ETSON

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TECHNICAL SAFETY
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NETWORK

ETSON WORKSHOP

OVERVIEW ON THE ASSESSMENTS OF EARTHQUAKE/FLOOD AND PROVISIONS

IN CASE OF STATION BLACKOUT (SBO) OR LOSS OF ULTIMATE HEAT SINK (LUHS), IN THE LIGHT OF FUKUSHIMA ACCIDENT

ETSON workshop, Paris, May 11-12, 2015

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1 GENERAL INTRODUCTION

Although regulatory overview of nuclear safety is a national responsibility, regulatory recommendations at an international level, especially by nuclear countries' neighbors, are emphasizing more strongly that nuclear accident consequences are likely to cross borders.

For that reason, after the Fukushima accident, the European Nuclear safety directives (NSD) were amended. The NSD specifies that new nuclear installations should be designed, sited, constructed, operated and decommissioned with the objective of preventing accidents and, should an accident occur, mitigating its consequences and avoiding: (a) early radioactive releases that would require off-site emergency measures but with insufficient time to implement them; (b) large radioactive releases that would require protective measures that could not be limited in area or time.

Such objectives are used as a reference for existing reactors.

After the Fukushima accident, specific attention was paid to the risks induced by natural hazards and to the consequential situations, in particular station blackout (SBO) or loss of ultimate heat sink (LUHS). In 2011-2012, stress-tests were performed on those subjects in all EU countries having NPP (plus Ukraine and Switzerland) and a first ETSON workshop was held in Garching in March 2013. The members presented the potential weaknesses identified and needs for improvement. Several conclusions were therefore issued, including the need to:

- exchange information on experiences and results in assessing natural hazards (different approaches for specifying the design basis earthquakes in the different ETSON member countries and on other natural hazards such as flooding), and to

- exchange information and data among the ETSON partners about the implementation of fixed features to enhance the robustness of NPPs against beyond design basis accident/hazards. The discussion should focus on the so-called "hardened safety core" in France and the comparison of similar approaches in other ETSON member countries.

The 2015 workshop objective was to identify, after the post-Fukushima stress tests, the common positions, good practices highlighted and shared questions regarding three main topics:

1. characterization of design basis flood (DBF) and beyond design basis flood (BDBF) that should be considered;

2. characterization of design basis earthquake (DBE) and beyond design basis earthquake (BDBE) that should be considered;

3. beyond design basis situations of SBO/ LUHS.

ETSON member organizations from Belgium, Czech Republic, France, Germany, Lithuania, Russia, Slovakia, Ukraine, and United Kingdom (UK), and invited representatives from Spain, discussed the different subjects, focusing on existing NPPs, except for the british participants who presented their approaches regarding submarines and associated facilities.

The report gives the different positions of the TSOs from Belgium, Czech Republic, France, Germany, Lithuania, Russia, Slovakia, Ukraine, and United Kingdom, with complementary elements from the TSO of Slovenia, who was not able to attend the meeting.

For each position indicated in this report, the following rules are applied:

- “all TSOs” means that all 10 TSOs agreed;
- “most of the TSOs”, is used when 7 to 9 TSOs agreed;
- “some TSOs” is used when 4 to 6 TSOs agreed;
- “few TSOs” means that less than 3 TSOs support this position.

The list of the TSOs and participants is given in appendix A.

2 HAZARDS

Belgium, Czech Republic, France, Germany, Lithuania, Russia, Slovakia, Spain, Ukraine, United Kingdom presented and discussed the methods used to define design basis and beyond design basis flood and earthquake.

The presentations pointed out the good practices to define such levels. The views of the TSOs were discussed concerning the important points that should be considered in defining hazard levels and during TSO assessment.

2.1
Flood

No major weaknesses were identified regarding flood during the stress-tests performed by the different members.

2.1.1
DESIGN BASIS FLOOD (DBF)

All TSOs agreed on the common target of maximum 10^{-4}/y exceedance frequency to define DBF (as proposed by WENRA[1]). They considered that the levels for the design basis flood of their country NPPs are consistent with this objective, especially for river flood and storm surge. Nevertheless, some questions have been raised about other flooding phenomena (e.g. local rainfall, groundwater raise), especially when industrial standards are applied.

All TSOs agreed on the importance of periodic safety review (PSR) to review the levels of hazards and consider that the design basis flood should be reevaluated at each PSR. Indeed, levels should be reevaluated due to possible improvements of knowledge, evolutions of the state of the art in methods used, consideration of experience feedback, and also to take into account environmental evolution.

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[1] *"The exceedance frequencies of design basis events shall be low enough to ensure a high degree of protection with respect to natural hazards. A common target value of frequency, not higher than 10–4 per annum, shall be used for each design basis event."* Report WENRA Safety Reference Levels for Existing Reactors - UPDATE IN RELATION TO LESSONS LEARNED FROM TEPCO FUKUSHIMA DAI-ICHI ACCIDENT - 24th September 2014.

Furthermore, participants focused on environment evolutions which may be due to climate changes, but also due to possible changes in human activities. Different examples were given: changes in industrial environment near a NPP site, changes on rivers, buildings that change rainfall run-off. Difficulties for the TSOs to encompass such evolutions were highlighted. In particular, access to information regarding non-nuclear activities' evolution (e.g. laying out of dams, harbors, dikes) remains an open issue. Finally, according to all TSOs, reconsidering the risks between two PSRs should be a possible option.

The references of the regulatory texts in force to define DBF in the different countries are given in appendix B.

Main water bodies

For river sites, lakes and coastal sites, in all countries, flood levels are mainly based on a statistical evaluation to determine a flooding level. For example, for rivers, a statistical evaluation for the river flow rate is performed, a margin factor is considered on the flow rate and models are used to determine the water levels. For coastal sites or lakes, a statistical evaluation of the water level and wind speed is performed, then a model is used (with consideration of wind conditions and modelling of waves, wind waves evaluation from data or modelling, extrapolation of the storm surge data, combination of storm surge and wind waves).

The following table gives an overview of the different approaches considered to define the current DBF.

	Current water levels considered for DBF	Observation
Belgium	For river site: ■ high river flow rates (1,000-yr flow rate (Upper Bound - UB of the 70% Confidence Interval - CI) increased by 15%) + wind waves + potential blockage of downstream dam; ■ failure of upstream dam. For coastal/estuary site: high tide + storm surge + wind waves.	For river site: initially only Historical flood (1926) +20%. All sites: initially no wind waves.
Czech Rep.	For river sites: ■ for NPPs, no risk (located on elevated sites in distance from river); ■ for research reactor, in Rez and Prague, located on shore of Vltava river-(500- years flood in August 2002, set of corrective measures implemented).	
France	For river sites: ■ 1,000-yr flow rate (UB of the 70% CI) +15%+ conservative value of influencing parameter (in flood plain modelling); ■ 1,000-yr flow rate (UB of the 70% CI) + conservative value of influencing parameter (in flood plain modelling) + 100-yr wind waves (UB of the 70% CI); ■ failure of the dam that would lead to the most serious consequences for the site. **For coastal sites:** highest tide + 1,000-yr storm surge (UB of the 70% CI) + 1 m (account for outliers in observed storm surges series) + change in mean sea level (extrapolated to the next PSR) + 100-yr wind waves (UB of the 70% CI).	

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	Current water levels considered for DBF	Observation
Germany	**River sites:** measured run-off extrapolated to 10^{-4}/y values. **Coastal sites:** peak water level in case of a 10^{-4}/y storm surge is derived from gauge measurements.	
Lithuania	Ignalina is located on the lake Druksiai. The levels of all three hydro-technical engineer structures, regulating the lake level, are lower than the site elevation.	
Russia	River (Greek) side - Measured run-off extrapolated to 10^{-4}/y values. Coastal (sea and lake) side - peak water level in case of storm surge is derived from gauge measurement to a 10^{-4}/y storm surge.	
Slovakia	Due to topology of NPP sites, rivers do not represent risk of flooding, nonetheless, maximum 1000-year flow rate and torrential rains are taken into account.	
Slovenia	River site only. Design flood 10.000 year, from statistical records + wind waves + local heavy rainstorm + failure of upstream dams.	Design flood estimated by Log-Pearson type III distribution form the hystoric records (since 1926).
Spain	-	
United Kingdom	Predicted frequency of exceedance of 1 in 10 000 years, conservatively derived to allow for uncertainties.[2] **For coastal sites:** maximum tide + storm surge (including wind and barometric effects climate changes over the life of the facility + wave).	
Ukraine	Greater than 0.5m over the 10^{-4}/y occurrence frequency maximum water level in surface water bodies	

All TSOs considered as a good practice to verify that historical events do not exceed in severity the 10^{-3}/y to 10^{-4}/y events.

Local precipitations

The evaluation of the level of water, on site, in case of heavy rainfall is not considered in all regulation or specific guides; when they are not specifically considered, industrial standards are mostly used to define associated levels.

Different approaches regarding rainfall are applied:

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[2] Ideally, UK regulators would want a demonstration of protection against 10^{-5}/y external hazards (in line with the target for internal hazards), but recognise the difficulty in obtaining substantiated data for 10^{-5}/y. The aim is that by requiring a conservative derivation of the 10^{-4}/y hazard, and a deterministic demonstration of protection against that hazard, the level of protection resulting will be similar to that for 10^{-5}/y hazards.

- in Belgium, the water levels on site are derived from site-specific models using data (i.e. rain intensity (in mm/h) vs. duration and frequency) for a return period of 100 years and covering several rain durations (minutes, hours, days); after the stress-tests, some re-evaluation is done or ongoing for rainfall events of 1,000 years return period (Upper Bound (UB) of the 95% CI);

- in Ukraine, two types of rains, long term (maximum daily precipitation) and short term (100 liter/s/ha during 20 minutes), are derived from industrial standards;

- in France, the reference rainfall events are defined by the upper bound of the 95% confidence interval for rainfall events of 100 years return period. Each rainfall event is characterized by a height of precipitation totaled over a given period of time (several minutes, to several hours). To consider, firstly the potential for obstruction of the drainage system during extreme events, and secondly events rarer than those defined in the reference rainfall events, the installation shall be able to cope with a second surface water runoff scenario when its local drainage system is completely blocked. This reference surface water runoff scenario is defined by the one-hundred-year return period rainfall event (value of the upper bound of the 95% confidence interval) lasting 1 hour.

Uncertainties

For DBF, all TSOs highlighted the difficulties to deal with uncertainties. During the TSO assessment, particular attention should be paid to licensee's demonstration that the margins cover uncertainties.

Some TSOs expressed the need for an own TSO evaluation confronted to the licensee evaluation, specifically in order to have a good estimate of uncertainties. However, few ETSON partners are able to carry out their own sensitivity analysis and own evaluation and therefore *e.g.* ask the licensee for sensitivity analysis. In the United Kingdom, the TSO would be expected to assess the licensee's evaluation, which should include an uncertainty analysis. The TSO would check that methods had been correctly applied and that the results were reasonable, but does not have independent models of storm surges to verify the use of the UK standard models, and would not be expected to.

Most of the TSOs pointed out that flood probabilistic evaluations would be a good way to better capture uncertainties in hazard assessment.

Some TSOs agreed on the interest to perform a benchmark with common data and using different methods to evaluate DBF, in order to appreciate the effect of the different models used, and the impact of the methods to deal with uncertainties. Such benchmark could be performed within ETSON framework or proposed to OECD/NEA.

2.1.2
BEYOND DESIGN BASIS FLOOD (BDBF)

Some countries indicated that they consider a BDBF. Such levels are defined considering:

- (DBF + margin); for example
  - ☐ for Tihange (Belgium), an additional margin of 1 metre is added to DBF;
  - ☐ for France, 1 additional metre to determine the sea level, or multiplication factor of 1.3 for river site flow rates.

- (DBF + loss of protections); for example
  - ☐ for Doel (Belgium), a storm surge combined with the dike rupture is considered;
  - ☐ for France, all inlets of the local drainage system are blocked in case of rainfall event;
  - ☐ for Ukraine, a combination of dams rupture with the wind generated waves (1 metre wave caused by the wind with speed 17 m/s was assumed).

In the United Kingdom, the requirement is to identify margins to loss of safety functions; setting a BDBF is not necessarily required. Different licensees have taken different approaches:

- set BDBF based on DBF + margin, where the margin is site-specific, using arguments based on the maximum credible contribution of the various flood mechanisms;

- set BDBF based on best-estimate extrapolation of measured data out to 1 in 100,000 years;

- set BDBF based on the maximum credible contribution of the various flood mechanisms;

  - not set BDBF, but demonstration that the consequences of a flood larger than the DBF are tolerable.

Cases based on each of these approaches have been accepted by the regulators.

Different pragmatic approaches are used, as there is no quantified target for the hazard. However, the use of deterministic margins raised the question of their consistency between different sites: indeed, deterministic increases of the levels don't have the same probability on each site.

Finally, probabilistic evaluations would be a good complement to define BDBF; all TSOs agree on the need to develop probabilistic approaches, although associated difficulties are recognized.

Few TSOs proposed that the frequency target should comply with the Core Damage Frequency and Large Release Frequency defined in the plant safety objectives.

2.1.3
PROTECTION MEASURES

Different approaches to define protection measures were presented. Generally, for DBF, all TSOs agreed that priority should be given to permanent protection. For BDBF, mobile/fixed equipment may be used.

2.2
Earthquake

Different definitions are used to deal with earthquake. The following table gives an overview of the different definitions used and their meaning during the workshop discussions.

OBE	Used in Belgium : Operating Basis Earthquake : earthquake level for which normal plant operation will not be interrupted. Structure System Component (SSC) remain functional. Used in United Kingdom: as for Belgium but with a target of 10^{-2}/y earthquake.	In Belgium: No target of exceedance frequency In the United Kingdom, the 10^{-2}/y earthquake is small, so the OBE is set large enough to avoid spurious shutdown (e.g. from passing vehicles).
DE	Defined (Design) Earthquake (used in Lithuania, Ukraine, Slovakia) Deterministic: based on historical data to obtain a target of exceedance frequency lower than 10^{-2}/y.	Similar to OBE.
MHPE	Maximum Historically probable Earthquake: Earthquake similar to past events that could happen in the future in a penalizing location for the facilities.	Used in France and in Germany (without using the specific term) for deterministic seismic hazard assessments.
SSE	Safe Shutdown earthquake (Belgium, Czech Rep, France,): SSC necessary to ensure a safe shutdown and cooling of the plant are required to withstand the SSE and are designed to remain functional.	Similar to MCE.

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MCE	Maximum Credible Earthquake (Belgium). Maximal Calculated Earthquake (Lithuania, Slovakia, Ukraine, Czech Rep, Russia). Safe shutdown and cooling of the plant. Deterministic: based on historical data to obtain a "target value" of exceedance frequency lower than 10^{-4}/y. Belgium : used in the seismic hazard assessment, it is the potential maximum earthquake based on geological evidence of the site.	Similar to SSE.
DBE (Russia)	Design basis earthquake – earthquake with repetition period equal to 1,000 years.	
DBE	Design basis earthquake: earthquake level for which certain SSC are designed to remain functional.	
RLE	Review Level Earthquake (Belgium, Slovakia, Germany); postulated value, greater than DBE, generally used for Seismic Margin Assessment (SMA).	
BDBE	Beyond Design basis earthquake: Spectrum and PGA used to guarantee no early or massive releases and to demonstrate no 'cliff-edge' effects beyond the design basis.. Belgium: earthquake more severe than the DBE.	In the United Kingdom this is sometimes referred to as the Seismic Margin Earthquake (SME).

A table (appendix C) gives the regulatory texts in force to define DBE in the different countries.

All TSO agree on the need to update regulatory documents or guides related to DBE to adjust them to the state of the art. This updating process is ongoing in several countries (Ukraine, Russia), or already completed for Belgium (new installations) and United Kingdom (new guide issued in 2014).

Generally, most of the TSOs agreed on the need for an **independent hazard assessment** by seismologists, on behalf of the TSO, for the review of seismic hazard provided by licensees. In the United Kingdom, the licensee would be required to organise an independent peer review of their hazard assessment; the TSO may then assess this review.

2.2.1
DESIGN BASIS EARTHQUAKE (DBE)

At the initial design stage of existing reactors, the approaches used to define the DBE (if existing) were all deterministic, except in the United Kingdom where probabilistic assessments were used in the design of the newest operating NPP (Sizewell B).

All TSOs agreed on the need for the DBE to be reviewed, and if necessary reevaluated, at each PSR, to ensure that it reflects modern knowledge, methods, etc.

The following table gives an overview of the different approaches considered to define DBE.

	Current methods to define DBE	Observations
Belgium	Deterministic Hazard assessment based on Maximum Credible Earthquake.	For new reactors (new regulation 2015): ▪ probabilistic Seismic Hazard based on 10^{-4} mean annual hazard exceedance frequency; ▪ deterministic Hazard assessment based on Maximum Credible Earthquake.
Czech Rep.	Deterministic assessment based on Maximum Credible Earthquake (10^{-4} frequency).	Due to the values PGA less than 0.05 g) PGA = 0,1 g taken for strengthening of SSC. Seismic monitoring implemented.
France	Deterministic – DBE spectrum envelop the spectra of: ▪ SSE considered. Use of Maximum Historically Probable Earthquake (MHPE) (historical & records) increased by 1 in intensity (equivalent to an increase of 0.5 in Magnitude); ▪ active fault in case of paleoseismic evidence; ▪ minimal spectrum scaled to 0.1g.	Progressive use of PSHA (10^{-4}) to test the DBE value.
Germany	Based on both deterministic and probabilistic evaluation: ▪ deterministic based on historical earthquakes and conservative assumptions w.r.t. the location of future earthquakes; ▪ probabilistic: exceedance frequency of 10^{-5}/y (median value) equivalent to 10^{-4}/y (CI 84%).	
Lithuania	For the Ignalina NPP the DBE defined as deterministic value based on historical records 6 points on the MSK-64 scale (maximum ground acceleration is 0.05g).	
Russia	Deterministic value based on historical records, national seismic map and on results of micro seismic zoning studies.	New regulation under review (introduction of PSHA).
Slovakia	Deterministic value based on historical records increased by safety margin and corresponding to maximum intensity earthquake with occurrence once in 10^5 years.	

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	Current methods to define DBE	Observations
Slovenia	Originally deterministic with SSE PGA = 0.3 g. Today PSHA (equivalent to SSE PGA = 0.6 g)	PSHA values used for all modifications.
Spain	-	
United Kingdom	Earthquake with predicted frequency of exceedance of 1 in 10,000 years. Operator must derive this, using conservative methods based on a site-specific probabilistic hazard assessment.	Most operators have used a standardized spectrum scaled at PGA of 0.25 g, although some operators have justified lower levels.
Ukraine	Deterministic based on survey plus a safety margin (~ 30%). Minimal PGA is 0.1 g.	Progressive use of PSHA (10^{-4}) to test the DBE value.

All TSOs consider as a good practice the use of historical evidence in defining the DBE (data considered should not be restricted to the last decade's records).

When deterministic approaches are considered, most countries use a seismotectonic zoning and:

- if the controlling earthquake happened in the same seismotectonic unit as the site, it is assumed that this earthquake occurs at the same intensity at the site;
- if the controlling earthquake happened in another seismotectonic unit than that of the site, it is assumed that a similar earthquake occurs at the point of this seismotectonic unit closest to the site.

The importance of "site effects" (Free field vibratory ground motion amplification/de-amplification due to site geology and topography) to determine the DBE was raised. This effect needs specific attention during the review.

All TSOs agreed on the 10,000 years target for the DBE return period. However, the deterministic approaches alone, are not sufficient to confirm this target. Therefore, the seismic hazard assessment should include a **probabilistic/statistical hazard assessment**, as information on the exceedance frequency of the DBE is needed to evaluate plant safety and to quantify the residual risk.

All TSOs agree on the need to use both deterministic and probabilistic values and that regulations that do not yet consider probabilistic/statistical approaches, should be improved to include both deterministic and probabilistic evaluations. Nevertheless, there is an open question on which final value should be used.

Concerning probabilistic evaluation of earthquake, particular attention should be paid to input parameters (minimum magnitude, maximum magnitude, etc.), for example using sensitivity studies to test such parameters values. Generally, regarding probabilistic evaluation of earthquake, there was a general need to improve TSO skills and to exchange information and practices between TSO.

2.2.2
BEYOND DESIGN BASIS EARTHQUAKE (BDBE)

Some TSOs pointed out that a requirement for a BDBE has been defined. Different methods to define the BDBE are used:

- an increase of the DBE (+ 50% in Belgium, + 40% or + 60% (depending on the operator) in United Kingdom, + 50% in

France to design the hardened safety core, + 40% in Russia (planned in new regulations);

- use of 0.1g for low seismicity zones;

- use of PSHA with an exceedance frequency strictly lower than 10^{-4}/y (return period of 20,000 years for France to design the hardened safety core and 100 000 years for United Kingdom);

- or a combination of the three previous approaches.

In the United Kingdom the operator must demonstrate that structures have ductile response to the BDBE (i.e. they deform without failure), with no step-change in consequences, and show that risks have been reduced to ALARP.

In most countries, Seismic Margin Assessments were performed and were considered as good practices to identify weaknesses of structures and equipment.

For new installations, all TSOs considered that there is a need to define provisions able to face BDBE.

2.2.3
SPECIFIC SUBJECTS

All TSOs considered that for low seismicity zones the Peak Ground Acceleration (PGA) should not be lower than 0.1g in accordance with IAEA recommendations.

Some questions were raised about the challenges associated to the performance of a PSHA in a low seismicity zone, due to the lack of data. Most of the TSOs considered as a good alternative the use of the "0.1g" as a minimal value of PGA. Nevertheless, further discussions are needed to define a common view on **Seismic Hazard Assessment in low seismicity areas.** Indeed, some countries pointed out that the minimum design requirements are not meant to replace site-specific hazard assessments; the United Kingdom experience is that applying a conservative approach to seismic hazard assessment usually produces a DBE larger than 0.1g for low seismicity zones.

Concerning the robustness of the plant in case of earthquake, some TSOs highlighted the need to share a database on SSC robustness. Moreover, they pointed out the need to discuss **methodology (approaches) for underground piping seismic resistance assessment.**

3 SBO AND LUHS

Belgium, Czech Republic, France, Germany, Lithuania, Russia, Slovakia, Spain, Ukraine and United Kingdom presented and discussed the provisions to cope with a SBO or LUHS in order to prevent a severe accident.

They pointed out good practices and raised questions. As TSOs, they discussed the important points that should be considered during TSO assessment of such situations.

3.1
Flexibility of the strategy

All TSOs agreed on the **need of flexibility of the strategies** to face beyond design situations.

Some TSOs presented possibilities to have **connections between the different installations on-site** to enhance such flexibility.

Moreover some TSOs indicated that, in complement with strategies relying on on-site equipment (mobile or fixed), specific off-site resources (human and equipment) have been implemented to back-up a site in difficulty; for example compressed air, mobile diesel generators, pumps, hoses, fuel, oil with dedicated means to bring equipment in devastated environments.

3.2
Post Fukushima situations to be considered

All TSOs considered that **SBO and LUHS situations must be studied in the safety demonstration**. After the Fukushima accident, a particular attention was paid to long duration SBO and LUHS, affecting the whole site .This was studied by each country in the framework of the European stress-tests in 2011-2012, in accordance with ENSREG requirements. Indeed, ENSREG asked to consider:

- **LOOP (Loss of off-site power) or LUHS,** during several days with the site isolated from delivery of heavy material for 72 hours; Robustness of the provisions (UHS and provisions in case of LOOP) in connection with seismic events and flooding were considered;

- **LOOP and loss of the ordinary back-up AC power source**, dealing with the robustness of the provisions required;

- **SBO and SBO+LUHS;** the stress-tests identified the measures which can be envisaged to increase robustness of the plants in case of loss of electrical power or loss of ultimate heat sink, focusing on the site autonomy , external actions foreseen and measures which can be envisaged.

The stress tests didn't explicitly deal with SBO and LUHS induced by a design or beyond design basis flood/earthquake.

Due to the fact that beyond design basis flood/earthquake are likely to involve a SBO/LUHS (as observed during Fukushima accident), discussions dealt with possible links between beyond design basis hazard, such as BDBF or BDBE, and SBO/LUHS situations. All TSOs agreed that **structures, systems and components or organizational measures should be available to cope with SBO/LUHS after a BDBF and BDBE.**

Good practices have been presented by the different countries:

- in Belgium, a pragmatic approach should be carried out (for example based on SQUG database) to define whether the existing fixed provisions are able to cope with a BDBE. Moreover, buildings used to store mobile equipment are designed to resist to BDBF and BDBE;

- in Germany, mobile equipment used in case of SBO/LUHS is stored in buildings (designed to withstand a DBE) or tents;

- in France, a "Hardened safety core" (HSC), complemented with some mobile provisions (brought by the FARN arriving on site within 24 hours), will be implemented on each NPP to face a SBO/LUHS induced by a BDBF or BDBE. The HSC consists of a set of fixed equipment;

- in Slovenia, offsite alternate AC source is available (a gas plant capable of black start within 15 minutes, not sensitive to potential flooding at the NPP and capable of direct connection with the NPP through a number of geographically independent 110 kV lines in case of grid collapse). In addition, hardened safety core is planned to be built within the Post Fukushima Action Plan, in addition to the full set of mobile equipment (FLEX).

During the discussions, some TSOs indicated that operators in their countries have implemented or will implement new systems to mitigate severe accident, designed to face beyond design basis hazards.

The participants also discussed on "which **other external hazards** (other than earthquake and flood) should be considered to design the provisions to face SBO/LUHS":

- Czech Republic mentioned that new vented cooling towers were designed against extreme winds on NPP Dukovany;

- in the United Kingdom, regulators expect wind, extreme temperatures, precipitation etc. to be considered, but in practice in the United Kingdom none of these other hazards are considered to be a credible cause of SBO or LUHS, and the consequences are bounded by earthquake and flood;

- France considers extreme tornadoes to design the HSC;

- Russia considers all natural and man-made phenomena relevant to the specific site;

- Slovakia considers strong winds and heavy snow falls;

- in Ukraine, the technical specifications for mobile equipment consider extreme meteorological conditions (temperatures, winds, snow, tornadoes, etc.).

Concerning the duration of the SBO/LUHS, all TSOs countries require **autonomy of, at least, 72 hours** for the provisions used (water, fuel oil, compressed air) in case of SBO/LUHS.

Finally, a special attention should be paid to **spent fuel pools, and measurements of water levels** in all situations.

3.3

Consideration of induced secondary effects

Participants focused on the risks induced in case of beyond design basis hazards, namely LOOP, internal flooding in the plant, loads drops, and fire.

Few TSOs indicated that they consider **dependent or induced leak of the reactor pressure boundary** in case of a beyond design basis earthquake (considering primary pump sealing leakage, or pipes breaks connected to the reactor vessel, etc.).

Most of the TSOs consider that a **fire in areas important to safety should be considered after DBE** and **after DBF** (hence the fire protection (such as detection, extinction, other measures, etc.) should still be available after a DBE or DBF). However, only some country operators consider a **fire after DBE** and, except in Germany, no operator consider a **fire after DBF**.

In most countries, a dedicated Fire Team is on-site. However, there is currently no specific approach in case of BDBE or BDBF (several fires?, etc.).

In conclusion, for induced hazards, all TSOs consider that a **pragmatic approach** should be carried out: **walk-downs** by qualified people (aware of the different risks induced by hazards and importance of equipment, etc.) are needed and important.

3.4

Requirements for SBO/LUHS provisions reliability

The reliability is based on design, qualification, fabrication and testing of plant equipment. The requirements associated to the reliability should not rely on the “type” of equipment (fixed vs mobile equipment) but on its safety function. However, specificities exist depending on the type of equipment.

All TSOs agreed on the **importance of periodic testing of provisions** needed to face SBO/LUHS, including mobile equipment. However, the TSOs highlighted the **difficulties to define/assess the representativeness of the tests performed** and on the particular attention that should be paid to such test conditions.

Sufficient **requirements for long-term operation** of provisions are also needed to guarantee their reliability, especially if replacing is difficult (accessibility, radiation, etc.). Some TSOs insisted on the need to have sufficient requirements for long-term operation of mobile pump.

During the assessment, it is important to check the **accessibility of connecting points** and to **perform tests** in order to verify the time needed for such connections. Use of mobile equipment should also be tested onsite.

A good practice identified was the **redundancy and physical separation for connecting points** (example of such provisions were given by Ukraine and Germany for mobile DG connections).

Several TSOs insisted on the importance to seek, when possible, **diversity of supplies** and redundancy (for specific means).

Some TSOs considered that **fixed SSC are needed** to cope with SBO and LUHS situations after a BDBF or BDBE, especially for short term functions or actions.

All TSOs agreed on the necessity to have a **good confidence in the reliability of the information** provided by the instrumentation needed for the reactor operation (and emergency, etc.), in case of extreme situation (including hazards).

Finally, the reliability of the provisions also depends on the **support systems** and adequate attention for their own reliability/ availability is needed.

In general, to assess such SBO/LUHS situations, all TSOs highlighted the need to be able to adapt and develop their own calculation models to simulate different situations and identify critical timeframes, such as the time before core meltdown.

4 CONCLUSION

The workshop was an excellent opportunity to share information between European TSOs on the characterization of earthquake and flood. Discussions highlighted the similarities between the different approaches. Participants also focused on particular points of attention or difficulties and needs to share experiences.

During the workshop, a general concern for TSOs was the need to have sufficient expertise to perform a second and independent opinion on the characterization of natural hazards, time available before meltdown in case of beyond design basis situations, etc.

Good practices were identified. All TSOs recognized the interest of such exchanges to improve knowledge, approaches, methodologies, guidance.

Presentations of good practices also gave possible means, when applicable to the different countries/sites, to enhance safety.

In conclusion, the participants highlighted the following points.

Concerning hazards, the approaches used nowadays are mostly deterministic or based on a mix of statistical evaluations and deterministic margins. The discussions highlighted the need to develop knowledge and to share information on the probabilistic evaluations of flood and earthquake, in order to be able to use both deterministic and probabilistic evaluation during the safety evaluation.

While assessing provisions to cope with SBO and LUHS, due attention should be paid to:

- finding a good balance between flexible and fixed provisions;
- a clear specification of the situations to cope with, in relation with the natural-hazard characterizations;
- the definition and implementation of pragmatic approaches for
  - ☐ the assessment of the resistance of fixed existing provisions against a BDBE;
  - ☐ the assessment of the impact of induced hazards on provisions;
- Requirements for reliability of provisions.

Furthermore, the report shows many

common positions, and sometimes points out specificities, between ETSON partners concerning (i) the assessment of design basis and beyond design basis flood or earthquake and (ii) assessment of SBO/LUHS situations. Further discussions are still needed to better understand the methods used by the different partners, applicability of the methods to the different countries, need to develop new methods.

However, common positions (*e.g.* concerning provisions to face SBO and LUHS) could be identified in order to propose recommendations on what has to be paid special attention to, during expert reviews; such discussions may be carried out with the objective to achieve common TSOs “assessment guides” on these subjects, using this report as a first milestone.

Finally, this report could as well be used to define subjects where additional discussions are needed to reach common positions (such as definition of flood or earthquake levels, database on equipment’s robustness, etc.), identify what problematic issues do not have sufficient methodological support or are not supported by actual data; then, priority areas for research on national as well as international levels could be proposed by ETSON members.

APPENDICES

Appendix A: list of TSOs and participants

Belgium	BEL V	P. DE GELDER D. GRYFFROY T. M. TANG M. VINCKE
Czech Republic	CVREZ	Z. KRIZ
Germany	GRS	C. STRACK T. STEINROETTER G. THUMA
France	IRSN	V. BERTRAND S. CADET MERCIER C. CLÉMENT P. DUPUY C. LAVARENNE C. PICOT V. REBOUR P. VOLANT
Lithuania	LEI	A. KALIATKA
Slovakia	VUJE	J. KLEPAC
Ukraine	SSTC	O. DYBACH D. RYZHOV O. ZHABIN
United Kingdom	AMEC	R. PARKER (UK Defence Nuclear Safety Regulator) S. POWER
Slovenia*	JSI	L. CIZELJ*
Spain	CIEMAT CSN	L. HERRANZ M. DE LA VEGA**
Russia	SEC NRS	D. MISTRYUGOV M. LANKIN

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* not able to attend the meeting but contributed to the positions indicated in this report

** not able to attend the meeting but contributed to the positions indicated in para 3 of this report

Appendix B: regulatory requirements in force to define DBF in the different countries

	Texts in force	Date of issue	Revision in-progress
Belgium	USNRC 10 CFR part 50 appendix A (GDC 2) USNRC RG 1.59 (Design Basis Flood for NPP) not strictly applied during the design. **For new installations:** "Guideline on the evaluation of the external flooding hazard for new class I nuclear installations" (FANC, February 2015).	2015	
Czech Republic	SÚJB regulation N°. 215/1997 "criteria on siting of nuclear facilities and important sources of radiation" (§ 4/e, § 5/c).	1997	Yes (2016)
France	ASN guide n°13 "Protection of Basic Nuclear Installations against external flooding".	2013	
Germany	KTA 2207 - Flood Protection for Nuclear Power Plants.	2004	No
Lithuania	-		
Russia	-		
Slovakia	Protection measures taken on the basis of extrapolation of historical records.	2011	Yes
Spain			
United Kingdom	Safety Assessment Principles for Nuclear Facilities: Principles EHA.4 and FA.5. NS-TAST-GD-013 Revision 5: External Hazards.	Nov 2014 Sep 2014	No No
Ukraine	SNRIU regulation НП 306.2.144-2008 "Requirements on NPP siting" (general requirements). Set of industrial standards, e.g. SNiP 2.04.03-85 "Drainage System. External Networks and Structures", SNiP 2.06.15-85 "Engineering Protection of Territories against Flooding".	2008	No

Appendix C: regulatory requirements in force to define DBE in the different countries

	Texts in force	Date of issue	Revision in-progress
Belgium	USNRC 10 CFR part 50 appendix A (GDC 2). USNRC 10 CFR part 100 appendix A ("Seismic and geologic siting criteria for NPPs"). For new installations: "Guideline on the evaluation of the seismic hazards for new class I nuclear installations" (FANC, February 2015).	2015	
Czech Rep.	SÚJB regulation N°. 215/1997 "criteria on siting of nuclear facilities and important sources of radiation" (§ 4/p)	1997	Yes (2016)
France	Basic safety rule 2001-01 - Determination of the seismic risk for the safety of surface basic nuclear installations.	2001	
Germany	KTA 2201 - Design of Nuclear Power Plants against Seismic Events.	2011	No
Lithuania	Rules and Norms in Atomic Energy PNAE G-7-002-86. Nuclear Safety Requirements BSR-2.1.3-2010 "General requirements on site evaluation for nuclear power plants".	1986 2010	- -
Russia	NP-031-01		Yes
Slovakia	Bohunice NPP: IAEA NS-G-3.3 (2002) and USNRC RG 1.165 (1997), Mochovce NPP: UJD SR regulation N°. 100/2011.	2002 2011	No No
Spain			
United Kingdom	Safety Assessment Principles for Nuclear Facilities: Principles EHA.4, EHA.9, and FA.5. NS-TAST-GD-013 Revision 5: External Hazards.	Nov 2014 Sep 2014	No No
Ukraine	PNAE-G-5-006-87 "Design of Seismic Resistant NPPs".	01.07.1988	Yes

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