SEISMIC LEVEL 2 PSA

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Core damage scenarios induced by external events have the potential to contribute significantly to the large early release frequency (LERF), as they may result in a higher conditional probability of large release than internal events such as transients and LOCA. Especially for seismic events, which may increase the failure probability of many systems, structures and components, the possibility that sequenes leading to core damage also result in large release, cannot easily be ruled out. For this reason, performing a Seismic Level 2 PSA is important for calculating the plant risk.

Since the confinement function is one of the most essential functions in Level 2 PSA, all containment penetrations have to be analyzed in detail. For example, systems with containment penetrations which are normally screened out in the Level 2 PSA for the containment isolation function, may need to be screened in for a seismic initiating event, as there is the potential of a containment bypass in such systems in case of a LOCA. Additionally, the operability of passive features may be compromised in the case of a beyond design basis earthquake, and human actions defined in the severe accident management guidelines (SAMG) may become more challenging.

We have found the following main steps when performing a Seismic Level 2 PSA:

- *Extension of the seismic equipment list (SEL) to include Level 2 PSA relevant systems.*
- *Determination of the systems within the existing SEL subject to increased requirements in case of a severe accident.*
- *Determination of essential components for which a dedicated fragility analysis needs to be performed.*
- *Identification of effects of the seismic initiating event on the accident progression.*
- *Effects of the seismic initiating event on the failure probability of mitigative human actions as defined in the SAMG.*

Seismic Level 2 PSA is an important tool for both existing and new nuclear power plants, especially for those at seismically active sites. The analysis is not trivial and may identify sequences which have a high conditional probability of containment failure in the event of core damage.

I. INTRODUCTION

For most external events, the calculation of the core damage frequency (CDF) in Level 1 PSA is sufficient to be able to show that the contribution of the event to the plant risk is negligible. However, it is not sufficient to compare the CDF of the external event to the total plant CDF, as consequences of external events that lead to core damage may have a significant impact on the large release frequency (LRF) or large early release frequency (LERF), even though their contribution to the CDF is low.

For this reason, the CDF for the external event should be compared to the LRF or to the LERF from internal events to be able to screen out the event for Level 2 PSA, or alternatively arguments should be given why the CDF of the external event will not contribute significantly to LERF.

For sites with a low seismic risk and a robust plant design, it can often be shown that the CDF in Seismic Level 1 PSA is low enough to use a simplified approach for Level 2 PSA. In Section III, it is assumed that this is not the case and the methodology for a full Seismic Level 2 PSA is discussed.

II. SIMPLIFIED SEISMIC LEVEL 2 PSA FOR LOW SEISMICITY SITES

The following simplified approach is used for low seismicity sites for which the CDF of seismic events is low: first, in Seismic Level 1 PSA, seismic events are typically divided into several bins, each of which has an initiating event frequency and a resulting CDF. Then, for each of the bins, a conservative conditional large release probability is assumed. This factor basically reflects the probability of early loss of the containment function. Finally it is shown that the LERF resulting from seismic events is small compared to the total LERF of the plant, and this justifies the simplified approach.

III. FULL SCOPE SEISMIC LEVEL 2 PSA

For many plants and sites, however, the simplified approach is not sufficient. The ASME PRA standard[1] states:

***"**The analysis must examine whether any accident sequences that are not in the LERF category in the internal-events PRA model need to be included in that category for the particular external event being evaluated."*

Based on this, a limited scope Seismic Level 2 PSA has been performed for some plants, e.g. for Beznau[2]. For other plants such as Krško[3], Level 2 PSA has been performed by simply assigning existing plant damage states to seismic core damage sequences. However, as we shall see below, even this approach is potentially optimistic.

A full-scope Seismic Level 2 PSA should consist of the following main steps:

- Extension of the seismic equipment list (SEL) to include systems relevant to Level 2 PSA (e.g. containment isolation system, features for core melt stabilization, hydrogen mitigation systems). This step is described in Section III.A.
- Determination of the systems within the existing SEL that are subject to increased requirements in case of a severe accident. This step is described in Section III.B.
- Determination of essential components for which a dedicated fragility analysis needs to be performed. This step is described in Section III.C.
- Deterministic accident progression calculation. This step is described in Section III.D.

After performance of these steps, the required work has been defined and the system analysis for Seismic Level 2 PSA can be performed in a similar way to the system analysis of Seismic Level 1 PSA.

Additionally, the phenomenology of the severe accident may be affected by the seismic event or by the failure of passive systems, the failure of which was not previously modeled in the Level 2 PSA for internal events. This is discussed in Section III.D.

III.A. Creating a Seismic Equipment List for Level 2 PSA

To perform a Seismic Level 2 PSA, the seismic equipment list (SEL) from Level 1 PSA is not sufficient. There are two types of systems, structures and components (SSC) that need to be considered in the case of Level 2 PSA, which may not be in the SEL for Level 1 PSA. These SSC types are:

- All systems with containment isolation valves (CIVs)
- SSCs which can be used for severe accident mitigation

Systems with CIVs have been screened for relevance to the containment isolation function in the Level 2 PSA for internal events. However, as is pointed out by Kassawara[4], this screening is performed on the assumption that there is no seismic event which could potentially endanger the integrity of the fluid system. Therefore, it is not sufficient to only screen in systems which have the potential for containment isolation failure in the case of CIVs failing to close. Instead, other systems need to be considered which would only have this potential in the case of the system being damaged by the earthquake. Subsection III.A.1 discusses the screening of CIVs for Seismic Level 2 PSA.

The second type of SSC which can be used for severe accident mitigation includes all SSCs which are relevant for Level 2 PSA. For many plants, this includes passive systems which will work correctly without any action and for which no failure is assumed for the internal events Level 2 PSA. An example of such an SSC would be the Passive Autocatalytic Recombiners (PAR), which are discussed in more detail in Subsection III.A.2.

III.A.1. Screening of Containment Penetrations for the Seismic Equipment List for Level 2 PSA

An example of such a system in a modern PWR would be the Nuclear Island Fire Protection System. This system has containment penetrations, yet if the CIVs fail to close, this would not directly result in loss of containment isolation. This is because the system is a closed system which is designed to withstand the containment pressure which may occur during a severe accident. If, however, an earthquake were to cause a break in this system, the system would become relevant for the containment isolation function.

In Level 2 PSA, containment penetrations can be classified in five different categories:

A. Systems with a direct connection to the reactor coolant system (either open in normal operation or closed using valves which may be erroneously open), e.g. extra borating system.
B. Systems with a connection to the reactor coolant system only in case of a break in a heat exchanger with coolant-carrying tubes, e.g. main steam system.
C. Closed systems without connections to the reactor coolant system, e.g. fire water system.
D. Systems with an open connection to the containment atmosphere, connection to the containment penetration is closed during normal operation, e.g. containment ventilation purge air.
E. Systems with an open connection to the containment atmosphere, connection to the containment penetration is open during normal operation, e.g. containment ventilation other than purge air.

Containment penetrations in categories A and B are generally modeled in Level 1 PSA (in plant damage states for steam generator tube rupture and interfacing systems LOCA). However, many potential break locations are screened out in the scope of Level 1 PSA. Therefore, such penetrations need to be reconsidered in the context of seismic PSA.

For containment penetrations of category E, a fault tree approach is generally used in Level 2 PSA. As these are not screened out, the seismic failure can be readily integrated.

Containment penetrations of categories C and D, however, can be screened out in Level 2 PSA if they are designed for sufficient pressure to not influence the accident progression. However, in seismic Level 2 PSA, the associated systems will fail with some probability based on their fragility, leading to a potential containment bypass path. Therefore it is expected that the SEL will require significant extension to include such systems.

III.A.2. Modeling of PARs in Seismic Level 2 PSA

Under severe accident conditions, the PARs will convert hydrogen to steam without any active functions and are therefore always operable during power operation. However, if an earthquake were to cause failure in the anchorage of the PARs, this would cause loss of the hydrogen recombination function and therefore affect the branch probabilities in Level 2 PSA. For this reason, the PARs are classified as a seismically relevant system in the EPR reactor.

As the recombiners are installed at many different locations inside the containment, and more specifically at different elevations, they will be subject to different accelerations, which can be calculated based on the different floor spectra. For this reason, it is suggested that the PAR are divided into several groups, and a graded failure rate of the different groups may be considered. Based on the relevance of this system for the result of the seismic Level 2 PSA, better results may be obtained by considering the effect of different configurations of failed PARs on the hydrogen risk. It is, for example, possible that failure of 50% of the PARs would not lead to a significant increase in hydrogen risk.

To be able to evaluate this effect properly, the anchorage of the PARs should be evaluated in a plant walkdown.

III.B. Determination of systems, structures and components subject to increased requirements in case of a severe accident

Some SSCs are present in the seismic equipment list for Level 1 PSA but require additional attention in a seismic Level 2 PSA because of increased requirements in the case of a severe accident. For example, some SSCs for which only integrity is required in Level 1 seismic PSA might be required operable after the earthquake in the case of a severe accident. An example of such a system would be the passive flooding valves in the EPR which are used to flood the melt after it has reached the spreading area. In seismic Level 1 PSA, it is only required that these valves remain closed to ensure that the inventory of the in-containment refueling water storage tank is not lost. Additionally, in seismic Level 2 PSA it is required that these valves are not stuck closed so that the melt in the spreading area can be cooled as designed.

A walkdown is required to be able to screen SSCs for the Level 2 PSA SEL.. It is already common practice to perform a plant walkdown for Level 1 seismic PSA and for Level 2 PSA, yet such a walkdown would be a combination of both .

The Level 2 PSA walkdown generally covers two main goals:

- Identification of the plant-specific fission product release paths, including the evaluation of pressure-dependent pathways (such as hatches, doors, rupture discs) and the path of the corium in case of a vessel failure.
- Evaluation of the containment penetrations and other potential threats to containment integrity in case of pressure buildup either in the containment or in the reactor building.

If seismic events are included in the Level 2 PSA, the seismic screening of Level 2 specific components is added as a third goal.

III.C. Determination of systems, structures and components for which a dedicated fragility analysis must be performed

In theory, a dedicated fragility analysis can be performed for all SSC which are listed in the SEL for Level 2 PSA, however, in practice this is often not feasible as such analyses are very time-consuming. Instead, first the risk relevance of the different component types is calculated and a selection of the critical SSCs which will potentially increase the LRF significantly if they fail is made.

The potential risk increase in case of failure is particularly prominent in case of containment penetrations. In the Level 2 PSA, a list of containment penetrations and failure modes is generally compiled. Usually this list contains, but may not be limited to:

- Equipment hatch
- Airlocks
- Pipe penetrations
- Cable penetrations
- Heating, ventilation and air-conditioning (HVAC) penetrations

The failure frequency of the containment is one side of the Level 2 PSA result, the magnitude of the release of fission products into the environment is another. For this reason, passive fission product filters may also end up being relevant to the plant source term risk.

III.D. Evaluation of human errors in mitigative actions

If the plant has implemented SAMGs, the Level 2 PSA for internal events may take credit for mitigative actions. Often, such actions cannot be performed solely from the main control room, but instead require the use of mobile equipment or include local actions. In the event of an earthquake, mobile equipment might not be available, and the transportation of mobile equipment and the accessibility of certain areas in the plant may be impeded. Therefore, some actions may not be possible, may require additional steps, or simply require more time. For this reason, all human actions in the Level 2 PSA need to be reevaluated and if necessary, adapted for seismic events.

III.E. Deterministic analysis of the accident progression

Although most potential accident progression sequences will be the same for seismic and non-seismic initiators, the possible failure of passive systems may lead to some significantly different accident progression paths. If such sequences have a significant frequency, they will need to be analyzed separately.

One such sequence may be the seismic failure of all or a large portion of the passive autocatalytic recombiners, leading to hydrogen concentrations that are more challenging to the containment.

IV. CONCLUSION

To date, seismic events have only been considered in a very simplified way in existing Level 2 PSAs. This approach is sufficient for sites with low seismicity. This paper presents a methodology for sites where the contribution of seismic events to the source term risk may be significant, in which case the analysis is not trivial. The analysis covered which components need to be on the seismic equipment list for Level 2 PSAs, and what other effects may need to be investigated.

The main conclusion is that the seismic equipment list from Level 1 PSA must be extended significantly and should not only include typical mitigative systems like the CMSS or PAR, but also systems with containment penetrations and passive components such as filters. Additionally, it has been shown that a plant-specific SEL needs to be compiled.

Finally it can be concluded that the fragility analysis of the containment should take into account seismic effects.

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