IRSN METHODOLOGY FOR THE SELECTION OF EXTERNAL HAZARDS CANDIDATE TO PROBABILISTIC ANALYSIS

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In order to be able to analyze the methodology proposed by EDF for the selection of external hazards for which a probabilistic analysis is necessary, IRSN has decided to develop its own approach. This approach will also serve to define and justify the external hazard probabilistic studies which appears relevant and feasible to conduct within the IRSN, taking also into account the available resources (comprehensive studies, targeted and partial developments). The IRSN external hazard probabilistic studies are intended mainly to be used in support of the expertise by IRSN of the external hazards probabilistic studies that will be developed by EDF for the nuclear power sites.

The approach for the selection of external hazards is based on IRSN experience and on internationally available knowledge, including ASAMPSA-E results. The approach will be applied firstly for a test site, in order to identify the possible methods enhancements and then will be generalized for other sites.

I. INTRODUCTION

The worldwide operating experience shows that external hazards are a threat for the safety of nuclear installations. Notably, they have the potential to cause initiating events and simultaneously to impair the safety systems necessary to limit the subsequent consequences on the installation.

In France several external events occurred, with the potential to threaten nuclear safety. The most significant one was the partial flooding of the Blayais NPP in December 1999 when, during a severe storm, high waves overtopped a protective dyke surrounding the site and partly submerged some areas. This event raised the questions of the design bases used for the protection of nuclear power plants against external flooding and the efficiency of the existing measures, especially the warning systems, the site protection measures, the protection of safety-related equipment, the procedures and the emergency organization.

Also, some other significant external events affected French NPPs, as for example:

- December 2003: Cruas - partial clogging of the pumping station filters due to a massive arrival of vegetable matters;
- December 2005 - Paluel site: ice formation on the grid transformers leading to shutdown of all four reactors and isolation from the external power supply;
- January 2009 – Chooz B – frazil ice formation (possible loss of heat sink risk);
- December 2009 - Cruas units 3 and 4: total loss of heat sink occurred due to the clogging of the pumping station filters due to a massive arrival of vegetable matters;
- December 2009 - Fessenheim unit 2: partial loss of heat sink occurred due to the clogging of the pumping station filtering drum screens due to vegetable matters.

It has to be noted that the identification of the risk of core damage related to the total loss of the ultimate heat sink, during the 80’s, as highlighted in the probabilistic safety assessments, led to define some operating and design modifications to cope with such a situation. Indeed, these plant improvements enabled to handle the 2009 Cruas site incident (mainly due to the use of the thermal inertia of the refueling water storage tank, throughout a containment spray system heat exchanger, as an emergency heat sink for temporarily cooling the component cooling water system) [1].

In the French PSA, even before Fukushima, accident sequences induced by external events were already taken into account. Many insight of these PSA were used, as complementary information, to enhance the safety level of the plants. The incidents related to the external events highlight the need for better assessment of the risk related to external hazards. Fukushima accident has confirmed the importance and the imperativeness of the external hazards analyses. In particular, the scope of the PSA should be extended, including all relevant external events and their combinations. In this context, both utility (EDF) and IRSN work, in addition to the review of deterministic bases and studies on external events, on probabilistic aspects related to external events PSA: hazards screening analysis, assessment of SSC fragility, Human Reliability Assessment (HRA)… and on improvement of probabilistic methods to better take into account in the PSA the long term of accident sequences induced by initiators which may affect the whole site containing several nuclear installations (reactors, fuel pools …).

It has to be noted that, at IRSN where in-house PSA models are developed to support the review of the PSAs performed by EDF, the next challenges are the "screening analysis" of the external hazards and combinations to be considered in the probabilistic assessments, and the definition of the specific approaches and methodological aspects to be applied in the context of external events PSAs. Efforts are thus ongoing to determine the appropriate methods in terms of hazards frequency assessment, SSC "fragility analyses", treatment of combinations of hazards and HRA.

Due to the difficulties related to some of these modeling aspects and as the development of external hazards PSAs requires important resources, IRSN intends to optimize the external events PSA development strategy. In this respect, IRSN has decided to develop its own approach for the selection of external hazards for which a probabilistic analysis is necessary.

II. IRSN GENERAL APPROACH FOR SCREENING OF EXTERNAL HAZARDS

II.A. Definitions

The external hazard is defined as an external phenomena or combination of external phenomena of sufficient intensity to induce a trigger event, were triggering event is any event, which may cause, directly or indirectly, an incident or accident situations.

By phenomena it is understood anything that can be observed or seen by experience and that is likely to repeat itself or be reproduced, having an objective and universal value. In general, external phenomena can be any natural or associated with the industrial or human activity phenomena, which is not internal to the installation.

Regarding the combinations of phenomena, two types can be defined:

- conjunction of correlated phenomena:
    - cause-effect relationships, or,
    - common cause;
- combination of non-correlated phenomena.

It has to be noted that comparing with a trigger event the initiating even is defined [2] as an event which disturbs the normal operation of the installation and leads to drift of the values of certain parameters of the installation (pressure, temperature, reactivity, etc.), from which an accident sequence can develop.

II.B. Approach

The approach for screening of the simple external phenomena, and of the combinations of external phenomena, consists of the identification, on the basis of elimination criteria ("screen-out"), the external phenomena or combinations of external phenomena which have a negligible contribution to risk of core damage and of large release and for which further probabilistic analysis is not necessary.

The elimination criteria are defined in such a way that the compliance with one criterion is sufficient for the screening-out of the situation. To reduce the required analysis effort, these criteria are ordered in a way to start with the examination of the easiest to demonstrate and gradually reach the one which requires more complex analysis. However, no hierarchy between the different criteria is defined.

In order to apply these criteria, as detail later, the hazards associated with each phenomenon or combination of phenomena should be characterized in terms of occurrence frequency of a given intensity of the phenomena (the notion of intensity is specific to each phenomenon: water level, wind speed, outside temperature ...). The screening criteria are then applicable for the resulting external hazards.

The screening criteria for the external hazards generated by combinations of external phenomena are the same as those used for screening the external hazards generated by simple external phenomena.

The screening process is applicable for both the reactor and the spent fuel pool.

A comparative analysis with the criteria proposed internationally, including by the IAEA [3], EPRI [4] and the Swedish Nuclear Inspectorate (SKI) [5] was performed. It shows that different approaches are broadly similar; the differences are mainly due to the practical application which is proposed for each approach.

III. SCREENING CRITERIA

The following criteria apply for a given external hazard, which, as described before represents the intensity level of a single external phenomena or of a combination of phenomena.

TABLE I. Screening criteria

Criteria	Type of criteria	Description
CS_1	Applicability	The external hazard cannot occur at the site or close enough for it to have an impact.
CS_2	Inclusion	The external hazard : • is included in other hazards already selected after the screening process, OR • it generate only potential damages which are equal or lower than the damages generated by : – other hazards already selected after the screening process, OR – other trigger events which are already studied in available probabilistic studies.
CS_3	Dynamic	The hazard is sufficiently slow, allowing reducing the risk to negligible values by the implementation of appropriate protections.
CS_4	Risk	The risk associated with the hazard is lower than 10^{-7}/r.y. for fuel damage frequency AND than 10^{-8}/r.y. for the risk of large releases with lasting effects frequency.

III.A. Criteria CS_1 "Applicability"

The criteria "Applicability" refers to the impossibility of occurrence of a hazard on the site, or close enough to the site to have an impact. It is thus equivalent with the "geographical" impossibility. This criterion applies for example in the case of a tsunami to a site remote from the sea or lake.

III.B. Criteria CS_2 "Inclusion"

The application of the criteria "Inclusion" means that the external hazard is not subject to individual analysis, the associated analysis being covered by the other probabilistic studies of hazards or trigger events (already selected following the screening process or already analyzed in a probabilistic manner in other studies).

In order to determine if that this criteria is fulfilled it is necessary to assess all the effects on the installation of the given external hazard, including the effects on:

- systems and human actions,
- applicable mitigations,
- duration of accident sequences,
- autonomy of reserves on the site.

The possible simultaneous impact on other site facilities (reactors or pools) should be also taken into account.

If the internal events PSA includes a large number of initiating events of "external origin" (loss of offsite power, loss of heat sink, loss of ventilations…) several external hazards may be screened out leading to a more reduced list of external hazards to be analyzed in detail.

In case of exclusion of a hazard under criterion "Inclusion", the frequency of non-analyzed phenomenon must be taken into account in the frequency of the event which includes them.

III.C. Criteria CS_3 "Dynamic"

The criteria "dynamic" can be applied to external hazards for which we can be very confident in the capability to implement appropriated protections. This criteria can be applied to phenomena with very slow kinetics, such as settlements, or to phenomena having more faster kinetics, such as river floods, if that specific provisions are implemented to ensure the monitoring of these phenomena and to take appropriate actions.

Nevertheless, the application of criteria "dynamic" to exclude from the scope of the PSA the given external hazard should not be based only on the argument of the existence of warning and protection systems.

The application of the criterion CS_3 must consider firstly the design capability of the protection to be implemented during the warning time (like the height of dams for flood risk). Accordingly, CS_3 criteria should not be used to exclude hazards (induced phenomena or combinations of events) having intensity greater than that taken into account for the design of protective provisions.

Also, the reliability of those protections, physical or organizational, must also be addressed, at least in a qualitative way, in order to determine if the associated risk is residual. The aspects to consider are the following:

- the nature of protective means (fixed or mobile, passive or active), the possible existence of additional resources on site or at the national level,
- the existence and scope of surveillance procedures (monitoring, implementation of means), the time available to perform the actions,
- probabilistic assessment of the human factor,
- the frequency of monitoring, compared with the kinetics of the phenomena,
- the reliability of the means for prevention or for protection against the external hazard (means and actions for surveillance, early warning systems, means for prevention and protection), based on their design requirements and operational surveillance,
- the impact of the hazard on the systems necessary to avoid the core melt in the selected safe state during the given external hazard.

In general, for phenomena with quite fast kinetics, especially when protection includes active measures, it is difficult to conclude that the risk is negligible only on the basis of qualitative analysis. In this case, it is better to apply the criterion CS_4 “Risk”, performing, for example, a simplified and conservative evaluation of the protections failure probability.

If after the analysis of the criteria CS_3, the external hazard cannot be eliminated all the mentioned aspects must be also evaluated in a quantitative manner, when applying the criterion CS_4 "Risk".

III.D. Criteria CS_4 “Risk”

When applying the criterion "risk", the risk of fuel melting or radioactive release associated with the external hazard must be evaluated.

Given the fact that a core damage frequency lower than 10^{-7}/r.y. does not guarantee that the frequency of large releases is lower than 10^{-8}/r.y. it is necessary to verify that both core damage frequency and large releases criteria are fulfilled. This aspect is particularly important in the case of the evaluation of the risk of fuel melting in the spent fuel pool.

The risk of core damage or large releases associated to the external hazard can be evaluated by simple and conservative quantitative analysis.

For example, a frequency lower than 10^{-7}/r.y. for core damage and 10^{-8}/r.y. for the large releases (the case of spent fuel pool without confinement) can be verified firstly by a lower frequency of occurrence of the given external hazard. However, this verification must take into account the uncertainties associated with the occurrence of such rare phenomena. In general, an estimate of extremely low but also highly uncertain occurrence is not sufficient to exclude a phenomenon or combination of phenomena.

IV. SCREENING METHOD

IV.A External hazards characterization

The application of the screening method involves the assessment of the characteristics of the external hazards associated with external phenomena or combinations of external phenomena.

Firstly, the characteristic parameters of each phenomenon must be identified. The following table lists the set of characteristic parameters for an external phenomenon.

Then the values of these parameters must be estimated. It should be noted that for some of these parameters, several ranges of values can be defined. These ranges of values and their combinations will then characterize the resulting external hazards associated with the external phenomenon or the combination of external phenomena (for example, for the rain, several external hazards can be defined as a function of water volume and duration).

In practice, as indicated in the following chapter, the characterization of the phenomena needs to be performed only for intensities which exceed a given level. For lower intensities it can be judged on the basis of a rapid analysis, that the induced risk is negligible.

TABLE II. Hazards parameters

Parameters	Parameters using
Frequency of exceeding a given intensity	Criteria CS_4
"Intensity" (according to phenomena): • seismic acceleration • water level • outside air temperature • wind speed • pressure • …	Criteria CS_2, Criteria CS_4
Time duration of the phenomena	Criteria CS_2, Criteria CS_4
Kinetic of the phenomena	Criteria CS_2, Criteria CS_3
Predictability of the phenomena	Criteria CS_4
Installation recovery time	Criteria CS_4
Magnitude / Size of the area (plant, site, region…) affected by the hazard	Criteria CS_2, Criteria CS_4

IV.A SCREENING PROCESSES

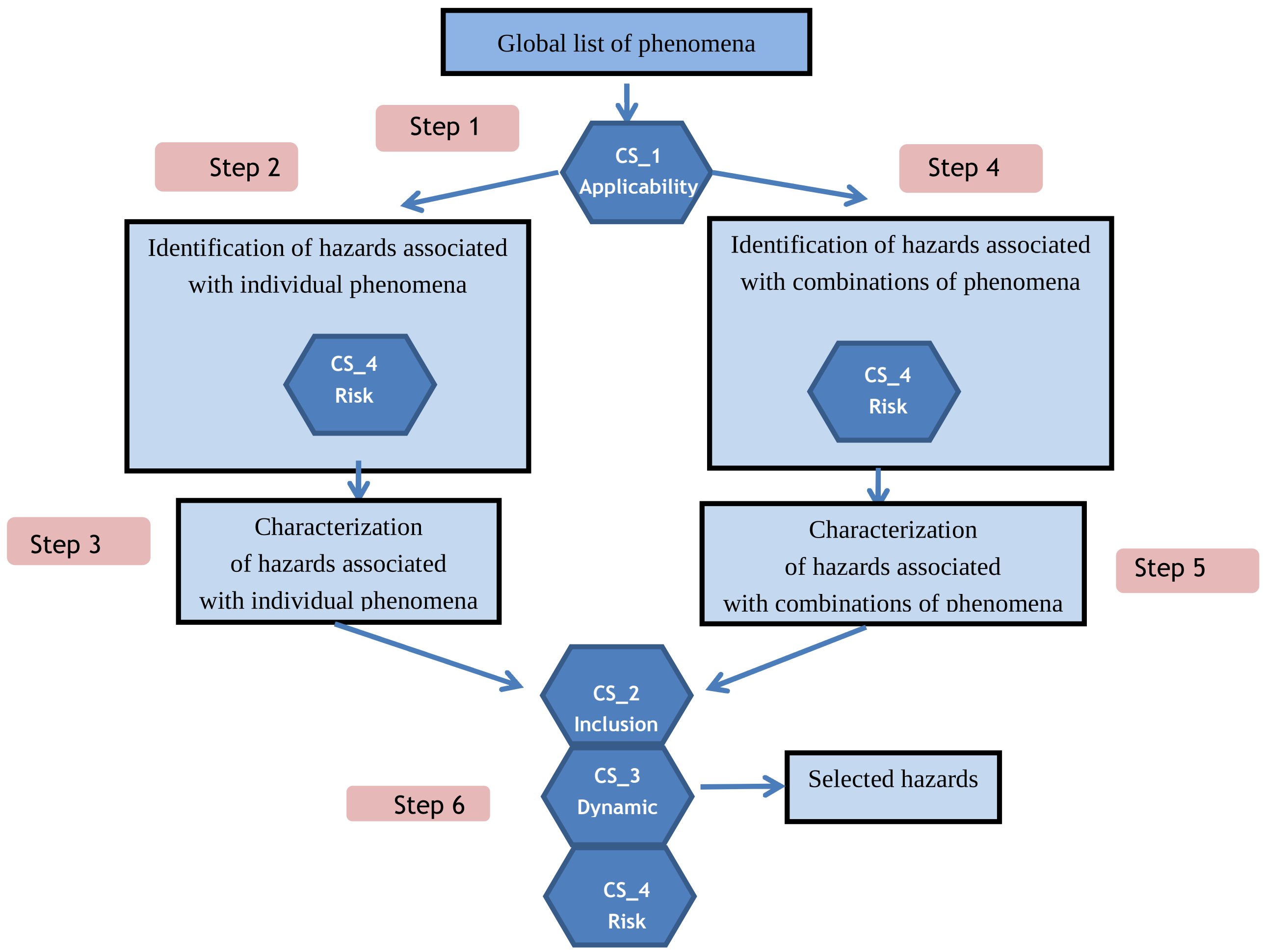

Figure 1. External hazards screening processes

The screening analysis should be performed following the processes presented in figure 1.

The comprehensive list of external phenomena which is foreseen in the IRSN approach was developed based on national and international available bibliography, including the ASAMPSA- E project results [6].

If the external hazard can be eliminated on the basis the hazard frequency (equivalent with the risk) with a good confidence level it is not necessary to evaluate all the parameters which characterize the hazard.

Particular attention should be paid to uncertainties (random and knowledge), in assessing the characteristics of the phenomena, or combinations of phenomena (frequencies, intensities…), as well as in the assessment of the external hazard impact on the installation, site, region…. It is particularly important to identify the “cliff-edge effects” on the core damage frequency or releases.

For the hazards leading directly to an initiating event, the CS_4 “Risk” criteria is mainly applicable. However, it should be noted that, even a hazard does not lead directly to an initiating event, it may cause the unavailability of safety or support systems and can induce an increase of risk of core damage or releases. Thus, the fact that a hazard does not lead to an initiating event is not a screening-out criteria.

The screening analysis steps which are foreseen are the following:

IV.B.1. Step 1

The global list of phenomena is filtered using the criteria CS_1 “Applicability” to exclude phenomena (and associated risks) irrelevant to the site from a geographical point of view. The resulting list will then be used for both the analysis of individual phenomena and for analyzing the combinations of phenomena.

IV.B.2. Step 2

For each relevant individual phenomenon, it is necessary to define (discretize) the different intensities of the phenomenon that will be analyzed as hazards. These intensities are characterized by their frequency and other specific magnitudes, as presented above (seismic acceleration, water level, temperature, wind speed…).

For some hazards, it is possible at this stage to assess in a simple way, with a good level of confidence, if the risk is less than the criterion CS_4 "Risk“, as for example:

- frequency less than 10^{-8} / year,
- frequency less than 10^{-7} / year and the hazard does not affect the containment,
- the existing design and operational provisions allow to conclude that the normal operation of the plant is not disturbed.

IV.B.3 Step 3

For hazards associated with individual phenomena that have not been eliminated, it is necessary to evaluate more precisely the parameters that characterize them, as presented above, which and required for verification of the criteria "Inclusion", "Dynamic" and " Risk".

IV.B.4 Step 4

In order to determine the hazards associated with combinations of phenomena, a matrix of possible combinations must be developed. Each combination must be analyzed individually.

Combinations of mutually exclusive events (as for example, combinations of phenomena not occurring in the same season) can be removed in a first step. Then all the hazards induced by the relevant combinations for the site of two or more phenomena must be examined by applying the same criteria as for the external hazards generated by individual phenomena.

Any dependencies between phenomena must be deeply analyzed at this stage.

Note that combinations of phenomena intensities can have a bigger impact on the installation compared with individual phenomena intensity. “Low” phenomena intensities that are not selected for probabilistic analysis by applying the CS_2 or CS_4 criteria (covered by another hazard, slow dynamic or low risk) can then be selected as external hazards induced by combinations of phenomena. For example, a given outside temperature high value may be not selected, as individual hazard, but may be selected in combination with another phenomena, like the earthquake or wind, taking into account the fragility of additional air conditioning equipment needed for high outside temperatures (In some cases the internal events PSA may already model the “summer/winter” conditions, and then this type of combination may easy to be analyzed).

IV.B.5 Step 5

For hazards associated with combinations of phenomena that have not been eliminated at this stage, it is necessary to evaluate the parameters that characterize them

This assessment can be more complex than individual phenomena and the associated uncertainties may be also higher.

IV.B.6 Step 6

For each hazard induced by individual phenomena or combinations of phenomena, not excluded at this stage, the verification of criteria "Inclusion", “Dynamic" and "Risk" must be performed.

The analysis carried out as part of the verification of criterion "Risk" must be quantitative taking into account the uncertainties (random and knowledge) in the evaluation of hazards characteristics and in the assessment consequences for the installation, as well as on the site and on the souring region.

It is particularly important to identify the cliff-edge effects on the risk.

V. CONCLUSION

The presented approach for screening of external hazards is now under application for a "test" site. The results of this test will be used to improve the proposed method.

Also, the IRSN review of the results of the screening of external hazards performed by EDF will take into account the different aspects presented here, especially regarding the approach used to identify the combinations of phenomena.

This approach will also serve to define and justify the external hazard probabilistic studies which appears relevant and feasible to conduct within the IRSN, taking also into account the available resources (comprehensive studies, targeted and partial developments).

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