The International Common Cause Failure Data Exchange (ICDE) Project – Recent Insights

Jan Stiller[a*], Hayat Chatri[b], Gunnar Johanson[c], Jeffery Wood[d]
[a]Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH, Köln, Germany
[b]Canadian Nuclear Safety Commission (CNSC), Ottawa, ONT, Canada
[c]ÅFRY, Stockholm, Sweden
[d]United States Nuclear Regulatory Commission (NRC), Washington, DC, United States of America

Abstract: Common cause failures (CCFs) can significantly impact the availability of safety systems of nuclear power plants. Since CCFs are rare events, it is necessary to combine operating experience from multiple countries to gain a comprehensive knowledge of CCF phenomena. For this reason, the International Common Cause Failure Data Exchange (ICDE) Project was initiated by several countries in 1994. Since 1997 it has been operated within the OECD/NEA framework successfully over eight consecutive phases. The ICDE Project allows countries to collaborate and to exchange CCF data with the aim of generating qualitative and quantitative insights into these failures. The ICDE Project has published eleven reports on the collection and analysis of CCF events of specific component types like centrifugal pumps, emergency diesel generators and motor operated valves, and six topical reports on different topics including multi-unit failure events and CCFs due to external environmental factors, while three additional topical reports on CCFs involving pre-initiator human failure events, CCFs with indications of safety culture deficiencies, and guidance on quantification and data interpretation are in preparation. The ICDE Project has significantly improved the knowledge on CCFs. Many insights would not have been gained without combining information from many data sources. This paper presents recent activities and their results including analyses of CCF of batteries.

Keywords: operating experience, common cause failure (CCF), probabilistic safety assessment (PSA)

1. INTRODUCTION

Common cause failures (CCFs) can significantly impact the availability of safety systems and other items important to safety of nuclear power plants (NPPs) even though CCF are rare events. Therefore, it is necessary to combine operating experience from multiple countries to gain a comprehensive knowledge of CCF phenomena. In many cases the national operating experience is insufficient for the quantification of CCF in probabilistic safety assessments (PSAs). For this reason, the International Common Cause Failure Data Exchange (ICDE) Project was initiated by several OECD Nuclear Energy Agency (NEA) member countries in 1994. Since 1997 it has been successfully operated within the OECD/NEA framework over eight consecutive phases (the current ninth phase being 2023 to 2026). The ICDE Project allows countries to collaborate and to exchange CCF data with the aim of generating qualitative and quantitative insights into these failures.

So far, the ICDE Project has published eleven reports on the collection and analysis of CCF events of specific component types (centrifugal pumps, emergency diesel generators, motor operated valves, safety and relief valves, check valves, circuit breakers, level measurement equipment, control rod drive assemblies, heat exchangers, and batteries) and six topical reports on different topics including multi-unit failure events, CCFs due to external environmental factors (e.g. freezing or clogging with foreign material), emergency diesel generator CCF events impacting the entire exposed population, CCFs due to plant modifications, improving testing as provision against CCFs, and intersystem CCF events. Three additional topical reports on CCFs involving pre-initiator human failure events, CCFs related to deficiencies in safety culture, and guidance on quantification and data interpretation are in preparation.

In this paper, the ICDE objectives and organization are described first. An overview over the technical scope of the ICDE activities is given and lessons learnt are presented, focusing on common cause failures of batteries. Then, ongoing activities are described. Finally, conclusions are drawn.

2. ICDE OBJECTIVES

The ICDE Project pursues the main aims to collect qualitative and quantitative information about CCFs in NPPs, analyse the collected data and distribute the insights gained about CCFs and methods to prevent CCFs to the concerned professional audience. The objectives of the ICDE Project as expressed in the ICDE agreement are to:

- collect and analyse Common Cause Failure (CCF) events over the long term to better understand such events, their causes, and their prevention,
- generate qualitative insights into the failure root causes and the event root causes of CCF events which can then be used to derive approaches or mechanisms for their prevention or for mitigating their consequences,
- establish a mechanism for the efficient feedback of experience gained in connection with CCF phenomena, including the development of defences against their occurrence, such as indicators for risk-based inspections,
- generate quantitative insights and record event attributes to facilitate quantification of CCF frequencies in member countries, and
- use ICDE data to estimate CCF parameters.

The ICDE Project is based upon a broad international cooperation: The countries that participate in the ICDE Project operate 202 NPP units, which is about 48% of all NPP units worldwide. With a generation capacity of 201,230 MWe these units provide 54% of the worlds' total nuclear generation capacity. Pressurized water reactors (PWRs), boiling water reactors (BWRs) and pressurized heavy-water reactors (PHWRs) are included in the data collection.

3. ICDE ORGANISATION

The ICDE Project agreement, signed by the participating member organizations, outlines the rules for operation of the ICDE Project and the roles of the participants.

The central body of the ICDE Project is the ICDE Management Board (formerly called "Steering Group") in which each participating country is represented by its National Coordinator. The Management Board controls the project, assisted by the NEA Project Secretary and the Operating Agent. The Management Board meets twice a year. The ICDE Management Board has the responsibility to:

- ensure the financial (approval of budget and accounts) and technical resources necessary to carry out the project,
- nominate the ICDE Project chairperson, to define the information flow (public information and confidentiality),
- approve the admittance of new members,
- nominate project task leaders and key persons for the Management Board tasks,
- define the priority of the task activities and to monitor the development of the project and task activities, and
- monitor the work of the Operating Agent and the project´s quality assurance and prepare the legal agreement for project operation.

In most ICDE member countries, the data exchange is carried out through the regulatory bodies, with the possibility to delegate it to other organizations. To ensure that the data collection is performed in a consistent and comparable way in all participating countries, the Management Board has developed and approved coding guidelines, which define the format and extent of the collected information. The ICDE database is available to the ICDE signatory organizations.

The project is based upon the willingness of the participants to share their operating experience, encouraging the participating organizations with the prospect of getting access to the database by providing their own contribution to the data collection. The relevant criterion is not the total amount but the completeness of the contributed data. For example, if a country submits its operating experience with emergency diesel generators (EDGs) from 1990 to 2010 it will get access to the complete operating experience with EDGs during that period, irrespective of the number of NPPs that are operated in that country and the number of events observed.

OECD/NEA appoints the Project Secretariat, which is responsible for administering the project.

The Operating Agent is responsible for the database and consistency analysis. It verifies whether the information provided by the National Coordinators complies with the ICDE coding guidelines. Jointly with the National Coordinators, it also verifies the correctness of the data included in the database. In addition, the Operating Agent operates the database.

The responsibilities of participants in terms of technical work, document control and quality assurance procedures as well as in all other matters dealing with work procedures are described in the ICDE Quality Assurance Programme [1].

The project has successfully completed eight phases of three to four years. It is currently in phase IX, which covers the period from January 2023 to December 2026. Member countries under the current phase and the organizations representing them in the project are Canada (CNSC), Czech Republic (ÚJV Řež), Finland (STUK), France (IRSN), Germany (GRS), Japan (NRA), Sweden (SSM), Switzerland (ENSI) and the United States of America (NRC). The participation of additional countries is always possible and welcome.

4. TECHNICAL SCOPE OF THE ICDE ACTIVITIES

4.1. Scope of the Data Collection

The ICDE operates with a clear separation of the collection and analysis activities. Currently, the analysis results mostly in qualitative CCF information. This information may be used for the assessment of

1. the effectiveness of defences against CCF events, and
2. the importance of CCF events in the probabilistic safety assessment (PSA) framework.

Qualitative and quantitative insights on CCF events generated are published as OECD/NEA Committee on the Safety of Nuclear Installations (CSNI) reports. The member countries are free to use the data in their quantitative and PSA related analyses.

The scope of ICDE is intended to include the key components of the safety relevant systems. Within the data collection, different types of safety related components are distinguished. Based on a generic coding guideline, for each component type an individual coding guideline is developed by the Management Board which defines how the data collection for that specific component type should be performed. These guidelines are made publicly available as a CSNI Technical Note [2].

An overview of the component types currently[1] covered is shown in Figure 1. New component types may be added in the future if there is a sufficient interest of participating parties.

The data collection concerns two distinct entities:

- Events, and
- Observed Populations.

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[1] as of April 30th, 2024

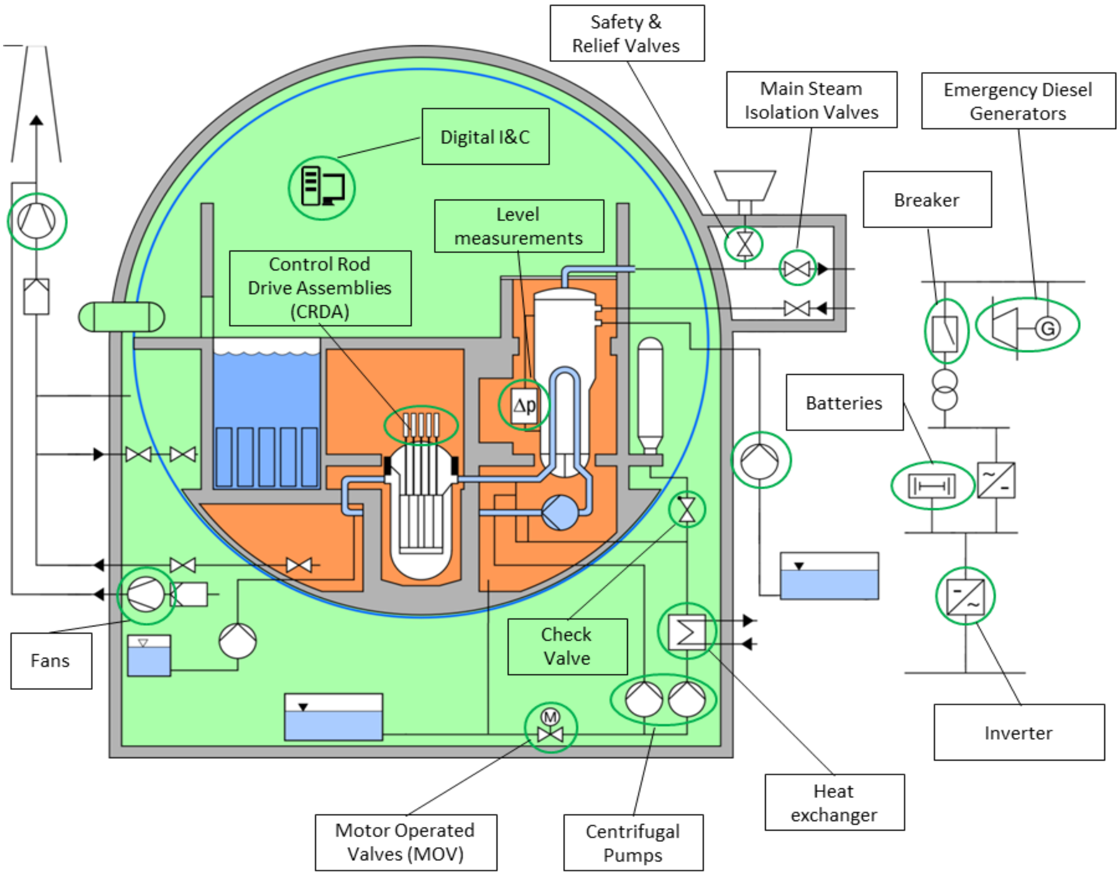

Figure 1. Technical scope of ICDE data collection

4.2. Definition of Events

The event data comprise CCF Events and other ICDE Events. In the framework of ICDE, a CCF Event is defined as “a dependent failure in which two or more component fault states exist simultaneously, or within a short time interval, and are a direct result of a shared cause.” ICDE Events are a generalization of CCFs that are commonly also denoted “potential CCFs.” In the framework of ICDE, they are defined as “impairment of two or more components (with respect to performing a specific function) that exists over a relevant time interval and is the direct result of a shared cause.” In this definition, an impairment refers to a complete failure of the component to perform its function, a degraded ability of the component to perform its function or an incipient failure of the component. A relevant time interval is defined as two pertinent inspection periods (for the particular impairment) or, if unknown, a scheduled outage period.

Information regarding the ICDE Events such as an event description, the failures and/or impairments of affected components, event causes, corrective actions etc. are included in the corresponding database records.

4.3. Definition of Observed Populations

An Observed Population is a set of similar components in the same system in the same plant that perform the same function.

Information regarding Observed Populations such as component type, size of the Observed Population, manufacturer of the equipment and a detailed description of the components, test interval and test scheme (staggered or non-staggered) and observed failure modes are included in the corresponding database records. These also include the observation times, i.e., the time interval(s) for which operating experience has been analysed. Furthermore, the number of independent component failures is included to allow for the quantification of CCF with the Alpha Factor Model.

4.4. Data Collection Overview

An overview of the database content with the number of CCF Events and the number of complete[2] and partial[3] CCFs for each component type is given in Table 1. Events are further analysed and categorized according to the ICDE failure analysis guidelines.

Table 1. Data Collection Overview

Component Type	Total CCF Event Count	Contribution to total CCFs [%]	Complete[2] CCF	Partial[3] CCF	Group Years
Centrifugal pumps	455	20.9	48	44	40 122
Diesels	386	17.8	36	21	7 245
Safety and relief valves	305	14.0	22	44	17 361
Motor operated valves	199	9.2	10	37	32 317
Control rod drive assembly	187	8.6	4	27	7 770
Level measurement	172	7.9	9	32	11 467
Check valves	124	5.7	15	26	24 836
Breakers	121	5.6	7	29	26 359
Battery	94	4.3	5	2	6 309
Heat exchanger	59	2.7	4	1	16 997
Fans	33	1.5	4	0	13 366
Main steam isolation valves	13	0.6	1	4	3 784
Digital I&C	10	0.5	5	0	59
Cross-component CCF	9	0.4	0	0	0
Inverters	6	0.3	2	0	407
Grand summaries	**2173**	**100**	**172**	**267**	**208 401**

The participating countries are gradually extending the data with more observation time and events. The frequency of observing an ICDE event in an observed population (CCF component group) is approximately 0.010/year (or 1.18 E-06/h). This low frequency by itself justifies an international collaboration on this issue.

Two new event types have been included in the ICDE Project in recent years: digital instrumentation and control (I&C) CCF Events and cross-component CCF Events. The use of digital I&C systems in operating NPPs is expected to expand in the coming years. Also, digital I&C systems are expected to be important for new and advanced reactor designs. The study of digital I&C CCF Events poses many challenges, including having only a small number of failure events that have been identified from operating experience. As the ICDE Project continues to collect digital I&C CCF Events, the members intend to focus on qualitative insights from the failures that can support developing lessons learned to assist designers, operators, and regulators in establishing the safety and reliability of these systems. The collection of cross-component CCF Events was motivated by a small number of identified events that involved subtle dependencies that contributed to failures of different component types. The collected cross-component CCF Events tend to involve electrical power systems, emergency diesel generators, or systems with cross-system piping connections. The modelling of cross-component CCFs can be expected to have a large impact on PSA results since multiple safety functions may be affected by such CCFs. This was quantitively demonstrated in a recent case study [3], [4]. Currently, the cross-component events may provide qualitative insights what cross-component CCFs should be considered in PSA studies. In the future, when more events are available, they also could be used to quantify such CCF.

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[2] Complete CCF: A common-cause failure in which all redundant components are failed simultaneously as a direct result of a shared cause.

[3] Partial CCF: A common-cause failure in which at least two components, but not all components, are completely failed.

Both digital I&C and cross-component CCF Events have unique aspects, which the ICDE Project intends to continue collecting and evaluating to develop qualitative insights.

The chronological sequence of the data collection is shown in Figure 2. The graph shows how new component types were added over time as well as the continuous data collection for the existing component types.

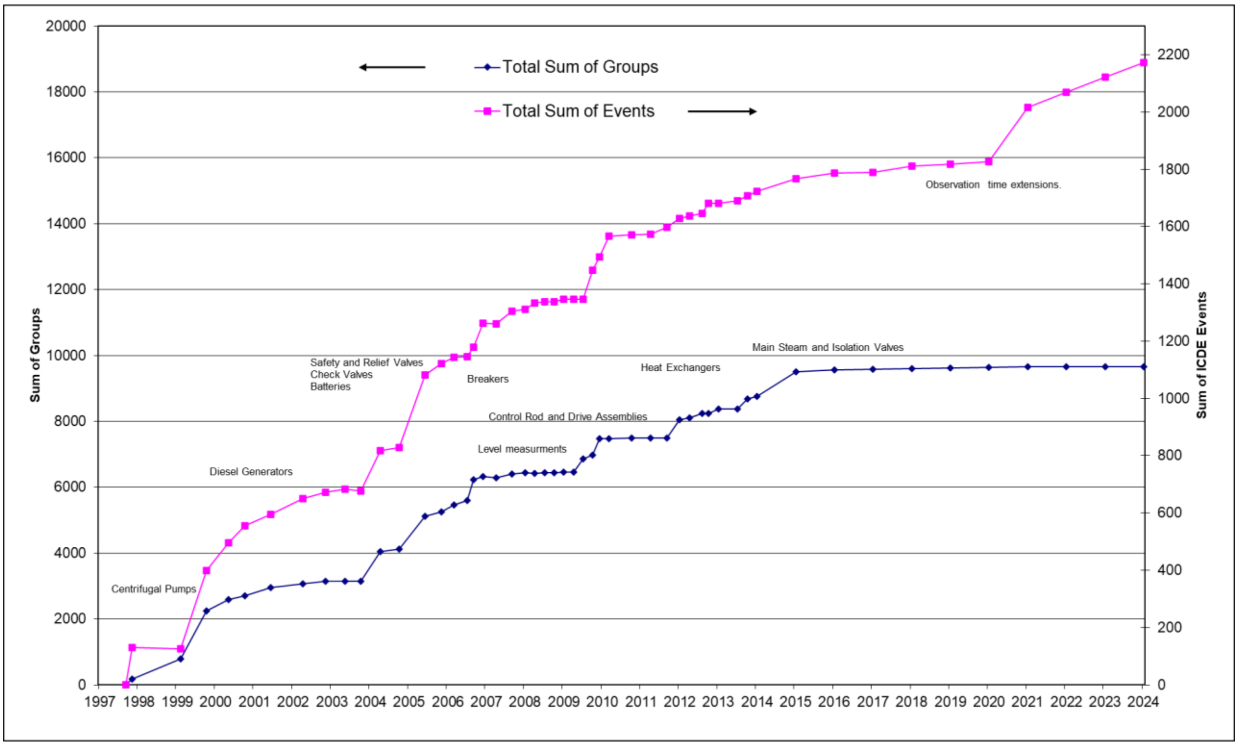

Figure 2. ICDE Data Collection Progress

In addition to plants in power operation, data is also collected for NPPs during decommissioning. In the first phases of decommissioning, several safety related components are still required, some of which are, however, operated differently than during power operation of the plant. This may include intermittent instead of continuous operation, different media or environmental temperatures, different test schedule or coverage and different monitoring. Furthermore, modifications are frequently carried out. Therefore, new CCF phenomena may occur. In the data base, data pertaining to this phase carry a special code.

5. RESULTS

The ICDE Management Board prepares publicly available reports containing insights and conclusions from the analysis performed whenever major steps (i.e., the analysis of a dataset for a certain component type like check valves) of the project have been completed. The ICDE Management Board assists the appointed lead person in reviewing the reports. Following this, an external review is provided by the CSNI. ICDE reporting also includes submitting papers to suitable international conferences such as PSAM and ANS PSA, and to journals. The intention is to make the lessons learnt available to a large nuclear safety audience.

The ICDE time schedules define the milestones of data collection tasks for each component group analysed. The time schedule is reassessed and revised at each ICDE Management Board meeting. The work starts with drafting the guidelines, getting comments, making a trial data collection, approving the guidelines, making the data exchange, resolving the remaining problem cases, and reporting.

Generally, it takes between 1.5 and 2 years from the first guideline draft to commence the data exchange itself. Furthermore, after that it takes about 2 to 4 years to publish the final report. Thereafter, new exchange rounds (database updating) are possible.

The database contains general information about event attributes like event cause, coupling factor, detection method, and corrective action taken. As of April 2024, data analysis and exchange have been performed for centrifugal pumps, diesel generators, motor-operated valves, safety relief valves, check valves, batteries, level measurements, switching devices and circuit breakers, control rod drive assemblies, heat exchangers, fans, main steam isolation valves and digital instrumentation and control (I&C) equipment.

Public reports for centrifugal pumps, diesel generators, motor-operated valves, safety & relief valves, check valves, batteries, level measurements, switching devices and circuit breakers, control rod drive assemblies, and heat exchangers have been issued in the NEA CSNI series [5] to [14], [16], [22].

In addition, topical analyses have been performed for a number of topics, including CCFs due to emergency diesel generator CCFs impacting the entire exposed population [15], CCFs due to plant modifications [17], provisions against CCFs by improving testing [18], multi-unit CCF Events [19], intersystem CCF Events [20] and pre-initiator human failure (PIHFE) ICDE Events [21].

In the following, the results of the analysis of batteries are discussed in detail. In addition, the objective, scope and status of the ongoing analyses are presented.

5.1. Common Cause Failures of Batteries

The ICDE Project has prepared an analysis of international operating experience of CCF data on batteries. A previous ICDE component study of batteries was published in 2003 and examined 50 battery CCF Events in the ICDE database [10]. The battery component study has been updated to include additional CCF Events that had been contributed to the database. The updated analysis includes 85 CCF Events that were reported during the observation time from 1980 through 2019. A final manuscript of the updated analysis, entitled “Lessons Learned from Common Cause Failures of Batteries,” has been prepared and approved for publication [22]. The report is expected to be publicly available in the near future.

The analysis includes assessment of the event cause, coupling factor, corrective action, CCF root cause, event severity, detection method and latency. Special attention is given to the most severe CCF Events, which are those events meeting the complete[2] CCF and partial[3] CCF severity categories according to the ICDE failure analysis guidelines [2]. Notable observations from the analysis of the battery CCF Events are:

- Across all events, deficiencies in the design of components or systems were the most common CCF root cause category.
- For the most severe events, deficiencies in procedures, contributing to human errors, was the most common CCF root cause category.
- Less severe CCF Events were noted to often involve low specific gravity of the battery electrolyte and are slowly developing events. Also, the events coded with high latency, i.e., more than three months before event detection, tended to be less severe events.
- As part of the event analysis, battery design errors resulting in loss of storage capacity were identified. These events were addressed by replacement with new batteries and in some cases replacement with a different battery technology.

Another notable observation is that all severe events, which account for about 8% of the total events, occurred before 1999. This may be an indication that procedure related issues have been addressed and that battery design problems have been resolved due to experience feedback. This observation prompted the authors to look at the trends in CCF event occurrences over time. Table 2 shows the ICDE event rate for the battery CCF Events at different time periods. The ICDE event rate is the ratio of the number of ICDE Events in the database to the observation time, which is measured for each observed component group for the observation period. The early observation periods prior to 1985 may not be accurate due to little or no data collected for those years. The ICDE Event rate for batteries peaked in the 1990s and had a drastic decrease after the year 2000. These changes are statistically significant – the credible intervals[4] of the event rates of, e.g., 1995 – 1999 and 2010 – 2014 do not overlap. This example demonstrates that CCF rates may vary significantly in time, which has been observed for many component types. Therefore, in PSA calculations CCF probabilities and rates estimated from recent operation experience should be used in order to allow for a realistic quantification and avoid overly conservative results. An additional study of the event trends for batteries and other components will be conducted as the ICDE project continues to expand the data collection.

Table 2. ICDE Event Rate for Batteries for 5-Year Observation Periods

5-year Period	**Observation Time [years]**	**Number of ICDE Events**	**Observed ICDE Event Rate [1/(100 years)]**	**95% Credible Interval[4] of Event Rate [1/(100 years)]**
1975 - 1979	0	0	n/a	n/a
1980 - 1984	43	0	0.00	[0.00, 4.47]
1985 - 1989	213	2	0.94	[0.20, 3.01]
1990 - 1994	1738	25	1.44	[0.95, 2.09]
1995 - 1999	1779	50	2.81	[2.11, 3.67]
2000 - 2004	943	2	0.21	[0.04, 0.68]
2005 - 2009	707	4	0.57	[0.19, 1.35]
2010 - 2014	424	2	0.47	[0.10, 1.51]
2015 - 2019	212	0	0.00	[0.00, 0.91]
Total	**6059**	**85**	**1.41**	n/a

The qualitative analysis of CCF Events of batteries is mainly intended for designers, operators and regulators to provide insights of the type of failure mechanisms and causes of the battery events in the ICDE database. The insights can give valuable experience to support and improve the understanding of failure mechanisms and phenomena involved in the events, their relationship to the CCF root cause and provide with possibilities for improvement within multiple areas.

5.2. Ongoing Analyses

5.1.1 Safety Culture

The analysis and review of CCF data from the ICDE Project has identified several severe events with an evidence of safety culture deficiencies as the main event cause. Hence, this topic has been analysed in more detail. Up to now, three data analysis workshops have been carried out. In the framework of this analysis, safety culture is understood in a broad sense, i.e. it includes all formal aspects like a safety management system or integrated management system and non-formal aspects like the safety attitude of employees or compliance to rules.

To classify the events, a coding scheme has been developed. It is based on the IAEA working document “A Harmonized Safety Culture Model” [23]. During the first workshop, several aspects were identified which needed to be added. Between events, the quality and detailedness of information about safety culture aspects varies considerably. Therefore, a method to state the analyst’s degree of certainty in the event analysis was developed. It includes four tiers:

- **Explicitly stated:** Explicitly stated in the event description and supported by the event coding.
- **High:** Indirectly deducible from event description and coding. Not explicitly stated, but the expert is sure from the information in the description and coding that the attribute must have been present. It is not reasonably conceivable how this event could have happened as described (and coded) if the attribute was not present.

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[4] The credible interval was calculated as interval from the 2.5% to the 97.5%-quantile of the posterior distribution of the true event rate using Jeffreys‘ noninformative prior. If no events were observed the interval from 0 to the 95%-quantile was used since the posterior distribution of the true event rate in that case peaks at 0.

- **Medium:** Very likely, given information in description and coding. The expert rates the presence of the attribute as very likely, given her/his experience and prior knowledge, but another cause cannot be entirely excluded.
- **Low:** The presence of the attribute is somewhat supported by the event coding and/or description.

Aspects regarding the (formal) management system were also added to the coding scheme. They were derived mainly from IAEA GSR Part 2 “Leadership and Management for Safety” [24] and comprise the following aspects:

- Integration of the management system,
- Documentation of the management system,
- Effectiveness of the management system,
- Measurement, assessment, and improvement of the management system, and
- Management of the supply chain.

Additional aspects like “implementation, supervision, and continual improvement of the management system by senior management” and “effectiveness of communication” were also added. Furthermore, abstract aspects like general deficits in safety culture were also supplemented to the coding scheme. These codes are used when deficits in safety culture are evident while specific information on the deficiencies is absent.

This coding scheme has proven to be suitable in application. Up to now, 142 events have been coded. Currently, the analysis of the data is ongoing. Preliminary results include the finding that a lack of adherence to procedures is strongly correlated with deficient work management and inadequate documentation.

5.1.2 Quantification

This ongoing effort, which commenced in phase VIII, aims at researching the use of ICDE data for quantification, i.e. for the estimation of CCF parameters for PSA calculations. As described above, the ICDE database contains all necessary information for the quantification of CCF, namely observation times and the number of failed and impaired components in the events observed. Furthermore, it also contains the number of independent failures, which is needed for the application of the Alpha Factor Model. Since every participant is required to submit a formal completeness statement, this data may be expected to be complete and accurate.

To adequately use the provided operation experience data for the quantification of CCF probabilities or rates, however, several different aspects need to be considered. These include e.g. the definition of component boundaries. For ICDE data, the component boundaries, i.e. the set of sub-components or piece parts that are considered to form the component, are defined in the coding guide. It must be verified that they match the definition for the PSA study the parameters are used for. If not, differences must be accounted for. E.g., ICDE Events with failures of equipment outside the component boundary as defined in the PSA study have to be disregarded.

The ICDE data can also be inhomogeneous. This may arise e.g. from different technical characteristics, operation, testing and maintenance of the equipment. While a possible inhomogeneity is a generic issue that always has to be considered when data from different components, systems and plants are combined, it can be expected to be more pronounced if data from different counties are included, since different counties have different technical standards and regulations. In addition, ICDE events are based on licensee reportable events (LERs). The reporting criteria in different countries are not identical. While actual CCF events with multiple component failures may be expected to be included in any case, the reporting of events with only (incipient) impairments and no actual failures may differ. The uncertainty associated with a possible inhomogeneity of the data needs to be adequately considered in quantification.

These and other issues are researched in detail by e.g. statistical analyses and exemplary quantifications of CCF probabilities and rates, applying different CCF quantification approaches and models. Based on the results, a guideline including a generic quantification procedure for ICDE data will be developed.

6. CONCLUSIONS

The ICDE Project has significantly changed the view on common cause failures. For instance, the determination of the fact that the most common cause of complete CCFs is human action as a part of operation or design, rather than manufacturing deficiencies, would not have been possible without deep plant data collection and combining of information from many sources.

This conclusion was confirmed, e.g., by a recent analysis of CCFs of batteries. Here, the most severe events were most commonly caused by deficiencies in procedures, contributing to human errors. The analysis of batteries also showed a significant time-dependence of event rates, which peaked in the 1990s and had a drastic decrease after the year 2000. This highlights that in PSA calculations CCF probabilities and rates estimated from recent operation experience should be used.

Maybe the most important generic lesson is that it is worth forming specialized data exchange projects like ICDE. This, however, requires first the will of several countries to form a critical mass by combining their operating experience efforts; second, it requires national efforts to collect lower level data than those made publicly available as LERs or reports of the Incident Reporting Systems for Nuclear Installations of the IAEA (IRS); third, it requires the forming of a legal framework to protect this proprietary data and, fourth, a long term commitment to consistently continue and develop the activity.

Currently, ICDE focusses on two topics: The first focus is the analysis of events caused by deficiencies in safety culture. Preliminary results include the finding that a lack of adherence to procedures is strongly correlated with deficient work management and inadequate documentation. The second focus is the research of the use of ICDE data for quantification, i.e. for the estimation of CCF parameters for PSA calculations. Based on the results, a guideline including a generic quantification procedure for ICDE data will be developed.

OECD/NEA and the Operating Agent, ÅF industry, have provided the means to run the international dimension of the ICDE. National efforts, however, are the key to the success of any project that relies on operating experience. The success of the ICDE resulted in further OECD/NEA Database projects including the Fire Events Records Exchange (FIRE) and the Component Operational Experience, Degradation and Ageing Programme (CODAP).

More information about ICDE may be obtained by visiting the NEA report site (https://www.oecd-nea.org/jcms/pl_25090/international-common-cause-failure-data-exchange-icde-project) and on the Operating Agent[5] website (https://projectportal.afconsult.com/ProjectPortal/icde).

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