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Lessons learned on probabilistic methodology for precursor analyses

Based on its experience in precursor assessment of operating experience from German NPP and related international activities in the field, GRS has identified areas for enhancing probabilistic methodology. These are related to improving the completeness of PSA models, to insufficiencies in probabilistic assessment approaches, and to enhancements of precursor assessment methods. Three examples from the recent practice in precursor assessments illustrating relevant methodological insights are provided and discussed in more detail. Our experience reinforces the importance of having full scope, current PSA models up to Level 2 PSA and including hazard scenarios for precursor analysis. Our lessons learned include that PSA models should be regularly updated regarding CCF data and inclusion of newly discovered CCF mechanisms or groups. Moreover, precursor classification schemes should be extended to degradations and unavailabilities of the containment function. Finally, PSA and precursor assessments should put more emphasis on the consideration of passive provisions for safety, e.g. by sensitivity cases.

Erfahrungen aus der probabilistischen Bewertungsmethode für Precursoranalysen. *Basierend auf ihren bei der Anwendung von Precursor-Analysen bei der Bewertung der Betriebserfahrungen deutscher Kernkraftwerke z.B. bei der Auswertung meldepflichtiger Ereignisse gewonnenen Erkenntnissen durch Precursor-Analysen und ihren internationalen Tätigkeiten auf diesem Arbeitsgebiet hat die GRS Ansätze für die Verbesserung von probabilistischen Methoden identifiziert. Diese zielen auf die Verbesserung der Vollständigkeit der zu Grunde liegenden PSA-Modelle und die Verringerung von Unzulänglichkeiten in der probabilistischen Methodik und auf Verbesserungspotentiale der Methoden für die Durchführung von Precursor-Analysen. Anhand von drei Beispielen werden relevante methodische Erkenntnisse aufgezeigt und diskutiert, die sich aus der jüngsten Praxis der Precursor-Analysen ergeben haben. Unsere Erfahrungen unterstreichen, dass für Precursor-Analysen vollständige, aktuelle Stufe 1- und Stufe 2-PSA-Modelle für die Analysen genutzt werden sollten. Sie zeigen weiterhin die Notwendigkeit auf, GVA-Daten regelmäßig zu aktualisieren sowie neu erkannte GVA-Mechanismen oder -Gruppen in die bestehenden PSA-Modelle zu integrieren. Darüber hinaus sollte das Precursor-Klassifikationsschema um Szenarien mit Beeinträchtigungen und Unverfügbarkeiten des Sicherheitseinschlusses durch das Containment erweitert werden. Schließlich sollten PSA und Precursor-Analysen passiven Sicherheitseinrichtungen mehr Beachtung schenken und diese verstärkt in die Bewertungen einbeziehen, z.B. mittels Sensitivitätsanalysen.*

1 Introduction

Shortly after the establishment of Probabilistic Safety Analysis (PSA) for Nuclear Power Plants (NPPs), it was recognized that PSA models can be utilized to complement the evaluation of operating experience with respect to its relevance for nuclear safety. The PSA model is used to calculate results conditional to the event, which allows for determining the event's risk significance, discover and quantify weaknesses in the plant design or operation relative to the event, and to improve the completeness of the PSA model itself. These studies are often called precursor studies in the frame of nuclear safety. Events from the operating experience in nuclear installations are classified as precursor events, if the conditional risk increase or contribution exceeds certain threshold values, e.g. 1 E-06 for conditional core damage probability (CCDP) or more precisely for the conditional risk increase of core damage (ΔCCDP). First results from precursor analyses were published in the United States in 1982 with continuous accident sequence precursor evaluations since 1986 (cf. references in [5]). Several countries initiated similar precursor evaluation programmes in the early 1980s [3]. In Germany, GRS published the German Precursor Study in 1985 [6]. Since then, GRS has continuously analysed the operating experience from German NPP with regard to precursor events and is involved in the corresponding international precursor activities.

Currently, systematic precursor studies are performed in several countries; publications by the IAEA [3, 4] and the OECD/NEA [7, 8] give an overview of the ongoing activities and methods applied in this context. Moreover, precursor assessment is considered in IAEA guidelines [1, 2] and is required in national regulations (e.g. [10, 11]) or is part of ongoing programmes by the regulatory body as e.g. in Germany [12]. Thereby, GRS complements the deterministic operating experience assessment and can identify risk-significant events for in-depth analysis.

Section 2 gives a brief overview over current practices in precursor assessment, in Germany as well as in other countries. Based on GRS's activities in this field on a national and international level in the recent past, the insights related to probabilistic methods and assessments for state-of-the-art precursor analyses and PSA models are summarized in Section 3 regarding

- completeness of PSA models,
- issues specific to precursor analysis,
- insufficiencies of current probabilistic methods.

The summary particularly focusses on emerging issues for precursor modelling. This will be complemented by a discussion of methodological issues on selected examples from recent work performed by GRS in Section 4. Last but not least, Section 5 provides a summary of the lessons learned.

2 Precursor assessment approaches

In recent years precursor analysis is being increasingly used by operators as well as regulators as an element of risk management and risk-informed decision making as it gives quantitative information on the risk significance of events from the operating experience of NPPs. Precursor assessment uses existing PSA models for the computation of the conditional core damage probability (CCDP) as a safety indicator.

The first systematic precursor analyses were carried out in the USA for events in the years 1969 up to 1979 [19], upon establishment of the U.S. NRC Accident Sequence Precursor (ASP) Program. Since 1984, there has been a continuous precursor assessment on behalf of the U.S. NRC [5, 20]. In the ASP Program, events with a conditional core damage probability (CCDP) ≥ 1 E-06 are considered as precursors, events with a CCDP ≥ 1 E-03 are categorised as significant precursors. To this end, the U.S. NRC in 2015 has maintained 75 Standardized Plant Analysis Risk (SPAR) models representing 99 commercial nuclear power reactors in the United States [20]. Every SPAR model includes Level 1 PSA models for internal events at full power operation. Certain models have an extended scope and e. g. include hazards such as fires, internal flooding, and seismic events [20]. In addition, certain SPAR models include Level 2 PSA for determining Large Early Release Frequency (LERF) results. Change in LERF due to an event is used in the significant determination process of the U.S. NRC. While not changing the fundamental precursor assessment approach or the precursor classification procedure, the NRC has been continuously expanding the PSA models used for precursor assessments, thus improving the significance of precursor assessments.

Precursor analyses in Germany are performed since 1997 by GRS as an element of the regulatory operating experience feedback program of the Federal regulator BMUB. The German practice for precursor classification was developed [22] against the background of typical Level 1 PSA for plant internal events at full power and PSA objectives published in INSAG-12 [23]. The current GRS approach 22 basically follows the recommendations from IAEA-TECDOC-1417 [4]. A limited set of safety significant events from the operating experience is determined by screening based on several criteria related to the affected redundancies of safety systems, the frequencies of applicable initiating events, the actuation of safety systems, and whether the event can be sensibly assessed by means of available probabilistic methods and models. Screened-in events are then initially analysed with generic PSA models. If the initial delta conditional hazard state probability[1] (ΔCHSP) exceeds 1 E-06 a more detailed analysis is performed. If the refined ΔCHSP value is greater equal 1 E-06, the classification as a precursor is confirmed. If ΔCHSP is greater equal 1 E-04, the event is classified as a significant precursor [22].

Comparing the quantitative results of German precursor analyses with those of other countries it has to be noted that ΔCHSP does not take into account accident management measures and other manually activated systems for controlling beyond design basis scenarios. Some specific assumptions of the GRS approach [22] include that prolonged event scenarios such as long-term degradations in safety systems are analysed over the whole period, even if this period significantly exceeds one year. The respective ΔCHSP are then aggregated over the whole period. For the treatment of operating experience exhibiting a common cause failure (CCF), the GRS approach considers the results of the CCF investigations. Degraded but not failed components are considered in the precursor assessment by specific failure probabilities as determined in the CCF assessment.

The precursor analysis approach adopted by the Spanish regulatory authority CSN closely follows the approach by the U.S. NRC [24]. In France, the operator EdF has continuously carried out precursor analysis since the mid-1990s, complemented by specific event investigations by IRSN. As EdF operates a standardized plant series of PWR, standardized PSA models are used. With regard to precursor assessment methods and classification criteria, no significant differences to the approach by the U.S. NRC are known.

In Belgium, the regulatory authority BEL V has systematically performed PSA-based event analyses of selected operational events [25] as part of its operating experience feedback process. This is complemented by precursor analyses performed by the utility for its own use in order to further enhance NPP safety. The approach includes a screening step based on PSA analysts' experience to select significant events that should be further analysed. For highly significant events complete and detailed precursor analyses are performed and documented. To this end, plant specific models, event specific boundary conditions, and additional probabilistic modelling as needed are employed.

The Swiss nuclear regulatory authority ENSI has issued the regulatory guideline ENSI-A06 [10], which requires Swiss utilities to perform probabilistic precursor assessments of events from the operating experience as part of their reporting duties for reportable events. For the probabilistic assessments plant-specific full scope PSA are applied. Additionally, the utilities annually report on the NNP's risk profile over the previous year, which includes a probabilistic assessment of all operating events as well as scheduled unavailabilities. ENSI-A06 defines specific risk measures and criteria for precursor assessments, notably the maximum annual peak risk and the incremental cumulative core damage probability in addition to the incremental conditional core damage probability [10].

The Finnish regulatory authority STUK is performing a risk follow-up on the events from NPP's operating experience as part of their safety indicator system. STUK uses lower numerical thresholds than other precursor assessment approaches and uses the following three classes. The most risk significant events start with CCDP ≥ 1 E-07, other significant events correspond to 1 E-08 ≤ CCDP < 1 E-07, while other (not significant) events have CCDP < 1 E-08. These indicators are documented at some detail in STUK's annual report. Moreover, STUK requires from the utilities with YVL A.10 [11] to perform precursor analyses with the PSA or to do other risk analysis as applicable. In addition, the licensees perform event investigations (precursor analysis or risk follow up) for their own purposes on a case by case basis.

In summary, precursor analysis is performed in various countries basically following the methodology outlined in IAEA TECDOC-1417 [4]. Generally, conditional core damage probability is used as risk measure, with some specific variation, e. g. in Germany or Switzerland, whereas a continuation to Level 2 PSA is not applied in most countries. The significance of precursor assessments has benefited from the

[1] In this context, a hazard state is to be assumed in accident sequence analysis if the plant reaches a core damage state unless dedicated, not automatically triggered preventive accident management measure are successfully implemented [17]. The hazard state is used as a strong leading indicator for a core or fuel damage state. In Germany, hazard states have to be determined in addition to core damage states [17]. ΔCHSP is calculated by subtracting the baseline hazard state probability from the conditional hazard state probability for the event under investigation.

further refinement of PSA models covering all operating states and also specific hazard PSA models.

3 Emerging methodological issues from precursor assessments

When performing precursor analysis, the events under consideration broadly fall into two classes: those events which are covered by the PSA model of the plant since they are (very similar to) standard PSA scenarios, and those requiring extensions of the probabilistic modelling. From the point of view of probabilistic methods, the latter events expose gaps in PSA models and can provide valuable insights with regard to insufficiencies of available probabilistic methodologies. In addition, there are some important issues, where precursor analysis needs to diverge from conventional PSA modelling since it treats those events which have actually occurred. From the work of GRS on precursor studies for German NPP and based on the information exchange in the international community, several areas have been identified where precursor studies provide valuable insights.

3.1 Completeness and representativeness of PSA models

It has been recognized from the start of precursor analysis programs that the analysis of actual events is an important tool for uncovering gaps in the PSA model. It is widely recognized that PSA models should be full scope, regularly updated and extended to hazard scenarios as well [2]. The GRS experience underpins the importance of up-to-date, design-specific PSA models using recent reliability data.

With regard to the completeness of PSA models, the following observations have to be pointed out:

- Events will routinely motivate the inclusion of new, additional common cause failure (CCF) groups or failure modes into the PSA model. Section 4.1 presents an example from the recent work of GRS. We recommend regular interaction between dedicated teams for the evaluation of operating experience on CCF and for precursor assessment.
- For recurring events, precursor analysis can re-inforce the need for an update of component failure rates or inclusion of additional basic events into PSA models.
- PSA models often neglect seasonal variations (e.g. environmental temperatures, see Section 4.1). Events have demonstrated that these may have important implications as certain observed effects are conditional to boundary conditions such as environmental temperature. This aspect should be considered in enhanced PSA models.
- Precursor analysis can identify additional operator actions for containing event sequences. These actions can be included in the PSA models if relevant.
- Actual events often represent complex scenarios. These are hard to map to PSA models due to their inherent simplifications, which in turn are often based on deterministic design assumptions. However, such simplifications can mask existing vulnerabilities, which a more detailed and systematic assessment that questions such simplifying assumptions might have revealed. One salient example related to phase faults in the electrical power supply is briefly discussed in Section 4.3. Further examples include the intrusion of smoke gases into the control room during a main transformer fire and the ingress of rainwater into the reactor and turbine buildings due to on overload of pipe connectors in the roof drainage pipework. GRS recommends to regularly re-examine the initiating event grouping of PSA models as well as the accident sequence modelling with regard to new and unexpected behaviour of the plant. Irrespectively of the actual precursor evaluation results, an extension of the PSA model or at least a sensitivity study should be considered.

3.2 Issues specific to precursor analysis

Based on GRS experience, the following issues have repeatedly arisen during precursor assessments.

- Treatment of events which span an extended period of time
  If a degraded or faulty state persists for a prolonged time period, precursor analysis usually aggregates the conditional risk figures over that period, even if it covers several years. It has to be pointed out that since conventional risk measures like CDF are calculated for one year, aggregation over many years may lead to misleading results. Moreover, the time dependency of risk figures will become important.
- Treatment of overlapping events and changes in plant configuration
  Related to the previous issue, particularly long-lasting events may overlap with another separate event. In this case, an explicitly time dependent evaluation of the event is necessary. This is also the case if the plant configuration is modified (e.g. change of plant operational state) while the event (e.g. degradation of a safety system) persists.
- Treatment of the actual plant configuration
  PSA models usually include the unavailability of redundant safety trains due to planned maintenance for the respective plant operating states. For precursor analysis, the actual status of all trains is known. This underlines the need for PSA models which can easily be adapted to the actual plant configuration. In this regard, risk monitor models are an important enhancement.
- Treatment of potential CCF events in precursor analysis
  In the frame of PSA, CCF events are often quantified assuming test intervals and detection intervals. For precursor analysis, the relevant analysis period may be significantly smaller than that assumed for CCF quantification. Therefore, the contribution of CCF events to precursor analysis results needs to be discussed.
- Assessment of (potential) operator actions; human reliability analysis (HRA) for precursor studies
  Actual events are often controlled by operator actions. Moreover, if sensitivity cases are investigated, these could be controlled by additional operator actions. These actions are often not included in the existing PSA models, since they were not identified as relevant. Adequate consideration of these actions in precursor analysis is important (see Section 4.1).
- Consideration of effects on accidental scenarios in precursor studies
  We are aware of several operating experience events, for which the degradation of the containment function or a potential containment bypass was an safety significant aspect. The German practice for precursor classification is based on Level 1 PSA results. It is therefore insensitive to degradations of containment effectiveness and thus insensitive to potential effects on release metrics such as large release frequency. Consequently, the risk significance of events for which accident management is not effective or for which

more severe release categories become dominant is not quantified. In light of the small values for large and for early release frequency (LRF/LERF) in recent Level 2 PSA studies, which are easily below 2 E-06 per year, precursor analyses should be extended in that direction.

- Classification of precursors
  The German practice for precursor classification was developed in the 1990s based on the typical results of Level 1 PSA for plant internal events at full power. Recent PSA models often give significantly smaller values, even if low power and shutdown states and events from internal and external hazards are considered as well. Consequently, the precursor classification needs to be re-examined.

3.3 Insufficiencies of existing probabilistic methods

In some cases, precursor analysis highlights specific weaknesses and gaps in current probabilistic assessment methods. The following issues can be mentioned from our experience:

- Passive barriers and elements are usually assumed to work as specified; failures are either neglected or screened out from modelling. However, operating experience shows that failures and degradations of passive barriers and installations do occur and can be probabilistically relevant. As an example, we point to degraded fire barriers due to missing mineral wool in interstices, presented in Section 4.2. Other examples from German operating experience include leakages from roof drainage pipes as mentioned above and incorrectly installed anchors for piping restraints. Methods for identifying and integrating potentially relevant failure modes into a detailed PSA model are missing. Given the complexity of addressing failures of passive safety features probabilistically, such methods may be difficult to develop. In light of the potential significance of these failure modes, scoping analyses and sensitivity cases should be part of PSA investigations.
- Electrical disturbances lead to electrical transients in power supply systems, which can propagate to I&C systems. The potential relevance of these scenarios has been recognized, see Section 4.3. Open methodological issues include an effective PSA modelling of electrical transients and a better understanding of the transient behaviour of power supply systems and consequential failures of a transient. This is also connected to the issue of simulating electrical disturbances in plant specific models.
- Operating experience keeps to underscore the limitations of current HRA methods. GRS can confirm this issue from its experience as well.

4 Examples from GRS work

In the following, three examples from recent GRS precursor assessment and the specific lessons learned regarding probabilistic analysis methods are presented.

4.1 Potential loss of ultimate heat sink and feedwater due to CCF mechanisms in medium voltage transformers in the electric power supply system

During nominal power plant operation, medium voltage (6/0.4 kV) transformer No. 3 in the in the emergency power supply (EPS) of the auxiliary power supply was tripped by Buchholz protection signals. This separated the subordinate 400 V busbar from its nominal power supply. Other subordinate EPS busbars were supplied by automatic switchover to redundant busbars. An overview of the EPS busbars is given in Fig. 1. Importantly, the loss of power at the directly subordi-

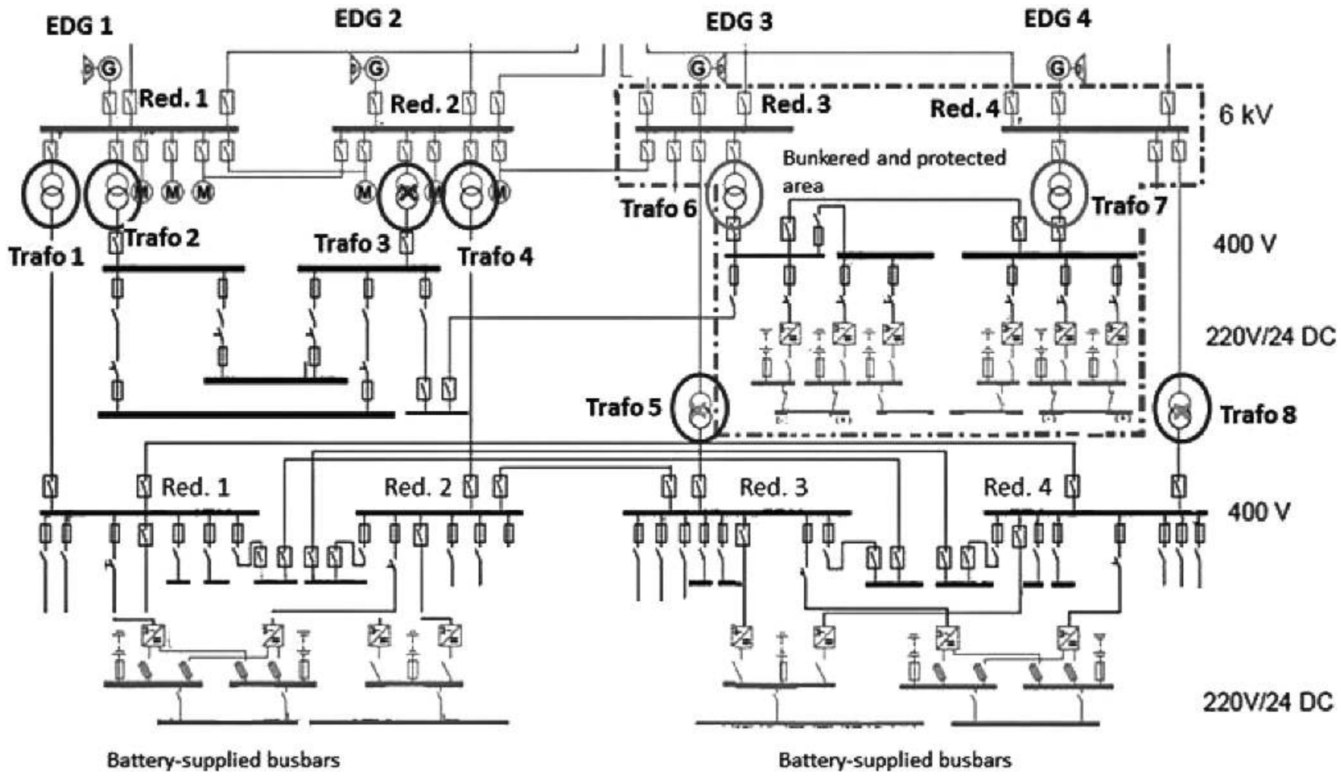

Fig. 1. Overview of EPS system on potentially affected transformers

nate busbar would have led to operational failure of emergency diesel generator (EDG) No. 2 after start-up as its cooling water stop valve would have remained in closed position and thus EDG cooling would have been unavailable.

Buchholz protection signals were triggered because of an insufficient quantity of transformer oil in the transformer No. 3. The transformer experienced oil temperatures of approximately 4 °C due to outside temperatures of – 18 °C and operation at a low load. Several contributing factors were identified after the event. The oil level indicator had a non-linear gauge for the oil level in the tank complicating surveillance and maintenance of the correct oil level. In addition, the plant processes and practices for maintenance, particularly the refilling of oil and drawing of oil samples, were not adequate and did not sufficiently consider influencing environmental conditions such as very low ambient temperatures. Subsequent inspections provided indications on insufficient oil levels at two additional transformers, No. 5 and No. 8.

The event was classified as a potential CCF event. Six of the eight transformers were exposed to comparable environmental conditions (circled black in Fig. 1), two were in a protected area and not exposed to these strong fluctuations in ambient temperature (circled grey in Fig. 1). Importantly, failures of transformers No. 5 and 8 do not impair the operation of EDG No. 3 and No. 4, since their coolant water stop valves are supplied by transformers No. 6 and No. 7.

For the probabilistic evaluation a 3-out-of-6 CCF event was assumed, with conditional failure probabilities for degraded transformers No. 5 and No. 8 of 0.5 and 0.4, respectively. This results in a conditional failure probability of both 400 V busbars for redundancy No. 3 and No. 4 of 0.2. Subordinate battery supplied DC busbars (cf. Figure 1) are assumed to be available for 2 h. This time period is sufficient for diagnosis and manual restoration of power supply to both 400 V busbars by manual switchover to 400 V redundancies No. 1 and No. 2 based on the instructions given in the operating manual. The failure probability for this measure was estimated as 6.3 E-02 applying the ASEP method [16, 17] for operator actions and the failure probabilities of the respective switches.

If such a 3-out-of-6 CCF event is not controlled successfully within two hours, it is assumed that the event sequence ultimately ends in the initiating event "loss of main heat sink and feedwater" due to automatic actions by the operational control and the reactor protection system. The unavailability of the remaining, not affected safety functions for controlling that event was calculated by means of PSA by setting appropriate boundary conditions on the existing model. This resulted in a ΔCHSP of 2.0 E-06. The event has therefore been classified as precursor.

It is important to note that this scenario was not considered in the existing PSA, but could be modelled with reasonable effort. To this end, the potential CCF of the medium voltage transformers combined with the failure of recovery actions was considered as a triggering event for the initiating event combined with specific boundary conditions in the PSA model. Nonetheless, a more thorough treatment of the CCF group, including an investigation of extending the CCF group to all eight transformers with PSA should be performed. Similar transformers in operational systems need also to be included in the probabilistic assessment. Finally, it has been pointed out that this scenario may give rise to a multi-unit event, which needs to be considered in PSA models as well.

GRS is currently drafting an Information Notice pointing out the safety significance of the event and providing recommendations for improving plant safety.

4.2 Missing mineral wool in fire barrier penetration seals of safety related buildings and interstices in the emergency feedwater building

During a fire specific plant walkdown, degraded penetration seals in fire barriers were found. Such elements are particularly relevant for nuclear safety if they are installed in fire barriers separating different redundant safety trains. Such degraded states were found in interstices between the walls and ceilings in the emergency feedwater building. The interstices were not correctly filled with mineral wool during the plant construction leading to less than the designed fire resistance rating. In case of fire in one redundant train in the emergency feedwater building and failure of the intended fire suppression means, hot gases, smoke and heat may spread through these incorrectly sealed interstices to the adjacent redundant train, e. g. due to overpressure. This may lead to failures in the electronic equipment of the second redundant train. In the worst case, failures of three redundant trains may occur, resulting in a hazard state.

The spreading of hot gases through passive elements in qualified fire walls was not taken into account in the available Fire PSA. Such scenarios have been excluded based on deterministic evaluations. The event illustrated that Fire PSA models are often incomplete by not including errors prior to the event disabling passive fire protection means. This resulted in a need for additional probabilistic modelling.

It was not known how many and which interstices were affected, as the utility has reconstructed all interstices in the building after the findings to meet the specifications. For precursor analysis it can be assumed that all interstices in the emergency feedwater building were not properly sealed. This is a conservative assumption in terms of a sensitivity analysis. Depending on the location where a fire in the emergency feedwater building is assumed, different items important to safety can be affected and different initiating events can be triggered. For all relevant fire occurrence locations the likely impacts were analysed taking into account the possibility of hot gas and smoke spreading to neighbouring redundant trains. For the fire occurrence frequencies and the unavailability of fire suppression, the plant specific Fire PSA was used. For each fire scenario, the unavailability of the remaining, not affected safety features to control the event was calculated by means of PSA.

For a period of one year, a ΔCHSP of approximately 1 E-06 was estimated. It has to be taken into account that this considers the conservative assumptions in terms of a sensitivity analysis under the boundary condition that all interstices in the emergency feedwater building are not suitably sealed. The event indicates that analysts should consider the possibility of failed or degraded passive means, in particular barriers, due to human error or faulty installation in PSA models, in particular when modelling the impacts from internal or external hazards. A conservative approach can identify sensitive measures or barriers not only for precursor assessment.

GRS has issued two Information Notices pointing out the safety significance of the event and providing further recommendations [13, 14].

4.3 Phase failures in the electrical power supply of NPP

A GRS Information Notice [15] has been issued after events with electrical phase failures in the internal and external power supply occurred in several foreign NPP. The events exposed some weaknesses in the design of the monitoring and protective devices in the electrical equipment as some phase failures could not effectively be detected by existing monitoring and protection facilities. As a result, automatic tripping of protection did not occur and countermeasures were not carried out automatically, terminating the electrical transient. Persistent, non-isolated phase failures can potentially affect the availability of grid connections and the auxiliary power supply as well as result in unavailability or even damages to components relevant to safety. For all plant operating states, the phenomena observed and failure mechanisms identified are potentially applicable to all Germany NPPs. In [15], GRS particularly recommends that under all phase failure conditions the incident management shall be ensured, that no safety relevant components shall be damaged due to such failures, unavailabilities of external grids shall be immediately detected, and that the availability of all safety important consumers shall be ensured in case of phase failure in the external grids.

Failures of individual phases in the electrical power supply are not included in the PSA models for German NPPs. Therefore, we considered how the safety significance of phase failures can be probabilistically assessed in the context of PSA and precursor analyses. This would require a considerable amount of work; however it is feasible in practice by extending the electric power supply modelling to these specific failure modes. Moreover, our initial assessment shows that phase fault scenarios can be probabilistically relevant contributors. In addition, GRS is aware that extensions of PSA models for power supply failures are underway for some foreign NPP [18]. GRS is planning a research and development project on probabilistic modelling of phase faults.

5 Discussion and lessons learned

It has been recognized from the start of precursor analysis that the evaluation of operating experience can contribute to the development of PSA models as well as probabilistic methods in addition to providing important insights with regard to the safety significance of events. Based on the experience with precursor analysis of operating experience from German NPP and related international activities, several emerging issues related to PSA and precursor assessment have been derived. These were illustrated by three examples from recent practice.

In summary, the following main lessons related to probabilistic methodology have been identified.

- Precursor assessment and CCF evaluation of operating experience should regularly exchange information. PSA models should be regularly updated regarding CCF data and inclusion of newly discovered CCF mechanisms or groups.
- Precursor classification schemes should be extended to include and be sensitive to degradations and unavailabilities of the containment function. Consequently, Level 2 PSA assessments should be performed if relevant. In that regard, precursor thresholds of 1 E-06 need to be re-examined.
- Precursor assessment of events persisting for a prolonged time period with several plant configurations and of overlapping events should be performed with an explicitly time-dependent treatment. To this end, PSA models which can easily be adapted to different plant configurations are highly important. If available, risk monitor models can be used.
- Both, PSA and precursor assessments, should put more emphasis on (systematic) failures of passive safety features. While detailed assessment methods might be hard to develop, at least scoping and sensitivity analyses for potentially relevant mechanisms should be performed.

Finally, GRS experience once again underscores the importance of using full scope, current PSA models up to Level 2 PSA and including hazard scenarios for precursor analysis.

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The objective of this Safety Requirements publication is to establish requirements that support Principle 3 of the Fundamental Safety Principles, in relation to establishing, sustaining and continuously improving leadership and management for safety, and an effective management system. This is essential in order to foster and sustain a strong safety culture in an organization. Another objective is to establish requirements that apply Principle 8, which states that "All practical efforts must be made to prevent and mitigate nuclear or radiation accidents."

The requirements in this Safety Requirements publication apply to all types of facilities and activities that give rise to radiation risks. They also apply in relation to the functions and activities of the regulatory body, as far as is appropriate. Regulatory bodies and other government organizations may need to adapt the requirements in accordance with then own organizations' accountabilities.

This Safety Requirements publication applies to registrants and licensees throughout the lifetime of facilities and the duration of activities, for all operational states and for accident conditions, and in a nuclear or radiological emergency. The lifetime of a facility includes its siting and site evaluation, design, construction, commissioning, operation and decommissioning (or closure and the post-closure period, including any subsequent period of institutional control), until its release from regulatory control.

This Safety Requirements publication comprises six sections. Section 2 establishes requirements for the responsibility for safety and for protecting people and the environment against radiation risks as an overriding priority. Section 3 establishes requirements for leadership for safety. Section 4 establishes requirements for management for safety. Section 5 establishes requirements on the organization to foster and support a culture for safety. Section 6 establishes requirements for measurement, assessment and improvement.