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External Events PSA – Requirements Applicable to New Nuclear Installations Projects after Fukushima Daiichi Accident

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ABSTRACT

Since the Fukushima Daiichi accident, external events analysis has become a priority issue within regulatory bodies, operators, and designers, raising concerns about the capabilities of nuclear power plants to withstand severe conditions.

Generally, the methodology applied to the Probabilistic Safety Assessment (PSA) of external events consists of the identification of potential single and combined external hazards, screening of external hazards, analysis of site and plant response, analysis of initiating events and quantification of accident sequences probabilities.

Therefore, in this paper, the requirements and other information on new nuclear installations projects necessary to implement a comprehensive PSA of external events throughout plant lifetime are evaluated.

In addition, it is necessary to clearly identify all the resources that must be available to continuously expand PSA scope to include all types of initiating events, levels of analysis and plant operation modes.

keywords: **Probabilistic Safety Analysis, External events, Nuclear safety.**

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1. INTRODUCTION

Hazards must be pre-assessed and periodically reassessed throughout the lifetime of a nuclear facility so that its design and operation assure that radiological risk will be maintained within an as low as reasonably achievable (ALARA) range. Thus, a safety analysis covering facility site, design and operation must be conducted, in which deterministic and probabilistic methods may be used.

Based on this safety analysis, it is possible to verify compliance with design criteria applicable to safety related structures, systems, and components, as well as to improve operational procedures, emergency procedures and guidelines for accident management. [1]

Probabilistic Safety Assessment (PSA) stands for a comprehensive and structured approach to identify hazards and evaluate possible accident scenarios arising from initiating events and constitutes an entire conceptual and mathematical tool for risk management at different phases of facility lifetime. [1]

In general terms, a PSA can be carried out at three distinct subsequent levels, which are: Level 1 – plant design and operation are evaluated by identifying event sequences that can lead to reactor core damage and the core damage frequency can be estimated; Level 2 – the chronological progression of accidents identified in Level 1 is developed and containment systems are modeled, evaluating the possibility of radioactive release to the environment; Level 3 – the risk to public health, the risk to the environment and the socio-economic impacts of an accident with radioactive release may be assessed.

After the Fukushima Daiichi accident, increased attention has been given to external hazards regarding accident initiating events, and the following implications for PSA may be mentioned.

- Search for a systematic approach to determine most relevant hazards (single and combined) for a particular site;
- Refinement of methods to assess potential magnitude and probability of occurrence of external hazards; and
- Clarification of the impact on safety related structures, systems, and components with respect to low probability and/or high impact external hazards. [2] [3]

Due to raising concerns about external hazard analysis, it is important to develop a systematic approach that could be applied to any site, to enhance magnitude and frequency evaluation of external hazards and their combination and assess the impact on nuclear power plant (NPP) safety functions, i.e., to improve the external events PSA process in order use of the available information efficiently.

The main objective of this paper is to define requirements and capabilities that are prerequisites for the implementation of a structured external event PSA throughout installation lifetime. Moreover, the importance of having a clear path to achieve a full scope PSA will be shown, considering modelling requirements, data requirements and calculation capabilities for an External Events PSA.

2. DISCUSSION

PSA scope and level of detail must be adequate for the expected use and applications of this study, taking into consideration installation lifetime phases, which are siting, design, construction, operation, life extension and decommissioning.

In particular, the PSA level of detail may vary as (i) facility design and operation are modelled; (ii) facility-specific experience is incorporated into models and input data; and (iii) knowledge on expected response under design criteria is gained. Thus, a PSA used as support study during facility design phase is not expected to have the same level of detail as a PSA developed for a facility with several years of operational experience. [4]

PSA applications may cover different stages of plant lifecycle as well as different project types. The engineering insights resulting from such PSAs must be gained by considering and properly assessing all the uncertainties involved. PSA quality and confidence in its results are determined by scope relevance, use of state-of-the-art methods, quality of input data, and proper review of the study.

The wide spectrum of PSA applications and the need to regularly update and/or modify it lead to requirements for the context in which the PSAs will be used. Living PSA programmes are being

developed, and to a different extent, implemented in several countries, in order to satisfy these requirements.

Such programmes comprise as their basic element a PSA study that is well structured, well documented, reviewed, highly detailed, and plant specific. The study is maintained 'living' by periodically updating it to reflect all relevant plant changes in the front line and support systems, procedures, practices, and management of operations.

The PSA also is updated to reflect changes in the database, improved understanding of the plant systems, and advancements in PSA methods, to meet the needs of new applications and enhance the completeness of PSA models. [5]

In this context, installation lifetime shall be divided into clear phases. According to CNEN NE 1.04 [6], which regulates the licensing of nuclear installations in Brazil, this process necessarily involves the request by an applicant, and the issuance by "*Comissão Nacional de Energia Nuclear"* (CNEN), of the following acts: a) site approval b) construction license c) authorization for use of nuclear material d) authorization for initial operation and e) authorization for permanent operation. Besides these authorizations, renewal of operation licenses, known as life extension licenses, may be requested.

Depending on the project stage, certain details concerning plant design and operation may not be available. Thus, the analysis may not represent the detailed balance of plant information, site specific information, plant specific data, or detailed operating procedures at the time the PSA is being performed.

Less strict requirements shall be set for such situations, but PSA models and documentation should be maintained and updated throughout the operating life of the plant to provide relevant representation of its features. This approach will gradually include the incorporation of as-built features, and detailed operating and maintenance procedures. Some details may be developed during construction and some as built features will be known at a relatively late project stage.

Regarding the modelling process, PSA studies use to start with the implementation of a basic Level 1 PSA for Internal Events to assess main initiating events, events trees, system fault trees, common cause, and dependency modelling, as well as numerical safety level goals. External Events initiators will be included when the Level 1 PSA for Internal Events is consolidated and allows the incorporation of new data requirements for the design and operation phases.

In Table 1, requirements associated with the implementation of an external event PSA in each phase of installation lifetime are presented. It is important to note that siting evaluation phase comprises an initial collection of data regarding external hazards in future installation vicinity prior to the development of the PSA. [5]

Typical data needed for external events analyses include, for example: seismic hazard curve; soil structure characteristics around the plant; component and structural fragilities to earthquakes; frequency and location of fires of different sizes; non-detection and no suppression probabilities; components susceptibility to fire and combustion products; frequency of flooding from different water and steam sources; size, duration, and coverage of floods; effects of floods on equipment; high wind hazard curves; probabilities of tornado induced missiles; building and equipment fragilities to winds; and the effects of operator errors related to external events. [5]

Requirements proposed in Table 1 consist of a graded approach for the progressive implementation of an External Events PSA during installation lifetime considering regulatory requirements and project maturity.

Table 1: Requirements and Capabilities applicable to External Events PSA.

Installation Life Time Phase	**PSA Modelling Requirements**	**Data Requirements**	**Calculation Capabilities**
Siting	-	1) Site Characteristics regarding seismology, geology, hydrology, and meteorology. 2) Data on industrial and military activities.	1)Preliminary analysis of frequency of occurrence and magnitude of external hazards in a specific site.
Design	-Conceptual/Early Design Level 1 Full Power Internal Events PSA	1) Design information at the engineering level of detail; 2) Design criteria of Structures, Systems and Components (SSC) for design basis external hazards; 3) Identification of single and combined potential external hazards.	1)Qualitative screening for single external hazards.

Construction	- Level 1 Full Power Internal Events PSA ; - Level 1 Full Power Internal Fire PSA ; - Level 1 Full Power Internal Flood PSA ; - Level 1 Low Power and Shutdown Internal Events PSA.	1) Assessment of frequency of ocurrence of all possible initiating events; 2) Vulnerability analysis of SSCs regarding external hazards ; 3) Incorporation of expected operator actions in PSA model.	1)Qualitative screening for single and combined hazards ; 2)Preliminary quantification of Conditional Core Damage Frequency (CCDP) / Conditional Large Early Release Frequency (CLERF) for selected hazards.
Operation / Life Extension	- Level 1 PSA; - Development of Level 2 and Level 3 PSA; - If required, PSA for others radiation sources – spent fuel pool.	1) Data update / upgrade using information on SSC's operation/maintenance and operatior actions according to a Living PSA program ; 2) Tracking of the evolution of external hazards parameters – increase of population/industrial activity, climate change, etc.	1) Determination of accident sequences, system minimal cut sets and quantification of Core Damage Frequency (CDF), including uncertainty analysis – Level 1 Full Power External Events PSA; 2) Quantification of LERF and risk metrics associated with offsite consequences – Development of Level 2 and Level 3 External Events PSA.
Decommissio ning	- If required, PSA for others radiation sources – spent fuel pool - PSA for the Decommissioning state.	1) Modifications during decommissioning process of spent fuel system and inventory considering low power and shutdown PSA models.	1) Determination of accident sequences, system minimal cut sets

3. CONCLUSION

Considering practical difficulties to comply with the requirements proposed in this paper and the necessary resources to develop a PSA study, it was common that designers/operators postpone the development of External Events PSA prior to the Fukushima Daiichi accident and include quantification of risk associated with external hazards in the PSA to be developed during the installation operation phase.

However, since regulatory requirements in the early stages of installation lifetime focus on PSA for internal events, calculation of a risk metric (CDF/LERF) associated with external hazards only in installation operation phase may result in an increment in the total risk metric for the installation.

Since a PSA is a study developed based on a comprehensive and complex logic, using a large amount of data, it is fundamental that regulatory authorities establish clear requirements and operating organizations managers foresee all different combinations of requirements that fulfill the objectives of an External Events PSA technically adequate under the possibility to unable the development of a structured PSA.

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