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NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

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PROBABILISTIC SAFETY ANALYSIS (PSA) OF OTHER EXTERNAL EVENTS THAN EARTHQUAKE

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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 friendly and economical use of nuclear energy for peaceful purposes, as well as
- 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 policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include safety and regulation of nuclear activities, radioactive waste management, 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.

In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

FOREWORD

As stated in the mandate of CSNI's Working Group on Risk Assessment (WGRisk), the working group supports improved uses of Probabilistic Safety Assessment (PSA) in risk informed regulation and safety management through the analysis of results and the development of perspectives regarding potentially important risk contributors and associated risk-reduction strategies. WGRisk's activities address the PSA methods, tools, and data needed to provide this information.

According to results of risk analyses that have been carried out in some countries, external events may have a significant contribution to the overall risk for nuclear plants depending on the specifics of their design and location. Traditionally, NPPs have carried out PSA studies of on-site fires, floods and earthquakes. Lately, more and more attention has been paid to other types of external events, including extreme weather conditions, the frequency of which seems to be increasing according to some latest international reviews. A technical discussion on this topic took place at the 2006 WGRisk annual meeting and led to a conclusion that a task would bring significant added value to CSNI member countries.

To address this topic, WGRisk initiated a task to review the methods for risk analysis of off-site external events other than earthquake as well as the results and the insights developed in these analyses in order to provide a basis for advances in the area. This report presents the results of this work and the basis for its main recommendations to follow research on climate change and its effects (including potential effects on nuclear power plants), to re-evaluate the situation on external event PSA in a few years and to encourage analysis of operating events caused by external hazards.

In addition to the individuals and organizations listed at the end of the report, whose inputs were invaluable to the task, the Working Group would like to thank P. Pyy, A. Huerta and A. Amri of the NEA Secretariat for their support throughout this work.

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EXECUTIVE SUMMARY

Background

Probabilistic Safety Analysis (PSA) is used widely in several OECD/NEA member countries to support nuclear power plant safety management by the utilities and regulatory activities by the safety authorities.

In recent years there has been increased interest in non-seismic external events. As identified in the general WGRISK survey on Use and Development of PSA [12], the results of some external events PSAs have shown that extreme meteorological and hydrological events can make a significant contribution to the total core damage frequency (CDF) of a nuclear power plant, depending upon the specifics of its design and location. These specifics affect the extent to which external events can simultaneously influence redundant and diverse safety systems and thereby induce common cause failures (CCFs) or common cause initiators (CCIs).

The discussion on the possible effects of climate change on nuclear power plant safety and some extreme weather events in the recent years have also increased interest in such external events.

In December 2006, the CSNI's Working Group on Risk Assessment (WGRisk) initiated a task to address the current state-of-practice regarding non-seismic external events.

Objective of the work

The objective of the task was to review the methods for risk analysis of off-site external events other than earthquake as well as the results and the insights developed in these analyses in order to present a basis for advances in the area.

Description of the work (summary of the Task Report)

The task group started its work in spring 2007. The principal participants in the task group were Finland, France, Germany, the United States and Chinese Taipei (as observer at OECD/NEA).

The main means to collect information was a questionnaire distributed to the regulatory authorities or their technical support organizations in the NEA countries. Answers were received from 12 countries: Belgium, Canada, Chinese Taipei, Finland, France, Germany, Japan, Korea, Mexico, the Slovak Republic, Switzerland and the United States. The answers can be considered representative of the situation in NEA member countries. They cover two thirds of the countries with nuclear power plants and about 85 % of nuclear power plants in the OECD countries.

The questionnaire included 19 questions grouped under four headings:

- Regulatory Requirements and Status of EE PSA
- Definition EE PSA scope

- Analysis Methods
- Results and Practical Applications.

The task group held four meetings to prepare the questionnaire, to discuss the results and to formulate the findings and recommendations.

Main results and their significance

A general finding is that the role of external events in PSAs is increasing, when considering new regulatory requirements, new versions of existing PSAs, or PSAs performed for new plants. One reason for this trend is perhaps that several hazards were not covered by older PSA versions, and safety improvements were implemented for the dominant internal initiators, while the introduction of hazards in the PSAs led to the identification of new problems. For example the relative contribution of external hazards is increasing in the case of new plants.

In regulatory requirements there is a general trend towards full-scope PSA, including external events. The national requirements range from no legal requirements on PSA to explicit requirements on Level 1 and Level 2 PSA for operating and new units for all operating states and for all groups of initiating events, with specific mention on off-site external events.

There are wide variations in the current status of external events PSAs in OECD countries. In a few countries external events PSAs with a fairly wide spectrum of initiating events have been performed or are underway for operating units. In some countries the analysis has been limited to the most severe events, such as hurricanes/typhoons, and in a few countries no external events PSAs have been done. In most countries external events PSA will be performed for new NPP units.

There are also differences in the role of external events PSA in the regulatory framework. In some countries external events PSA has an important role in assessing whether the protection against extreme external events is sufficient, especially as regards older units. In other countries the emphasis is on deterministic design requirements.

The results of the questionnaire do not provide a definitive picture of the magnitude of the non-seismic external events risk contribution at currently operating plants. This is, in part, because such events are not included in many PSAs. Furthermore, for the PSAs where they are treated, simplified approaches are often used. However, for some individual plants, such events have been found to be quite significant**.** Based on the results of EE PSAs, a need for practical safety measures has been identified and, in many cases, implemented.

A general trend towards full scope PSAs can be seen in the results of the questionnaire. In the future, PSAs will generally include also treatment of non-seismic external events.

International and some national standards/guides on external events PSA are available. The approaches used to treat external hazards in PSA are similar in all the countries and the questionnaire responses did not identify general deficiencies in these methods. The questionnaire did identify a number of differences in application, including differences in: (1) analysis scope (e.g., regarding which hazards were to be addressed, as discussed above); (2) the screening of events; (3) the treatment of operator actions as affected by the external events; (4) the treatment of dependencies, both hazard and plant related (e.g. modelling of CCFs and CCIs); and (5) the treatment of multi-unit effects. The questionnaire responses also briefly discussed a number of ongoing research activities aimed at improving the current state of knowledge regarding specific topics (e.g., the potential PSA implications of climate change).

Conclusions and recommendations

Non-seismic external events, as a group, do not appear to be dominant risk contributors. However, depending upon the specifics of a plant's design and location, such events can be significant contributors. The frequency and intensity of extreme weather events, and consequently their risk significance, may be affected by natural climate variability and by human-induced global warming. So far little information is available on the prediction of changes, especially on a regional level, but intensive research is going on worldwide.

The following general recommendations are proposed to all parties active in the PSA field, including international organizations, utilities, regulatory authorities, PSA consultants and research organizations:

- Follow research on climate change and its effects (including potential effects on nuclear power plants, such as those being studied by IAEA).
- Re-evaluate the situation on external events PSA in a few years.
- Encourage analysis of operating events caused by external hazards.
- Participate in sessions on external events in international conferences, e.g.PSAM and PSA.

1. INTRODUCTION

1.1 Background

The results of external events PSAs have shown that external events can make a significant contribution to the total core damage frequency (CDF) of a nuclear power plant. Regarding external events, seismic risk analyses have become a well established part of PSA, and the topic has been included in NEA activities [1, 2, 3, 4].

Recently increased interest has been aroused by off-site external events other than earthquakes. The reasons include recent natural catastrophes and widespread discussion on climate change as well as operating events at nuclear power plants and the results of some external events PSAs. For example, storm and high tide have caused nuclear power plant flooding in Europe and high wind and ice storms have damaged main power transmission lines in Europe and Canada.

In December 2006 CSNI set up the task group WGRISK (2006)1 *Probabilistic Safety Analysis (PSA) of Other Off-site External Events than Earthquake.* In the kick-off meeting in April 2007 the group agreed that the work would be based on a questionnaire distributed to WGRISK member countries. The following countries took an active part in the task: Chinese Taipei (as observer at OECD/NEA), Finland, France, Germany and USA.

1.2 Questionnaire

The task group drew up a questionnaire (Appendix 2) which was distributed at the end of June 2007. In September - October 2007 answers were received from 12 countries: Belgium, Canada, Finland, France, Germany, Japan, Korea, Mexico, the Slovak Republic, Switzerland, Chinese Taipei and the United States.

The answers can be considered representative of the situation in NEA member countries. They cover two thirds of the countries with nuclear power plants and about 85 % of nuclear power plants in the OECD countries.

The questionnaire included 17 questions grouped under four headings:

- Regulatory Requirements and Status of EE-PSA
- Definition EE PSA scope
- Analysis Methods
- Results and Practical Applications.

Two additional questions on analysis of dependencies of initiating events and safety system failures and aggregation of results were distributed in April 2008.

2. SUMMARY OF ANSWERS

2.1 Regulatory Requirements and Status of EE-PSA

Regulatory requirements on External Events PSA for other hazards than earthquake (EE PSA) (Question 1)

A general trend towards full scope PSA, including external events, can be seen in national requirements. However, there are still large variations between countries in regulatory requirements on external events PSA.

The Slovak Republic, Finland and Switzerland reported that they have requirements on full scope Level 1 and Level 2 PSA, including external events, for all operating states, for both operating units and new units. In **Germany** national regulatory guide of 2005 and its technical reference documents set requirements on Level 1 EE PSA for operating units.

In the **USA** there is no legal requirement for licensees to perform PSA for operating units. However, a PSA that addresses risk significant contributors is important for supporting risk informed applications at the regulatory and licensee side. Regarding future reactors, 10CFR 52.47 and 10 CFR 52.79 require design-specific PSA to be included in the application for design certification and combined licence. There are no specific regulatory requirements on EE PSA, but guidance for a technically acceptable PSA (including external events) is available.

In **Korea** and **Chinese Taipei** external events PSA is not explicitly required for the operating units, but for new units Level 1 and 2 external events PSA is required for power operation.

In **France**, for the operating reactors, recently, formal requirements on EE PSA were formulated by the Safety Authority. These requirements are based on the WENRA recommendations and the first developments are required for the next periodic safety review of 1300 MWe plants. For new units, there are no formal requirements on EE PSA, but technical guidelines set a target on the overall CDF including all hazards, and so the quantification of the external hazards contribution to risk is necessary.

In **Canada** full scope PSA is required in principle, but external events PSA can be substituted with alternative methods. **Belgium, Japan and Mexico** reported that they have no regulatory requirements on external events PSA.

A summary of regulatory requirements on external events PSA is given in Table 1.

Table 1. Regulatory requirements on external events PSA (other than seismic) in different countries. Required legally or by technical guidelines (R), no requirement (NR), prerequirement for risk informed applications (P).

	Operating units		New units	
Country	**Level 1**	**Level 2**	**Level 1**	**Level 2**
Belgium	NR	NR	NR	NR
Canada	NR 1)	NR	NR 1)	NR 1)
Finland	R	R	R	R
France	NR	NR	R	NR
Germany	R	NR	n/a 2)	n/a
Japan	NR	NR	NR	NR
Korea	NR	NR	R	R
Mexico	NR	NR	NR	NR
Slovakia	R	R	R	R
Switzerland	R	R	R	R
Chinese Taipei	NR	NR	R	R
USA	P	P	R 3)	R 3)

1) Full scope PSA required but external event PSA can be substituted by alternative methods.

2) Building of new units not considered in Germany.

3) Plant specific PSA required; guidance for a technically acceptable PSA (including external events) is available.

Current status of EE PSA (Question 2)

In **Finland, Slovakia** and **Switzerland** external events PSAs with a fairly wide scope have been carried out for all operating units. In **France** separate external events PSAs have not been performed for the operating units, but some external hazards have been included in internal events PSA (loss of ultimate heat sink and loss of off-site power due to harsh weather). In **Chinese Taipei** typhoons have been included in PSAs of operating units. In **Germany** and the **Slovak Republic,** external events PSAs are in preparation.

In **Finland**, **France** and **Chinese Taipei** external events PSAs are performed for new NPP units.

In the **USA**, Individual Plant Examinations of External Events (IPEEEs) for severe accident vulnerabilities associated with external events (including high wind, external flooding, accidental aircraft crash, transportation and off-site industrial events) were requested from all licensees (Generic Letter 88-20, Supplement 4). However, only a limited number of licensees performed PSAs for external events other than seismic events and internal fire. Work is ongoing to develop Standardized Plant Analysis Risk (SPAR) Models that include limited treatment of external events.

Belgium, **Canada**, **Japan, Korea** and **Mexico** reported that external events PSAs as defined in this report have not been carried out. However, some probabilistic studies on external events have been performed. For example, in Canada simple screening has been performed to identify potentially significant EEs. In Mexico, the loss of off-site power frequency in the risk monitor is increased when extreme weather conditions are expected.

The objectives of EE PSA (Question 3)

The reported goals of external events PSA are mainly the general goals of PSA in each country (assessment of the overall risk and balance of risk profile, demonstration of probabilistic safety goals, identification of plant vulnerabilities, assessment of plant modifications and technical specifications etc.). Assessment of the adequacy of design basis for external events was mentioned as an objective by several countries (Finland, France, Korea, Switzerland).

In the **USA** the primary goal of the IPEEE program was for licensees to identify plant-specific vulnerabilities to severe accidents, if any, and to report the results together with any licensee-determined improvements and corrective actions to the NRC.

National or international guides on EE PSA methods (Question 4)

National standards and guides relevant to external events PSA were reported by USA, Germany and Slovakia (Table 2). The Swedish regulatory authority SKI has published a report on external events PSA methods based on the Swedish and Finnish practice. In addition a number of IAEA publications include relevant information for external events PSA (Table 3).

Table 2. National standards and guides on external events PSA.

Country	Title	Comment
USA	Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications, ASME/ANS RA-S-2008	Part 4 of ASME/ANS RA-S-2008 is for external events. Regulatory Guide 1.200, Rev. 2 (to be published December 2008) will provide the NRC staff position on the standard.
USA	NUREG-1407, Procedure and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities	Key results of IPEEEs summarised in NUREG-1742
Sweden	Swedish Nuclear Safety Authority SKI Research Report 02:27, Knochenhauer and Louko, Guidance for External Events Analysis, 2002	The Finnish experiences on EE PSA are also taken into account in the report.
Slovakia	Requirements for PSA performance, UJD SR, BNS I.4.2/2006, Bratislava, Slovakia, 2006	
Germany	Facharbeitskreis "Probabilistische Sicherheitsanalyse für Kernkraftwerke": Methoden zur probabilistischen Sicherheitsanalyse für Kernkraftwerke, BfS SCHR 37/05, August 2005	

Table 3. IAEA publications relevant to external events PSA

The Role of Probabilistic Safety Assessment and Probabilistic Safety Criteria in Nuclear Power Plant Safety, Safety Series No. 106, IAEA, 1992
Safety Assessments and Verification for Nuclear Power Plants, Safety Guide No. NS-G-1.2, IAEA, 2001
Treatment of External Hazards in Probabilistic Safety Assessment for Nuclear Power Plants, IAEA-Safety Reports Series No. 50-P-7, 1995
Flood Hazard for Nuclear Power Plants on Coastal and River Sites, Safety Guide, Safety Standards Series No. NS-G-3.5, IAEA, Vienna, 2004.
External Events Excluding Earthquakes in the Design of Nuclear Power Plants, Safety Guide, Safety Standards Series No. NS-G-1.5, IAEA, Vienna, 2004.
Site Evaluation for Nuclear Installations, Safety Requirements, Safety Standards Series No. NS-R-3, IAEA, Vienna, 2003
External Human Induced Events in Site Evaluation for Nuclear Power Plants, NS-G-3.1, 2002
Extreme External Events in the Design and Assessment of Nuclear Power Plants, IAEA TECDOC Series No. 1341, IAEA, Vienna 2003

2.2 Definition of EE PSA scope

Criteria for including initiating events in EE PSA (Question 5)

Some of the initiating events analyzed in internal events PSA, such as loss of off-site power and loss of ultimate heat sink, may be caused also by harsh weather or other external events. To ensure that such cases are included only once in the initiating event frequency and to facilitate comparison of different PSAs, the criteria for including events in the EE PSA have to be specified.

The answers to Question 5 indicate that there are basically two different ways to decide whether an event is considered in the EE-PSA:

1. In some countries (e.g. Chinese Taipei) the decision is based on a general consideration of the geological or meteorological conditions in the country. Also the difference in the methodologies used for the analysis is sometimes considered in making the decision whether an event is included in the external event PSA or other parts of PSA.

2. Other countries (e.g. Canada) use a somewhat more systematic definition of external events. Typically these definitions include one or more of the following aspects: (i) The event originates outside the plant perimeter, (ii) the event has the capability of initiating transients or loss of coolant accidents, and (iii) the event might impair the function of (more than one) safety system*.

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*The different definitions of 'external event' ranging from all events that are not caused by the technical process of producing nuclear power (with the subsequent separation of 'external events' into 'internal hazards' such as plant internal fires and 'external hazards' such as storms) to events which originate from outside the plant perimeter sometimes leads to confusion. Some countries favour the term 'off-site external events' to clearly exclude all events which have their origin at the plant itself.

The second approach is more prevalent. But it should be mentioned that the distinction between the two approaches is not as clear as it might seem at a first glance, because approach 1 might well be based on similar considerations as approach 2 without mentioning the applied external event definition and screening criteria explicitly.

In general, loss of off-site power and loss of the ultimate heat sink e.g., seawater cooling) are considered as internal events, because their consequences are limited, if no other safety systems are impaired.

The scope of external hazards to be analyzed (Question 6)

There is a wide variety of off-site external events considered in the countries which answered the questionnaire. Of course, not all of these events are analysed in detail. Most of them are screened out due to their low occurrence probability. To provide some guidance on what types of events might be worth considering, the following table lists some external hazards mentioned in the literature [5,7,9,12].

Table 4. Examples for potentially hazardous off-site external events

Natural hazards	
Wind	
	Strong winds (e.g hurricane)
	Tornado
	Salt storm
	Sand storm
Temperature	
	High air temperature
	Low air temperature
	Extreme air pressure (high/low/gradient)
	High sea/river water temperature
	Low sea/river water temperature
	White frost
	Soil frost
	Surface ice
	Frazil ice
	Ice barriers
Precipitation	
	Extreme rain
	Extreme snow (including snow storm)
	Ice storm/ sub-cooled rain
	Extreme hail
	Fog

Low water level	
	Drought
	Low sea/river water level
	River diversions
Flooding	
	High sea/river water level (e.g. high tide)
	Storm surge
	Strong water current
	Seiche
	Tsunami
	Other extraordinary waves
Geology	
	Seismic events
	Land rise
	Soil shrink/swell
	Landslide
	Under-water landslide
	Costal erosion
	Avalanche
Lightning	
	Lightning
Meteorites	
	Meteorite
Volcanic	
	Volcanic phenomena
Biological	
	Animals
	Organic material in water
	Other biological impacts
Chemical	
	Corrosion (e.g. from salt water)
Fire	
	Forest fire
	Other external fire

Man-made hazards	
	Fires (e.g. after transportation accident, pipeline accident, or industrial accidents) including the impact of smoke on the plant
	Explosion (e.g. after transportation accident, pipeline accident, or industrial accidents)
	Chemical release (e.g. after transportation accident, pipeline accident, or industrial accidents)
	Radioactive releases
	Electromagnetic disturbance
	Satellite crash
	Airplane crash
	Excavation work
	Missiles from military activity
	Missiles from other installations
	Solid or fluid impurities from ship release
	Chemical release to water
	Direct impact from ship collision
	Ground vibration (e.g. due to nearby explosions)
	Eddy currents into ground

Some countries restrict the analysis right from the beginning to a limited set of hazards known to be relevant under the given geological and meteorological conditions in the country (e.g. Chinese Taipei). Some other countries start with an extensive list of imaginable hazards, which is boiled down to a manageable number of hazards to be analysed in detail by a screening process taking into account the site specific conditions and some kind of probabilistic consideration or expert judgement (e.g. Finland).

In the framework of many PSAs some external hazards are not treated explicitly as initiating events but are used as boundary conditions in the analyses of internal events (e.g. high water or air temperatures).
Typical hazards that are considered in the detailed analyses are earthquakes, storms (e.g. typhoons, tornados or snow storms), frazil ice or ice formation in general, biological phenomena (e.g. algae or mussels), aircraft crashes, and industrial accidents. Due to the lack of experience with EE PSA in most countries, the answers do not allow for an identification of significant risk contributors.

2.3 Analysis Methods

Introduction

The methodological aspects concern the identification of potentially significant external hazards, qualitative and/or quantitative screening of events and PSA modelling and quantification of the events not screened out. Recent methodological developments, research and available references are also mentioned.
The general opinion is that initiating events caused by external hazards need to be regarded as being on the same position as the internal initiating events.

For some hazards, their definition as initiating events and the determination of their effects on the plant are specialized areas of PSA. The incorporation of the plant failures due to hazards into the PSA is, however, in principle the same as for the internal initiating events and commonly the same PSA structures/models are used.

An important feature of most hazards is that they can cause a disturbance to the operation of the plant and can also disable or degrade the safety systems. Therefore, the modelling of dependencies is a key point in the analysis.

In this chapter, only the responses related to the External Events PSA methodology are included. The treatment of external events in the frame of initial deterministic design of the plants is considered outside of the scope of the EE PSA methodology.

Identification of potentially significant external events (Question 7)

The selection of hazards for incorporation into the PSA usually starts with a list of hazards which is as complete as possible, regardless, in the first instance, of their potential for causing damage of defences built into the plant. The survey shows that, in general, the starting point in developing the list of external events to be considered in the PSA is the list of external hazards which are nowadays considered for the initial deterministic design. The list is based on the operating experience, event analysis and expert judgment. For some older plants, however, a systematic evaluation of all external events was not done for the deterministic design basis.

Additionally, specific analyses directly related to the consideration of external hazards in the PSA were performed in several countries. These analysis include the analyses of the international information from available sources (all the countries which developed EE PSA indicated the analysis of international experience). An example list of international references is presented below:

- SKI Research Report 02:27, Knochenhauer and Louko, Guidance for External Events Analysis, 2002.
- NUREG/CR-2300, “Probabilistic Risk Assessment (PRA) Procedures Guide”.
- ANSI/ANS-58.21-2003 “External-Events PRA Methodology”.
- IAEA Safety Guide No. NS-G-1.5 “External Events Excluding Earthquakes in the Design of Nuclear Power Plants”.
- IAEA 50-P-7, “Treatment of External Hazards in PSA”.
- IAEA siting guides.
- WASH-1400, “Reactor Safety Study – An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants”.
- “Examination Guide for Safety Design for Nuclear Power Facilities”, Japan.
- Guideline HSK-A05 Switzerland.
- “Procedural and Submittal Guidance for the Individual Plant Examination of External Events for Severe Accident Vulnerabilities,” NUREG-1407.
- “List of External Events Requiring Consideration,” Appendix A of ANS-58.21-2007 (adapted from NUREG/CR-2300, “PRA Procedures Guide: A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants”).

The analyses are then completed by events analysis of weather phenomena and human induced hazards in the vicinity of the plant (like in Canada, Finland, Korea and Slovakia), the analysis of other EE PSA results and EE PSA expert judgment (like in Korea and Chinese Taipei).

Specific guides presenting the list of external events to be analysed in PSA were developed in several cases (USA and Switzerland) or this list is prescribed by the regulatory authority (like in Germany).

In several countries (like Canada, France) a limited number of initiating events that can be caused by external hazards (loss of heat sink, loss of off-site power) are considered in the frame of internal events PSA. The selection of these hazards is based on obvious observations.

In the USA, the determination of significance is a function of how the PSA is being, or is intended to be, used. When a PSA is being used to support an application, the significance of an accident sequence or contributor is measured with respect to whether its consideration has an impact on the decision being made. For the base PSA model, significance can be measured with respect to the contribution to the total Core Damage Frequency (CDF) or Large Early Release Frequency (LERF), or it can be measured with respect to the contribution to the CDF or LERF for a specific hazard group or plant operational state, depending on the context.

In Regulatory Guide 1.200, the NRC staff has endorsed the following definitions:

- *Hazard:* the physical effects of a natural phenomenon such as flooding, tornado, or earthquake that can pose potential danger (for example, the physical effects such as ground shaking, faulting, landsliding, and liquefaction that underlie an earthquake's potential danger).
- *Hazard Group:* a group of similar hazards that are assessed in a PSA using a common approach, methods, and likelihood data for characterizing the effect on the plant. Typical hazard groups considered in a nuclear power plant PSA include: internal events, seismic events, internal fires, high winds, external flooding, etc. By convention, internal flooding is considered part of the internal events hazard group. In some cases, it may be appropriate to treat internal flooding as a separate hazard group.
- *Significant Accident Sequence:* one of the set of accident sequences resulting from the analysis of a specific hazard group, defined at the functional or systematic level, that, when rank-ordered by decreasing frequency, sum to a specified percentage of the core damage frequency for that hazard group, or that individually contribute more than a specified percentage of core damage frequency. For the current version of the ASME/ANS standard, the summed percentage is 95 % and the individual percentage is 1% of the applicable hazard group. For hazard groups that are analyzed using methods and assumptions that can be demonstrated to be conservative or bounding, alternative numerical criteria may be more appropriate, and, if used, should be justified.
- *Significant Accident Progression Sequence:* one of the set of accident sequences contributing to large early release frequency resulting from the analysis of a specific hazard group that, when rank-ordered by decreasing frequency, sum to a specified percentage of the large early release frequency, or that individually contribute more than a specified percentage of large early release frequency for that hazard group. For the current version of the standard, the summed percentage is 95 % and the individual percentage is 1% of the applicable hazard group. For hazard groups that are analyzed using methods and assumptions that can be demonstrated to be conservative or bounding, alternative numerical criteria may be more appropriate, and, if used, should be justified.

Identification of significant combinations of external hazards (Question 8)

Combinations of external hazards can threaten simultaneously diverse safety systems. However, the frequency of combination of external hazards is, in general, expected to be very low for independent hazards. The international survey shows that combinations of external hazards are considered only if the hazards are correlated. In practice, the selected combinations of correlated external hazards are dependent on local conditions. Some examples of combinations of external hazards modelled in the EE PSA are presented below:

In Finland combined events are identified by analyzing the correlations and the effects on the plant. The analysis of possible correlations (dependency) between events has been made by assessing the physical bases of the phenomena, observed data, actual operating events and general knowledge of local conditions. Expert judgment and rough quantitative analysis are often used for estimation of correlations. In most cases the observed data for intensities relevant to EE PSA is sufficient only for order of magnitude estimates of correlations. For example, it is known that high wind often results in high seawater level and organic material in seawater (algae). The combination could simultaneously endanger off-site power and diesel generator cooling water intake, and it is analyzed as a combined event. Extreme wind speeds have been measured in winter and could be associated with snowfall resulting in possibility of simultaneous loss of off-site power and loss of diesel generators due to blockage of combustion air intake. Simultaneous high air and seawater temperature could endanger, e.g., instrument room cooling also at units with diverse cooling system heat sinks.

In Germany only the combinations of extreme weather situations are considered.

In Korea it is found that a big typhoon sometimes results in large amounts of algae or other organic material in non-essential seawater intakes and threaten simultaneously external grid (caused loss of off-site power). The loss of off-site power events have been considered in internal PSA already. The effect of non-essential seawater intakes blockage due to typhoon or organic material would be considered in internal PSA sooner or later.

In Slovakia the impact of EE is evaluated on the power supply from the external grid. For example, extreme cold weather can lead to the loss of external grid.

In Switzerland the hazard combinations were identified by engineering judgment. Examples of combinations of EEs which shall be considered according to the draft guideline HSK-A05 are:

- Harsh winter conditions including snow (drift), low temperatures, and ice cover,
- Harsh summer conditions including high temperatures, drought, forest fire, and low river water level.

In Chinese Taipei, loss of off-site power due to typhoon event was considered as an initiating event to cause plant shutdown. Bad seawater condition was also considered, because of its high possibility to affect the operation of service water system. Usually, there will be a heavy rain along with a typhoon attack. Large amounts of debris from the river side and woods upstream of the river will go into the sea through the river near the nuclear power plant. These impurities may gather around the service water intake and significantly reduce the service water flow.

In the USA, the ASME/ANS standard requires a dependency analysis of the external events. It is discussed in Part 4 of the standard. Part 4 covers external events (or hazard groups) which include earthquakes, high winds, and external flooding. The causes for these hazards are external plant occurrences. For example, for high winds, the occurrences to be considered include, at a minimum, tornadoes, hurricanes, tropical storms.

The consequences (e.g., algae buildup) of these events on plant performance (e.g., multiple system operators) are addressed in the standard.

Although the standard does require treatment of events, and some events can involve multiple hazards (e.g., a hurricane could cause high winds, storm surge, spawned tornadoes and associated missiles, and delayed flooding from precipitation), there currently is little explicit guidance on the treatment of dependent multiple hazards. This issue was not addressed by the IPEEE submittals, and its risk implications are uncertain. (Note that a formal analysis would, for delayed hazards, have to address shutdown operations. Note also that such operations are unlikely to involve such higher-risk evolutions as mid-loop operation important to analyses of planned outages.)

Screening methods (Question 9)

The list of candidate hazards has to be reduced by screening out. The screening is in general done in several stages, first by judgment, then by rough estimates of frequency/impact and finally by more detailed estimates.

Some examples of screening methods, in countries which developed EE PSA are:

In Finland, for example, in Olkiluoto 1 and 2 EE PSA events are screened out of further analysis according to the following criteria:

- the phenomenon will not exceed the plant design basis,
- if dangerous intensity of a phenomenon can be foreseen at least eight hours beforehand, only cold shut-down reactor is considered,
- intensity with effects on the plant is extremely improbable; cut-off frequency is 10-8/year (event frequency or preliminary core damage frequency estimate),
- the event is included in another part of PSA,
- an event is included in a combined event if it causes risk increase in connection with some other event,
- an event is not analyzed in detail if there are ongoing plant modifications to remove the risk.

In Korea the identification of potential external events and the event selection for further analysis were done by the expert judgement and screening analyses (occurring frequency).

In Slovakia the selection of external events for detailed modelling and quantitative analysis is performed based on specific site and nuclear installation conditions.

In Switzerland, a hazard or a combination of hazards can be screened out of the list of hazards subjected to screening analysis (according to the draft guideline HSK-A05), if it is demonstrated that at least one of the following conditions is met:

- based on a qualitative argument, the hazard does not lead to an initiating event,
- the hazard cannot occur or a bounding analysis yields a hazard frequency of less than 10^{-8} per reactor year and the containment integrity will not be affected,
- a bounding analysis of the CDF due to the hazard yields a result less than 10^{-9} per reactor year.

In Chinese Taipei, the identification of potential external events and the event selection for further analysis were done at the same time by the expert judgment through a series of meetings.

In the USA, requirements for screening and conservative analysis are given in Part 4 of the ASME/ANS Standard. First, all potential external events that may affect the site must be identified. The events then go through a process where they are "screened out" (excluded from further consideration in the PSA analysis) on a defined basis or subjected to analysis using a PSA (either a limited PSA or a detailed PSA). A demonstrably conservative or bounding analysis, when used together with quantitative screening criteria, can also provide the basis for screening out an event without the need for a detailed analysis.

In 1991, to support the NRC request in supplement 4 to Generic Letter 88-20, guidance was given for conducting high winds, floods, and other external events analyses for the IPEEE program. In Section 5 of NUREG-1407, "Procedural and Submittal Guidance for the Individual Plant Examination of External Events for Severe Accident Vulnerabilities," a progressive screening approach was described, summarized below, which followed a series of steps or analysis in increasing level of detail and effort:

- Review the plant-specific hazard data and licensing basis and determine whether there were any significant changes since the issuance of the operating license that could affect the IPEEE
- Determine whether the plant conforms to the guidance in the NRC's 1975 Standard Review Plan (SRP), NUREG-0800, and perform a plant walkdown
- If the plant does not conform to the 1975 SRP guidance, perform one or more of the following steps:
    - Determine if the hazard frequency of the original design is acceptably low (i.e., less than 1E-5 per year).
    - If the event cannot be screened out based on hazard frequency, perform a bounding analysis to show that the hazard would not result in a CDF contribution of 1E-6 per reactor-year.
    - Perform a PSA.

Initiator frequency and uncertainties estimation (Question 10)

In general the estimation of the frequency of external events is more or less related to the observation of phenomena occurrences. The methods applied to analyse the available observations and to determine the EE PSA hazard frequency, are dependent on the hazard type. The quantitative treatment of uncertainties is, however, in general not very developed. The impact of uncertainties on the analysis is in general substituted by conservative estimations. Example methods for external event initiators frequency and estimation, in countries which developed EE PSA, are the following:

In Finland the frequency - intensity distributions are determined by fitting the generalized extreme value distribution to the observations. Usually the more conservative parameter selections are used. Some comparative studies have been carried out with the Peak Over Threshold (POT) method. For some events, e.g. *algae in seawater,* the frequency is based directly on observations and real event data. For oil spill frequency, the estimates are based on analysis of local and worldwide shipping and accident statistics.

In Korea there is no specific methodology to determine the frequency. The frequencies are extracted from the foreign or domestic experience data. No special uncertainty analysis was done except for seismic PSA.

In Slovakia the event frequencies or frequency - intensity distributions are determined based on IAEA guidelines. The parameters and characteristics of external events use conservative assumptions. Evaluation of historical data is the basis for frequency calculation.

Some details of Switzerland practices on EE frequency determination (as described in the draft guideline HSK-A05) are given below:

- High Winds

Translational winds and tornadoes are the types of extreme winds to be considered. Based on the experience in Switzerland, specific data are proposed in the guideline for the determination of the initiating event frequency for tornadoes. Translational wind occurrence and peak wind accelerations can be obtained based on short-term site-specific historical wind velocity data and wind-data from long-term measurement from a fixed weather station or airport near the plant. Measured wind speeds are to be mapped to specific heights of interest.

- External Flooding

Flooding events required to be considered are heavy rainstorms or sudden snow melt causing high river water level at the plant, failures of water flow control structures (e.g. dams, weirs, levees) and intense precipitation events. Maximum river water level exceedance frequency curve is to be developed using measured data and (e.g.) a Pearson-III probability distribution.

- Aircraft Crash

The aircraft categories considered are commercial aircraft, military aircraft and light aircraft. The risk contribution of IEs involving commercial aircraft crash on the reactor building, on the bunkered emergency building, on other buildings as relevant and on the remaining plant area shall be quantified. Depending on the plant location, the analysis of commercial aircraft crash frequency shall consider the number of aircraft operation and failure rate for each flight phase (i.e. variations of the Seabrook-Model are used).

Direct and indirect impacts of all the above IEs are required to be considered while evaluating the possible initiating events due to these EEs.

In Chinese Taipei the hazard curve (speed of wind and its associated frequency of occurrence) of typhoon events was obtained by the data collected at local meteorological station. No uncertainty analysis was done for the hazard curve.

In the USA, two types of uncertainties are addressed: parameter and model. A source of model uncertainty, as endorsed by NRC staff in RG 1.200, is one that is related to an issue in which there is no consensus approach or model and where the choice of approach or model is known to have an effect on the PSA model (e.g., introduction of a new basic event, changes to basic probabilities, change in success criterion, introduction of a new initiating).

The NRC's view with regard to the treatment of sources of uncertainty is as follows:

- Parameter uncertainties are addressed through the quantification process, where mean values are calculated. External initiating event category mean frequencies and their distributions are estimated by using methods similar to those used for internal event initiating event categories. For example, ample data exists for dam failures (for different types of dams) in the United States. Thus, the frequency and distribution can be calculated by using the actual data; this is similar to estimating internal events transient initiating event category frequency. Another example is the frequency estimation for high-intensity seismic events. Since there is no or extremely scarce data for these events, its frequency and distribution are estimated by expert opinion. This method is similar to the expert opinion estimates recently done by the NRC for estimating frequency of Large Loss-of-Coolant Accident (LOCA) event initiating event category for internal events.

- The sources of model uncertainty need to be identified and characterized; it is not necessary to quantitatively evaluate every source of model uncertainty for the base PSA. The impact of those sources of model uncertainty that can impact the PSA results used to support an application only need to be evaluated in the context of that application.

The uncertainties in the external EE PSA results are addressed as discussed in the PSA standard (ASME/ANS RA-S-2008) and associated guidance documents (RG 1.174, RG 1.200, and NUREG-1855).

Impact on plant, initiating events (Question 11)

In general the plants are designed to withstand specified levels and types of external events. If it has already been demonstrated in a deterministic manner that the hazards within the design basis will not lead to core damage, then it is common practice to assume in the EE PSA that the risks coming from design basis hazards are negligible. However, if the probability that a hazard within the design basis will lead to unacceptable consequences is significant, the hazard can be included in a refined analysis.

The impacts on the plants that can be caused by external hazards are in general identified by analysis and operating experiences. However, the international survey shows that potentially induced internal hazards (fire, flooding) are in general, not considered in the analyses done up to now (however methodological improvements are foreseen).

Several examples of the assessment of the external hazard impact on the plant, from countries which developed EE PSA, are presented below:

In Canada initiating events are identified by literature search and operating experience.

In Finland the methods used in the identification of initiating events include, for example:

- analysis of possible consequences of structural failures,
- analysis of incipient structural failures caused by occurred external events,
- analysis of operating experience involving functional degradation or unavailability of systems due to external events.

For example, it is estimated based on experience that wind speed 28 m/s (3 second average) is sufficient to rip of steel panels which may cause short term loss of off-site power if flown to the switchyard. Wind speed 39 m/s may cause damage to the main grid and a long-term loss of off-site power. Algae, frazil ice and oil slick may cause partial or total blockage of sea water intake (EE), resulting in total or partial loss of service water (IE). Internal hazards (fires, flooding) are not included in EE PSA. Fires induced by lightning are, in principle, covered by Fire PSA.

In Germany, due to the fact that the statistics from the operating experience are not meaningful for German NPPs (the number of experienced events much too low for statistical treatment) the initiating events are mainly identified by expert judgment and analyses.

In Slovakia the operating experience and analyses are used to identify the initiating events caused by EE.

In Switzerland the direct effect of the external hazards (e.g., wind-induced collapses, mechanical impact of aircraft crash) and the indirect effects (e.g., wind induced missiles, impact of collateral mechanical loads and fire/explosion effects resulting from aircraft crash) are both required to be analyzed as part of the EEs analysis. The initiating events that can be caused by each external hazard are identified by expert judgment taking into account insights gained from analysis and operating experiences.

In Chinese Taipei the possible initiating events following a typhoon were identified by the pre-tree (similar to event tree). Off-site power transmission line, switchyard and gas turbine were considered as the headings of pre-tree. Each sequence was considered as an initiating event with its specific plant operating status.

In the USA, the initiating events (and consequential effects, e.g., flooding) are generally identified through analysis of the effects of the external hazard. Effects, such as the following, are examined for flooding:

- Potential flood area
- Propagation pathways
- Cause/effect on structures, systems, and components.

Fires and flooding initiated internal to the plant are evaluated as part of the internal events analysis.

Impact on plant systems and dependencies treatment (Question 11bis)

An important consideration in EE PSA is whether the hazards analyzed can, in addition to disturbing the operation of the plant, also disable or degrade the safety systems. Thus, the modelling of dependencies is a key point in the analysis. This aspect can be important even during initial screening, since the screening out of external hazards without consideration of dependencies can underestimate the associated risk. Note that analyses considering external induced initiating events in the frame of internal events PSA (e.g., extreme-weather induced losses of off-site power) may not always consider important dependencies (e.g., a snow storm leading to loss of off-site power and to degradation of diesel generators).

Some examples of the dependencies treatment, in the frame of EE PSA, are presented below.

In Finland, external events PSA is focused on situations where an external influence can cause an initiating event and simultaneously degrade safety systems.

The identification of dependencies is based on operating experience, interviews of designers and operating and maintenance personnel and systematic analysis of plant systems and components and their design basis. The identification of dependencies has been done in the early phases of external events PSA and is updated for new revisions of external events PSA.

A typical modelling technique is to define special initiating events which include a usual transient (loss of off-site power, loss of feedwater, scram) caused by an external event and a simultaneous total or partial loss of safety or support systems. For example, a blockage caused by algae or frazil ice at seawater intake is modelled in EE PSA as one of the following initiating events:

- Loss of feedwater (due to trip of main seawater pumps) and partial loss of service water
- Loss of feedwater and total loss of service water.

If algae or frazil ice only causes trip of main seawater pumps, the event is included in the corresponding transient frequency in internal events PSA.

The EE PSA initiating events (i.e. combinations of a transient and loss of safety systems) are defined and their frequencies are calculated with separate event trees outside the PSA model.

When transients caused by external events are modelled in internal events PSA, the dependencies are not generally considered.

Correlated external events are modelled as combined events in EE PSA. For example, an extremely high wind may damage the external power grid and simultaneously waves may bring algae to the seawater intake. This can be modelled as a combined event “loss of off-site power and algae”. The event involves at the same time loss of off-site power and total or partial loss of service water leading to loss of the corresponding diesels. (Loss of off-site power event implies loss of main feedwater.)

In France no EE PSA was developed for the moment. Regarding the external events included in the internal events PSA (the loss of ultimate heat sink, and the loss of external power supply),only functional dependencies are taken into account (loss of support systems), the dependencies between the initiator and the plant systems (induced by the natural phenomena) are not considered.

In Japan, regarding the identification of the dependencies between the initiating events and the safety system the answer is not available because no EE-PSA other than for earthquake and earthquake induced hazard such as Tsunami has been performed in Japan. However, the approach to the identification of the dependencies between earthquake induced Tsunami and the safety system in Tsunami PSA is briefly presented. In Tsunami PSA, after Tsunami hazard curve evaluation, the fragilities for mainly outdoor facilities such as seawater intake structures, seawater pumps, oil tanks are evaluated under the Tsunami run-up analysis. Using the fragilities, the probabilities of both loss of off-site power induced by Tsunami and loss of safety functions such as ECCS and emergency DG are evaluated. Namely, the probabilities of failure of individual components are evaluated as functions of the size of Tsunami. From these functions, the conditional probabilities of system failures and core damage for a given size of Tsunami are calculated. Then the Tsunami hazard curve and conditional core damage probability are used to calculate the core damage frequency. In this way the dependencies between the initiating event induced and the safety system degraded by Tsunami are taken into account in Tsunami PSA.
The loss of off-site power due to external events is included in the internal events PSA. However, the dependencies between the loss of off-site power and the safety system are not considered.

In Slovakia, only those events are considered in EE PSA which can disturb the operation of the plant and need successful operation of safety systems. Identification of dependencies between the external events and the safety systems is performed with detailed analyses. Identified dependencies are included into PSA model by new gate or new basic event, which reflect status of the plant after events.

In Switzerland, dependencies caused by external hazards are identified in the course of PSA plant walkdowns and by an analysis of the plant conditions during the EE. The identification of the relevant dependencies is usually done prior to the EE PSA modelling. The dependencies are considered in the PSA model. For each relevant external event, an event tree is developed based on the general transient event tree (which already considers the internal dependencies).

In Chinese Taipei, the only external event considered is the typhoon during summer time. Strong wind and heavy rain are the main concern when typhoon attacks. For heavy rain, it will have no direct impact on plant operation. But the experience showed that, heavy rain may cause bad seawater condition which will significantly reduce the intake flow of seawater and affect the operation of service water system. For strong wind, system or component such as switchyard or electric transmission grid which were not secured inside building may be affected. Only loss of off-site power was considered as an initiating event during typhoon attack. Probability of bad seawater condition caused by typhoon was considered as a basic event which will fail the operation of service water.

In the USA, the dependency analysis is an essential element of a PSA and is included in the ASME/ANS standard. It is required and is performed throughout the development of the PSA model. The standard requires that the ability of events to impair a mitigating (e.g., safety) system be assessed. Examples of an assessment include:

- Identification of the phenomenological conditions created by the event (e.g., missiles, adverse temperatures, debris).
- Identification of time-phase dependencies (e.g., DC battery adequacy—time dependent discharge).
- Identification of dependence between components.
- Identification of the design conditions (e.g., trip signals) that will cause a system to fail to start or fail to continue to operate (e.g., excessive room temperature, inadequate net positive suction head).

Impact on the human factor (Question 12)

External events may lead to harsh personnel working conditions, problems in getting external aid and increase their decision burden. Examples include, e.g., site isolation in consequence of a storm, worrying about the situation of family members, adverse conditions for countermeasures requiring working outdoors (wind, rain, snow, heat, cold). In general, the international survey shows that the impact of external events on the quantification of human factor in the EE PSA is in general based on the "extension" of the existing Human Reliability Analysis (HRA) methods. No specific methods have been proposed up to now. This "extension" can be the use of more pessimistic factors in the human error probability (HEP) quantification or the rough modification of the quantified HEP. Several examples, from countries which developed EE PSA, are presented below:

In Germany, the effects of external events on the reliability of human actions are not explicitly considered in the PSA. However, the HRA takes into account the potentially very different environmental conditions affecting the human behaviour in case of an EE.

In Korea, the human reliability is not credited or very high conservative human error value is usually used in EE PSA.

In Slovakia increased human error probabilities are used after occurrence of EE and higher level of dependencies between the human errors are applied.

In Switzerland the effect of the EE on the quantification on the human reliability has to be considered taking into account all the relevant issues (some of which are stated in the example above). No specific method is defined for this purpose.

In Chinese Taipei the human error probabilities used in internal event analysis were increased by factor 3. It is a suggestion from consultants to take into account for special stress of operating crew and possible damage (or blockage) to the pathway from control room area to other areas where the components are located.

In the USA, most commonly-used human reliability analysis (HRA) methods provide some mechanisms to address external event-caused effects (e.g., local environmental changes). Some of the newer "second generation" methods (e.g., ATHEANA) place a heavy emphasis on the description of the context for operator actions, and on the potential of challenging situations to increase the likelihood of error. NRC continues to do research in improving HRA methods to support the different events considered in PSA. Examples include:

- The International HRA Empirical Study in which human actions performed by operator crews (at the Halden Reactor Project simulator) are analyzed using different HRA methods and the results are compared to crew simulator performance in an effort to benchmark HRA methods using empirical data. This study is supported by 13 countries, including the NRC and the Electric Power Research Institute (EPRI).
- The Human Event Repository and Analysis (HERA) system, which provides a framework to collect and code human performance event data to support HRA activities. Operational events as well as simulator data are loaded into HERA. The objective of HERA is to support both the improvement of HRA models as well as estimation of human error probabilities.
- NRC/EPRI collaborative work (under initiation) to address the NRC Commission direction (SRM-M061020) to address HRA model differences in an effort to propose a single model for the agency to use or guidance on which model(s) should be used in specific circumstances.
- NRC/EPRI collaborative work to develop HRA guidance to support fire PSA/HRA, that is, guidance for analyzing operator actions modelled in a fire PSA.
- HRA Gap Analysis, a review of the existing HRA good practices (NUREG-1792) with respect to their adequacy to address HRA needs for the EPR design.

However, even with these programs, the NRC recognizes the need to expand the capability of current HRA methods to address the needs of PSAs for external events.

Impact on the multi-unit sites (Question 13)

External hazards threaten simultaneously all the units at the site. The assumptions about dependencies may influence the results. The units at a multi-unit site may be able to support each other in emergency situations (loss of electric power supply etc.). On the other hand, problems at one unit may require resources from other units. However, the practices to consider in the analysis the impact on the multi-unit sites are different.

In Canada common mode impacts that may affect more than one unit are fully addressed in internal events PSA models and will be addressed in any future EE studies.

In Finland no special analyses have been carried out for multi-unit sites. However, some interconnections between units have been modelled.

In France, the external events included in the internal events PSA done by IRSN (i.e. loss of heat sink and loss of external power) consider the impact on the multi-unit sites. Both, the advantages and the disadvantages of the multi-unit sites are modelled (plants dependency on some equipment and resources sharing but also the possibility of mutual back-up).

In Germany there are no special considerations for analyzing multi-unit sites.

In Japan in the internal event PSA "cross-tie of electric power supplies" among units at the multi-unit sites is taken into account because the cross-tie is realized as one of accident management measures. There are many research activities in simultaneous failure in seismic PSA.

In Korea there is no special consideration for analyzing multi-unit sites. Only a research program was performed for multi-unit loss of off-site power induced by typhoon. A research program for multi-unit sites effects is being prepared.

In Slovakia, total loss of all off-site power supplies to multi-units is considered only in case of seismic event.

In Switzerland the support from systems of the other unit (located in the same site) is accounted in the model, it shall be considered that these systems may not be available due to the external initiating event.

In Chinese Taipei there is no special consideration for analyzing multi-unit sites.

In the USA currently, the risk is evaluated on a per unit basis for U.S. plants. Whether the risk for the entire site should be evaluated is an NRC Commission policy issue that has not yet been addressed. Further, most recent studies have not addressed the potential for a single external hazard to cause concurrent accidents at multiple units.

However, in the ASME/ANS standard, while the risk (e.g., CDF from external effects) is calculated on a per unit basis, the effects of one unit on the shared systems at multiple-unit sites have to be addressed.

PSA integrated models (Question 14)

It is generally accepted that the risk coming from the external hazards should be accounted for in the PSA. Some will need detailed analysis with specialist input as for example the aircraft crash. Others, which are clearly only going to make a minor contribution to risk, may be treated by an approximate treatment (hand calculations may suffice). In the latter case, it is desirable for the results of the hand calculations to be incorporated in the computerized evaluation of the PSA, so that importance factors can be calculated and sensitivity studies performed without recourse to supplementary manual manipulations.

However, the status of the development of integrated PSA models including the external events varies. Nevertheless, all the countries are aware of the importance of considering the external events contributions while performing PSA applications. Some examples are presented below:

In Finland the External Events are included in the integrated Living PSA models. Some early versions of EE PSA were separate models.

In France, the internal events PSA model incorporates model for the loss of heat sink and loss of off-site power initiating events.

In Germany, EE PSA are partly integrated in the Level 1 PSA model, developed e.g. with the RiskSpectrum program, and partly treated separately.

In Japan EE PSA has not been performed. However, the PSA application is made within the risk information obtained from the PSAs, in accordance with the purpose of application. For example, when risk information is used for assessing acceptability of a change in allowed outage time (AOT) of a safety system, the risk increase due to the change will be estimated mainly by the internal event PSA at the rated power operation. Need for PSA to quantify the risk increase caused by other types of initiating events may be eliminated if some qualitative consideration can show the risk increase would be small. On the other hand, when a PSA is to be used to assess the overall risk of a NPP and compare the risk with the proposed safety goal of the Nuclear Safety Commission, it is necessary to include all types of accidents, caused by external and internal initiating events except for those caused by sabotage, as far as they may have significant contribution to the total risk. Reference: Special Committee on Safety Goals, Nuclear Safety Commission, "Interim Report on a Study on Safety Goals", December 2003.

In Korea, integration of all event groups in one PSA model is ongoing. The EE PSA contribution in PSA application is always considered.

In Mexico, at the moment, when extreme weather condition is expected, there is an increase of the loss of off-site power frequency in the risk monitor to take into account their effects.

In Slovakia the external events are included in the integrated PSA models.

In Switzerland, external events are required to be integrated in the PSA model.

In Chinese Taipei, quantitative PSA model for external events was developed.

In the USA, generally, the risk associated with each hazard group (e.g., internal fire, earthquakes, high winds) is calculated in separate risk models, not in a single integrated PSA model. The results (e.g., CDF) from each individual model are then summed to provide the overall risk (e.g., total CDF). In either case, when combining the results from the different hazard groups, it is essential to account for the differences in levels of conservatism and levels of detail so that the conclusions drawn from the results are not overly biased or distorted. To support this objective, the ASME/ANS standard is structured so that requirements for the analysis of the PSA results, including identification of significant contributors, identification and characterization of sources of uncertainty, and identification of assumptions are included.

Recent developments and research, Available documents (Question 15)

The need for further research and methodological improvements in order to improve the external events contributions consideration in the overall risk profile of the plants is generally recognized. Some examples of research projects and methodological developments are presented below. These projects concern in general methods development, determination of rare event frequency/intensity distributions, assessment of effects of climate change, etc.

In Finland, plant site specific studies focused on intensity - frequency distributions for extreme wind speed, temperature and high seawater level have been contracted by STUK and by the licensees from the Finnish Meteorological Institute and Institute of Marine Research. Extreme weather conditions and the effects of climate change have been included as a new topic in the Finnish national nuclear safety research program SAFIR2010.

In Germany R&D projects for development of advanced methods for treating EE in PSA are ongoing (e.g. earthquake) or planned (other EE, in particular for LP/SD states). A pre-research study is being carried out for finding out if methods have to be developed specifically for considering the recent climate changes and weather conditions in Europe.

A few papers prepared in Japan are presented below:

(1) PSA for volcanic activity; Tetsukuni OIKAWA et al., "Development of Screening Method for Volcanic Activity", Proceedings of The 4th International Conference on Probabilistic Safety Assessment and Management (PSAM-4), New York (1998). This paper presents a development of a screening method for volcanic activity for use in the first step of probabilistic safety assessment (PSA) of nuclear power plants (NPPs).

(2) Tsunami PSA and Slope PSA; The examination guide for seismic design of nuclear power reactor facilities revised in September, 2006 requires the consideration for the accompanying events of earthquake. Therefore JNES have started to develop the methodologies for Tsunami PSA and Slope PSA. The available references are the followings:

   (a) Tsunami PSA: M.Sakagami et al., "Development of Tsunami PSA method for nuclear power plants", Proceedings of the Autumn Conference of the Atomic Energy Society of Japan, Kitakyushu, Japan (2007).

   (b) Slope PSA: Hideharu Sugino et al., "Development of probabilistic safety assessment considering slope collapse by earthquake", Proceedings of the Specialists Meeting on Seismic Probabilistic Safety Assessment (SPSA) of Nuclear Facilities, in Jeju, Korea (2006).

In Korea some research or updating programs related to external hazards can be mentioned:

- new methodology for fire PSA using the simple fire information table (fire sources, fire mitigation system, fire wall design, etc.) without detailed quantification process is under development,
- new methodology to combine individual PSA models (internal, external and low power & shutdown PSA, etc.) into a single integrated PSA model is under development,
- new research program for seismic PSA updating is in progress.

In the USA, some examples of new developments related to external events PSA are the following:

- NRC's SPAR models project

  The NRC is developing Standardized Plant Analysis Risk (SPAR) models for each plant and is in the process of benchmarking the models against licensee PSAs. NRC's SPAR models are Level 1, internal event, at-power PSAs. Work is ongoing to develop large early release frequency (LERF) models and to address events at shutdown and external events. "External events" in these models are defined to include internal flooding, internal fires, seismic events, high winds and hurricanes, external floods, and other external events. The models address the effect of external events through user-defined model elements (the models do not provide full phenomenological treatments of the external events themselves).

  The objective of SPAR-EE (external events) models is to complete the plant risk profile so that when the NRC analysts estimate the importance of plant conditions and events, they can get an accurate (more complete) estimate, as opposed to limiting their analyses to internal events only. This completeness is required by the current procedures for the NRC's Significance Determination Process.

- Revised external events standard

  The American Society of Mechanical Engineers (ASME) and the American Nuclear Society (ANS) jointly issued a PSA standard, "Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications," ASME/ANS RA-S-2008. This standard is for operating light water reactors (LWRs) and the scope of this standard is internal and external events (Part 4 of this standard is for external events). The NRC staff position on this standard is in Revision 2 of RG 1.200 (to be published December 2008.) A draft of Revision 2 (DG 1200) was issued for public review and comment June 2008.

- "Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants," Regulatory Guides 1.76, Revision 1 and "Tornado Climatology of the Contiguous United States," NUREG/CR-4461, Revision 2.

  Regulatory Guide 1.76 provides new guidance for use in selecting the design-basis tornado and design-basis tornado-generated missiles that a nuclear power plant should be designed to withstand to prevent undue risk to the health and safety of the public. It uses new data and the Enhanced-Fujita scale. It makes use of NUREG/CR-4461, Revision 2.

- NRC work on Hurricanes

  The NRC's Office of Nuclear Regulatory Research, in conjunction with the Office of Nuclear Reactor Regulation, is working on the definition of design-basis hurricanes in order to develop a regulatory guide on hurricanes.

- U.S. research on hurricane frequency

  Research groups, such as Kerry Emanuel's at MIT, are doing work on how hurricane intensity depends on the earth's surface temperature. This may link hurricane frequency with global warming concerns.

2.4 Results and Practical Applications

Examples of results, identified vulnerabilities and safety improvements (Question 16)

Results:

Most of the survey respondents either indicated that the question was not applicable, or did not provide results in their answers. For the respondents that did answer the question, their analyses have found EEs to range from having no significant effect on risk, to being worthy of note and the investment of limited effort to improve plants and their operating practices. Insufficient information has been provided to determine the degree of uncertainty in the results.

While the detailed responses can be found in Appendix 3, key aspects of the responses follow. The **Slovak Republic** has considered meteorological conditions and concluded that they do not need to be included in PSA. They also determined that other EEs have only negligible contributions to risk. **Switzerland** found that EEs are not dominant, but in some cases (for their plants with the lowest CDFs or LERFs) they are relevant (specifically, in descending order of importance: high winds, aircraft crash, and external flood).

Vulnerabilities and safety improvements:

No vulnerabilities have been identified from considerations of EEs, but practical safety measures have been identified, considered for implementation, and in many cases carried out. Just under half of the survey respondents provided example safety measures. These safety measures include plant modifications and changes to operating procedures. Also, in Switzerland, full scope PSA results with EEs have been used to derive scenarios for emergency exercises and to improve emergency response instructions.

Regarding the counties' specific responses, the **USA** did not identify any vulnerabilities, but improvements were considered and some were implemented. In the USA's IPEEE program, none of the 70 IPEEE submittals identified any high winds, floods, and other external events (HFO) - related vulnerabilities. However, 34 submittals reported that they had either made, or were considering, a total of 64 HFO-related improvements (examples of which can be found in Appendix 3). Based on the EE PSA in **Korea**, minor suggested modifications were made to various areas, including installing a spray system in a switchyard to protect against salt contamination transferred by typhoon. **Chinese Taipei** performed a typhoon PSA which resulted in suggested modifications being made regarding the gas turbine, the alternate AC power source if a loss of off-site power (LOSP) event occurs. The suggestions included improving the fragility of the gas turbine building and burying the power transmission cable from the gas turbine to the switchyard. Corrective measures initiated by PSA in **Finland** include plant modifications and procedure development to prevent the risk of seawater intake blockage due to frazil ice formation, algae, or oil slick as well as prevention of blockage of diesel generator combustion air intakes. EEs are also currently being taken into account in the PSA of the new reactor under construction in Finland, Olkiluoto 3. In the design of Olkiluoto 3, special care has been taken to remove risks due to external hazards (e.g., protection of diesel generator air intakes and underground cables from a gas turbine plant).

Integration of the EE PSA results in the overall risk and treatment of uncertainty (Question 16 bis)

If EE PSA is done, the results are in general integrated in the overall risk.

For external events the uncertainties are large and uncertainty analysis and sensitivity analysis can be especially important. However, special considerations of uncertainty analysis were not reported in general. In Chinese Taipei's answer it was pointed out that the contribution of typhoon risk is less than 3% of the overall risk and there is no special measure taken to highlight the uncertainty.

It was pointed out in the USA answer that, for many applications, it is necessary to combine the PSA results from different hazard groups (e.g., from internal events, internal fires, and external initiating events). For this reason, an important aspect in interpreting the PSA results is understanding both the level of detail associated with the modeling of each of the hazard groups, and the hazard group-specific model uncertainties. With respect to the level of detail, for example, the analysis of specific scope items such as internal fire, internal flooding, or seismic initiating events typically involves a successive screening approach, so that more detailed analysis can focus on the more significant contributions. The potential conservatism associated with the evaluation of the less significant contributors using this approach is assessed for each hazard group. In addition, each of the hazard groups has unique sources of model uncertainty. The assumptions made in response to these sources of model uncertainty and any conservatisms introduced by the analysis approaches can bias the assessment of importance measures with respect to the combined risk assessment and the relative contributions of the hazard groups to the various risk metrics. Therefore, the sources of model uncertainty are identified and their impact on the results analyzed for each hazard group individually, so that, when it is necessary to combine the PSA results, the overall results can be characterized appropriately. The sensitivity of the model results to model boundary conditions and other assumptions is evaluated, using sensitivity analyses to look at assumptions both individually and in logical combinations. The combinations analyzed are chosen to account for interactions among the variables. NUREG-1855 provides guidance on the treatment of uncertainties associated with PSA. The understanding gained from these analyses is used to appropriately characterize the relative significance of the contributions from each hazard group.

In Finland the contribution of external events is significant but formal uncertainty analysis has not been done. It was also pointed out that a bias due to conservative assumptions is possible, but, in general, it is not considered a serious problem regarding decision making. If a problem area is identified with external events PSA, alternative actions are examined, including refinement of the analysis, improving EOPs, additional training and plant modifications. Decisions on actions will be taken on a case by case basis considering also deterministic design principles and the SAHARA principle.

In PSA applications, such as RI-ISI, RI-IST and RI-TechSpecs, the decisions are usually based on risk increments related to equipment unavailability. The uncertainty and possible overly conservative treatment of external events does not in general affect the decisions.

The large uncertainty and conservatism in the treatment of external events may affect risk informed decision making in some special cases, e.g., when seawater systems and decay heat removal are considered. In risk informed review of Technical Specifications decisions have to be made on allowable outage times and on continued operation versus shutdown. In such applications comparison of risks due to internal failures and external events may be necessary. If the level of conservatism is different for different types of events, the optimal solution will be biased.

However, the risk assessment of the EEs may be reconsidered and refined for particular PSA applications (e.g. if the assessment of an EE is potentially crucial for a risk-informed plant modification or for an assessment of an event).

Events caused by harsh weather—examples and effects on performing EE PSA (Question 17)

Examples:

Most project participants reported example EEs. These included conditions related to precipitation and low temperatures, wind, ocean level changes, organic material buildup around water intakes, and combinations of issues due to events such as typhoons or hurricanes. Such EEs have led to unavailable components and degraded systems (both internal and external to the plant), and thus effected plant capabilities and risk levels. Because of EEs, licensees have had to address issues such as LOSP, water intake blockage, reactor scrams, and decisions to shutdown plants in anticipation of and during EEs.

Regarding example EEs related to precipitation and low temperature conditions, **Belgium** reported that harsh weather conditions (especially extreme cold conditions) have led to a few reactor scrams without further complications. Belgium also observed some partial system unavailabilities due to extreme cold weather, but again they did not cause further complications. Regarding ice, **Canada** reported that the freezing of water pipes caused by open ventilation panels lead to flooding. In **France**, ice formation lead to the loss of four main transformers and partial plugging of a pumping station. Several countries reported examples of events related to snow. In **Finland**, diesel generators failed to run during testing due to snow blocking the combustion air filters. In **Japan**, heavy snowfall caused LOSP twice in one week (where in one case, one of the off-site power lines and an emergency diesel generator were unavailable for maintenance). **Korea** mentioned experiencing heavy snow, but did not provide further details.

Several countries reported blockage of water intake, both caused by organic material and typhoon; other typhoon related issued were also mentioned. **Finland** reported partial blockages of service water intake by frazil ice, algae, and mussels. **France** reported pumping station partial plugging due to algae, mollusks, and sand. **Korea** and **Chinese Taipei** both reported typhoon related issues, including intake blockage. Chinese Taipei reported typhoon related operating events such as intake blockages leading to a manual scram, wind damaging a switchyard and causing the reactor to scram due to LOSP, a plant losing one of its off-site power supply sources due to lightening damaging the offsite power grid, and a reactor scramming due to LOSP when high salt concentration in the air lead to the instability of the power grid.

Other issues reported include **France** mentioning a flooding example at one of their sites, and **Korea** noting a local forest fire. The **USA** reported examples of LOSP caused by weather-related conditions. **Germany** indicated that they had no reported cases of events caused by harsh weather conditions.

Effects of operating events on PSA:

For countries that have had operating events due to EEs, some have not reported any EE PSA changes, one country indicated they were considering incorporating events into their EE PSA at a later time, and some have changed their PSAs. Only Finland reported a non-nuclear plant event that influenced EE PSAs. None of the respondents identified any events with significant complications (e.g., dependent failures) that might require a re-examination of the way EE analyses are performed.

Following heavy snowfall and LOSP in **Japan**, accident sequence precursor analysis was carried out for the events; but this did not become a motivation for developing EE PSA other than seismic PSA. **Korea** indicated that some of the events they have observed may be considered in internal or external events PSA. **Switzerland** reported that in consequence to increases in public interest after some occurrences, and in order to allow for sound comparisons of the PSA results, it became important to further harmonize the EE analyses-methodologies used in the Swiss PSAs. Events in **Finland** have been incorporated into their PSAs, including an occurrence at a conventional power plant (where there was a loss of the external power grid connection due to steel panels being torn off from a plant's walls and flown to the switchyard).

3. CURRENT STATUS AND ISSUES OF EXTERNAL EVENTS PSA

In regulatory requirements there is a general trend towards full-scope PSA, including external events. The national requirements range from no legal requirements on PSA to explicit requirements on Level 1 and Level 2 PSA for operating and new units for all operating states and for all groups of initiating events, with specific mention on off-site external events.

There are wide variations in the current status of external events PSAs in OECD countries. In a few countries external events PSAs with a fairly wide spectrum of initiating events have been performed or are underway for operating units. In some countries the analysis has been limited to the most severe events, such as hurricanes/typhoons, and in a few countries no external events PSAs have been carried out. In most countries external events PSA will be performed for new NPP units.

There are also differences in the role of external events PSA in the regulatory framework. In some countries external events PSA has an important role in assessing whether the protection against extreme external events is sufficient, especially as regards older units. In other countries the emphasis is on deterministic design requirements.

The results of the questionnaire do not show a general trend that external events are especially important risk contributors. However, for some individual plants external events have been found to be quite significant. At two plants significant risks due to external hazards have been identified and mainly eliminated by plant modifications. At one of them off-site external events still account for 18 % of the total CDF.

Based on the questionnaire it is not possible to evaluate what are the reasons for differences in the importance of external events for different plants. The difference may be due to local conditions and differences in technical solutions. However, it is also possible that the differences in results are due to differences in the analysis methods and level of details in modelling.

Depending on design- and site-specific details, severe external events may have the potential to simultaneously affect redundant and diverse safety systems and thereby induce common cause failures (CCFs) or common cause initiators (CCIs). The results of external events PSA depend largely on the possibility of common cause failures of safety systems. The results are sensitive to the modelling of dependencies between initiating events and safety system failures as well as between failures of different safety systems. Different approach to the analysis of potential common cause failures and identification of dependencies may have significant influence on the results. However, well established methods for the treatment of dependencies between extreme weather conditions were not reported. The analysis seems to be done on a case by case basis.

The questionnaire did not reveal general deficiencies in methods, but only a few extensive external events PSAs were reported. The external events PSA is started by identification of potentially significant events and combinations of correlated events. The second phase is typically screening analysis to select the events and combinations of events to quantitative analysis. The frequencies of potential extreme weather conditions are difficult to estimate and uncertainties are large. Screening events out of EE PSA seems to be largely based on expert judgement. The screening results may be influenced by the treatment of uncertainties and dependencies between extreme weather conditions. This topic could not be treated in detail in this task.

Standards and guides are available. ANS has published a standard on external events PSA and, for example, SKI has published a report describing methods used in Sweden and Finland. In addition, IAEA has published several reports on external events.

4. RECOMMENDATIONS

According to the findings of the Task Group, more work, including research, is needed in the following areas:

- Effects of climate change on extreme events and NPP safety
- Uncertainties related to extreme weather conditions
- Treatment of dependencies
  - between external events, e.g., extreme weather conditions
  - between initiating events and safety system failures
- Criteria for screening phenomena out of EE PSA.

Systematic analysis of operating events due to harsh weather and other external conditions would provide valuable input for EE PSA.

Identification of significant external events analysis requires good knowledge on local conditions. The national regulatory authorities, licensees and PSA consultants should evaluate whether they have sufficient awareness of external events and adequate analysis capabilities.

However, international cooperation would be valuable to enlarge the data basis in the analysis of operating events due to harsh weather and other external conditions.

Only limited actions to follow up developments in the field of external events PSA are recommended: NEA member countries should follow research on climate change and its effects. In practice this can be done by reporting developments on external events PSA in WGRISK meetings, and by keeping abreast of particular programs (including an IAEA program assessing potential effects of climate change on nuclear power plants). The CSNI/WGRISK should re-evaluate the situation on external events PSA in a few years.

Moreover, WGRISK should check possibilities to analyse operating events due to external events in co-operation with WGOE and possibly with IAEA and EU. Some earlier preliminary studies suggest that external events are significant contributors to certain types of operating events, such as loss of off-site power, loss of emergency power and loss of ultimate heat sink. Systematic analyses, however, are not publicly available.

External events issues have been treated on several international forums, for example, in special sessions of the PSAM and PSA conferences. Continuation of the practice is recommended and licensees, regulators and research organizations of NEA member countries are encouraged to participate in these activities to exchange information on off-site external events.

Based on these conclusions, the following general recommendations are proposed to all parties active in the PSA field, including international organizations, utilities, regulatory authorities, PSA consultants and research organizations):

- Follow research on climate change and its effects (including potential effects on nuclear power plants, such as those being studied by IAEA).
- Re-evaluate the situation on external events PSA in a few years.
- Encourage analysis of operating events caused by external hazards.
- Participate in sessions on external events in international conferences, e.g.PSAM and PSA.

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APPENDIX 1. TASK WGRISK (2006)1 CAPS

WGRisk (2006)1

Project/Activity Title	**Probabilistic Safety Analysis (PSA) of Other Off-site External Events than Earthquake**
Objective	The objective of the task is to review the methods for risk analysis of off-site external events other than earthquake as well as the results and the insights developed in these analyses in order to present a basis for advances in the area.
Scope/Justification/ **Deliverables, Expected results and users, Relation to other projects**	Justification: According to risk analysis results that have been carried out in some countries, off-site external events may have a high contribution to the overall risk for nuclear plants. Traditionally, NPPs have carried out PSA studies of on-site fires, floods and off-site earthquakes. Lately, more and more attention has been paid to other types of external events, too, like extreme weather conditions, the frequency of which seems to be increasing according to some latest international reviews. A technical discussion on this topic has taken place during the 2006 WGRISK meeting and it led to a conclusion that a task would bring significant added value to CSNI member countries. Relation to other projects: WGRisk has already carried out a task on Fire PSA and a Workshop on seismic PSA in November 2006. Scope: The new activity intends to be a complement of the earlier work by collecting information related to the probabilistic treatment of other off-site external hazards (high winds and tornados, extreme temperatures, rain and snowfall, etc.). Deliverables: A report presenting the status and new method developments will be prepared. It will include a compilation of the PSA studies carried out for other off-site external events than seismic. The report will also address the methods (initiating events identification and quantification, accident sequences identification, etc.), off-site event uncertainties (e.g. initiator frequency & population, combined phenomena, effect on plant, plant personnel actions in extreme conditions) as well as the insights and results (off-site event contribution to the overall risk, lessons learnt, plants modifications, etc.).

Safety significance/ priority (see priority criteria in Section IV.1)	The activity corresponds to all the CSNI criteria, especially: - High safety significance - Better accomplished by international group - Likely to bring results in a reasonable time frame
Safety Issue and topic covered	The proposal is particularly related to three CSNI safety issues: Technical basis for risk-informed regulation, risk-informed safety management and external events.
Milestones (deliverables vs. time)	2007: Planning of scope. Preparation of a questionnaire Collection of information by the questionnaire. 2008: Draft report on comparison, evaluation, recommendations if appropriate available for 2008 WGRisk meeting. Decision point about follow-up proposals. Submission of the report to the CSNI. The information collection will be done mainly by e-mail. Two or three work meetings will be organized for writing the report.
Lead organization(s) and coordination	CNSC, Canada; STUK, Finland (chair); USNRC (USA); HSK, (Switzerland); IRSN (France). The work will be coordinated with the IAEA.
Participants (individuals and organizations)	All the WGRISK member countries are asked to participate in replying to the questionnaire. In –depth work with those countries having carried out method development and studies.
Resources	For lead countries the effort will consist of drafting the questionnaire, compiling the replies and drafting the report. It is expected that this will take in the order of 3-4 man months. Replying to the questionnaire will take depending on the experience and insights to be shared from 1 hour to two weeks (the latter estimate will be divided into many shorter periods and includes the working meetings). This will lead to an estimated overall effort of about 1 man-year.
Requested action from PRG/CSNI	
PRG Recommendation	
CSNI Disposition	

APPENDIX 2. QUESTIONNAIRE ON EXTERNAL EVENTS PSA (OTHER THAN SEISMIC)

Identification

Please identify your organization
Name of organization:
Contact person:
Address:
Telephone:
Telefax:
E-mail:

Return address

Please fill in your answers in this file and return it by e-mail to Dr. Jorma Sandberg, Radiation and Nuclear Safety Authority - STUK, e-mail jorma.sandberg@stuk.fi, by **7 September 2007**and a copy to Dr. Pekka Pyy, OECD/NEA, e-mail: pekka.pyy@oecd.org .

Introduction

In December 2006 OECD/NEA Committee on the Safety of Nuclear Installations (CSNI) set up a Task Group on PSA of Other Off-site External Events than Earthquake (EE PSA) The objective of the task is to review the methods in this field as well as the results and the insights developed in these analyses in order to present a basis for advances in the area.

An essential part of the task is collecting information related to the probabilistic treatment of other off-site external hazards (high winds and tornados, extreme temperatures, rain and snowfall, etc.) with this questionnaire.

Based on this information the Task Group will produce a report presenting the status and new method developments. It will include a compilation of PSA/PRA studies carried out for other off-site external events than seismic. The report will also address the methods (initiating events identification and quantification, accident sequences identification etc.), off-site event uncertainties (e.g. initiator frequency & population, combined phenomena, effect on plant, plant personnel actions in extreme conditions) as well as the insights and results (off-site event contribution to the overall risk, lessons learnt, plants modifications, etc.). [1]

The US approach to external events PSA/PRA is described in the ANSI/ANS Standard on external events PRA [2]. A fairly detailed description of the procedure used for EE PSA in Finland and Sweden and a comprehensive list of potentially important external events is presented in [3].

Draft answers given by Finland and Taiwan are attached to this questionnaire.

References

1. CSNI WGRisk Task 2006 - 1 Description, OECD/NEA, 2006.

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1. Regulatory Requirements and Status of EE-PSA

The purpose of questions 1 - 4 is to collect information on regulatory requirements and actual status of PSA of external events other than seismic as well as on the role of EE PSA in the regulatory process.

Q1. Are there **regulatory requirements** on External Events PSA for other hazards than earthquake (EE PSA) in your country? Please specify possible requirements concerning:

- power operation and shutdown states
- Level 1 and Level 2 analyses.
- existing units and new units under design or construction
- relevant regulatory guides.

Q2. What is the current status of EE PSA?

- Have EE PSAs in general been done for NPPs in your country?
- Include also information of screening studies, simple quantifications and semi probabilistic evaluations
- Are there plans to carry out additional analyses?

Q3. What are the objectives of EE PSA?

- E.g, demonstration of fulfilment of probabilistic safety criteria, adequacy of design basis, identification of vulnerabilities.
- Demonstrating that there are no “cliff edges” related to exceeding of design values.
- The role of EE-PSA in the regulatory process, current situation, possible future plans.

Q4. What are the most important national or international guides on EE PSA methods applied in your country?

2. Definition of EE PSA scope

The purpose of questions 5-6 is to find out how EE-PSA is defined in different countries and what its the scope typically is.

Q5. What are the criteria for including an initiating event in EE PSA instead of, e.g., internal events PSA?

Note: Some initiating events caused by external hazards are typically included in the internal events PSA initiating event frequencies, if they do not have direct impact on the performance of safety systems. EE PSA covers events causing plant shutdown or an initiating event and simultaneously degrading safety systems.

- E.g., is the Loss of Off-site Power considered in internal or external events PSA?

Q6. What is the scope of external hazards (other than seismic) to be analyzed?

- E.g., harsh weather conditions, oceanographic events, floods, oil spills, organic material in cooling water (algae, mussels, medusas, fish), external explosions, transportation accidents etc.

- A list of events which typically have been included in EE PSA is appended. Please give national information (representative examples) on events:

  a. included in screening analysis
  b. selected for quantification
  c. identified as important risk contributors

- Are there significant differences in the scope of EE PSA between power operation and shutdown states or between Level 1 and Level 2.

3. Analysis Methods

Questions 7 - 15 are related to analysis methods. The formulation of the questions is based on a stepwise method including identification of potentially significant external hazards, qualitative and/or quantitative screening of events and PSA modelling and quantification of the events not screened out. If some of the questions are not directly applicable to your approach to EE PSA, please give relevant information.

Q7. Please explain the identification of potentially significant external events.

Note: An example of a list of potentially significant external events is shown in Appendix 1.

Q8. How are significant combinations of external hazards identified? Give examples of combinations of hazards considered in EE PSA and of the methods used to analyse the dependencies.

Note: Combinations of dependent external hazards have been found significant if they threaten simultaneously diverse safety systems. For example, a storm may result in large amounts of algae or other organic material in seawater intakes and threaten simultaneously external grid and diesel generator cooling water intake.

Q9. Please describe the screening procedures and criteria for selecting EEs for detailed modelling and quantitative analysis.

Q10. How are event frequencies or frequency – intensity distributions determined for external hazards (general principles and/or examples)? How are uncertainties treated?

Q11. How do you identify initiating events caused by external hazards (analyses, operating experience and/or expert judgment)? Are the potential induced internal hazards (fire, flooding) also considered in the analysis?

Note: In some EE PSAs the external condition or event, e.g., *algae in seawater* is called an external hazard and the event at the plant, e.g., *the blockage of seawater intake by algae* is an initiating event (loss of service water).

Q12. Are there any special methods to evaluate the effect of external events on human reliability?

Note: External events may lead to harsh personnel working conditions, problems in getting external aid and increase their decision burden. Examples of include, e.g., site isolation in consequence of a storm, worrying about the situation of family members, adverse conditions for countermeasures requiring working outdoors (wind, rain, snow, heat, cold).

Q13. Are there any special considerations for analysing multi-unit sites?

Note: External hazards threaten simultaneously all the units at the site. The assumptions about dependencies may influence the results. The units at a multi-unit site may be able to support each other in emergency situations (loss of electric power supply etc.). On the other hand, problems at one unit may require resources from other units.

Q14. Are the EEs included in a PSA integrated model? If not, please indicate how the PSA applications taking into account the EE contributions are usually performed?

Q15. If applicable, list any research projects and publications related to external hazards in your country or any other information you would like to share.

- recent methods development (past few years)
- determination of rare event frequency/intensity distributions
- methods development
- effects of climate change, any ongoing or planned projects.

4. Results and Practical Applications

Q16. Give examples of result of EE PSAs, uncertainty of results, identified vulnerabilities and practical safety measures based on the results.
E.g., plant modifications, operating procedures, definition of design basis for EEs.

Q17. Give some examples of events which have been caused by harsh weather conditions or other EEs in your country. Have operating events changed the way of doing EE PSA?
Also events from other than nuclear plants which have influenced EE PSAs.

Appendix 1, List and Characterisation of External Events
Based on Ringhals (Sweden) EEA [SKI 02:27]

ADDITIONAL QUESTIONS

Background

The NEA/CSNI Task Group on PSA of Other Off-site External Events than Earthquake distributed a questionnaire on 28 June 2007. Drafting the task report has been started based on the answers. In the Task Group meeting on 3 March 2008 it was agreed that two additional questions will be distributed, one on treating the dependencies between initiating events and safety system degradation and one on the aggregation of PSA results.
The task group would appreciate if you could answer the questions by 7 June 2008.

Identification

Please identify your organization
Name of organization:
Contact person:
Address:
Telephone:
Telefax:
E-mail:

Return address

Please fill in your answers in this file and return it by e-mail to Dr. Jorma Sandberg, Radiation and Nuclear Safety Authority - STUK, e-mail jorma.sandberg@stuk.fi, by **7 June 2008** and a copy to Dr. Nathan Siu (nos@nrc.gov) and Dr. Gabriel Georgescu (gabriel.georgescu@irsn.fr).

Additional question I (Question 11bis)

An important consideration in EE PSA is whether the hazards analyzed can, in addition to disturbing the operation of the plant, also disable or degrade the safety systems. Thus, the modeling of dependencies is a key point in the analysis. This aspect can be important even during initial screening, since the screening out of external hazards without consideration of dependencies can underestimate the associated risk. Note that analyses considering external induced initiating events in the frame of internal events PSA (e.g., extreme-weather induced losses of offsite power) may not always consider important dependencies (e.g., a snow storm leading to loss of offsite power and to degradation of diesel generators).

How do you identify the dependencies between the initiating events caused by external hazards and the safety systems?

At which stage of the analysis is this identification done? How are the dependencies modeled in the EE PSA?

For the external induced initiating events considered in the frame of the internal events PSA, are these dependencies considered?

Additional question II (Question 16bis)

The uncertainties in the results of an EE PSA are due to uncertainties in the frequency and magnitude of the external events, and to uncertainties in the effect of these events on the plant. Past analyses have shown that EE PSA uncertainties can be considerably larger than the uncertainties in internal events PSA results. Furthermore, recognizing that many EE analyses are conducted at a screening level, the calculated risk for a given hazard may be conservatively biased. These observations raise a question as to how the results of EE PSA are used in decision support applications.

When used to support decisions involving consideration of total plant risk, are the results of EE PSA presented separately from the results of internal events PSA, or are they integrated into a statement of overall risk? If the latter, are there any special measures taken to highlight potentially significant biases and uncertainties in the EE PSA results?

List and Characterisation of External Events Based on Ringhals (Sweden) EEA [SKI 02:27]

Code	External Events	Event Definition	Interfaces and Comments
A01	Strong winds	The event is defined as damage to the plants due to strong winds. It includes both direct damage from wind pressure and indirect damage due to wind-carried missiles.	The event does not include tornado (A2) due to the unique characteristics of this event. The event does not include the differentiating effects from snow storm (included in A7), salt storm (A12) or sand storm (A13). However, the wind effects from these events are included. Effects from storm surges are covered by the event high sea water level (W3)
A02	Tornado	The event is defined as damage to the plants due to tornadoes. The event is separated from other strong winds due to its special characteristics both with respect to duration, wind speed, and frequency of occurrence.	
A03	High air temperature	The event is defined as plant impact due to high air temperature.	Plant impact due to high water temperature is treated separately (W4).
A04	Low air temperature	The event is defined as plant impact due to low air temperature.	Plant impact due to low water temperature (W4) or ice impact (W7, W8, and W9) are treated separately.
A05	Extreme air pressure (high / low / gradient)	Plant impact from high or low air pressure or from quick pressure changes.	
A06	Extreme rain	The event is defined as damage to the plants due to extreme rain. It includes both damage from rain load on structures and damage due to rain induced flooding.	
A07	Extreme snow (including snow storm)	The event is defined as damage to the plants due to extreme snow, including snow storms.	Wind effects from snow storms are covered by the event strong wind (A1). Flooding effects due to melting of snow judged to be bounded by flooding effects from extreme rain (A6).
A08	Extreme hail	The event is defined as damage to the plants due to extreme hail. It includes damage from hail load on structures.	Flooding effects due to melting of hail are bounded by flooding effects from extreme rain (A6). Any possible effects on the ultimate heat sink are judged to be bounded by ice events (W7, W8 and W9).
A09	Mist	The event is defined as plant impact due to mist.	
A10	White frost	The event is defined as plant impact due to white frost.	
A11	Drought	The event is defined as an extended drought period that lowers the water level of lakes, rivers and open water basins.	Possible plant effects due to high air temperature (A3) or high water temperature (W4) are covered by the analysis of these events. No effect on water level (heat sink).
A12	Salt storm	The event is defined as a storm involving salt covering of plant structures.	Wind effects from salt storms are covered by the event strong wind (A1).
A13	Sand storm	The event is defined as plant impact from a storm carrying sand.	Wind effects from sand storms are covered by the event strong wind (A1).

Code	External Events	Event Definition	Interfaces and Comments
A14	Lightning	The event is defined as plant damage due to lightning. The impact may be direct, causing structural damage or LOSP events, or indirect through the electromagnetic field or fire started by lightning.	Fire started by lightning is bounded by external fire (G7) and by the internal fire analysis.
A15	Meteorite	The event is defined as plant damage due to meteorite impact.	
A16	Explosion within plant	The event covers damage to the plants due to explosions (deflagration or detonation) of solid substances or gas clouds within the site. The damage may be due to pressure impact or impact from missiles.	Damage from missiles generated at another plant on the site are handled as part of (G11). Explosions in connection with transportation accidents within the site are handled as part of (A18). Toxic effects from a chemical release are covered by (A20).
A17	Explosion outside plant	The event covers damage to the plants due to explosions (deflagration or detonation) of solid substances or gas clouds outside the site. The damage may be due to pressure impact or impact from missiles.	The event does not include explosions in connection with transportation accidents outside the site (A18) or originating from pipelines (A19). Toxic effects from a chemical release are covered by (A20).
A18	Explosion after transportation accident	The event covers damage to the plants due to ground transportation inside and outside the site or due to sea transportation accidents. The damage may be due to pressure impact or impact from missiles.	The event does not includes damage due to airplane crash (A25) or originating from pipeline accident (A19). Toxic effects from a chemical release are covered by (A21).
A19	Explosion after pipeline accident	The event covers damage to the plants due to explosions (deflagration or detonation) after a pipe-line accident. The damage may be due to pressure impact or impact from missiles.	Toxic effects from a chemical release are covered by (A22).
A20	Chemical release outside or inside site	The event includes toxic impact due to chemical release outside or inside the site. These releases may originate from process accidents inside or outside the plant or from leakages of substances stored inside or outside the plant.	Explosion effects from a release outside or inside the site are covered by (A16 and A17). Toxic effects after transportation or pipeline accidents are analysed in A21 and A22.
A21	Chemical release after transportation accident	The event includes toxic impact due to chemical release after ground transportation accidents inside and outside the site or due to sea transportation accidents.	Explosion effects from transportation accidents are covered by (A18).
A22	Chemical release after pipeline accident	The event includes toxic impact due to chemical release after a pipeline accident.	Explosion effects from a pipeline accident are covered by (A18).
A23	Magnetic disturbance	The event includes impact from man-made magnetic or electric fields. The main examples of such fields are fields from radar, radio or from mobile phones.	
A24	Satellite crash	The event is defined as plant damage due to satellite impact.	
A25	Airplane crash	The event includes damage to plant structures due to an airplane crash within the site area. The airplane may be either commercial, private or military.	
G01	Land rise	The event is defined as impact on the plant from land rise.	
G02	Soil frost	The event is defined as impact on the plant from soil frost.	

Code	External Events	Event Definition	Interfaces and Comments
G03	Animals	The event is defined as impact on the plant from animals.	Impact on intake water from fish, mussels, etc., is covered by (W10).
G04	Volcanic phenomena	The event is defined as impact on the plant from volcanic eruptions.	
G05	Avalanche	The event is defined as impact on the plant from avalanches.	
G06	Above-water landslide	The event is defined as impact on the plant from above-ground landslide.	
G07	External fire	The event is defined as impact on the plant from fires originating from outside the plants, inside or outside the site area.	Internal fires spreading from another plant on site are treated separately (G12). Fires resulting as secondary effects from other external events are treated as part of these events (A16, A18, A25). Internal fires are analysed as part of the PSA area events analysis.
G08	Excavation work	The event is defined as impact on the plant from excavation work, inside or outside the site area.	
G09	Direct impact from heavy transportation within site	The event is defined as damage to the plant from direct impact from heavy transportation within site. This also includes the containment external maintenance platform.	
G10	Missiles from military activity	The event is defined as impact on the plant from missiles from military activity.	Impact on power supply and heat sink assumed to be bounded by other events.
G11	Missiles from other plant on site	The event includes damage from missiles generated at another plant on the site.	
G12	Internal fire spreading from other plant	The event is defined as impact on the plant from fires originating in another plant on the site.	External fires are treated separately (G7). Fires resulting as secondary effects from other external events are treated as part of these events (A16, A18, A25).
W01	Strong water current (under-water erosion)	The event includes damage to plant structures due to strong water current.	The effects from under-water landslide are treated separately (W6).
W02	Low sea water level	The event is defined as plant impact due to low sea water level.	Level decrease due to land rise is covered by (G1).
W03	High sea water level	The event is defined as plant impact due to high sea water level. The high levels may be due to storm surges, waves, and seiches. They are also affected by variations due to tide.	
W04	High sea water temperature	The event is defined as plant impact due to high water temperature.	Plant impact due to high air temperature is treated separately (A3).
W05	Low sea water temperature	The event is defined as plant impact due to low water temperature.	Plant impact due to low air temperature (A4) or ice impact (W7, W8, and W9) are treated separately.
W06	Under-water landslide	The event is defined as plant impact due to under-water landslide. An under-water landslide may be due to above-water causes, such as prolonged intense precipitation.	Plant impact due to under-water erosion is treated as part of the strong current event (W1).
W07	Surface ice	The event is defined as plant impact due to thick surface ice.	The event does not include effects due to frazil ice (W8) and ice barriers (W9).
W08	Frazil ice	The event is defined as plant impact due to formation of frazil ice in the cooling water intake.	
W09	Ice barriers	The event is defined as plant impact due to formation of ice barriers.	

APPENDIX 3. ANSWERS TO THE EXTERNAL EVENTS PSA QUESTIONNAIRE

Answers to the original questionnaire

Belgium answers

Identification

Please identify your organization

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ANSWER 1: No.

ANSWER 2: there is no EE PSA performed in Belgium and there are no plans in the near future.

ANSWER 3: Not applicable.

ANSWER 4: Not applicable.

2. Definition of EE PSA scope

ANSWER 5: Not applicable.

ANSWER 6: Not applicable.

3. Analysis Methods

ANSWER 7: Not applicable.

ANSWER 8: Not applicable.

ANSWER 9: Not applicable.

ANSWER 10: Not applicable.

ANSWER 11: Not applicable.

ANSWER 12: Not applicable.

ANSWER 13: Not applicable.

ANSWER 14: Not applicable.

ANSWER 15: Not applicable.

4. Results and Practical Applications

ANSWER 16: Not applicable.

ANSWER 17: . Harsh weather conditions (especially extreme cold conditions) have led to a few events (reactor scram) without further complications. Also some partial system unavailabilities due to extreme cold weather have been observed, without causing further complications. These events have not had any impact on performance of EE PSA for the Belgian NPPs.

Canada answers

Identification

Please identify your organization

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1. Regulatory Requirements and Status of EE-PSA

ANSWER 1: *CNSC Regulatory Standard S-294 contains the following:*
- *Perform a facility specific level 2 PSA for each NPP in question*
- *Include both internal and external events in the PSA*
- *For external events, the licensee may, with the agreement of "persons authorized" by the Commission, choose an alternative analysis method to conduct the assessment. In such cases, the external event may be excluded from the PSA.*

ANSWER 2: *No EE PSAs have been attempted at OPG*
- *A simple screening has been performed by the utility to identify potentially significant EEs*
- *The utility is considering an assessment of seismic risk*
- *An assessment of tornado risk may be required*
- *Qualitative assessments of fire and other external events have been completed*

ANSWER 3: *EE PSA is intended to:*
- *demonstrate that safety goals are met*
- *extend the scope of risk-informed decision making at operating plants.*

ANSWER 4: *There is no national guidance. In general, IAEA guidance would be followed.*

2. Definition of EE PSA scope

ANSWER 5: *EE PSA is intended to address events originating from outside the site boundary, however a limited number of events that meet this definition are included in the internal events PSA: Loss of Offsite Power, frazil ice or algae blocking the cooling water intake lines, extreme temperatures (hot and cold).*

ANSWER 6:
a-. *included in screening analysis*
Earthquake
Fire
Aircraft impact
Accidents at nearby industrial facilities and surface transportation
External Floods
Extreme winds
Extreme meteorological conditions
Missiles generated by turbine
Collisions of floating bodies with water intakes and ultimate heat sink components
Biological phenomena
Electromagnetic interference

b-. *selected for quantification*
Earthquake
Fire
Tornado
Aircraft crash

c- *identified as important risk contributors*
not completed

3. Analysis Methods

ANSWER 7: *Currently, only those external events related to the internal events PSA have been identified, i.e., those that can affect the function of internal plant systems and components (e.g.,loss of cooling water, power, freezing, overheating due to loss of air conditioning)*

ANSWER 8: *The IE PSA model contains flags that reflect possible impacts of external events (i.e. temperature)*

ANSWER 9: *A comprehensive list of external events can be found in the Nuclear Regulatory Commission (NRC) NUREG/CR-2300, "Probabilistic Risk Assessment (PRA) Procedures Guide",* *ANSI/ANS-58.21-2003 "External-Events PRA Methodology", and International Atomic Energy Agency (IAEA) Safety Guide No. NS-G-1.5 "External Events Excluding Earthquakes in the Design of Nuclear Power Plants".*

ANSWER 10:
Not addressed in screening analysis.

ANSWER 11: *Events are identified by literature search and operating experience*

ANSWER 12: *No*

ANSWER 13: *Common mode impacts that may affect more than one unit are fully addressed in internal PSA models and will be addressed in any future EE studies.*

ANSWER 14:*EE PSA has not been undertaken to date.*

4. Results and Practical Applications

ANSWER 16: *N/A*

ANSWER 17: *Freezing of water pipes caused by open ventilation panels leading to flooding*

Chinese Taipei answers

1. Regulatory Requirements and Status of EE-PSA

ASWER 1. No external hazard PSA was explicitly required by the regulatory agency (AEC) for three operating nuclear power plants. For Lungmen nuclear power plant, which is under construction, CDF and LERF of both internal and external events are required in FSAR.

ANSWER 2. For operating plants, only seismic and typhoon events were selected as the external initiating events. Level 1 PSA was first done in 1987. LERF estimation was then completed in 2003. New update for operating experience and response to the peer review comments were completed in 2007. Both level 1 PSA and LERF estimation are full scope quantitative analysis. The PRA procedure of NUREG/CR-2300 was followed for level 1 analysis. Simplified quantitative method of NUREG/CR-6595 was adopted for LERF calculation. No additional analysis was planed for the time being.

Lungmen (under construction now) living PSA is now being developed. In addition to seismic and typhoon events, tsunami was also considered as a possible initiating event. Qualitative screening study was first performed for typhoon event and tsunami event. Typhoon event was categorized as a loss of offsite power event in the internal event analysis. Tsunami event was screened out for its negligible impact on plant operation.

ANSWER 3. Since there is no regulatory requirement for external event PSA, the original objective to develop external event PSA was to estimate the total risk of the plant. As the AEC accepts to review the applications for online maintenance and limited safety issues in a risk-informed way, both internal and external events were often required for estimating the risk change. For the time being, the external event is maintained on the purpose of supporting the estimation of risk change (for both CDF and LERF).

ANSWER 4. The original external event PSAs were completed in 1996. No specific guide was available at that time.

2. Definition of EE PSA scope

ANSWER 5. Because of the lack of operating experience and model development, no explicit criteria was used for including an initiating event of external event analysis. Based on the specific climate and geographic condition, typhoon and earthquake were selected as the external initiating events. The reason is that these two initiating events need specific methodology to estimate the risk which is quite different than what was used in internal event studies. Initiating events other than typhoon and earthquake were implicitly considered in internal event analysis even those initiating events will cause both reactor scram and unavailable of some safety related supporting systems.

ANSWER 6. Only typhoon (if seismic event was excluded) is considered as an external initiating event in Taiwan. It is a typical extreme weather condition in summer time. Based on the experience of the past, several typhoons may attack the plant per year. Some typhoons may have strong wind which may damage the switch yard (outdoor design) and cause a loss of offsite power event. For Lungmen nuclear power plant (under construction), switch yard is an indoor design and will have no impact during typhoon attack. So that typhoon was considered as an internal event if loss of offsite power was occurred due to the unavailability of power grid outside the plant.

3. Analysis Methods

ANSWER 7. The identification of potential external events was based on the expert judgement through series of meeting. Experienced PSA consultants were invited to discuss the potential external events and then determine which event may be risk significant by considering the initiating event frequency and the impact to plant system.

ANSWER 8. For typhoon event, loss of offsite power was considered as the initiating event to cause plant shutdown. Because of the high possibility to affect the operation of service water system, bad sea water condition was also considered in the fault tree as a basic event.

ANSWER 9. The identification of potential external events and the event selection for further analysis were done at the same time by the expert judgement through series of meetings.

ANSWER 10. The hazard curve (speed of wind and its associated frequency of occurrence) of typhoon events was obtained by the data collected at local meteorological station. No uncertainty analysis was done for the hazard curve.

ANSWER 11. The possible initiating events following a typhoon event were identified by the pre-tree (similar to event tree). Offsite power transmission line, switch yard and gas turbine were considered as the headings of pre-tree. Each sequence was considered as an initiating event with its specific plant operating status.

ANSWER 12. Human error probabilities from internal event analysis were increased 3 times. It is a suggestion from consultants to take into account for special stress of operating crew and possible damage (or blockage) to the pathway from control room area to other areas which the components located.

ANSWER 13. There is no special consideration for analysing multi-unit sites.

ANSWER 14. Yes, quantitative PSA model for external events were developed.

ANSWER 15. For the time being, there is no research project related to external hazards.

4. Results and Practical Applications

ANSWER 16. Based on the typhoon PSA, modification suggestions were made to the gas turbine. Gas turbine is the alternate AC power source if loss of offsite power event occurred. First suggestion is to improve the fragility of gas turbine building. The roof of the gas turbine building was redesigned against strong wind during typhoon attack. The other suggestion is to bury the power transmission cable from gas turbine to switch yard. Burying the power cable underground will eliminate the damage of cable during typhoon attack and maintain the availability of plant AC power supply from gas turbine.

ANSWER 17. Examples of operating events caused by typhoon attack at Taiwan's nuclear power plant were listed below.

- An unexpected strong wind damaged the switch yard and caused the reactor scram. According to the plant operating procedure, manual intervention is required to reduce power or maintain reactor at hot shutdown if local typhoon alert is announced by the central weather bureau. The timing of manual intervention is based on the response of average wind speed (in 10 or 15 minutes) measured at the site. An instantaneous and unexpected strong wind which far exceeded the resisting capability of the switch yard occurred and damaged the switch yard and caused the reactor scram due to loss of offsite power.
- A huge number of small fish (seaweed mixed with trash) move into the intake channel of circulating water. Screens of circulating water intake were blocked by the shoal of fish. Operator scram the reactor manually due to the low flow of circulating water pump.
- Offsite power grid was damaged due to lightening and caused the plant lost one of the offsite power supply sources.
- Due to the high salt concentration in the air, the insulators on the electric power transmission tower were covered with a layer of salt. The salt layer reduced the insulation ability of the insulator and caused the instability of the power grid. Reactor scrammed due to loss of offsite power.
- One electric power transmission tower which is about 150 km away from the nuclear power plant was tumbled down due to land slide after a heavy rain. The event caused the crash of north Taiwan's power grid. Reactor scrammed due to loss of offsite power.

Finland answers

Identification

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1. Regulatory Requirements and Status of EE-PSA

ANSWER 1. In Finland PSA requirements are set forth in Regulatory Guide YVL 2.8 issued by STUK. A full scope Level 1 and Level 2 PSA for full power operation and for low power and shutdown states is required for existing and new NPP units. It is required in YVL 2.8 that "*Events such as internal failures, disturbances and faults, loss of off-site power, fires, floods, harsh weather conditions, seismic events and other external and human caused initiators shall be dealt with as initiating events.*"

For a new NPP unit, a preliminary EE PSA shall be included in the design phase PSA which is appended to the construction licence application. The EE PSA shall completed during construction and appended to the operating licence application. During operation the EE PSA shall be updated regularly.

ANSWER 2.

Existing units
External events PSAs have been done for the operating units (two VVER 440 units in Loviisa and two BWR units in Olkiluoto). The EE PSA of the Loviisa NPP covers Level 1 and is in progress for Level 2 for all operating states. The EE PSA of the Olkiluoto NPP includes quantification of EEs for Level 1 and Level 2 but only for power operation. Accident sequences from EEs go from Level 1 to Level 2 in similar way as from other parts of PSA. The analyses of both plants will be gradually completed as part of the Living PSA process.

The analyses start with a list of about 50 potentially important external events. A screening process is used to select events for detailed quantification. If the core damage frequency due to an event can be shown to be less than 1E-8/a with order of magnitude estimates, the event is screened out of detailed modelling and quantification.

Unit under construction (OL3)
A preliminary Level 1 EE PSA has been done for OL3. A list of about 50 external events was used as the starting point of the analysis. After a screening analysis, the following three events were selected to quantification: "*frazil ice*", "*organic material in seawater (algae)*" and the combined event "*high wind and snow*".

ANSWER 3. The objectives of EE_PSA in Finland are

- The first objective of EE_PSA, like all other parts of PSA, is to have as complete a model as possible in a risk analysis tool for different applications to support the decision making of the utility, which is responsible for the safety of the plant.

- As a part of the full scope PSA, EE PSA is used in support of regulatory decision making throughout the life cycle of a NPP.

- Demonstration of fulfilment of overall probabilistic safety criteria set in YVL 2.8

- Core damage frequency shall be less than 1E-5/a and large release frequency less than 5E-7/a

- Checking the adequacy of design basis
  - The design phase PSA shall be used for its part to demonstrate that the plant design basis is adequate and design requirements are sufficient.
  - Particularly, such potential high-consequence phenomena whose frequency of occurrence and consequences include large uncertainties shall be carefully examined. These are for example exceptional weather conditions, external flooding events and seismic events.
  - Analysis of "cliff edges".

- Full scope PSA is used as the basis for risk informed applications (Risk-informed in service inspections and testing, risk-informed technical specifications etc.).

ANSWER 4. As the EE PSA studies were started in Finland around 1990, no specific standards or guides were available and the procedures were developed by the utilities.

The EE PSA methods used in Finland (and Sweden) were later documented in the SKI Research Report 02:27, Knochenhauer and Louko, *Guidance for External Events Analysis*, 2002 published by the Swedish Nuclear Safety Authority SKI. This report been used as a reference for Olkiluoto 3 screening analysis.

2. Definition of EE PSA scope

ANSWER 5. An external event is considered as an initiating event in the EE PSA if it requires the start of plant shutdown (automatic or administrative) and simultaneously affects some safety systems challenged. If the challenged safety systems are not affected, the event is generally considered in internal events PSA. For example, if storm causes only Loss of Off-site Power (LOOP), the frequency is included in the internal events PSA LOOP frequency. If safety systems, e.g., diesel generators are degraded simultaneously, the event is included in EE PSA.

For example, the Loss of Instrument Room Ventilation (LIRV) due to component failures is considered in the Loviisa internal events PSA, but the effect of external air temperature on the consequences and recovery possibilities is taken into account. The possibility of LIRV as a consequence of high air temperature is considered in EE PSA.

For shutdown states initiating event means degradation of decay heat removal systems.

ANSWER 6. A list of about 50 external events has been used as the starting point of the screening process. The list is about the same as in the SKI Research Report 02:27 (see Appendix 1).

The origin of the event may be in the air, on or in the ground or in the sea. The quantified events in the EE PSAs of Finnish NPPs cover harsh weather conditions (high wind speeds, exceptionally high air temperature, heavy snowing, lightning), oceanographic events (extremely high or low seawater level, frazil ice), organic material (algae, mussels, etc.) in seawater, oil spills from ships. In additions, combinations of dependent events have been considered.

The following events have been found significant in Finland:

- algae in seawater
- mussels growing on seawater tunnel walls
- frazil ice (prompt freezing of subcooled water)
- oil slick in seawater (oil tanker wrecks) during PWR cold shutdown
- high wind (including tornadoes)
- snow storm

As refuelling shutdowns are during summer, frazil ice and snow storms are not included in shutdown PSA.

As Loviisa has an additional emergency feedwater system which is independent of seawater cooling, oil slick is significant only during cold shutdown states with open primary circuit when residual heat removal function through the secondary circuit is not available.

The risk due to some of these events has been reduced with modifications of the plant systems or procedures.

Loviisa EE PSA covers all operating states for Level 1. Level 2 analysis is in progress and some preliminary results are available. For Olkiluoto 1 and 2 the EE PSA covers only Level 1 for full power operation. As EEs are not significant risk contributors in Olkiluoto, detailed analyses for shutdown states or Level 2 have not been carried out.

3. Analysis Methods

ANSWER 7. A list of potentially significant external events has been compiled by analysing weather phenomena and human induced hazards in the vicinity of the plant. Operating experience and lists of external hazards included in IAEA siting guides, WASH-1400 and in other international publications have also been taken into consideration.

ANSWER 8. The frequency of simultaneous occurrence of two or more external hazards with dangerous intensity is usually significant only if the hazards are correlated. Combined events are identified by analysing the correlations and the effects on the plant.

The analysis of possible correlations (dependency) between events has been made by assessing the physical bases of the phenomena, observed data, actual operating events and general knowledge of local conditions.

Expert judgment and rough quantitative analysis is often used for estimation of correlations. In most cases the observed data for intensities relevant to EE PSA is sufficient only for order of magnitude estimates of correlations.

For example, it is known that high wind often results in high seawater level and organic material in seawater (algae). The combination could simultaneously endanger off-site power and diesel generator cooling water intake, and it is analyzed as a combined event.

Extreme wind speeds have been measured in winter and could be associated with snowfall resulting in possibility of simultaneous loss of off-site power and loss of diesel generators due to blockage of combustion air intake (see also Answer 17).

Simultaneous high air and seawater temperature could endanger, e.g., instrument room cooling also at units with diverse cooling system heat sinks.

ANSWER 9. For example, in Olkiluoto 1 and 2 EE PSA events are screened out of further analysis according to the following criteria.

1. The phenomenon will not exceed the plant design basis
2. If dangerous intensity of a phenomenon can be foreseen at least eight hours beforehand, only cold shut-down reactor is considered.
3. Intensity with effects on the plant is extremely improbable, cut-off frequency is 10^{-8}/year (event frequency or preliminary core damage frequency estimate).
4. The event is included in another part of PSA
5. An event is included in a combined event if it causes risk increase in connection with some other event.
6. An event is not analysed in detail if there are ongoing plant modifications to remove the risk.

ANSWER 10. The frequency - intensity distributions are determined by fitting the generalized extreme value distribution to the observations. Usually the more conservative parameter selections are used. Some comparative studies have been carried out with the Peak Over Threshold (POT) method.

For some events, e.g. *algae in seawater,* the frequency is based directly on observations and real event data. For oil spill frequency, the estimates are based on analysis of local and worldwide shipping and accident statistics.

ANSWER 11. Methods used in the identification of initiating events include, for example:

- analysis of possible consequences of structural failures
- analysis of incipient structural failures caused by occurred external events
- analysis of operating experience involving functional degradation or unavailability of systems due to external events.

For example, it is estimated based on experience that wind speed 28 m/s (3 second average) is sufficient to rip of steel panels which may cause short term loss of offsite power if flown to the switchyard. Wind speed 39 m/s may cause damage to the main grid and a long-term loss of offsite power.

Algae, frazil ice and oil slick may cause partial or total blockage of sea water intake (EE), resulting in total or partial loss of service water (IE).

Internal hazards (fires, flooding) are not included in EE PSA. Fires induced by lightning are covered by Fire PSA.

ANSWER 12: No.

ANSWER 13. No special analyses have been carried out for multi-unit sites in Finland. However, some interconnections between units have been modelled.

ANSWER 14. External Events are included in the integrated the Living PSA models. Some early versions of EE PSA were separate models.

ANSWER 15. Plant site specific studies focused on intensity - frequency distributions for extreme wind speed, temperature and seawater level have been contracted by STUK and by the licensees from the Finnish Meteorological Institute and Institute of Marine Research.

Extreme weather conditions and the effects of climate change have been included as a new topic in the Finnish national nuclear safety research program SAFIR2010.

4. Results and Practical Applications

ANSWER 16. Plant modifications and procedure development to prevent the risk of seawater intake blockage due to frazil ice formation, algae or oil slick can be mentioned as examples of corrective measure initiated by PSA:

- pressure difference measurements over band screens to trip main seawater pumps on incipient blockage of seawater intake (Loviisa)
- alternative service water intake to cope with blockage of normal seawater intake (Loviisa)
- installation of pipelines to supply of warm water to sea water intake channel if conditions for fast freezing of subcooled water are noticed (Olkiluoto).

In the design of Olkiluoto 3 special care has been taken to remove risks due to external hazards, e.g., protection of diesel generator air intakes and underground cables from a gas turbine plant.

Some examples of numerical results.

Loviisa 1 and 2

According to the PSA of 1994 the CDF due to off-site external events other than seismic was $4.7 \cdot 10^{-4}$/a which was a major contributor to the total CDF of the Loviisa NPP. The risk was mainly due algae causing blockage of the essential service water system ($3.0 \cdot 10^{-4}$/a) and high wind causing loss of offsite power with simultaneous blockage of diesel generator air intakes by snow etc. ($1.5 \cdot 10^{-4}$/a). Plant modifications were carried on the basis of the PSA results. An important addition was measurement of the pressure difference across the seawater band screens. Automatic trip of one or more main seawater pumps at high pressure difference was implemented. Alternative air intakes for diesel generators were also built. According to the updated analysis of 1998, the CDF due to off-site external events was $4.25 \cdot 10^{-5}$/a. The relatively simple modifications of plant systems and operating procedures reduced the risk due to off-site external events by about

90 per cent. Even after the plant modifications, the contribution of the off-site external events was about 40 per cent of the total core damage frequency $1.07 \cdot 10^{-4}$/a for power operation.

Off-site external events were analyzed for refuelling shutdowns in 2003/2004. According to the 2004 analyses the most important contributor during shutdown was oil spill from tanker ship accidents in the Gulf of Finland which is an important export route of Russian oil. The contribution of oil spills was $2 \cdot 10^{-5}$/a or 55 per cent of the CDF $3.6 \cdot 10^{-5}$/a for refuelling shutdown. Modifications of the plant and operating procedures were initiated to reduce the risk of seawater intake blockage. An alternative service water intake line from the outlet channel was built for situations were oil spills or other events endanger the normal seawater intake.

According to the PSA updated in 2006, non-seismic off-site external events account for about 19 per cent of the total CDF $3.9 \cdot 10^{-5}$/a for power operation and 17 per cent of the CDF $4.34 \cdot 10^{-5}$ /a for shutdown states. During power operation the most important off-site external event is high seawater level with 55 per cent contribution to non-seismic off-site external events CDF and during shut down states oil spill from tanker ship accidents at the Gulf of Finland is the most important off-site external event with 72 per cent contribution.

Olkiluoto 1 and 2
The possibility of snow blocking diesel generator combustion air intake was included in the PSA in 1995. When an alternative air intake was installed in 1996 the total CDF estimate (excluding seismic) was reduced from $2.76 \cdot 10^{-5}$/a to $8 \cdot 10^{-6}$/a (reduction of 71 per cent). Currently the contribution of off-site external events (excluding seismic) is $1.25 \cdot 10^{-6}$ 1/a or about one per cent of the total core damage frequency (the current results are not directly comparable with 1996 results due to the extended scope of PSA).

Even if the original large CDF estimates may have been quite conservative, the plant modifications to reduce the risk due to external events can be considered very effective.

ANSWER 17. Examples of operating events caused by harsh weather conditions at Finnish NPPs.

- failure of diesel generators to run during testing due to blockage of combustion air filters by snow
- partial blockages of seawater intake by frazil ice, algae and mussels.

An example of operating event at conventional power plant with relevance to nuclear safety is the loss of the external power grid connection due to steel panels torn off from the plant walls and flown to the switchyard.

The events mentioned above have been included in EE PSAs.

France answers

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1. Regulatory Requirements and Status of EE-PSA

ANSWER 1:

In France there are no formal requirements to develop External Events PSA. Nevertheless, for new plants, such EPR, the Technical Guidelines indicate that *"the implementation of improvements in the "defence-in-depth" should lead to the achievement of a global frequency of core melt of less that 10^{-5} per plant operating year, uncertainties and all types of failures and hazards being taken into account".* In this context the probabilistic approaches should be used to quantify the external events contribution to the global core damage frequency.

No regulatory guide covering the EE PSA is available for the moment.

ANSWER 2:
Properly speaking, no EE PSA was developed for the NPPs in France. However, several internal initiating events PSA include external hazards, as the loss of offsite power (including severe whether conditions and grid black-out) and loss of ultimate heat sink (intake channel failure). The impact of some additional hazards, as plane crash and external industrial and transportation hazards, is also determined by using probabilistic methods (assessment of initiator frequency). However, in the future it is clearly intended to develop EE PSA for significant hazards (earthquake, external flooding, severe water conditions, etc.) for the exiting plants, mainly in the frame of the application of the "cost-benefit" methods. For new plants, the application of probabilistic methods to determine the EE impact will be more complete, some of the hazards being included in the scope of the EE PSA (the hazards screening is not yet finalised for the FLA3 NPP).

ANSWER 3:
In France the objectives of the EE PSA are not yet defined. However, for existing plants they will include the verification of the adequacy of design basis, the identification of vulnerabilities in order to define improvements of the plants safety to cope with external hazards. For new plants the EE PSA should participate to demonstrate overall plant safety level.

ANSWER 4:
No national or international guides on EE PSA methods are applied.

2. Definition of EE PSA scope

ANSWER 5:

At IRSN no explicit criteria is used to decide wherever to include a given external initiating event in the frame internal or external events PSA. However, the loss of ultimate heat sink and the loss of offsite power are considered in the internal initiating events PSA, taking into account that they affect a limited number of systems..

ANSWER 6:

For the existing plants, at the design stage, the external hazards of natural origin or due to the human activity were analyzed and, if necessary, taken into account in the design. These external hazards are typically the followings: earthquake, flood, exceptional weather conditions, plane crash, risks due to the industrial environment and the transportation, emission of projectiles by the turbine. The probabilistic assessment was used for the hazards where "valid" statistics were available. It is the case of the risks related to the human activities (plane crash, explosions of industrial facilities or transport of dangerous matters). Protective measures are defined when the frequency of unacceptable consequences are higher than 10^{-7}/year for a given hazard (10^{-6} for all hazards).
In the frame of periodic safety review (every 10 years) the significant external hazards impact is reassessed and if necessary plants improvements are defined. For the next periodic safety review it is planned to use cost-benefit methods where the PSA play a major role.

For new plants, the Technical Guidelines mentions the followings external hazards:

- earthquake,
- airplane crash,
- external explosion,
- lightning and electromagnetic interference,
- groundwater,
- extreme meteorological conditions (temperature, wind, snow, rain, ...)
- external flooding,
- drought,
- ice formation,
- toxic, corrosive or burnable gases.

In practice, for FLA3 (EPR) NPP the following hazards are taken into account at the design stage:

External events, other than earthquake, actually considered

- airplane crash
- industrial risks
- external Flooding
- extreme climatic conditions:
- heat wave
- cold, snow, wind
- frazil
- freezing
- lighting
- pumping station plugging

Some of these hazards will be included in the EE PSA (the list is not yet decided).

3. Analysis Methods

ANSWER 7:
Not yet developed.

ANSWER 8:
Not yet developed.

ANSWER 9:
Not yet developed.

ANSWER 10:
Not yet developed.

ANSWER 11:
Not yet developed.

ANSWER 12:
Not yet developed.

ANSWER 13:
Not yet developed.

ANSWER 14:
Not yet developed.

ANSWER 15:
Not yet developed

4. Results and Practical Applications

ANSWER 16:
Not available.

ANSWER 17:

- Blayais 1999 (4 x 900 MWe): flooding of the site,
- Paluel 2005 (4 x 1300 MWe): loss of 4 main transformers by ice formation,
- Pumping station partial plugging:
  - Algae (Paluel, Flamanville),
  - Molluscs (Gravelines),
  - Sand (Chinon, Penly),
  - Ice (Saint Laurent A, Bugey).

Germany answers

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1. Regulatory Requirements and Status of EE-PSA

ANSWER1:

Due to the decision of nuclear phase-out new NPP are not considered in Germany. For the existing plants the spectrum of external events to be considered in the PSA is laid down in the guideline for probabilistic safety analyses and the corresponding technical reference documents mentioned below. For different initiating external events different depth of the analyses are required. In general, the EE aircraft crash, explosion pressure wave, external flooding / high water level, and earthquake have to be covered in a Level 1 PSA; the EE analyses are limited to full power operational states.

The relevant German national regulatory guide is:

Bundesanzeiger (BA):

Bekanntmachung des Leitfadens zur Durchführung der "Sicherheitsüberprüfung gemäß § 19 a des Atomgesetztes - Leitfaden Probabilistische Sicherheitsanalyse -" für Kernkraftwerke in der Bundesrepublik Deutschland, 30.08.2006

with its related technical guidance documents:

- Facharbeitskreis "Probabilistische Sicherheitsanalyse für Kernkraft- werke":
  Daten zur probabilistischen Sicherheitsanalyse für Kernkraftwerke
  BfS-SCHR-38/05, August 2005
- Facharbeitskreis "Probabilistische Sicherheitsanalyse für Kernkraft-werke":
  Methoden zur probabilistischen Sicherheitsanalyse für Kernkraftwerke
  BfS-SCHR-37/05, August 2005

ANSWER 2:

At the time being, several PSA are being performed in the frame of the (periodic) safety reviews required by the regulatory authorities. At least two of these PSA include more detailed analyses for external events (earthquake, flooding. These EE PSAs have not yet been presented to the regulatory authority.

For those NPPs having performed PSAs in the past, these PSA studies included mainly screening studies for EE, to some extent added by some more simplified or semi-probabilistic quantifications.

The actual German guidance documents require for all PSA to be performed in the frame of the periodic safety reviews at least more or less in-depth probabilistic investigations for the EE earthquake, accidental aircraft crash, external flooding and explosion pressure wave. For all the other EE only simplified rough estimations are recommended.

ANSWER 3:

The objectives of PSA including EE PSA in Germany are to demonstrate that the design of the NPP is still adequate and that the deterministic safety goals are met. PSA shall support the deterministic analysis as a complementary tool. Furthermore, the probabilistic analyses shall identify weaknesses.

ANSWER4:

The most important national guidance document is:

- Facharbeitskreis "Probabilistische Sicherheitsanalyse für Kernkraft-werke": Methoden zur probabilistischen Sicherheitsanalyse für Kernkraftwerke BfS-SCHR-37/05, August 2005

The most important international documents are:

- International Atomic Energy Agency (IAEA):
  The Role of Probabilistic Safety Assessment and Probabilistic Safety Criteria in Nuclear Power Plant Safety, Safety Series No. 106, IAEA, Vienna (1992)
- International Atomic Energy Agency:
  Safety Assessments and Verification for Nuclear Power Plants,
  Safety Guide No. NS-G-1.2, Wien, 2001

2. Definition of EE PSA scope

ANSWER 5:

Events (i) originating from outside of the plant perimeter and (ii) having the potential to impair more than one safety train are considered as 'external events'.

ANSWER 6:

The spectrum of external events to be dealt with in the PSA is prescribed by the regulatory authority, based on the general experience (frequency, severity) with external hazards in Germany. For the EE identified as potentially significant risk contributors, such as earthquake, aircraft crash, flooding and explosion pressure wave, detailed guidance is given. The list of EE to be considered also includes:

- Toxic gas clouds,
- External fires,
- Collision of ships with the intake building,

- Extreme weather conditions such as lightning, storm, snow, ice and combinations of extreme weather conditions.
- Biological phenomena.

These EE have to be considered in the screening process.

3. Analysis Methods

ANSWER 7:
The spectrum of external events to be dealt with in the PSA is prescribed by the regulatory authority, based on the general experience (frequency, severity) with external hazards in Germany (see Q 6)..

ANSWER 8:
At the time being, such combinations (besides combinations of extreme weather situations) are in general not considered in Germany due to the extremely low frequencies.

ANSWER 9:
See answers to Q 6-8

ANSWER 10:
The frequencies are different depending on the event type.

ANSWER 11:
Due to the fact that the statistics from the operating experience are not meaningful for German NPPS (number much too low for statistical treatment) the initiating events are mainly identified by expert judgment and analyses.

ANSWER 12:
Up to now the effects of external events on the reliability of human actions are not explicitly considered in the PSA. However, the HRA takes into account the potentially very different environmental conditions affecting the human behavior in case of an EE..

ANSWER 13:
There are no special considerations for analyzing multi-unit sites.

ANSWER 14:
EE PSA are partly integrated in the Level 1 PSA model, such as RiskSpectrum, and partly treated separately.

ANSWER 15:
R&D project for development of advanced methods for treating EE in PSA are ongoing (e.g. earthquake) or planned (other EE, in particular for LP/SD states). A pre-research study is being carried out for finding out, if methods have to be developed specifically for considering the recent climate changes and weather conditions in Europe.

4. Results and Practical Applications

ANSWER 16:
Up to now, the results of ÜSA including EE PSA carried out for German NPPs in the frame of the (periodic) safety reviews and the consequential measures are only partly available to GRS and can only be internationally presented with the official permits of the regulatory authorities and licensees.

ANSWER 17:
In principle, extreme weather conditions as well as earthquakes exceeding the design basis ones are quite rare in Germany, therefore we cannot give good examples.

Japan answers

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1. Regulatory Requirements and Status of EE-PSA

ANSWER 1:

(1) No, there is no regulatory requirement on EE-PSA in Japan. To begin with, though PSA is recognized as the convincing tool of supplementing the deterministic method to discuss balanced design and procedures and examine accident management of NPPs, PSA itself is not required in the current regulatory procedures. With the progress of PSA technology and study of severe accident phenomenology, application area of PSA has been expanded. With regard to the examination guide for seismic design of nuclear power reactor facilities revised on September 19, 2006, the regulatory body of Nuclear and Industrial Safety Agency (NISA) required the utilities to make a review on the seismic safety of the existing nuclear facilities based on the new guideline and to report NISA the results of their reviews, including evaluation of the residual risk[1] of the facilities by seismic PSA.

(2) Examination Guide for Safety Design for Nuclear Power Facilities requires design considerations on natural phenomena and human induced external events, where the appropriateness for the design consideraration in air craft crash is examined based on the probabirity of air craft crash, but which is not EE-PSA.

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1 "Residual Risk" is defined as such a risk that, by extension of the effect of the ground motion which exceeds the planned out design ground motion of Facilities, impairing events would occur to Facilities and the event in whick massive radioactive materials diffuse from Facilities would break out, or the result of these events would cause radiological exposure hazards to the public in the vicinity of Facilities.

ANSWER 2:

(1) We have made no EE-PSA other than earthquake in Japan.

(2) Utilities evaluate the probabilities of air craft crash for all NPPs when they apply for reactor establishment license. But this is not a PSA. The evaluation is examined based on the criteria for the probability of air craft crash on commercial power reactor.

(3) Outside the regulatory framework, JNES is developing methodology for tsunami PSA and JAEA, PSA for volcanic activities, respectively.

ANSWER 3:

(1) We have made no EE-PSA in Japan.

(2) The evaluation of probability of air craft crash on the NPP is made to confirm the NPP satisfies the criterion of less than 10^{-7}/y for air craft crash probability.

(3) Tsunami is considered to be a part of residual risk of earthquake.

ANSWER 4:

(1) There is no guide on EE-PSA so far in Japan other than seismic PSA.

(2) The probability of air craft crash is evaluated based on "Evaluation of probability of air craft crash on commercial power reactor facilities", NISA-151b-02-02, July 30, 2002.

2. Definition of EE PSA scope

ANSWER 5:

As there is no guideline for EE-PSA, the following is respondents' opinion.

(1) If an external hazard may directly lead to core damage or loss of containment function, it should be included in EE-PSA, such as air craft crash.

(2) If an initiating event caused by an external hazard does not directly affect any safety systems for mitigating the initiating event, the initiating event may be included in internal event PSA.

(3) If an initiating event caused by an external hazard directly affects any safety systems for mitigating the initiating event through a cause-consequence relationship not included in usual internal event PSA, the initiating event should be included in an external event PSA. An example of this type of external events is tsunami which initiates transients and may also damage components of sea water systems that support various safety systems.

(4) Although, in general, loss of off-site power affects one of the mitigating systems such as the power conversion system, the initiating event is included in internal PSA in accordance with customary practice.

(5) If an external hazard causes other types of hazards, such hazards should be included in EE-PSA as one external hazard. Earthquake accompanied by tsunami and collapse of the inclined

slope is the example. However if tsunami hazards expected at the site are dominated by earthquakes that occur at a long distance from the site and are not likely to have direct effects to the plant, it may be treated as an independent external hazard.

ANSWER 6:

(1) We have made no EE-PSA. The following is the relevant treatment of external events other than earthquake in the licensing process.

(2) “Examination Guide for Safety Design for Nuclear Power Facilities” requires design considerations for natural phenomena and human induced external events. These are candidates of external events for EE-PSA.

(3) In the application for reactor establishment license, high wind such as typhoon, snow accumulation, freeze, tsunami/high water, flood, lightning and so on are considered for the design as natural phenomena if necessary taking into accout natural enviroment of the NPP site vicinity. The effects of external events are evaluated based on the previous records considering the period and amount of data accumulated in the NPP vicinity.

(4) In the application for reactor establishment license, air craft crash, dam collapse, explosion and so on are considered for the design as human induced external events if necessary. The effects of external events are evaluated based on the previous records considering the period and amount of data accumulated in the NPP vicinity.

3. Analysis Methods

ANSWER 7:

The same answer as that of question 6.

ANSWER 8:

(1) We have made no EE-PSA. The following is the relevant treatment of external events other than earthquake in the licensing process.

(2) “Examination Guide for Safety Design for Nuclear Power Facilities” requires consideration for combined external events based on the previous records, the spot investigation and so on, if nesseary.

ANSWER 9:

(1) We have made no EE-PSA. The following is the relevant treatment of external events other than earthquake in the licensing process.

(2) If the frequency of air craft crash is less than 10^{-7}/y, the design consideration is not required.

ANSWER 10:

(1) We have made no EE-PSA. The following is the relevant treatment of external events other than earthquake in the licensing process.

(2) In the application for reactor establishment license, for example, for high wind the largest typhoon is considered for the design based on the construction standard law taking into account the observation values in the site vicinity.

ANSWER 11:

We have not made EE-PSA in Japan. Screening methodologies for initiating events caused by tsunami and volcanic activities are being developed by JNES and JAEA.

ANSWER 12:

No information available so far. We have not made EE-PSA in Japan.

ANSWER 13:

We have made no EE-PSA in Japan. The following is just information.

(1) In the internal event PSA "cross-tie of electric power supplies" among units at the multi-unit sites is taken into account because the cross-tie is realised as one of accident management measures.

(2) There are many research activites in simultaneous failure in seismic PSA.

ANSWER 14:

We have made no EE-PSA.

(1) The PSA application is made within the risk information obtained from the PSAs, in accordance with the purpose of application. For example, when we use risk information for assessing acceptability of a change in allowed outage time (AOT) of a safety system, the risk increase due to the change will be estimated mainly by the internal event PSA at the rated power operation. Need for PSA to quantify the risk increase caused by other types of initiating events may be eliminated if some qualitative consideration can show the risk increase would be small.

(2) On the other hand, when a PSA is to be used to assess overall risk of a NPP and compare the risk with the proposed safety goal of the nuclear safety commission, it is necessary to include all types of accidents, caused by external and internal initiating events except for those caused by sabotage, as far as they may have significant contribution to the total risk.

Reference:
Special Committee on Safety Goals, Nuclear Safety Commission, "Interim Report on a Study on Safety Goals", December 2003.

ANSWER 15:

(1) PSA for volcanic activity

Since there are not many publications on risk of volcanoes, the following paper could be worth sharing. However this work was terminated after this paper.

[Reference]

Tetsukuni OIKAWA et al., "Development of Screening Method for Volcanic Activity", Proceedings of The 4th International Conference on Probabilistic Safety Assessment and Management (PSAM-4), New York (1998).

Abstract

This paper presents a development of a screening method for volcanic activity for use in the first step of probabilistic safety assessment (PSA) of nuclear power plants (NPPs). Although volcanoes have possibilities of affecting NPPs by various volcanic hazards, the authors selected the pyroclastic flow, mudflow, collapse of mountain slope and falls of volcanic ash and pyroclastic material among hazards for screening based on literature survey. The screening method consists of the following steps: (1) identification of volcanoes around the site, (2) survey of eruption history for each identified volcano, (3) screening of volcanoes by distance between the site and each volcano, eruption frequency and rough estimation of thickness of volcanic ash fall. This paper also shows discussions of the results of trial application to selected sites to confirm feasibility of our method.

(2) Tsunami PSA and Slope PSA

The examination guide for seismic design of nuclear power reactor facilities revised in September, 2006 requires the consideration for the accompanying events of earthquake as follows.

- Safety functions of Facilities shall not be significantly affected by the collapses of the inclined planes around Facilities which could be postulated in the seismic events.
- Safety functions of Facilities shall not be significantly affected by tsunami which could be postulated appropriately to attack but very scarcely in the operational period of Facilities.

Therefore JNES have started to develop the methodologies for Tsunami PSA and Slope PSA.

(a) Tsunami PSA

[Reference]

M.SAKAGAMI et al., "Development of Tsunami PSA method for nuclear power plants", Proceedings of the Autumn Conference of the Atomic Energy Society of Japan, Kitakyushu, Japan (2007).

Abstract

Tsunami PSA consists of tsunami hazard analysis, component fragility analysis as function of wave height and accident sequence analysis under appropriate plant data collection.

In tsunami hazard analysis earthquakes inducing tsunami are specified and the relations between maximum wave height and its occurrence frequency are analysed in the vicinity of the NPP based on displacement model of active faults and tsunami analysis to obtain tsunami hazard curves.

In tsunami fragility analysis probabilities of inundation exceeding equipment levels are evaluated considering fluctuation of wave height and flow analysis in the area surrounding the NPP.

In accident sequence analysis sequences to core damage are quantified considering disabled components and systems due to water immersion, wave power and sand movement every wave height.

(b) Slope PSA

[Reference]

Hideharu SUGINO et al., "Development of probabilistic safety assessment considering slope collapse by earthquake", Proceedings of the Specialists Meeting on Seismic Probabilistic Safety Assessment (SPSA) of Nuclear Facilities, in Jeju, Korea (2006).

Abstract

In Japan, a part of nuclear power plants is surrounded by the land slope. In such a nuclear power plant, it is necessary to evaluate the stability on the slope under the deterministic seismic condition, and to ascertain that the plant is kept in a safe condition even if collapse of the slope might occur due to earthquakes.

A probabilistic safety assessment methodology considering the slope collapse (Slope PSA) has been developed as a part of seismic PSA at JNES. This method consists of slope collapse hazard evaluation, fragility evaluation (evaluation of secondary influences on nuclear facilities) and system reliability analysis. In the slope collapse hazard evaluation, probabilities of slope stability, failure modes, collapse behaviour, rock reach area and shock force to nuclear facility are analyzed and calculated.

This report describes the slope collapse hazard evaluation procedure and sample calculations for a model slope, and also results of parametric studies for the rock block behaviour analysis.

4. Results and Practical Applications

ANSWER 16:

Not available because we have made no EE-PSA.

ANSWER 17:

In December 2005 heavy snowfall caused loss of off-site power in a BWR twice a week, both of which continued about 2 hours. In the first loss of off-site power, one of off-site power lines and one of emergency diesel generators were unavailable for maintenance. JNES carried out accident sequence precursor analysis for the events, of which conditional core damage frequency was estimated to be 10^{-5}~10^{-4} by using internal event PSA. This did not become a motivation of developing EE-PSA other than seismic PSA.

[Reference]

JNES/SAE06-062, "Analysis and assessment of safety information =Accident Sequence Precursor Analysis=" (in Japanese), Japan Nuclear Energy Safety Organization, Japan (2007).

Korea answers

ANSWER 1. No external hazard PSA other than earthquake was explicitly required by the regulatory agency (KINS) for operating nuclear power plants. But, the new nuclear power plant under construction, EE PSA(CDF and LERF) is demanded for OL(operation license) during power operation only. For operation plants, the EE PSA is demanded to estimate the total risk of the plant.

ANSWER 2. All operating plants in Korea, the some events(seismic, internal flooding and internal fire induced) have been done for the external initiating events.

ANSWER 3. The objective to develop external event PSA was to estimate the total risk of the plant, adequacy of design basis, identification of vulnerabilities.

ANSWER 4. The first external event PSAs were completed in 1992 based on international consultant. We have our own guide for EE PSA referring from foreign reference now.

2. Definition of EE PSA scope

ANSWER 5. There are no explicit criteria to classify an initiating event and external event analysis. All events excluding seismic, internal flooding and internal fire induced are included in internal events PSA. The typhoon induced events such as Loss of Off-site Power and organic material in cooling water are considered in internal PSA.

ANSWER 6. The external floods, external explosions and transportation accidents etc. have usually been screened out in screening analysis of EE PSA by expert judgement or very low occurring frequencies in Korea. The internal fire, internal flooding and seismic events are included in EE PSA. The other events were included in internal PSA except that.

3. Analysis Methods

ANSWER 7. The identification of potentially significant external events are determined based on operating experience, other EE PSA results and EE PSA expert judgement.

ANSWER 8. The big typhoon result in sometimes large amounts of algae or other organic material in non-essential seawater intakes and threaten simultaneously external grid(caused Loss of Off-site Power). The Loss of Off-site power events have been considered in internal PSA already. The effect of non-essential seawater intakes blockage due to typhoon or organic material would be considered in internal PSA sooner or later.

ANSWER 9. The identification of potential external events and the event selection for further analysis were done by the expert judgement and screening analyses(occurring frequency).

ANSWER 10. There is no specific methodology to determine the frequency. We extracted the frequencies from used the foreign or domestic experience data. No special uncertainty analysis was done except seismic PSA.

ANSWER 11. The other initiating events excluding seismic, internal flooding and internal fire induced are included in internal initiating events analysis.

ANSWER 12. In EE PSA, the human reliability is not credit or very high conservative human error value is usually used .

ANSWER 13. There is no special consideration for analysing multi-unit sites. Only a research program was performed for multi-unit Loss of Off-site Power induced by typhoon. The research program for multi-unit sites effect is preparing.

ANSWER 14. We are trying to integrate all models in a PSA. We also consider the EE PSA contribution in PSA application.

ANSWER 15. For the time being, there is a few research or updating program related to external hazards.

- New methodology for fire PSA using the fire simple information table(fire sources, fire mitigation system, fire wall design and etc,) without detail quantification process is developing,
- New methodology to combine individual PSA models(Internal, external and low power & shutdown PSA, etc.) into integrated one PSA model is developing.
- The new research program for seismic PSA updating is performing.

4. Results and Practical Applications

ANSWER 16. Based on the EEs PSA, minor modification suggestions were made to the various areas. For example, the spray system was installed in switchyard to protect salt contamination transferred by typhoon.

ANSWER 17. Various events that have experienced in Korea such as local forest fire, heavy snow, intake blockage due to typhoon or organic material, etc. may be considered in internal or external PSA respectively.

Mexico answers

Identification

Please identify your organization

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1. Regulatory Requirements and Status of EE-PSA

ANSWER 1:

No external Events PSA was explicitly required by the regulatory body (CNSNS) and there is not plan to request it in short time (2 or 3 years) for existing units.

ANSWER 2:

ANSWER 3:

ANSWER 4:

2. Definition of EE PSA scope

ANSWER 5:

ANSWER 6:

3. Analysis Methods

ANSWER 7:

ANSWER 8:

ANSWER 9:

ANSWER 10:

ANSWER 11:

ANSWER 12:

ANSWER 13:

ANSWER 14: At the moment, when extreme weather condition is expected, there is an increase of the loss of site power frequency in the risk monitor to take into account their effects.

ANSWER 15:

4. Results and Practical Applications

ANSWER 16:

ANSWER 17:

Slovak Republic answers

Identification

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1. Regulatory Requirements and Status of EE-PSA

ANSWER 1: Act on Peaceful use of nuclear energy “Atomic Act” (No.541/2004 Call.) and set of regulations according to the act define a legal framework for the PSA performance and its applications in Slovakia.

The utility obligations are described that:

“The licence holder shall submit to the UJD (i.e. regulatory body) PSA level 1, which represents an assessment of the risk of nuclear fuel damage at the nuclear facility for all operating modes and includes analysis of internal and external events” (§20, item (1) of the Regulation No. 58/2006 Call.).

“The licence holder shall submit to the UJD (i.e. regulatory body) PSA level 2, which represents an assessment of the risk of radioactive releases into the environment” (§20, item (2) of the Regulation No. 58/2006 Call.). The scope of the level 2 PSA is given by the scope of the level 1 PSA.

UJD uses a system of regulatory guides to specify and clarify the requirements of generally binding regulations. The guideline - Requirements for PSA performance, UJD SR, BNS I.4.2/2006, Bratislava, Slovakia, 2006 characterizes the regulatory body approach to the PSA and its applications in practice. The utility obligations are described that: “The licence holder shall submit to the UJD a specific PSA level 1, which represents an assessment of the risk of nuclear fuel damage at the nuclear facility for all operating modes and includes important initiating events and risks”.

The following EEs are considered: internal fires and floods, aircraft crash, extreme meteorological conditions, impact of the neighbouring industry and earthquake.

ANSWER 2: The external event PSA has been done for all operating nuclear power plants in Slovakia (Bohunice NPP and Mochovce NPP). The analyses include geographical, meteorological, geophysical, hydrological information, human activities, and characteristics of industry in near region. The screening study is performed. After the screening processes the following EEs are considered in the PSA: aircraft crash, extreme meteorological conditions, impact of the neighbouring industry and earthquake.

ANSWER 3: The objectives of EE PSA correspond to the PSA objectives, and are dependent on the purpose of the PSA, in general. The PSA objectives are provided in the national regulations and regulatory guides. They include: an assessment of the risk; demonstration of safety and fulfilment of probabilistic safety criteria; identification of design and operation vulnerabilities.

ANSWER 4: Internationally accepted documents are used for the preparation of the external event PSA (NUREGs, IAEA guidelines, and UJD guideline), for example:

- Treatment of External Hazards in Probabilistic Safety Assessment for Nuclear Power Plants, IAEA-Safety Reports Series No. 50-P-7, November 1995;
- NUREG/CR-5042, ”Evaluation of External Hazards to NPPs in the USA” October 1987;
- Accident Analysis for Aircraft Crash into Hazardous Facilities, US DOE-STD-3014-96; and
- Requirements for PSA performance, UJD SR, BNS I.4.2/2006, Bratislava, Slovakia, 2006.

2. Definition of EE PSA scope

ANSWER 5: The frequency of initiating event is the criteria for including the external event into the PSA. If the initiating event frequency is less as 1.0E-7/y the event is screened out and not implemented into the PSA model.

ANSWER 6: The first task is to draw up a list of events that is relevant to the particular study and nuclear installation. These events are always site dependent, and are often design dependent. A full list of external hazards is provided in Safety Guide 50-SG-S9; the Probabilistic Reliability Analysis Procedures Guide (NUREG/CR-2300) also list two pages of different hazards, some of which may not be obvious sources of threat to any particular nuclear installation. Various probabilistic hazard safety assessments have concentrated most of the effort on relatively few of these hazards. After careful analyses of generic list of external hazards, it was concluded, can be exposed to the following external events: seismic event; aircraft crash; extreme meteorological conditions; and impact of neighbouring industry. The other external events from the generic list of external hazards are screened out.

The contribution from the external initiators (with the exception of seismic event analyses) to the total risk is very small. Therefore, these events were not implemented into the main PSA model.

3. Analysis Methods

ANSWER 7: External events are identified, which have the potential to lead to the core damage if additional failures of safety systems occur. A list of potentially significant external events has been compiled by event analysis.

ANSWER 8: Impact of EE is evaluated on the power supply from the external grid. For example extreme cold water can lead to the loss of external grid.

ANSWER 9: Selection of external events for detailed modelling and quantitative analysis is performed based on determination of external hazards need to be included based on specific site and nuclear installation conditions.

ANSWER 10: The event frequencies or frequency - intensity distributions are determined based on IAEA guidelines. The parameters and characteristics of external events use conservative assumptions. Evaluation of historical data is the basis for frequency calculation.

ANSWER 11: Operating experience and analyses are used to identify the initiating events caused by EE.

ANSWER 12: Increased human error probabilities are used after occurrence of EE and higher level of dependencies between the human errors are applied.

ANSWER 13: Total loss of all offsite power supplies to multi-units is considered only in case of seismic event.

ANSWER 14: External Events are included in the integrated PSA models.

ANSWER 15: The analyses perform to support PSA activities are available.

4. Results and Practical Applications

ANSWER 16: Contribution to the risk arises only from the internal fire and seismic event. The other external initiators have negligible risk contribution. However, the seismic event analysis was simplified (it was assumed that the seismically qualified components will withstand the initiating events, the other components will be lost). More detailed seismic event analysis has to be performed in the future.

ANSWER 17: The effect of extreme meteorological conditions to operation of safety systems during their accident mitigation actions has been analysed. The results of the analysis have shown us that the safety systems are designed to withstand extreme meteorological conditions. Design of safety systems in conjunction with the safety operation procedures eliminates the possible failure. Therefore, it is not necessary to include the influence of extreme meteorological conditions into the PSA model of NPP.

Switzerland answers

Identification

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1. Regulatory Requirements and Status of EE-PSA

ANSWER 1: The legal basis for the implementation of PSA in the regulatory safety oversight process is defined in the Nuclear Energy Law and an accompanying Nuclear Energy Ordinance in Switzerland**.** The ordinance specifies requirement of a full-scope (i.e. Level 1 and Level 2 PSA for full power, low power and shutdown, including all credible internal and external initiators), plant-specific PSA. For the construction permit of a new NPP a preliminary, full-scope PSA is required to be submitted. For the operational permit this PSA has to be updated. Furthermore, the ordinance requires a "living PSA". The requirements on the scope and quality of the PSA for Level 1, Level 2 are specified in more detail in a draft regulatory guideline HSK-A05, which is currently published for public comment.

Certain external events such as earthquake, external flooding and aircraft crash shall be quantified and included in the model independently of a screening criterion. Furthermore, a specific set of external events (determined based on the long experience in Swiss PSA updates) shall be addressed/discussed and if necessary quantified. A screening criterion is under discussion.

ANSWER 2: Full-scope (i.e. Level 1, Level 2 PSAs for full power, and a Level 1 PSA for low-power and shutdown modes, including all credible internal and external initiators) plant-specific PSA studies have been performed for all Swiss NPPs. These studies have been extensively reviewed, resulting in continuous updates and improvements over the last 15 years.

Currently, the scope of the PSAs is being extended to Level 2 PSAs for low-power and shutdown mode including all credible internal and external initiators.

ANSWER 3: PSA shall be used to assess the overall risk, the adequacy of design basis, the balance of the risk (identification of cliff edge effects), plant modifications including changes of technical specifications and events. HSK follows a risk-informed approach, where PSA is one element in the decision making.

The ordinance requires that for the construction permit of a new nuclear power plant, it has to be demonstrated that the core damage frequency is below 10^{-5} per year. This risk criterion is also expected to be fulfilled by the existing plants, to the extent that is reasonably achievable.

ANSWER 4: HSK has released the guideline HSK-A05 'Scope and Quality of a PSA' for public comment. This guideline specifies also the requirements of EE PSA.

2. Definition of EE PSA scope

ANSWER 5: In the draft of the guideline HSK-A05 the scope and quality requirements for treatment of internal and external (EE) events in PSA is defined. The guideline describes the scope of the internal, the area- and the external events.

ANSWER 6: According to the draft guideline HSK-A05, regardless of any screening criteria, external flooding, extreme winds, tornadoes, (accidental) aircraft crashes are required to be considered in the plant-specific quantitative risk evaluation. Other external events to be included in the screening analysis: drought, erosion, forest fire, high summer temperature, ice cover, industrial or military facility accident, landslide, lightning, low river water level, low winter temperature, pipeline accident, release of chemicals in onsite storage, river diversion, river transported material leading to water intake plugging (e.g. logs, leaves, sediments, mussels, algae) snow (drift), soil-shrink-swell consolidation, ground transportation accidents.

The scope of the EE PSA for shutdown state and full power state PSA is the same as for the Level 1 PSA and Level 2 PSA.

3. Analysis Methods

ANSWER 7: Since the Swiss NPP PSAs have been extensively reviewed resulting in continuous updates and improvements over the last 15 years, there was significant experience to identify the specific list of EEs, which have to be addressed according to the draft guideline HSK-A05. (Please see also answer to Q6.).

ANSWER 8: Combinations were identified by engineering judgment. Examples of combinations of EEs which shall be considered according to the draft guideline HSK-A05 are:

- Harsh winter conditions including snow (drift), low temperatures, and ice cover
- Harsh summer conditions including high temperatures, drought, forest fire, and low river water level

ANSWER 9: Out of the hazards subjected to screening analysis, a hazard or a combination of hazards can be screened out (according to the draft guideline HSK-A05), if it is demonstrated that at least one of the following conditions is met.

- Based on a qualitative argument, the hazard does not lead to an initiating event.
- The hazard cannot occur or a bounding analysis yields a hazard frequency of less than 10-8 per reactor year and the containment integrity will not be affected.
- A bounding analysis of the CDF due to the hazard yields a result less than 10-9 per reactor year.

ANSWER 10: Some details of the draft guideline HSK-A05 on EE frequency determination are given below.

High Winds
Translational winds and tornadoes are the types of extreme winds to be considered. Based on the experience in Switzerland, specific data are proposed in the guideline for the determination of the initiating event frequency for tornados. Translational wind occurrence and peak wind accelerations can be obtained based on short-term site-specific historical wind velocity data and wind-data from long-term measurement from a fixed weather station or airport near the plant. Measured wind speeds are to be mapped to specific heights of interest.

External Flooding
Flooding events required to be considered are heavy rainstorms or sudden snow melt causing high river water level at the plant, failures of water flow control structures (e.g. dams, weirs, levees) and intense precipitation events. Maximum river water level exceedance frequency curve is to be developed using measured data and (e.g.) a Pearson-III probability distribution.

Aircraft Crash
The aircraft categories considered are commercial aircraft, military aircraft and light aircraft. The risk contribution of IEs involving commercial aircraft crash on the reactor building, on the bunkered emergency building, on other buildings as relevant and on the remaining plant area shall be quantified. Depending on the plant location, the analysis of commercial aircraft crash frequency shall consider the number of aircraft operation and failure rate for each flight phase (i.e. variations of the Seabroak-Model are used).

Direct and indirect impacts of all the above IEs are required to be considered while evaluating the possible initiating events due to these EEs.

ANSWER 11: The direct effect of the external hazards (e.g., wind-induced collapses, mechanical impact of aircraft crash) and the indirect effects (e.g., wind induced missiles, impact of collateral mechanical loads and fire/explosion effects resulting from air craft crash) are both required to be analysed as part of the EEs analysis. The initiating events that can be caused by each external hazard are identified by expert judgement taking into account insights gained from analysis and operating experiences.

ANSWER 12: The effect of the EE on the quantification on the human reliability is required to be considered taking into account all the relevant issues (some of which are stated in the example above). No specific method is defined for this purpose.

ANSWER 13: If the support from systems of the other unit (located in the same site) is accounted in the model, it shall be considered that these systems may not be available due to the external initiating event.

ANSWER 14: EEs are required to be integrated in the PSA model.

ANSWER 15: There are currently no such research projects.

4. Results and Practical Applications

ANSWER 16: The CDF (full power operation, including all external and internal event) for the Swiss NPPs varies between 5.0E-06/yr and 2.0E-05/yr.

In general, the contributions of the quantified EEs are:

High winds: Contribution to CDF varies from negligible to a few percent of the CDF.

Aircraft crash: Observed more relevant to the Level 2 PSA results but also not dominant. The contribution to CDF is (close to) below 1%.

External flooding: Not a dominant contributor: The contribution to CDF is less than 1%.
For NPPs with a low CDF or LERF some EEs may be relevant but not found dominant (seismic events are an exception). To some extent the CDF from EE is low due to the independent, bunkered emergency safety systems.

The full scope PSA results with external events have been used to derive scenarios for emergency exercises for EEs and to improve instructions.

ANSWER 17: After events such as high wind or heavy rainfall in combination with snow melt, the public interest about the risk of such events increased. In consequence, and in order to allow for sound comparisons of the PSA results it became important to further harmonize the EE analyses-methodologies used in the Swiss PSAs.

USA answers

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1. Regulatory Requirements and Status of EE-PSA

ANSWER 1:

The adoption of a risk-informed approach is voluntary for current operating U.S. reactors (i.e., there is no legal requirement for a licensee to develop a PSA). While there is no legal requirement for risk-informed applications, all such applications have to address all the contributors (i.e., both internal and external events); that is, if external events are important to the risk-informed application, they have to be included in the risk evaluation. The United States Nuclear Regulatory Commission (NRC) has assigned low priority to those risk-informed activities not supported by a PSA that address the risk significant contributors. If a licensee does choose to adopt a risk-informed approach though, guidance for a technically acceptable base PSA to support the risk-informed decision under consideration is provided in Regulatory Guide (RG) 1.200. RG 1.200 provides the staff position (1) for a technically acceptable Level 1 and Level 2 all mode PSA for both internal and external events, for operating light water reactors (LWRs) and new advanced-LWRs; and (2) on national consensus standards for the same PSA scope.

Regarding new reactors (advanced-LWRs), 10 CFR 52.47 requires that an application for standard design certification contain, among other things, a design-specific PSA. Similarly, 10 CFR 52.79 requires that an application for a combined license contain a design-specific PSA. This PSA is to be a full scope PSA, which includes an EE PSA. Guidance and standards for EE PSA are dealt with under later questions in this questionnaire.

ANSWER 2:

In 1991 the NRC issued Supplement 4 to Generic Letter 88-20 which requested that each licensee perform an Individual Plant Examination of External Events (IPEEE) for severe accident vulnerabilities associated with external events (including high wind, external flooding, accidental aircraft crash, transportation, and offsite industrial events) and internal fire events. The specific definition as to what constituted a vulnerability was left to the discretion of the licensees. In response to the generic letter, a very limited number of plants performed an EE PSA for their IPEEE. The majority of the plants used other methods (e.g., qualitative screening method) to address their external event analysis. Key results of the IPEEE program are summarized in NUREG-1742.

The NRC is developing Standardized Plant Analysis Risk (SPAR) models for each plant and is in the process of benchmarking the models against licensee PSAs. NRC's SPAR models are Level 1, internal event, at-power PSAs. Work is ongoing to develop large early release frequency (LERF) models and to address events at shutdown and external events. "External events" in these models are defined to include internal flooding, internal fires, seismic events, high winds and hurricanes, external floods, and other external events. The models address the effect of external events through user-defined model elements (the models do not provide full phenomenological treatments of the external events themselves).

ANSWER 3:

The primary goal of the IPEEE program was for licensees to identify plant-specific vulnerabilities to severe accidents, if any, and to report the results together with any licensee-determined improvements and corrective actions to the NRC. The following four supporting objectives for each licensee were identified:

- Develop an improved understanding of severe accident behavior
- Understand the most likely severe accident sequences that could occur at the licensee's plant under full-power operating conditions
- Gain a qualitative understanding of the overall likelihood of core damage and fission product releases
- Reduce, if necessary, the overall likelihood of core damage and radioactive material releases by modifying, where appropriate, hardware and procedures that would prevent or mitigate severe accidents

The Standardized Plant Analysis Risk (SPAR) models are Level 1 PSAs used by the NRC staff in a number of applications, for example: evaluation of the significance of inspection findings (Phase 3 of the Significance Determination Process of the reactor oversight process, ROP), evaluation of the risk associated with accident precursors involving operational events and degraded conditions, identification and prioritization of modeling issues to support agency efforts to improve PSA quality, providing support for the resolution of generic safety issues, and providing support to risk-informed reviews of licensing applications.

The objective of SPAR-EE (external events) models is to complete the plant risk profile so that when the NRC analysts estimate the importance of plant conditions and events, they can get an accurate (more complete) estimate, as opposed to limiting their analyses to internal events only. This completeness is required by the current procedures for the NRC's Significance Determination Process.

Regarding operating reactors, for risk-informed applications, all risk contributors (e.g., external events) have to be considered. For new reactors, 10 CFR 52.47 requires a full scope PSA, which includes external events.

ANSWER 4:

PSA/PRA Standards

The American Society of Mechanical Engineers (ASME) and the American Nuclear Society (ANS) jointly issued a PSA standard, "Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications," ASME/ANS RA-S-2008. This standard is for operating light water reactors (LWRs) and the scope of this standard is internal and external events (Part 4 of this standard is for external events). The NRC staff position on this standard is in Revision 2 of RG 1.200 (to be published December 2008.) A draft of Revision 2 (DG 1200) was issued for public review and comment June 2008 (NRC's ADAMS accession #ML081200566).

IPEEE Program

NUREG-1407, "Procedure and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities," provided guidelines for conducting IPEEEs. While licensees had the choice of how to fulfill IPEEE requirements, a very limited number of plants (roughly

15%) chose to address non-seismic EEs through PSAs. Key results of the IPEEE program are summarized in NUREG-1742. Work is currently underway to expand the standard to address new advanced LWRs, and to address PSAs developed in the design stage.

2. Definition of EE PSA scope

ANSWER 5:
In Regulatory Guide 1.200, the NRC staff has endorsed the following definitions:

- *External Event:* an event originating outside a nuclear power plant that causes safety system failures, operator errors, or both, that in turn may lead to core damage or large early release. Events such as earthquakes, tornadoes, and floods from sources outside the plant and fires from sources outside the plant are considered external events. By convention, LOSP not caused by another external event is considered to be an internal event.
- *Internal Event:* an event originating within a nuclear power plant that includes failure of equipment from internal plant causes (such as hardware faults, operator actions, floods, or fires), and that, in combination with safety system failures and/or operator errors, can affect the operability of plant systems and may lead to core damage or large early release. Internal events can be classified as either "internal hardware events" (such as transients and loss of coolant accidents) or "internal area events" (such as floods and fires). By convention, loss of offsite power is considered to be an internal event.

ANSWER 6:
In general, the scope of a PSA (including external events) that is needed for an application is determined by the decision under consideration. The scope of the EE standard (Part 4 of ASME/ANS RA-S-2008) is independent of the application and includes all external events (as defined above in Question 5).

The list of external events covered within Part 4 of this standard's scope include both natural external events (e.g., high winds, and external flooding) and human made external events (e.g., airplane crashed, explosions at nearby industrial facilities, and the impacts from nearby transportation activities). The scope of a PSA covered by Part 4 of this standard is limited to analyzing accident sequences initiated by external events that might occur while a nuclear power plant is at power. It is further limited to requirements for (a) a Level 1 analysis of the core damage frequency and (b) a limited Level 2 analysis sufficient to evaluate the large early release frequency. The standard will ultimately include low-power/shutdown operation.

3. Analysis Methods

ANSWER 7:
Please see the answer to Question 6 regarding the selection of events for analysis. The following text deals with the question of significance.

The determination of significance is a function of how the PSA is being, or is intended to be, used. When a PSA is being used to support an application, the significance of an accident sequence or contributor is measured with respect to whether its consideration has an impact on the decision being made. For the base PSA model, significance can be measured with respect to the contribution to the total core damage frequency (CDF) or LERF, or it can be measured with respect to the contribution to the CDF or LERF for a specific hazard group or plant operational state, depending on the context.

In Regulatory Guide 1.200, the NRC staff has endorsed the following definitions:

- *Hazard:* the physical effects of a natural phenomenon such as flooding, tornado, or earthquake that can pose potential danger (for example, the physical effects such as ground shaking, faulting, landsliding, and liquefaction that underlie an earthquake's potential danger).
- *Hazard Group:* a group of similar hazards that are assessed in a PSA using a common approach, methods, and likelihood data for characterizing the effect on the plant. Typical hazard groups considered in a nuclear power plant PSA include: internal events, seismic events, internal fires, high winds, external flooding, etc. By convention, internal flooding is considered part of the internal events hazard group. In some cases, it may be appropriate to treat internal flooding as a separate hazard group.
- *Significant Accident Sequence:* one of the set of accident sequences resulting from the analysis of a specific hazard group, defined at the functional or systematic level, that, when rank-ordered by decreasing frequency, sum to a specified percentage of the core damage frequency for that hazard group, or that individually contribute more than a specified percentage of core damage frequency. For the current version of the ASME/ANS standard, the summed percentage is 95 % and the individual percentage is 1% of the applicable hazard group. For hazard groups that are analyzed using methods and assumptions that can be demonstrated to be conservative or bounding, alternative numerical criteria may be more appropriate, and, if used, should be justified.
- *Significant Accident Progression Sequence:* one of the set of accident sequences contributing to large early release frequency resulting from the analysis of a specific hazard group that, when rank-ordered by decreasing frequency, sum to a specified percentage of the large early release frequency, or that individually contribute more than a specified percentage of large early release frequency for that hazard group. For the current version of the standard, the summed percentage is 95 % and the individual percentage is 1% of the applicable hazard group. For hazard groups that are analyzed using methods and assumptions that can be demonstrated to be conservative or bounding, alternative numerical criteria may be more appropriate, and, if used, should be justified.

ANSWER 8:

The ASME/ANS standard requires a dependency analysis of the external events. It is discussed in Part 4 of the standard. Part 4 covers external events (or hazard groups) which includes earthquakes, high winds, and external flooding. The causes for these hazards are external plant occurrences. For example, for high winds, the occurrences to be considered include, at a minimum, tornadoes, hurricanes, tropical storms. The consequences (e.g., algae buildup) of these events on plant performance (e.g., multiple system operators) are addressed in the standard.

Although the standard does require treatment of events, and some events can involve multiple hazards (e.g., a hurricane could cause high winds, storm surge, spawned tornadoes and associated missiles, and delayed flooding from precipitation), there currently is little explicit guidance on the treatment of dependent multiple hazards. This issue was not addressed by the IPEEE submittals, and its risk implications are uncertain. (Note that a formal analysis would, for delayed hazards, have to address shutdown operations. Note also that such operations are unlikely to involve such higher-risk evolutions as mid-loop operation important to analyses of planned outages.)

ANSWER 9:

In the ASME/ANS standard, Part 4, requirements for screening and conservative analysis are given. First, all potential external events that may affect the site must be identified. The events then go through a process where they are “screened out” (excluded from further consideration in the PSA analysis) on a defined basis or subjected to analysis using a PSA (either a limited PSA or a detailed PSA). A demonstrably conservative or bounding analysis, when used together with quantitative screening criteria, can also provide the basis for screening out an event without the need for a detailed analysis.

In 1991, to support the NRC request in supplement 4 to Generic Letter 88-20, guidance was given for conducting high winds, floods, and other external events analyses for the IPEEE program. In Section 5 of NUREG-1407, "Procedural and Submittal Guidance for the Individual Plant Examination of External Events for Severe Accident Vulnerabilities," a progressive screening approach was described, summarized below, which followed a series of steps or analysis in increasing level of detail and effort:

- Review the plant-specific hazard data and licensing basis and determine whether there were any significant changes since the issuance of the operating license that could affect the IPEEE
- Determine whether the plant conforms to the guidance in the NRC's 1975 Standard Review Plan (SRP), NUREG-0800, and perform a plant walkdown
- If the plant does not conform to the 1975 SRP guidance, perform one or more of the following steps:
    - Determine if the hazard frequency of the original design is acceptably low (i.e., less than 1E-5 per year).
    - If the event cannot be screened out based on hazard frequency, perform a bounding analysis to show that the hazard would not result in a CDF contribution of 1E-6 per reactor-year.
    - Perform a PSA.

ANSWER 10:

Two types of uncertainties are addressed: parameter and model. A source of model uncertainty, as endorsed by NRC staff in RG 1.200, is one that is related to an issue in which there is no consensus approach or model and where the choice of approach or model is known to have an effect on the PSA model (e.g., introduction of a new basic event, changes to basic probabilities, change in success criterion, introduction of a new initiating).

The NRC's view with regard to the treatment of sources of uncertainty is as follows:

- Parameter uncertainties are addressed through the quantification process, where mean values are calculated. External initiating event category mean frequencies and their distributions are estimated by using methods similar to those used for internal event initiating event categories. For example, ample data exists for dam failures (for different types of dams) in the United States. Thus, the frequency and distribution can be calculated by using the actual data; this is similar to estimating internal events transient initiating event category frequency. Another example is the frequency estimation for high-intensity seismic events. Since there is no or extremely scarce data for these events, its frequency and distribution are estimated by expert opinion. This method is similar to the expert opinion estimates recently done by the NRC for estimating frequency of Large Loss-of-Coolant Accident (LOCA) event initiating event category for internal events.

- The sources of model uncertainty need to be identified and characterized; it is not necessary to quantitatively evaluate every source of model uncertainty for the base PSA. The impact of those sources of model uncertainty that can impact the PSA results used to support an application only need to be evaluated in the context of that application.

The uncertainties in the external EE PSA results are addressed as discussed in the PSA standard (ASME/ANS RA-S-2008) and associated guidance documents (RG 1.174, RG 1.200, and NUREG-1855).

ANSWER 11:

Initiating events (and consequential effects, e.g., flooding) are generally identified through analysis of the effects of the external hazard. Effects, such as the following, are examined for flooding:

- Potential flood area
- Propagation pathways
- Cause/effect on structures, systems, and components

Fires and flooding initiated internal to the plant are evaluated as part of the internal events analysis (see definitions of external and internal events above in Question 5).

ANSWER 12:

In principle, most commonly-used human reliability analysis (HRA) methods provide some mechanisms to address external event-caused effects (e.g., local environmental changes). Some of the newer "second generation" methods (e.g.,, ATHEANA) place a heavy emphasis on the description of the context for operator actions, and on the potential of challenging situations to increase the likelihood of error. NRC continues to do research in improving HRA methods to support the different events considered in PSA. Examples include:

- The International HRA Empirical Study in which human actions performed by operator crews (at the Halden Reactor Project simulator) are analyzed using different HRA methods and the results are compared to crew simulator performance in an effort to benchmark HRA methods using empirical data. This study is supported by 13 countries, including the NRC and the Electric Power Research Institute (EPRI).
- The Human Event Repository and Analysis (HERA) system, which provides a framework to collect and code human performance event data to support HRA activities. Operational events as well as simulator data are loaded into HERA. The objective of HERA is to support both the improvement of HRA models as well as estimation of human error probabilities.
- NRC/EPRI collaborative work (under initiation) to address the NRC Commission direction (SRM-M061020) to address HRA model differences in an effort to propose a single model for the agency to use or guidance on which model(s) should be used in specific circumstances.
- NRC/EPRI collaborative work to develop HRA guidance to support fire PSA/HRA, that is, guidance for analyzing operator actions modeled in a fire PSA.
- HRA Gap Analysis, a review of the existing HRA good practices (NUREG-1792) with respect to their adequacy to address HRA needs for the EPR design.

However, even with these program, the NRC recognizes the need to expand the capability of current HRA methods to address the needs of PSAs for external events.

ANSWER 13:

Currently, the risk is evaluated on a per unit basis for U.S. plants. Whether the risk for the entire site should be evaluated is an NRC Commission policy issue that has not yet been addressed. Further, most recent studies have not addressed the potential for a single external hazard to cause concurrent accidents at multiple units.

However, in the ASME/ANS standard, while the risk (e.g., CDF from external effects) is calculated on a per unit basis, the effects of one unit on the shared systems at multiple-unit sites have to be addressed.

ANSWER 14:

Generally, the risk associated with each hazard group (e.g., internal fire, earthquakes, high winds) is calculated in separate risk models, not in a single integrated PSA model. The results (e.g., CDF) from each individual model are then summed to provide the overall risk (e.g., total CDF). In either case, when combining the results from the different hazard groups, it is essential to account for the differences in levels of conservatism and levels of detail so that the conclusions drawn from the results are not overly biased or distorted. To support this objective, the ASME/ANS standard is structured so that requirements for the analysis of the PSA results, including identification of significant contributors, identification and characterization of sources of uncertainty, and identification of assumptions are included.

ANSWER 15:

1. *NRC's SPAR models project*
   Please see Answers 2 and 3.

2. *Revised external events standard*
   Please see Answer 4 regarding the ASME/ANS standard.

3. *"Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants," Regulatory Guides 1.76, Revision 1 and "Tornado Climatology of the Contiguous United States," NUREG/CR-4461, Revision 2*
   Regulatory Guide 1.76 provides new guidance for use in selecting the design-basis tornado and design-basis tornado-generated missiles that a nuclear power plant should be designed to withstand to prevent undue risk to the health and safety of the public. It uses new data and the Enhanced-Fujita scale. It makes use of NUREG/CR-4461, Revision 2.

4. *NRC work on Hurricanes*
   The NRC's Office of Nuclear Regulatory Research, in conjunction with the Office of Nuclear Reactor Regulation, is working on the definition of design-basis hurricanes in order to develop a regulatory guide on hurricanes.

5. *U.S. research on hurricane frequency*
   Research groups, such as Kerry Emanuel's at MIT, are doing work on how hurricane intensity depends on the earth's surface temperature. This may link hurricane frequency with global warming concerns.

4. Results and Practical Applications

ANSWER 16:

In the IPEEE program, none of the 70 IPEEE submittals identified any high winds, floods, and other external events (HFO) - related vulnerabilities. However, 34 submittals reported that they had either made, or were considering, a total of 64 HFO-related improvements. Improvements included the following:

- Added scuppers to parapet walls of auxiliary building to relieve roof load during heavy rainfall
- Emergency procedures revised to prepare portable ventilation fans and generator for adequate ventilation in switchgear rooms during hurricanes
- Restrictions added to prevent air flights over protected areas
- Had Coast Guard stop shipments of explosives on river near plant
- Provisions for specific operator training in the use of two different instrument rooms together in the event of tornadoes
- Added seiche protection barrier to protect diesel generator fuel oil transfer pumps during heavy rainfall
- Diesel generator exhaust stacks were modified to accommodate higher wind loads
- Refurbished existing flood wall and stop logs
- Emergency diesel generator fuel oil transfer pump elevated to protect against hurricane surge

- Added air cooled diesel generator
- Procedures to remove snow and ice during winter storms
- To prevent ice formation in service water pumps causing common mode failure of diesel generators, the licensee (1) implemented procedures to check on this condition, (2) installed permanent temperature monitoring equipment, (3) installed fiberglass curtain to reduce wind chill effects, and (4) modified terminations of cold weather lines to reduce chilling effect
- Concrete barriers installed around propane tank near diesel generator rooms to protect against vehicle impact

ANSWER 17:
Loss of off-site power events, caused by weather-related conditions, provide the best examples. References to such events are provided in Appendix A to NUREG/CR-6890, "Reevaluation of the Station Blackout Risk at Nuclear Power Plants." Some U.S. plants have identified other events in their studies. One plant postulated that wind generated missiles could fail the diesel generators, service water system condensate storage tank, or ventilation system, thereby leading to core damage. Another plant identified the diesel fuel oil transfer pumps and lines as being exposed to tornado-induced missiles. Additional plants identified flood-related damage, including the loss of function of the intake structure; failures of diesel fuel oil transfer pumps; and potential failures of safety-related equipment in the diesel generator, auxiliary, and turbine buildings. Operating events have not necessarily changed the "method" for doing EE PSA, but have identified the importance of external events and the need to include them in the risk evaluation. The ASME/ANS standard does require the analysis to consider data (e.g., events) from other nuclear plants for their applicability.

Answers to the additional questions

Chinese Taipei answers to the additional questions

Background

The NEA/CSNI Task Group on PSA of Other Off-site External Events than Earthquake distributed a questionnaire on 28 June 2007. Drafting the task report has been started based on the answers. In the Task Group meeting on 3 March 2008 it was agreed that two additional questions will be distributed, one on treating the dependencies between initiating events and safety system degradation and one on the aggregation of PSA results.

The task group would appreciate if you could answer the questions by 7 June 2008.

Identification

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Please fill in your answers in this file and return it by e-mail to Dr. Jorma Sandberg, Radiation and Nuclear Safety Authority - STUK, e-mail jorma.sandberg@stuk.fi, by **7 June 2008** and a copy to Dr. Nathan Siu (nos@nrc.gov) and Dr. Gabriel Georgescu (gabriel.georgescu@irsn.fr).

Additional question I (Question 11bis)

An important consideration in EE PSA is whether the hazards analyzed can, in addition to disturbing the operation of the plant, also disable or degrade the safety systems. Thus, the modelling of dependencies is a key point in the analysis. This aspect can be important even during initial screening, since the screening out of external hazards without consideration of dependencies can underestimate the associated risk. Note that analyses considering external induced initiating events in the frame of internal events PSA (e.g., extreme-weather induced losses of offsite power) may not always consider important dependencies (e.g., a snow storm leading to loss of offsite power and to degradation of diesel generators).

How do you identify the dependencies between the initiating events caused by external hazards and the safety systems?
At which stage of the analysis is this identification done? How are the dependencies modelled in the EE PSA?
For the external induced initiating events considered in the frame of the internal events PSA, are these dependencies considered?

ANSWER 11bis
The only external event considered in Taiwan is the typhoon during summer time. Strong wind and heavy rain are the main concern when typhoon attacks. For heavy rain, it will have no direct impact on plant operation. But the experience showed that, heavy rain may cause bad seawater condition which will significantly reduce the intake flow of seawater and affect the operation of service water system. For strong wind, system or component such as switchyard or electric transmission grid which were not secured inside building may be affect. Only loss of offsite power was considered as an initiating event during typhoon attack. Probability of bad seawater condition caused by typhoon was considered as a basic event which will fail the operation of service water.

Additional question II (Question 16bis)

The uncertainties in the results of an EE PSA are due to uncertainties in the frequency and magnitude of the external events, and to uncertainties in the effect of these events on the plant. Past analyses have shown that EE PSA uncertainties can be considerably larger than the uncertainties in internal events PSA results. Furthermore, recognizing that many EE analyses are conducted at a screening level, the calculated risk for a given hazard may be conservatively biased. These observations raise a question as to how the results of EE PSA are used in decision support applications.

When used to support decisions involving consideration of total plant risk, are the results of EE PSA presented separately from the results of internal events PSA, or are they integrated into a statement of overall risk? If the latter, are there any special measures taken to highlight potentially significant biases and uncertainties in the EE PSA results?

ANSWER 16bis:

The contribution of typhoon risk is less than 3% of the overall risk. The result is integrated into the statement of overall risk. There is no special measure taken to highlight the uncertainty.

Finland answers to the additional questions

Identification

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ANSWER 11bis

External events PSA is focused on situations where an external influence can cause an initiating event and simultaneously degrade safety systems.

The identification of dependencies is based on operating experience, interviews of designers and operating and maintenance personnel and systematic analysis of plant systems and components and their design basis. The identification of dependencies has been done in the early phases of external events PSA and is updated for new revisions of external events PSA.

A typical modelling technique is to define special initiating events which include a usual transient (loss of offsite power, loss of feedwater, scram) caused by an external event and a simultaneous total or partial loss of safety or support systems. For example, a blockage caused by algae or frazil ice at seawater intake is modelled in EE PSA as one of the following initiating events:

- loss of feedwater (due to trip of main seawater pumps) and partial loss of service water
- loss of feedwater and total loss of service water.

If algae or frazil ice only causes trip of main seawater pumps, the event is included in the corresponding transient frequency in internal events PSA.

The EE PSA initiating events (i.e. combinations of a transient and loss of safety systems) are defined and their frequencies are calculated with separate event trees outside the PSA model.

When transients caused by external events are modelled in internal events PSA, the dependencies are not generally considered.

Correlated external events are modelled as combined events in EE PSA. For example, an extremely high wind may damage the external power grid and simultaneously waves may loosen algae. This can be modelled as a combined event “loss of offsite power and algae”. The event involves at the same time loss of offsite power and total or partial loss of service water leading to loss of the corresponding diesels. (Loss of offsite power event implies loss of main feedwater.)

ANSWER 16bis:

External events analysis is integrated in the living PSA models and the results are included in the overall risk.

In one PSA the contribution of external events is small and the possible bias and the large uncertainties have not been considered problems.

In another PSA the contribution of external events is significant. In this PSA formal uncertainty analysis has not been done.

A bias due to conservative assumptions is possible, but, in general, it is not considered a serious problem regarding decision making. If a problem area is identified with external events PSA, alternative actions are examined, including refinement of the analysis, improving EOPs, additional training and plant modifications. Decisions on actions will be taken on a case by case basis considering also deterministic design principles and the SAHARA principle.

In PSA applications, such as RI-ISI, RI-IST and RI-TechSpecs, the decisions are usually based on risk increments related to equipment unavailability. The uncertainty and possible overly conservative treatment of external events does not generally affect the decisions.

The large uncertainty and conservatism in the treatment of external events may affect risk informed decision making in some special cases, e.g., when seawater systems and decay heat removal are considered. In risk informed review of Technical Specifications decisions have to be made on allowable outage times and on continued operation versus shutdown. In such applications comparison of risks due to internal failures and external events may be necessary. If the level of conservatism is different for different types of events, the optimal solution will be biased.

France answers to the additional questions

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ANSWER 11bis

In France no EE PSA was developed for the moment.
For the external events included in the internal events PSA (the loss of ultimate heat sink, and the loss of external power supply),only functional dependencies are taken into account (loss of support systems), the dependencies between the initiator and the plant systems (induced by the natural phenomena) are not considered.

ANSWER 16bis

In France no EE PSA has been developed yet.
In the frame of PSA applications the impact of external events is considered mainly on a deterministic basis. If a given risk issue has an impact on the plant safety demonstration (including the plant design to cope with external events) the deterministic aspects are taken into account for the decision making. This process is however limited to the hazards included in the design basis.
In the future, when EE PSA will be developed, theirs results and insights would be integrated in the decision making process.

Japan answers to the additional questions

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ANSWER 11bis

(1) Identification of the dependencies between the initiating events and the safety system

Answer is not available because we have made no EE-PSA other than for earthquake and earthquake induced hazard such as Tsunami in Japan.

However, as the approach to the identification of the dependencies between earthquake induced Tsunami and the safety system in Tsunami PSA will be useful information, we present it briefly. In Tsunami PSA after Tsunami hazard evaluation to have Tsunami hazard curve the fragilities for mainly outdoor facilities such as seawater intake structures, seawater pumps, oil tanks are evaluated under the Tsunami run-up analysis. Using the fragilities the probabilities of both loss of off-site power induced by Tsunami and loss of safety functions such as ECCS and emergency DG are evaluated. Namely, the probabilities of failure of individual components are evaluated as functions of the size of Tsunami. From these functions, the conditional probabilities of system failures and core damage for a given size of Tsunami are calculated. Then the Tsunami hazard curve and conditional core damage probability are used to calculate the core damage frequency. In this way the dependencies between the initiating event induced and the safety system degraded by tsunami are taken into account in Tsunami PSA.

(2) The dependencies between the external induced initiating events and the safety system in the internal events PSA

Loss of off-site power is included in the internal events PSA. However, the dependencies between the loss of off-site power and the safety system are not considered.

ANSWER 16bis

Answer is not available because we have made no EE-PSA in Japan.

Slovak Republic answers to the additional questions

Identification

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ANSWER 11bis

Only those events are considered in EE PSA which can disturb the operation of the plant and need successful operation of safety systems. Identification of dependencies between the external events and the safety systems is performed with detailed analyses. Identified dependencies are included into PSA model by new gate or new basic event, which reflect status of the plant after events.

ANSWER 16bis

Total plant risk presents the mean value which involves risks from internal and external hazards. The results of EE PSA are presented separately as well as are integrated into a statement of overall risk (plant risk).

PSA models are preformed with RISKSPECTRUM software. RISKSPCTRUM calculates different importance measures, uncertainties and sensitivity of the results.

Switzerland answers to the additional questions

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ANSWER 11bis

Dependencies caused by external hazards are identified in the course of PSA plant walkdowns and by an analysis of the plant conditions during the EE. The identification of the relevant dependencies is usually done prior to the EE PSA modeling.

The dependencies are considered in the PSA model. For each relevant external event an event tree is developed based on the general transient event tree (which already considers the internal dependencies).

ANSWER 16bis

HSK follows an integrated regulatory oversight process, where PSA is an additional element in the decision making. For the PSA applications EEs are included in the risk assessment and are not treated separately.

However, the risk assessment of the EEs may be reconsidered and refined for particular PSA applications (e.g. if the assessment of an EE is potentially crucial for a risk-informed plant modification or for an assessment of an event).

USA answers to the additional questions

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ANSWER TO ADDITIONAL QUESTION I (Answer 11bis)

A dependency analysis is an essential element of a PSA and is included in the ASME/ANS standard. It is required and is performed throughout the development of the PSA model. The standard requires that the ability of events to impair a mitigating (e.g., safety) system be assessed. Examples of an assessment include:

- Identification of the phenomenological conditions created by the event (e.g., missiles, adverse temperatures, debris)
- Identification of time-phase dependencies (e.g., DC battery adequacy—time dependent discharge)
- Identification of dependence between components
- Identification of the design conditions (e.g., trip signals) that will cause a system to fail to start or fail to continue to operate (e.g., excessive room temperature, inadequate net positive suction head)

ANSWER TO ADDITIONAL QUESTION II (Answer 16bis

As noted in response to Question 14, for many applications, it is necessary to combine the PSA results from different hazard groups (e.g., from internal events, internal fires, and external initiating events). For this reason, an important aspect in interpreting the PSA results is understanding both the level of detail associated with the modeling of each of the hazard groups, and the hazard group-specific model uncertainties. With respect to the level of detail, for example, the analysis of specific scope items such as internal fire, internal flooding, or seismic initiating events typically involves a successive screening approach, so that more detailed analysis can focus on the more significant contributions. The potential conservatism associated with the evaluation of the less significant contributors using this approach is assessed for each hazard group. In addition, each of the hazard groups has unique sources of model uncertainty. The assumptions made in response to these sources of model uncertainty and any conservatisms introduced by the analysis approaches can bias the assessment of importance measures with respect to the combined risk assessment and the relative contributions of the hazard groups to the various risk metrics. Therefore, the sources of model uncertainty are identified and their impact on the results analyzed for each hazard group individually, so that, when it is necessary to combine the PSA results, the overall results can be characterized appropriately. The sensitivity of the model results to model boundary conditions and other assumptions is evaluated, using sensitivity analyses to look at assumptions both individually or in logical combinations. The combinations analyzed are chosen to account for interactions among the variables. NUREG-1855 provides guidance on the treatment of uncertainties associated with PSA. The understanding gained from these analyses is used to appropriately characterize the relative significance of the contributions from each hazard group.