuclear installations, was high with substantial working being conducted both within the nuclear field and in other industries.

Challenges and gaps identified:

- A balance is needed between the appropriate consideration of the spectrum of associated effects from flooding and the information necessary to support decision making for adequately protecting the facility from realistic external floods.
- The concept of a "dry site" needs to be reconsidered. It was the general view from the discussions at the workshop that due to the evolving understanding of flooding

hazards, even sites that were designed with the "dry site" concept need to consider flooding effects. This is due, in part, to the potential for local intense precipitation to create localised flooding on the site.

2.5. Workshop closing session

At the beginning of the closing session the rapporteurs summarised the content of the presentations and discussions of the three technical sessions. Stimulated by these summaries, the participants raised, among others, the following points that deserve future consideration:

- There are various methods for flooding hazard assessment, from very simple approaches to highly complex and sophisticated models. Each method has its specific advantages, drawbacks and sources of uncertainties. These factors should be considered carefully when choosing the most suitable hazard assessment method for a given purpose.
- For any hazard assessment availability of data is of paramount importance. Unfortunately, the database with respect to flooding is limited. Therefore, ways have to be found to increase the relevant database and to supplement the data by additional information, e.g. from physics-based models/simulations.
- Flooding can have many different causes (e.g. rising water levels in adjacent waterbodies or heavy precipitation) and may affect an installation in many ways. Therefore, the hazard assessment should not focus on a particular flooding scenario but should try to cover all reasonable scenarios.
- Both flooding hazard assessment and flooding protection measure reliability involve uncertainties. To account for the uncertainties and to increase the robustness of nuclear installations with respect to flooding risks, the flooding protection concept should comprise multiple layers, e.g. selection of an elevated site, augmented by a dyke and waterproofing of safety related buildings as a third line of defence.
- The demonstration of the effectiveness of flooding protection measures should consider ageing effects and should not be limited to the consideration of the water level (i.e. hydrostatic pressure) but should also include associated effects such as debris and dynamic loads.
- As the protection against one hazard may also affect the protection measures against other hazards, the potential adverse effects of increasing the robustness with respect to a specific hazard should be considered carefully.
- 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. Sharing 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 external hazards.

- Probabilistic safety assessment provides an important input for a traceable and reproducible risk-informed regulatory decision-making process, but as highlighted in recent work on PSA for natural hazards done by the Working Group on Risk Assessment (WGRISK) (see, e.g. Workshop Proceedings NEA/CSNI/R(2014)9), challenges remain for areas such as fragility analysis for non-seismic hazards, including external flooding as discussed during this workshop. Within this context, research results related to external flooding, including PFHA, 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 NPPs and other NIs.

The insights gained during the workshop, as noted above and based on 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 several countries, deterministic methods such as the stylised, probable maximum flooding 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 than 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 PFHAs; leveraging data collected and maintained on riverine flooding from organisations outside the nuclear industry; and establishing criteria related to riverine flooding 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 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 being made by the Nuclear Energy Agency based on workshop presentations and discussions during particular technical sessions and other, 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 power plants (NPPs) and other nuclear installations. Data received from neighbouring countries can also be used to broaden information on flooding 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 be 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 important aspects: 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 Nuclear Energy Agency Working Group on External Events (WGEV) with other Nuclear Energy Agency (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 NPPs and other nuclear installations. 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. New approaches and models will need to be developed to identify and address these challenges.

4. References

NEA (2018) "Technical Note on Riverine Flooding – Hazard Assessment and Protection of Nuclear Installations", OECD, Paris, NEA/SEN/SIN/WGEV(2018)1.

Appendix 1: List of participants

BELGIUM

Mr Dries GRYFFROY	Bel V

CANADA

Dr John PERDIKARIS	Ontario Power Generation
Mr Joey WANG	Canadian Nuclear Safety Commission

FINLAND

Mr Marko MARJAMÄKI	Säteilyturvakeskus

FRANCE

Mr Riadh ATA	Électricité de France
Ms Karine BEKADDOUR	Institut de Radioprotection et de Sûreté Nucléaire
Mr Hervé CORDIER	Électricité de France
Mr Vincent COULON	Électricité de France
Ms Claire-Marie DULUC	Institut de Radioprotection et de Sûreté Nucléaire
Mr Yasser HAMDI	Institut de Radioprotection et de Sûreté Nucléaire
Mr Denis JAUTZY	Électricité de France
Mr Erik LECLERC	Institut de Radioprotection et de Sûreté Nucléaire
Mr Giovanni MATTAROLO	Électricité de France
Ms Céline PICOT	Institut de Radioprotection et de Sûreté Nucléaire
Dr Vincent REBOUR	Institut de Radioprotection et de Sûreté Nucléaire
Mr Sylvain SAVIOT	Électricité de France

GERMANY

Dr Gernot THUMA	Gesellschaft für Anlagen- und Reaktorsicherheit gGmbH
Mr Christian STRACK	Gesellschaft für Anlagen- und Reaktorsicherheit gGmbH
Mr Timo SCHMITT	TÜV SÜD Industrie Service GmbH

JAPAN

Mr Taichi SATO	Nuclear Regulation Authority
Mr Takuya TORIYAMA	Nuclear Regulation Authority

SWITZERLAND

Mr Rainer HAUSHERR	Swiss Federal Nuclear Safety Inspectorate
Mr Carlo SCAPOZZA	Federal Office for the Environment
Mr Vinh DANG	Paul Scherrer Institute

THE NETHERLANDS

Ms Linda JANSSEN	Autoriteit Nucleaire Veiligheid en Stralingsbescherming
Ms Saskia VAN VUREN	Rijkswaterstaat

UNITED STATES

Mr John NAKOSKI	United States Nuclear Regulatory Commission
Dr Joseph KANNEY	United States Nuclear Regulatory Commission
Dr Christopher COOK	United States Nuclear Regulatory Commission
Dr Roger KAY	US Army Corps of Engineers
Dr Michelle BENSI	University of Maryland
Dr Curtis L. SMITH	Idaho National Laboratory

INTERNATIONAL ORGANISATIONS

European Commission

Dr Zdenko SIMIC	European Commission, Joint Research Centre

International Atomic Energy Agency

Mr Yoshi FUKUSHIMA	International Atomic Energy Agency

Nuclear Energy Agency

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

World Meteorological Organisation

Dr Yuri SIMONOV	World Meteorological Organization

Appendix 2: Workshop programme

WEDNESDAY, 21 MARCH 2018

8:30-9:00	Registration of the participants
9:00-9:15	**OPENING SESSION**
	Session chaired by **Dr Gernot THUMA – Workshop Chair *(GRS, Germany)***
09:00	**NEA WELCOME AND OPENING REMARKS** Andrew White, Deputy Head of Nuclear Safety Technology and Regulation Division *(NEA)*
09:05	**WELCOME AND WORKSHOP INTRODUCTION, BACKGROUND, AND OBJECTIVES, PRIORITIES AND CHALLENGES** Gernot Thuma, Chief, Reactor Safety Analyses Division *(GRS)*
09:10	**WORKSHOP ORGANISATION & LOGISTICS** Victor Neretin *(NEA)*
Session 1	**REGULATORY APPROACHES AND OPERATING EXPERIENCE**
9:15 – 17:30	Session chaired by **Mr John NAKOSKI *(NRC, USA)***
9:15 – 10:15	**IAEA GUIDANCE FOR FLOOD HAZARD ASSESSMENT AND FLOOD PROTECTION AT NI SITES** Yoshimitsu Fukushima *(IAEA)*
10:15 – 10:45	**REGULATORY CONSIDERATIONS FOR FLOOD HAZARD ASSESSMENT AND FLOOD PROTECTION OF NIs IN THE USA** Christopher Cook *(NRC, USA)*
10:45 – 11:15	***Coffee Break***
11:15 – 11:45	**REGULATORY REQUIREMENTS FOR FLOOD HAZARD ASSESSMENT AND FLOOD PROTECTION OF NIs IN FRANCE** Vincent Rebour *(IRSN, France)*

11:15 – 12:45	**UNDERTAKING VULNERABILITY ASSESSMENTS OF CRITICAL WATER RESOURCES INFRASTRUCTURE** John Perdikaris *(Ontario Power Generation, Canada)*
12:45 – 13:45	***Lunch Break***
Session 1	**REGULATORY APPROACHES AND OPERATING EXPERIENCE (cont.)**
13:45 – 14:15	**OPERATING EXPERIENCE AT FORT CALHOUN** Roger Kay *(US Army Corps of Engineers, USA)*
14:15 – 14:45	**RIVERINE FLOOD HAZARD ASSESSMENT IN GERMANY** Christian Strack *(GRS, Germany)*
14:45 – 15:15	***Questions and answers on regulatory approaches and operating experience***
15:15 – 15:45	***Coffee Break***
15:45 – 17:15	**PANEL SESSION 1** Open discussion from the floor with all the presenters in the Session 1 Panellists – John Perdikaris *(Ontario Power Generation)*; Christopher Cook *(US NRC);* Rainer Hausherr *(ENSI);* Vincent Rebour *(IRSN);* Rapporteur – Joey Zhaoliang Wang *(CNSC)*
17:15 – 18:00	***WGEV members internal discussion***

THURSDAY, 22 MARCH 2018

Session 2	**TECHNICAL METHODS FOR HAZARD ASSESSMENT**
9:00 – 9:10	***Recap of Day, Overview of Session 2 Objectives***
9:10-17:30	Session chaired by **Dr Vincent REBOUR *(IRSN, France)***
9:10 – 9:35	**RIVERINE FLOOD HAZARD ASSESSMENT BASED ON PROBABLE MAXIMUM PRECIPITATION AND PROBABLE MAXIMUM FLOOD** Yuri Simonov *(Expert WMO, Hydro-meteorological Research Centre, Russia)*
9:35 – 10:30	**PMP AND PMF UNDER A CHANGING CLIMATE** John Perdikaris *(Ontario Power Generation, Canada)*
10:30 – 10:55	**PROBABILISTIC FLOOD HAZARD ASSESSMENT FOR RIVERS AND UPDATES ON THE PRA STANDARD** Michelle Bensi *(University of Maryland, USA)*

10:55 – 11:20	***Coffee Break***
11:20 – 12:00	**RIVERINE FLOOD HAZARD ASSESSMENT AND CURRENT DEVELOPMENTS IN FRANCE** **GLOBAL SENSITIVITY ANALYSES APPLIED TO HYDRAULIC MODELLING** Claire-Marie Duluc *(IRSN, France)* **ILLUSTRATIVE EXAMPLE - NUCLEAR PLANT ALONG THE RHÔNE RIVER** Sylvain Saviot *(EDF, France)*
12:00 – 12:30	**RIVERINE FLOOD HAZARD ASSESSMENT IN SWITZERLAND** Carlo Scapozza *(Federal Office for the Environment)* and Vinh Dang *(Paul Scherrer Institute)*
12:30 – 13:30	***Lunch Break***
13:30 – 14:00	**DATA COLLECTION, AND ADVANCES IN MODELLING RIVER FLOODS** Roger Kay *(US Army Corps of Engineers, USA)*
14:00 – 14:30	***Questions and answers on technical methods for hazard assessment***
14:30 – 15:30	**PANEL SESSION 2** Open discussion from the floor with all the presenters in the Session 2 Panellists – Michelle Bensi *(University of Maryland)*; Carlo Scapozza *(Federal Office for the Environment)*; John Perdikaris *(Ontario Power Generation)*; Gernot Thuma *(GRS)*; Rapporteur – Christopher Cook *(US NRC)*
15:30 – 16:00	***Coffee Break***
16:00 – 16:10	***Recap of Day, Overview of Session 3 Objectives***
Session 3	**PROTECTION OF NIS AGAINST RIVER FLOODS**
16:10-18:15	Chaired by ***Mr Dries GRYFFROY (Bel V, Belgium)***
16:10 – 16:45	**PROTECTION OF NIS AGAINST RIVER FLOODS IN BELGIUM** Dries Gryffroy *(Bel V, Belgium)*
16:45 – 17:15	**PROTECTION OF NIS AGAINST RIVER FLOODS IN FRANCE** Denis Jautzy *(EDF, France)*
17:15 – 17:45	**PROTECTION OF NIS AGAINST RIVER FLOODS IN GERMANY** Gernot Thuma *(GRS, Germany)*
17:45 – 18:15	**PROTECTION OF NIS AGAINST RIVER FLOODS IN SWITZERLAND** Rainer Hausherr *(ENSI, Switzerland)*

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Session 3	**PROTECTION OF NIS AGAINST RIVER FLOODS (cont.)**
9:00 – 9:30	**OPERATING EXPERIENCE WITH FLOOD PROTECTION MEASURES** Zdenko Simic *(JRC, EC)*
9:30 – 10:00	**ADVANCES IN FLOOD RISK MANAGEMENT IN THE NETHERLANDS - DYKE FAILURE & SOLUTIONS** Saskia van Vuren *(RWS, The Netherlands)*
10:00 – 10:30	***Questions and answers on flood protection measures***
10:30 – 11:00	***Coffee Break***
11:00 – 12:30	**PANEL SESSION 3**
	Open discussion from the floor with all the presenters in the Session 3
	Panellists – Saskia van Vuren *(RWS);* Roger Kay *(US Army Corps of Engineers)*; Denis Jautzy *(EDF)*; Dries Gryffroy *(Bel V)*; Rapporteur – Michelle Bensi *(University of Maryland)*
12:30 – 13:30	***Lunch Break***
13:30-15:00	**CLOSING SESSION**
	Session chaired by **Dr Gernot *THUMA* – Workshop Chair *(GRS, Germany)*** and panel members **Mr John Nakoski *(US NRC),* Mr Dries Gryffroy *(Bel V, Belgium)*** and **Dr Vincent REBOUR *(IRSN, France)***
	FINDINGS AND CONCLUSIONS
	RECOMMENDATIONS FOR FURTHER WORK
15:00	**CLOSING REMARKS – Dr Gernot THUMA, Workshop Chair *(GRS, Germany)***
15:15	***WGEV members internal discussion***