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Development of a Reference Book on Common Cause Failures in German Nuclear Power Plants

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GRS is analysing reportable events from nuclear power plants (NPPs) in Germany for more than 40 years. This also includes the consideration of common cause failures (CCFs). For this purpose, GRS has created a database containing CCF events. Amongst others, this database has been applied to estimate CCF probabilities as input parameters for probabilistic safety analyses (PSA).
In the frame of a recent research and development project, the collected data are being used in their entirety for a generic analysis of CCF of components in German NPPs. This research activity aims at providing a comprehensive reference book with respect to CCF. For this purpose, the events recorded in the database will be sorted by different categories, such as "component affected" or "characteristic aspect". In this context, a characteristic aspect is a keyword—such as a description of the cause of the event, for example "corrosion" or "incorrect or missing specifications." Commonalities of the events will be identified and described.
This paper presents an overview of the database contents, a brief description of the planned analysis and the methodology applied as well as first results.

Keywords: common cause failure, CCF, generic analysis, nuclear power plant, operating experience, systematic fault.

1. Introduction

Common cause failures (CCFs) play a central role in the safety assessment of nuclear facilities. In such events, several components of the same type (e.g., pumps, isolation valves or emergency diesel generators) in multiple subsystems of the safety system fail simultaneously due to the same cause. Probabilistic safety analyses (PSAs) of nuclear power plants (NPPs) have shown that in many cases, particularly for plants with a high degree of redundancy in the safety system such as the German NPPs, events with CCFs dominate the risk of damage states.

With the end of commercial power generation by German NPPs, a holistic view of the accumulated German operating experience with CCFs shall be compiled. For this purpose, the collected data on CCF will be subjected to a generic analysis.

The results of the generic analysis will be compiled in a reference book. This comprehensive reference book serves as a summary of the information on CCFs in German NPPs in order to facilitate the future use of this information.

In the following, the data basis for this analysis and the procedure of the analysis are described, and preliminary results are presented.

2. Databases for the Generic Analysis

Information on observed CCF events is stored in two databases at GRS: the CCF Event Database contains the most important information on CCF phenomena, including a qualitative and quantitative assessment. The so-called CCF Check List is a systematic summary of the CCF phenomena observed. Kreuser et. al. (2010). The databases contain German operating experience up to the end of 2018. A brief description of both databases is given below.

2.1. *CCF Event Database*

Events from the operating experience of German NPPs are screened regarding their relevance for CCFs and, if appropriate, stored in the CCF Event Database. The first part of an entry is the master data of the event, such as the affected plant unit, reactor type, event date, etc. In addition, narrative data of the event are recorded, such as the affected set of components, failure mode(s), size of the CCF group, number of failed components.

The entries are subdivided into categories and classified according to their relevance for analysis on CCF. The entries are differentiated according to if there is e.g., a functional dependency that led to multiple failures of components, or the event is a common cause initiator. Further categories are CCF phenomena without loss of function of a component, CCF events affecting components or equipment that are modelled in a PSA, and other CCF events.

For entries of CCF events affecting components or equipment modelled within a PSA, a quantitative assessment is performed by multiple experts and stored in the database. In the process, the experts determine the input parameters for CCF quantification, i.e., the component impairments, independently of each other. Stiller (2011), FAK (2016).

2.2. *CCF Check List*

If a systematic cause of an event is identified, usually measures are taken to prevent a recurrence of the CCF phenomenon present. Several CCF phenomena have been observed so far from the German operating experience, against which precautions have been taken. For a systematic and holistic comprehensive summary of the observed CCF phenomena, the CCF Check List (cf. Kreuser et al. (2010)) was developed, based on a similar effort by the U.S. NRC. Wiermann et. al. (2003).

The CCF Check List is a collection of the German operating experience with CCF phenomena occurred at active components including mechanical, electrical, and I&C components. The CCF phenomena observed are systematically classified to support a review of the precautionary measures taken against the those known so far.

The entries in the CCF Check List are classified by five categories: A key distinguishing feature of the events is the component type involved. Many CCF phenomena are specific to a particular component type; this is introduced as the first category. The system affected is introduced as the second category. The third category is represented by the type of equipment affected, i.e., if the event involved mechanical, electrical, or I&C equipment. In the fourth category named “fault-triggering activity”, a high-level cause classification of the event is stored by identifying the fault introducing working process The fifth category, “characteristic aspect”, characterises the most important features and accompanying circumstances of the CCF phenomenon in a generic keyword form. Several suitable values can be assigned to an entry here to describe several aspects of the event in a generic way.

In addition, each entry in the CCF Check List contains a brief description of the observed phenomenon and the identifier of the entry in the database for reference.

3. Outline of the Generic Analysis and Development of the Reference Book

The two databases, CCF Event Database and CCF Check List, are actually subject to a joint evaluation. The findings from this analysis will be recorded in a comprehensive reference book. In this way, a quick reference tool will be created for questions regarding CCF phenomena observed in German NPPs.

All entries that have been assessed in the CCF Event Database as CCF entries as well as those that have been included in the CCF Check List are considered. At the time being, 466 entries are under consideration.

In a first step, the entries for each component type are analysed. A summary description of the events and a subsequent evaluation are generated. Commonalities between the individual CCF phenomena are to be elaborated. Currently, the databases contain events from about 50 different component types.

Furthermore, the events are to be sorted and listed according to characteristic aspects. Possible commonalities or notable features will also be high-

lighted. The characteristic aspects of CCF phenomena can be roughly subdivided into six categories: There are aspects dealing with "errors in specifications and human actions", "faults in components and other technical equipment", "errors in design and construction", "faults due to physical or chemical effects", "faults due to electrical effects" and "miscellaneous faults and errors".

All results are compiled in the reference book and made available for future use. The main part of the reference book is the analysis of the entries by component groups and the description of the underlying events. A second part will contain lists with the entries sorted according to characteristic aspects. Each list entry will reference the event descriptions in the previous part to allow a convenient overview of the underlying events.

4. First Preliminary Results

The generic analysis of the available data has been started and two examples of the preliminary evaluation will be presented in the following. First, a generic analysis of CCFs occurring at the component type "batteries" is described. In addition, a short summary of events with the characteristic aspect "incorrect or missing specifications" is presented.

2.1. *Batteries*

For the component type "batteries" there are five entries to be considered according to the scope of the analysis. Four of these entries concern batteries for direct current (DC) generation and distribution systems, one entry is for batteries from stationary fire detection systems.

In case of the batteries for DC generation and distribution systems, a failure of the required technical function occurred only in one battery. In this case, a high total chlorine content dissolved from the PVC plate separators led to corrosion of the pole plates. The resulting increase in the volume of the plates caused damage to the separators and consequently short circuits which reduced the capacity of the batteries below the minimum level required.

In one event, four batteries from the secured 48 V emergency power supply became simultaneously unavailable due to a system insulation fault.

Other phenomena that led to systematic damage were ageing phenomena that were attributed to manufacturing defects. On the one hand, this resulted in the formation of cracks in battery containers due to mechanical stress since material selection and handling were not subject to a suitable qualification system. On the other hand, manufacturing defects led to the failure of battery cells due to internal short circuits.

In the event involving batteries of the stationary fire detection systems, a voltage break-down occurred in two batteries. The cause was a manufacturing error leading to the failure of battery cells due to an internal short circuit.

4.2. *Incorrect or Missing Specifications*

For the characteristic aspect "incorrect or missing specification" , 37 entries are being considered. Most of the components affected are fire dampers (5 entries) and centrifugal pumps (5 entries).

The five entries concerning fire dampers are due to the same phenomenon. As the result of maintenance intervals exceeding common practice, the operation of fire dampers became stiff due to foreign particles, or impurities. These events occurred in 1999, no events of this type have been recorded by GRS since then because of corrective actions taken in German NPPs.

Events concerning centrifugal pumps are subdivided into 4 entries on failures due to faults in design and construction and one entry due to a maintenance fault. In those cases where the failure was due to design and manufacturing, incorrect specifications led to systematic degradations of the centrifugal pumps, resulting in the failure of at least one pump per entry. The case with faulty maintenance resulted in the failure of a pump due to off-specification clamping of impellers with their shafts. As the clearance between the wear rings and the impeller was too large, one shaft broke due to increased bending stress.

5. Summary and Outlook

In this paper, the objectives as well as the implementation of the current holistic analysis of CCFs by GRS have been briefly outlined. Preliminary results have been presented for two exemplary categories. The analysis is ongoing. In addition, the GRS databases on CCFs are currently being

updated considering the operating experience from 2019 up to the end of 2022. The additional results will also be included in the databases and final conclusions drawn.

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