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Progression of Station Blackout Event in PWR Plant

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ABSTRACT

The progression of the event in the nuclear power plant and corresponding consequences depend on the number of parameters and corresponding uncertainties. The goal of this study is identify, classify and analyse the main sources of uncertainties of the parameters that affect the progression and consequences of one selected event for the nuclear power plant.

The selected event for the purposes of this study is Station Blackout (SBO) event resulting in loss of all alternate current power sources in the nuclear power plant. This event was selected as one of the most demanding events for the light water reactors.

The identification of the most important parameters was done on basis of results of the previous parametric studies and sensitivity analysis of deterministic calculations.

Identified most important parameters and corresponding uncertainties were classified in two categories: external and internal. The internal parameters were defined as those parameters that indicate the state of the primary coolant system of the nuclear power plant (and secondary system in case of pressurized water reactors). All other parameters were classified as external.

The analysis of the uncertainties of the selected parameters shows that dominant contribution to the progression of the event and final consequences, for SBO event, have operator actions (especially recovery of system safety functions). The remaining parameters have small/negligible impact on the event progression so they can be omitted in further analyses.

Based on the above analysis the SBO event progression tree is developed with main events and operator actions that are expected to be considered in further analyses, for example with the Bayesian belief network, of extended SBO.

1 INTRODUCTION

The main purpose of the nuclear safety is the prevention of the release of radioactive materials, ensuring that the operation of nuclear power plants (NPPs) does not contribute significantly to individual and societal health risk [1]. The main specific issue of the nuclear safety is the need for removing the decay heat, necessary even for a reactor in shutdown.

The NPP power systems are divided into safety related Class 1E and Non-1E power system [2]. Figure 1 shows example NPP electrical energy distribution system with main constituting elements. The Class 1E power system of the NPP is marked with dashed rectangles on Figure 1.

Main elements of the Class 1E power system include safety buses, emergency diesel generators (DG1 and DG2) and plant batteries (Bat A and Bat B on Figure 1).

The loss of offsite power (LOOP) initiating event occurs when all electrical power to the plant from external sources is lost (red and green lines on Figure 1). Loss of alternating current (AC) as a result of complete failure of both offsite and on-site AC power sources is referred to as a station blackout (SBO) [3]. The NPPs are equipped with batteries (BAT A and BAT B on Figure 1) that provide electrical power for the essential safety systems (Essential I&C) for limited time known as station blackout coping time. Typical stations blackout coping times for existing NPPs range from 2 to 8 hours.

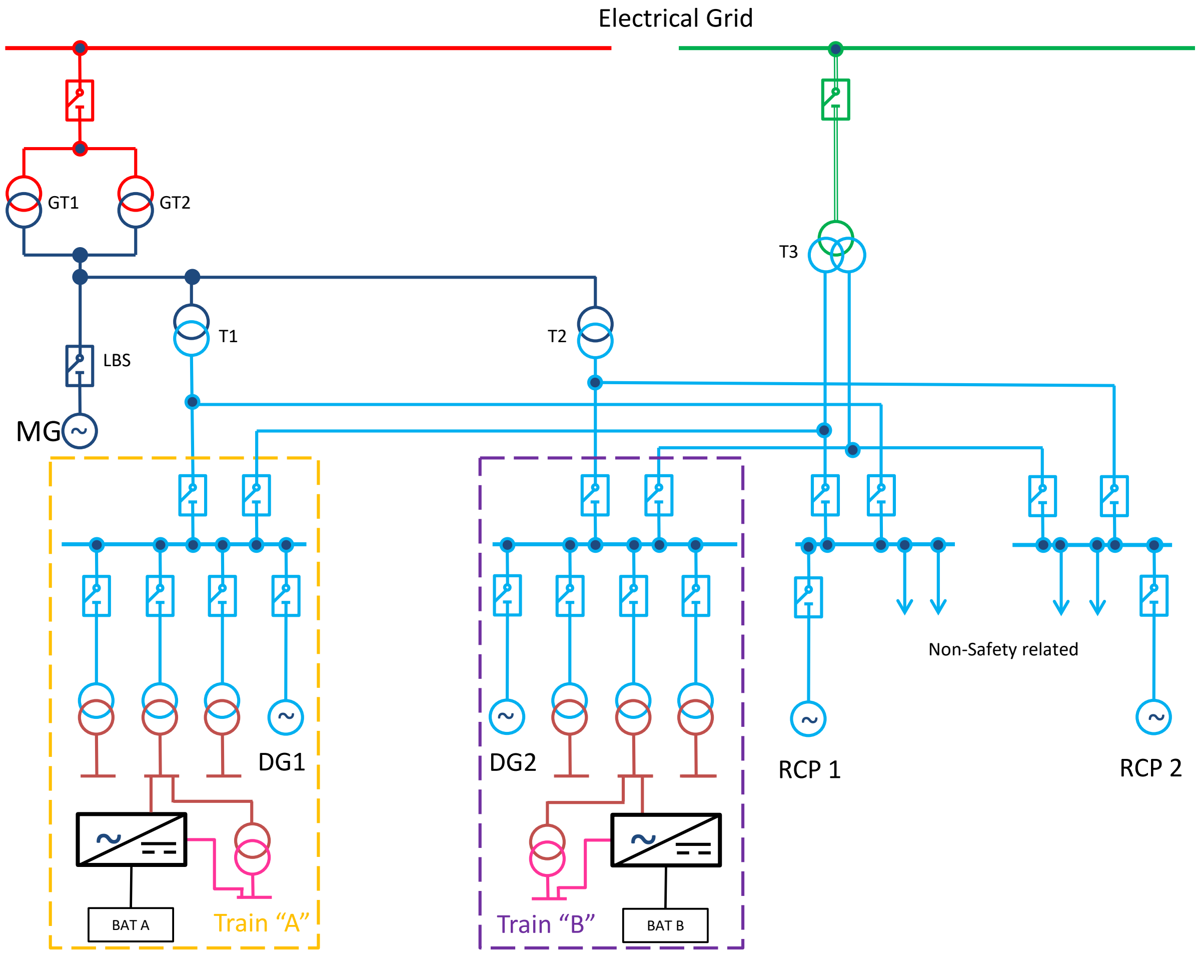

Figure 1: Example NPP electrical energy distribution system

The results of the Probabilistic Safety Assessment (PSA) show that initiating events LOOP and SBO are amongst the most important contributors to the core damage frequency (CDF) including the shutdown CDF [4].

2 UNCERTAINTIES CLASSIFICATION AND QUALIFICATION

The uncertainties of the nuclear safety analyses, probabilistic and deterministic, can be classified in the following three main categories [5]: parameter, model and completeness uncertainties.

Parameter uncertainty relates to the uncertainty in the computation of the input parameter values used to quantify the models in the corresponding analyses. For example, in the PSA, the parameter uncertainty relates to the values used for the probabilities of failures of the events. The parameters uncertainties result from their interdependence with modelling assumptions, lack of statistically significant data, expert opinion and rarity of modelled events.

Model uncertainty arises because different models are used for same systems and processes. Uncertainty exists with regard to which model appropriately represents that aspect of the nuclear power plant (NPP) being modelled.

Completeness uncertainties are uncertainties due to the portion of risk that is not explicitly included in the PSA.

Some of the uncertainties can be resulting from the several sources. For example earthquake as an external event can result in different consequences/failures in the plant. The uncertainty is which failures will be considered and how to model those failures into the safety analyses.

For the purposes of this study the parameters and corresponding uncertainties are divided in two main categories. The external parameters are all those parameters characterizing/affecting the progression of the event that are not related to the status of the primary coolant system of the NPP.

The primary coolant system of the NPP includes the reactor core and all the vessels and pipes where the reactor coolant flows.

For example, the external parameters include time when LOOP and/or SBO event happened, the availability/reliability of external power sources etc.

The internal parameters include all parameters that characterise the state of the primary coolant system. For example, the temperature and pressure in the primary coolant system, if/what size is loss of coolant event within primary coolant system etc.

Study presented in publication [6] shows that following external parameters are identified as most important for the development of the SBO event:

- Time delay between LOOP and extended SBO (what time the emergency diesel generator's (EDG’s) are operational)
- Time delays between the extended SBO start and start of the pump injections to steam generator (SG)

The following internal parameters are identified [6] as the most important for SBO scenario development:

- Types of reactor coolant system (RCS) coolant loss scenarios (existence of normal system leakage, seal and letdown loss, success of depressurization).
- Primary system depressurization strategy (depressurization using primary or secondary safety and relief valves, valves setpoints, time delays between the extended SBO and start of depressurization).

These parameters with corresponding uncertainties are discussed in the following sections.

2.1 External parameters uncertainties

Two external parameters are identified as the most important for the development of the SBO event [6].

First parameter is time interval between loss of external power to the NPP (LOOP event) and time when all electrical power in plant is lost (extended SBO). This time interval was considered in the study [6] in order to simulate the accident corresponding to Fukushima Dai-ichi NPP accident scenario.

The earthquake resulted in LOOP at the Fukushima Dai-ichi NPP and consequential start of EDG's providing power to the operating safety systems. Approximately one hour after the earthquake the subsequent tsunami hit the site resulting in loss of all electrical power sources (extended blackout).

Operation of the emergency diesel generator (EDG) for 1 h in pressurized water reactor (PWR), as shown in [6], extends the available time for the start of pump injecting into SG on 4 h (reactor cooling through the SG). The operational interval has large uncertainties and depends on design of the plant (protection from hazards) and operational guidelines (if/what actions are planned for the operator).

Second important parameter identified in [6] is time interval between loss of cooling (as a result of loss of electricity) and restoration of cooling by other/alternate means. This time depends if/what type of restoration strategies exist in the plant, utilization of mobile and/or fixed equipment, consideration of these actions in operator training and guidelines etc.

The uniform distribution is recommended for characterization of the uncertainties of both parameters with minimal and maximal values given in Table 1. The maximum value was estimated based on previous studies and expected time when given system can effectively change the event progression.

Table 1 Description of external uncertainty parameters

Parameter	Distribution type	Unit	Min	Max
EDG operation time	Uniform	Time [hr]	0	8
Restoration of Cooling	Uniform	Time [hr]	0	4

2.2 Internal parameters uncertainties

The analysis of the SBO event [6] shows that most important parameter considering progression of the event is existence and type of loss of coolant accident (LOCA) scenario causing RCS inventory loss, leading to core uncovery and later core heatup. For example, the failure to isolate letdown results in core damage before 24 h in all analysed scenarios. Alternative strategy to isolate letdown loss is to depressurize primary system pressure below opening setpoint of letdown relief valve to pressurizer relief tank (PRT). The consideration of the normal system leakage (allowed leakage for normal operation, not considered LOCA) has small impact on the results. The existence and size of the reactor coolant pump (RCP) seal loss (called seal LOCA) is identified as important for the development of the event.

The primary system pressure is assessed as important for scenarios where seal loss is not existent or is small, and depends on success of depressurization actions on the secondary side of the PWR. The parameters intervals are assessed from [6] and are given in Table 2.

Table 2 Description of internal uncertainty parameters

Parameter	Distribution type	Unit	Min	Max
Normal system leakage	Uniform	Flow [l/s]	0	0.6
Seal LOCA	Uniform	Flow [l/s]	0	1.3
Letdown leakage	Uniform	Flow [l/s]	0	5.7
Start of depressurization	Uniform	Time [hr]	0	1

3 SBO PROGRESSION TREE

The progression of the SBO event scenario with the main events and operator actions that are expected to be included in the analyses of the event are given on Figure 2.

First important element defining the progression of the SBO scenario is the EDG's start. In case of successful start the next important element is the operational time of the EDG's. In case of EDG's failures the important event is availability and capacity of the batteries to power essential electrical systems and turbine-driven auxiliary feed water system.

All these events related to power system availability are directly dependant on operator's actions to start and/or restore them.

The progression of the event also depends on the state and events in the reactor cooling system: presence and type of leakages, operator actions (depressurization) in the system etc.

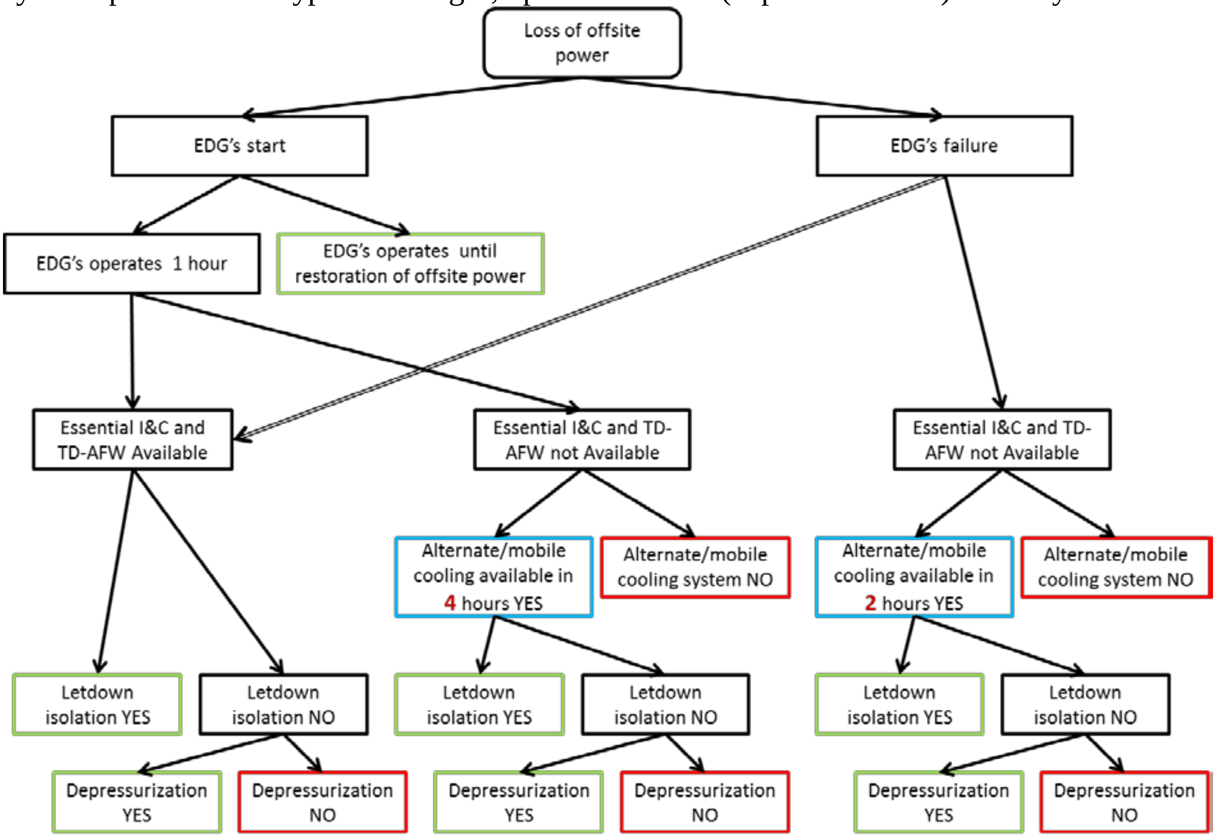

Figure 2: SBO event progression tree

Figure 2 shows that first event following the loss of the offsite power is the start of the EDG's in the NPP. If EDG's started successfully the next parameter is their operational time.

If EDG's operate all the time until we restore the offsite power then plant safety is expected to be assured (marked with green box on Figure 2). If EDG's start but operate only for one hour (because of some event for ex. tsunami) then progression of the event depends on the availability of the essential instrumentation and control (essential I&C powered by plant batteries) and turbine-driven auxiliary feed water system (TD-AFW system powered by steam from steam generators).

If the essential I&C and TD-AFW system are available then isolation of the letdown leakage (thru letdown relief valve) is required in order to obtain safe plant condition (green box Letdown isolation YES). In case of unsuccessful isolation of the letdown leakage the safe state can be obtained by successful depressurization of the primary system of the NPP bellow pressure set point for opening of the letdown relief valve (green box Depressurization YES). Unsuccessful depressurization leads to core uncover and ultimately core damage (red box Depressurization NO).

If essential I&C and TD-AFW are not available then progression of the event depends on the availability of the alternate/mobile system for the cooling of the plant. This system should be connected and started within limited timeframe which is specific for each plant. Indicative value of 4 hours is given on the Figure 2 obtained from the referenced studies [1,6]. If no cooling is restored within this period then core damage is inevitable (red box Alternate/mobile cooling system NO). If alternate/mobile cooling system is activated within 4 hours then successful isolation of the letdown leakage results in safe plant state. In case of unsuccessful letdown isolation the safe state can be obtained by successful depressurization of the primary system.

If EDG’s fail concurrently with the loss of offsite power (which means that EDG’s were lost immediately/together with the electrical grid resulting in station blackout) the progression of the scenario/event is similar to the scenario of EDG’s failure after 1 hour. The only difference is that available time for utilization of alternate/mobile cooling system (when essential I&C and TD_AFW are not available) is shorter and now is 2 hours (blue box Alternate/mobile cooling available in 2 hours YES).

The events (and corresponding operator actions) given on Figure 2 are expected to be included in the Bayesian Belief Network (BBN) corresponding to SBO event. The available time for restoration of the safety functions for given plant and design were assessed with the utilization of the deterministic code and corresponding calculations.

4 CONCLUSION

Based on the analysis presented in the previous sections the most important parameters that are affecting the development of the SBO event are identified. The parameters are classified into internal and external considering related type of the plant system.

The indicative values for the characterization of the uncertainties of those parameters are provided.

The modelling of the station blackout event in other models/tools (for example Bayesian Belief network) is expected to include identified important parameters. In case of modelling of operator/human actions the human failure probability for these actions can be assessed and included in the study.

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REFERENCES

[1] A. Volkanovski and A. Prošek. Extension of station blackout coping capability and implications on nuclear safety. Nuclear Engineering and Design, 255 (1), 16-27, 2013

[2] IEEE. IEEE Standard Criteria for Class 1E Power Systems for Nuclear Power Generating Stations. IEEE Std 308-2001 (Revision of IEEE Std 308-1991), 0_1-26, 2002

[3] U.S. NRC. Station Blackout. Regulatory Guide 1.155, Washington, 1988.

[4] M. Nishio and H. Fujimoto. Study on Seismic PSA for a BWR in shutdown state. ANS PSA 2011 International Topical Meeting on Probabilistic Safety Assesment and Analysis. American Nuclear Society, Wilmington, NC, 2011.

[5] A. Volkanovski and M. Čepin. Implication of PSA uncertainties on risk-informed decision making. Mavko Borut, H.Y.A., Cizelj Leon (Ed.), Special issue on the International Conference NENE 2009, September 14 and 17, 2009, Bled, Slovenija, Printed. ed. North-Holland, NLD, 2011.

[6] A. Prošek and A. Volkanovski. Extended blackout mitigation strategy for PWR. Nuclear Engineering and Design, 295 360-373, 2015