**Nuclear Safety**
**NEA/CSNI/R(2023)9**
June 2025
www.oecd-nea.org

# ICDE Project Report: Summary of Phase VIII of the International Common-Cause Failure Data Exchange Project

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NEA/CSNI/R(2023)9

Unclassified English text only

17 June 2025

NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

# ICDE Project Report: Summary of Phase VIII of the International Common-Cause Failure Data Exchange Project

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JT03568260

## ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of 38 democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

The OECD member countries are: Australia, Austria, Belgium, Canada, Chile, Colombia, Costa Rica, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Türkiye, the United Kingdom and the United States. The European Commission takes part in the work of the OECD.

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## NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1 February 1958. Current NEA membership consists of 34 countries: Argentina, Australia, Austria, Belgium, Bulgaria, Canada, Czechia, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, Romania, Russia (suspended), the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Türkiye, the United Kingdom and the United States. The European Commission and the International Atomic Energy Agency also take part in the work of the Agency.

The mission of the NEA is:

- to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes;
- to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management and decommissioning, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

# *Committee on the Safety of Nuclear Installations (CSNI)*

The Committee on the Safety of Nuclear Installations (CSNI) addresses NEA programmes and activities that support maintaining and advancing the scientific and technical knowledge base of the safety of nuclear installations.

The Committee constitutes a forum for the exchange of technical information and for collaboration between organisations, which can contribute to its activities from their respective backgrounds in research, development, and engineering. It has regard to the exchange of information between member countries and safety R&D programmes of various sizes to keep all member countries involved in and abreast of developments in technical safety matters.

The Committee reviews the state of knowledge on important topics of nuclear safety science and techniques and of safety assessments and ensures that operating experience is appropriately accounted for in its activities. It initiates and conducts programmes identified by these reviews and assessments to confirm safety, overcome discrepancies, develop improvements, and reach consensus on technical issues of common interest. It promotes the co-ordination of work in different member countries that serve to maintain and enhance competence in nuclear safety matters, including the establishment of joint undertakings (e.g. joint research and data projects), and assists in the feedback of the results to participating organisations. The Committee ensures that valuable end-products of the technical reviews and analyses are provided to members in a timely manner, and made publicly available when appropriate, to support broader nuclear safety.

The Committee focuses primarily on the safety aspects of existing power reactors, other nuclear installations, and new power reactors. It considers the safety implications of scientific and technical developments of future reactor technologies and designs as well as human and organisational research activities and technical developments that affect nuclear safety.

# *Foreword*

Common cause failure (CCF) events can significantly impact the availability of the safety systems of nuclear power plants. For this reason, several countries initiated the International Common-Cause Failure Data Exchange (ICDE) Project in 1994. In 1997, the Nuclear Energy Agency (NEA) Committee on the Safety of Nuclear Installations (CSNI) formally approved this project to be carried out within the NEA framework. Since then, the project has operated over eight consecutive terms. Phase 9 started in January 2023 and will end in December 2026.

The purpose of the ICDE Project is to allow multiple countries to collaborate and exchange common cause failure (CCF) data to enhance the quality of risk analyses that include CCF modelling. Because CCF events are typically rare, most countries do not experience enough CCF events to perform meaningful analyses. Data combined from several countries, however, yield sufficient material for more rigorous analyses.

The objectives of the ICDE Project are to:

- collect and analyse common cause failure (CCF) events over the long term so as to better understand such events, their causes and their prevention;
- generate qualitative insights into the root causes of CCF events that 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 the ICDE data to estimate CCF parameters.

The qualitative insights gained from the analysis of CCF events are made available in reports that are made publicly available. It is not the aim of these reports to provide direct access to the CCF raw data recorded in the ICDE database. The confidentiality of the data is a prerequisite of operating the project. The ICDE database is accessible only to those members of the ICDE Project Working Group who have contributed data to the databank.

Database requirements are specified by the members of the ICDE Project working group and are fixed in guidelines. Each member with access to the ICDE database is free to use the collected data. It is assumed that the data will be used by the members in the context of PSA/PRA reviews and application.

The ICDE Project has produced the following reports, which can be accessed through the NEA website:

- NEA (1999), *ICDE Project Report: Collection and Analysis of Common-Cause Failure of Centrifugal Pumps*, NEA/CSNI/R(99)2, OECD Publishing, Paris, www.oecd-nea.org/jcms/pl_16434.
- NEA (2000), *ICDE Project Report: Collection and Analysis of Common-Cause Failures of Emergency Diesel Generators*, NEA/CSNI/R(2000)20, OECD Publishing, Paris, www.oecd-nea.org/jcms/pl_17470.

- NEA (2001), *ICDE Project Report: Collection and Analysis of Common-Cause Failure of Motor-Operated Valves*, NEA/CSNI/R(2001)10, OECD Publishing, Paris, www.oecd-nea.org/jcms/pl_17516.
- NEA (2002), *ICDE Project Report: Collection and Analysis of Common-Cause Failure of Safety Valves and Relief Valves*, NEA/CSNI/R(2002)19, OECD Publishing, Paris, www.oecd-nea.org/jcms/pl_17748.
- NEA(2002), *Proceedings of ICDE Workshop on the Qualitative and Quantitative Use of ICDE Data*, NEA/CSNI/R(2001)8, OECD Publishing, Paris, www.oecd-nea.org/jcms/pl_17508.
- NEA(2003), *ICDE Project Report: Collection and Analysis of Common-Cause Failure of Check Valves*, NEA/CSNI/R(2003)15, OECD Publishing, Paris, www.oecd-nea.org/jcms/pl_17948.
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- NEA (2015), *Workshop on Collection and Analysis of Common-Cause Failures due to External Factors: International Common-Cause Failure Data Exchange (ICDE) Project Report*, NEA/CSNI/R(2015)17, OECD Publishing, Paris, www.oecd-nea.org/jcms/pl_19670.
- NEA (2017), *Workshop on the Collection and Analysis of Emergency Diesel Generator Common-Cause Failures Impacting Entire Exposed Populations: International Common-Cause Failure Data Exchange (ICDE) Project Report*, NEA/CSNI/R(2017)8, OECD Publishing, Paris, www.oecd-nea.org/jcms/pl_19784.
- NEA (2018), *Lessons Learnt from Common-Cause Failure of Emergency Diesel Generators in Nuclear Power Plants: A Report from the International Common-Cause Failure Data Exchange (ICDE) Project*, NEA/CSNI/R(2018)5, OECD Publishing, Paris, www.oecd-nea.org/jcms/pl_19852.

- NEA (2019), *ICDE Project Report: Summary Phase VII of the International Common-cause Exchange Project of Nuclear Power Plant Events*, NEA/CSNI/R(2019)3, OECD Publishing, Paris, www.oecd-nea.org/jcms/pl_36527.
- NEA (2019), *ICDE Topical Report: Collection and Analysis of Common-Cause Failures due to Plant Modifications*, NEA/CSNI/R(2019)4, OECD Publishing, Paris, www.oecd-nea.org/jcms/pl_36527.
- NEA (2022), *ICDE Topical Report: Provision Against Common-cause Failures by Improving Testing*, NEA/CSNI/R(2019)5, OECD Publishing, Paris, www.oecd-nea.org/jcms/pl_75196.
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- NEA (2024), *ICDE Project Report: Common-Cause Failures of Safety and Relief Valves*, NEA/CSNI/R(2020)17, OECD Publishing, Paris, www.oecd-nea.org/jcms/pl_91728.
- NEA (2023), *ICDE Topical Report: Operational Experience on Common-Cause Failures due to External Environmental Factors*, NEA/CSNI/R(2020)16, OECD Publishing, Paris, www.oecd-nea.org/jcms/pl_82225.
- NEA (forthcoming), *ICDE Project Report: Lessons Learnt from Common-Cause Failures of Motor-Operated Valves*, NEA/CSNI/R(2021)7, OECD Publishing, Paris, www.oecd-nea.org/jcms/pl_103274.
- NEA (forthcoming), *ICDE Topical Report: Collection and Analysis of Common-Cause Pre-Initiator Human Failure Events*, NEA/CSNI/R(2022)1, OECD Publishing, Paris.

This report was approved by the CSNI at its 72nd meeting on 1-2 December 2022.

# *List of abbreviations and acronyms*

| | |
|---|---|
| AFWS | Auxiliary feed water system |
| ASIC | Application-specific integrated circuits |
| BWR | Boiling water reactors |
| CCCG | Common cause component groups |
| CCF | Common cause failure |
| CCW | Component cooling system |
| CODAP | Component Operational Experience, Degradation and Ageing Programme |
| CP | Centrifugal pump |
| CRDA | Control rod and drive assembly |
| CSNI | Committee on the Safety of Nuclear Installations (NEA) |
| CV | Check valve |
| CVCS | Chemical and volume control system |
| DC | Direct current |
| ECCS | Emergency core cooling system |
| EDG | Emergency diesel generator |
| ESFAS | Engineered safety feature actuation system |
| FIRE | Fire Incidents Records Exchange |
| FPGA | Field programmable gate arrays |
| HFE | Human failure event |
| HRA | Human reliability analysis |
| I&C | Instrumentation and control |
| ICDE | International Common Cause Failure Data Exchange |
| IRS | International reporting system for operating experience |
| LOSP | Loss of off-site power |
| MOV | Motor-operated valve |
| MP | Motor pump |
| MSIV | Main steam isolation valves |
| MUPSA | Multi-unit probabilistic safety assessment |
| NEA | Nuclear Energy Agency |
| OA | Operating agent |
| OECD | Organisation for Economic Co-operation and Development |
| OP | Observed population |

| | |
|---|---|
| PHWR | Pressurised heavy-water reactor |
| PRA | Probabilistic risk assessment |
| PSA | Probabilistic safety analysis |
| PSF | Performance shaping factor |
| QA | Quality assurance |
| RPS | Reactor protection system |
| RTB | Reactor trip breakers |
| RTS | Reactor trip system |
| SG | Steering group |
| SRV | Safety and relief valve |
| UPS | Uninterruptible power supply/source |
| WGOE | Working Group on Operating Experience (NEA) |

# *Organisations*

| | |
|---|---|
| ANVS | Autoriteit Nucleaire Veiligheid en Stralingsbescherming (Authority for Nuclear Safety and Radiation Protection, Netherlands) |
| CNSC | Canadian Nuclear Safety Commission (Canada) |
| CSN | Consejo de Seguridad Nuclear (Spanish Nuclear Safety Council) |
| ENSI | Eidgenössisches Nuklearsicherheitsinspektorat (Federal Nuclear Safety Inspectorate, Switzerland) |
| GRS | Gesellschaft für Anlagen- und Reaktorsicherheit (Germany) |
| IRSN | Institut de Radioprotection et de Sûreté Nucléaire (Institute of radiological protection and nuclear safety, now ASNR, Autorité de sûreté nucléaire et de radioprotection, France) |
| KAERI | Korea Atomic Energy Research Institute |
| NRA | Nuclear Regulatory Authority (Japan) |
| NRC | Nuclear Regulatory Commission (United States) |
| SSM | Swedish Radiation Safety Authority (Sweden) |
| STUK | Finnish Centre for Radiation and Nuclear Safety (Finland) |
| UJV | Nuclear Research Institute (Czechia) |

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# *Executive summary*

While common cause failure (CCF) events can significantly affect the safety systems of nuclear power plants, they are typically rare, meaning that most countries do not experience enough CCF events to perform comprehensive analyses. The International Common Cause Failure Data Exchange (ICDE) Project was initiated in 1994 to allow countries to collaborate and exchange CCF data to enhance the quality of risk analyses, which include CCF modelling. The project has operated over eight consecutive terms. This summary report presents recent activities and lessons learnt from the data collection and the results of topical analyses of the ICDE Project after phase VIII (2019-2022).

During this phase, the component reports for motor-operated valves (NEA, 2025), safety and relief valves (NEA, 2024) and batteries (NEA, forthcoming a) were updated. Also, topical analyses were performed for the following topics: external environmental factors (NEA, 2015), severe emergency diesel generator events (NEA, 2017), plant modifications (NEA, 2020), improving testing (NEA, 2022a), multi-unit events (NEA, 2022b), intersystem dependencies (NEA, 2022c) and pre-initiator human failure events (NEA, forthcoming b). Lastly, an example of the use of ICDE data to quantify CCF in probabilistic safety assessment (PSA) models is under development.

The most important lessons learnt from the studies in this phase are summarised below:

- The components most susceptible to **failures due to external factors** are centrifugal pumps, followed by emergency diesel generators and heat exchangers. The results of this analysis may serve as input for an in-depth review of the methods and assumptions used in external hazards probabilistic risk assessments (PRA).
- To prevent CCF **events due to modifications**, a stringent, comprehensive planning of the intended modifications should be performed, including the assessment of possible interactions on system-level. Modifications to instrumentation and control (I&C) systems and protection devices deserve special care.
- The largest category in the **analysis of severe emergency diesel generator events** was “maintenance or testing of component”. A common error is improper re-installation or re-assembly after testing/maintenance.
- Verification of **operability after tests**, maintenance activities and modifications is essential, especially after maintenance to prevent latent failures and the occurrence of CCF. Using feedback from other units and previous similar events can help detect latent failures in time.
- The most common CCF root cause (nearly 60%) for **multi-unit** CCF events was deficiency in the design of components and systems. Hence, design is significantly overrepresented in this group. Emergency diesel generators and centrifugal pumps accounted for more than 50% of the events.
- Procedure deficiency was the dominant CCF root cause for the more severe **intersystem events.** Intersystem CCFs are rare, yet their risk significance means that they should be considered in a PRA, while also considering their rarity and credit defences that could prevent or mitigate them.
- Deficiency in procedures was the main CCF root cause for **pre-initiator human failure event (HFE) CCFs**. Faulty procedures may be prevented by factors such as personnel training, safety culture and plant management. The events from the ICDE database provide dependencies that are not typically modelled in a human reliability analysis (HRA).

In conclusion, it can be said that the ICDE Project has fulfilled its objectives for phase VIII. The ICDE Project has generated useful insights related to CCFs. For instance, the insight that the most common cause of complete CCFs seems to be human action or design, rather than manufacturing deficiencies, would not have been possible without collecting deep plant data and combining information from many sources.

# 1. Introduction

The safety systems of nuclear power plants can be impacted significantly by common cause failure (CCF) events. In recognition of this, CCF data are systematically being collected and analysed in several countries. Due to the low probability of occurrence of such events, it is not possible to derive a comprehensive evaluation of all relevant CCF phenomena only from the operating experience from one country. Therefore, it is necessary to make use of the international operating experience of other countries using similar technology.

The use of nuclear power plants' operating experience of CCFs around the world requires a common understanding what CCFs are and how to collect data about them. To develop such a common understanding, an international common cause failure working group was founded in 1994. This working group has elaborated the International Common-Cause Failure Data Exchange (ICDE) Project.

The ICDE Project collects qualitative and quantitative information about CCFs in nuclear power plants, analyses the collected data and distributes the insights gained about CCFs and methods to prevent CCFs in the form of reports to a concerned professional audience. More specifically, the objectives of the ICDE Project as expressed in its Agreement are to:

- provide a framework for multinational co-operation;
- collect and analyse CCF events over the long term to better understand such events, their causes and their prevention;
- generate qualitative insight into the root causes of CCF events that can then be used to derive approaches or mechanisms for their prevention or for mitigation of their consequences;
- establish a mechanism for the efficient gathering of feedback on 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 the ICDE data to estimate CCF parameters.

## 1.1. ICDE organisation

The ICDE Project is based upon broad international co-operation. The central body of the ICDE Project is the ICDE steering group (SG) in which each participating country is represented by its national co-ordinator. The SG controls the project, assisted by the NEA project secretary and the operating agent (OA). The OA is responsible for the database and consistency analysis. The NEA Secretariat is responsible for administering the project. The SG meets twice a year on average.

The ICDE steering group has the responsibility to:

- secure the financial (approval of budget and accounts) and technical resources necessary to carry out the project;
- nominate the ICDE Project chairman, to define the information flow (public information and confidentiality);
- approve the admittance of new members;
- nominate project task leaders (lead countries) and key persons for the SG tasks;

- define the priority of the task activities and monitor the development of the project and task activities;
- monitor the work of the OA and the projects' quality assurance and prepare the legal agreement for project operation.

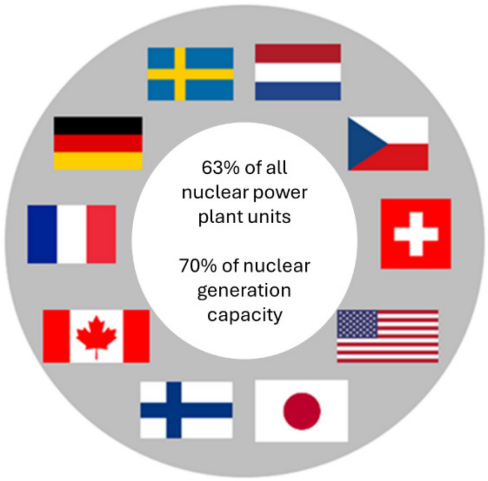
In most countries, the data exchange is carried out through the regulatory bodies, with the possibility to delegate it to other organisations. To ensure that the data collection is performed in a consistent and comparable way in all participating countries, the SG has developed and approved "coding guides"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

The project is based upon the willingness of the participants to share their operating experience. To encourage this, the participating organisations have access to the database in accordance with their own contribution to the data collection. The relevant criterion is not the total amount but the completeness of the contributed data. For example, when a country submits its operating experience with emergency diesel generators (EDG) from 1990-2010 it will get access to the complete operating experience with EDGs for that period, irrespective of the number of nuclear power plants that are operated in that country.

Member countries under the Phase VIII Agreement of the NEA and the organisations representing them in the project are Canada (CNSC), Czechia (UJV), Finland (STUK), France (IRSN), Germany (GRS), Japan (NRA), Netherlands (ANVS), Sweden (SSM), Switzerland (ENSI) and the United States (NRC). The previous phase had included Korea (KAERI) and Spain (CSN). The participation of other NEA member countries is always possible and welcome.

The countries that participate in the ICDE Project operate 282 nuclear power plant units, which is about 63% of all nuclear power plant units worldwide (see Figure 1.1). With a generation capacity of 275 864 megawatts, these 282 units provide more than 70% of the world's total nuclear generation capacity. The 282 units comprise 191 pressurised water reactors (PWR), 68 boiling water reactors (BWR) and 23 pressurised heavy-water reactors (PHWR) so the majority of nuclear power plant types is covered.

**Figure 1.1. International co-operation and operating experience**



The SG has established a comprehensive quality assurance programme. 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* (internal Project report ICDEPR05).

## 1.2. Project schedule and resources

Milestones and planning:

The legal agreements are made between the signatories for three-year periods. For this period, a generic project plan is written, with a more detailed plan presented for every year. The ICDE time schedule defines the milestones of generic data collection tasks. The time schedule is reassessed and revised at each ICDE steering group meeting. The steering group develops plans. The project status is evaluated at each meeting and decisions on how to proceed are made.

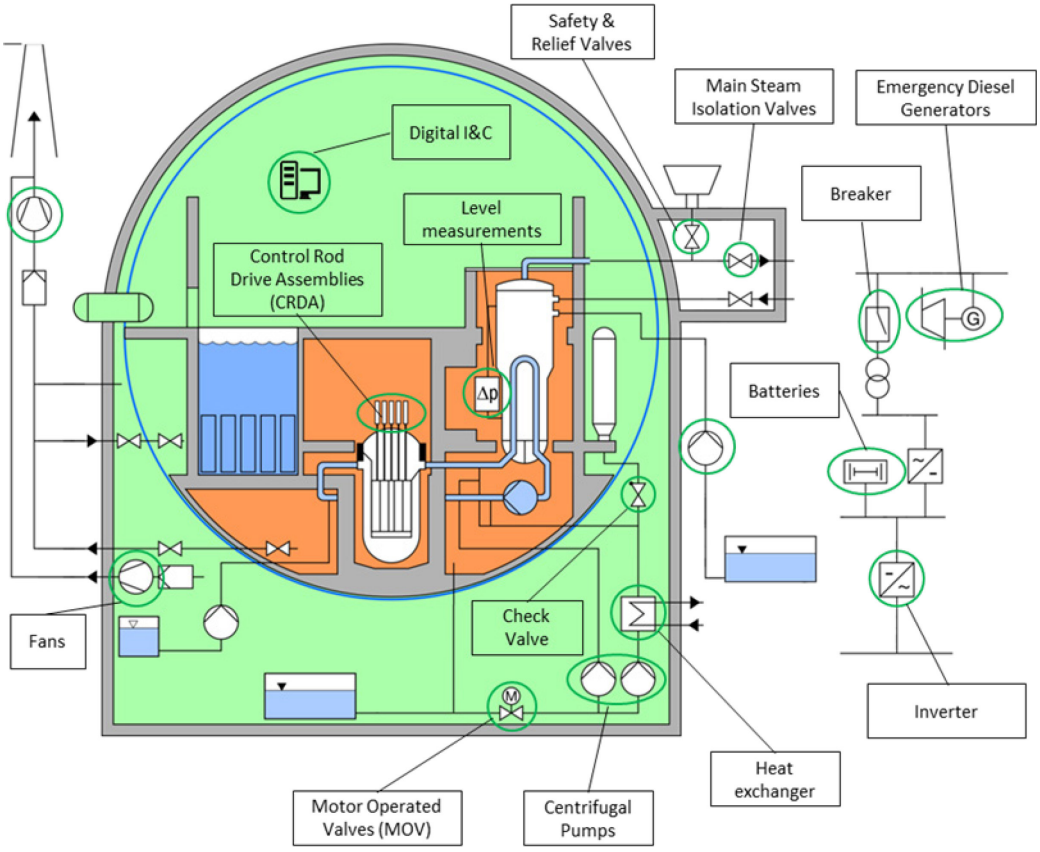
Financial resources:

The NEA, together with the OA, prepares a general budget frame for the three-year period and specific yearly budgets. All these are subject to SG approval. The NEA makes contracts with the OA for a period of one year unless decided otherwise. Participating countries make contributions to an NEA special project account for reimbursement of the costs of the ICDE Project OA and the NEA secretariat. In addition, each participant shall carry all other costs associated with participation in the project.

# 2. Technical scope of ICDE activities

The scope of ICDE activities is intended to include the key components of the safety relevant systems. Within the data collection, different types of safety relevant components are distinguished. For each component type an individual "coding guide" is developed by the steering group that defines how the data collection for that specific component type should be performed (see Section 3.3 for details). An overview of the currently covered component types is shown in Figure 2.1. New component types are added if a participating country is interested.

**Figure 2.1. Technical scope of ICDE activities**




## 2.1. Component types

The component types that are covered by the ICDE Project are described below.

Centrifugal pumps (CP)

This family of pumps is comprised of those centrifugal pumps (CP) that are motor driven and are used for the purpose of establishing flow to or from the primary system, the secondary system, or support systems. This includes, among others, the auxiliary/emergency feedwater, high- and low-pressure safety injection, residual heat removal, essential service water, and essential raw cooling water system.

For data evaluation purposes, the family of centrifugal pumps is subdivided into six subgroups characterised by pump delivery head and mass flow rate.

Motor-operated valves (MOV)

This family of valves is comprised of those emergency core cooling system (ECCS) valves that are motor operated and are used for the purpose of establishing or isolating flow to or from the primary system, the secondary system or support systems. This includes, among others, the auxiliary/emergency feedwater, high- and low-pressure safety injection, residual heat removal, essential service water, and essential raw cooling water system.

Emergency diesel generators (EDG)

Emergency diesel generators (EDG) are part of the electrical power distribution system providing emergency power in the event of loss of offsite power (LOSP) to electrical buses that supply the safety systems of the reactor plant.

Safety and relief valves (SRV)

The function of the safety and relief valves (SRV) is to prevent overpressure of the components and system piping. The system's respective components for which SRVs are installed and data are collected are the steam generators' discharge headers, the pressuriser vapour volume, and the reactor coolant system (main steam headers)

Check valves (CV)

Check valves are used to establish or isolate flow to or from the fluid system. They are comprised of a valve and its internal piece part components. The function of the check valve is to form a conditional boundary (i.e. one direction) between the high-pressure and low-pressure sections of a system during static conditions. By design, the valve will open to allow flow when the low-pressure section has experienced a pressure increase (e.g. pump start). This component is operated by system pressure overcoming gravity. Typically, there is no capability to manually open, close or isolate these valves; however, some check valves have manual hand wheels or levers (stop-check) and can be manually closed. Some check valves are "air-testable", which should not affect normal component operation, and in some cases the air supply is turned off during operation as a precaution. Typically, no power is required for valve operation. Check valves are mainly installed in systems in the following areas: Pump discharge, pump suction, system inter- or cross-connection, and pump turbine steam inlet.

Batteries (BA)

The family of batteries is comprised of those batteries that provide DC emergency power in the event of a LOSP to DC buses that supply the safety systems of the reactor plant. The voltage to be supplied typically ranges from 24 to 500 V DC.

Level measurement (LM)

The function of the "level measurement" component is to monitor the level in safety relevant vessels, tanks and piping. The output signal of the component triggers protection signals in subsequent reactor protection logic systems if the level is too high or too low. In ICDE data collection, only those level measurement components are considered which are part of the reactor protection system or part of the engineered safety feature actuation system. Level measurement components that are only used for operational needs (e.g. level control) are not considered.

Switching devices and circuit breakers (BR)

The switching devices and circuit breakers of interest are those that belong to (low/medium voltage) electrical distribution systems (busbar/MCC feeder and load breaker) and reactor trip breakers.

Diesel generator (EDG), motor-operated valve (MOV), and motor pump (MP) breakers are included within their equipment boundaries.

The reactor trip breakers (RTBs) are part of the reactor protection system (RPS) of PWRs and CANDUs, and supply power to the control rod drive mechanisms. Both AC and DC breakers are used for the RTBs. On a reactor trip signal, the breakers will open, removing power from the control rod drive mechanisms. The control rods will then unlatch and drop into the reactor core due to gravity.

Control rod and drive assembly (CRDA)

The purpose of the control rod and drive assembly (CRDA) is to control reactivity when the reactor is in normal operating conditions and during rapid transients, and to provide sufficient additional negative reactivity for emergency operating conditions. The consequences of a failure of the CRDA system depend on the initiator, the plant state before scram, and the necessary effectiveness of the control rod population, which is expressed by the minimal number of control rod clusters required at the position in the core cross section where the control rod clusters failed to insert.

Heat exchanger (HX)

A heat exchanger is a device built for efficient heat transfer from one fluid to another, where the fluids are separated by a solid wall so that they never mix. Heat exchangers are widely used in refrigeration, air conditioning, space heating and power production.

Data are collected for all heat exchangers in safety relevant systems, particularly the heat removal chain (residual heat removal system -> component cooling system -> essential service water).

Fans

The general function of a fan is to ensure the circulation and distribution of air for buildings and rooms (e.g. emergency diesel generator rooms, electrical rooms and electronic equipment rooms). The component operation settings are “running/alternating” or “standby”.

Fan data are being collected for the inlet air, extracted air and recirculating air systems of the safety-significant buildings. Fans that are within the boundaries of other components (such as motors, pumps or diesels) are not part of the data collection.

Main steam isolation valves (MSIV)

Main steam isolation valves (MSIV) are fast-closing, impulse-operated valves. The purpose of main steam isolation valves is to isolate the containment or the steam flow to the turbine unit and interfacing auxiliary systems (depending on the plant design). Some plants use separate sets of fast-closing, impulse-operated steam isolation valves with safety relevant functions in the main steam or in the auxiliary steam system for isolation of, for example, auxiliary steam, main steam relief valves or main steam safety valves. These valves are also covered in this data collection.

Digital instrumentation and control (I&C)

Digital instrumentation and control (I&C) systems are used in different safety related and safety systems of nuclear power plants, such as the reactor trip system (RTS), the engineered safety feature actuation system (ESFAS), and limitation systems.

They are characterised by the fact that discrete values are used to represent information, e.g. physical parameters. To process the information, they typically comprise computers (which run system and application specific software), microprocessors, microcontrollers,

field programmable gate arrays (FPGA) or other complex electronic devices such as application specific integrated circuits (ASIC). In many cases, different devices are connected by digital busses.

Inverters

An inverter is a device for converting a direct current into an alternating current. The inverters are used for the purpose of establishing battery backed altering current on safety bus bars. Three types of inverters can be distinguished: static inverters, rotating inverters, UPS (uninterruptible power supply/source).

The data collection covers all inverters that are used in safety relevant systems.

## 2.2. Cross-component group CCF (X-CCF)

An X-CCF event is an event where a single failure mechanism simultaneously affects multiple observed populations (OPs). An X-CCF may affect multiple component groups of the same component type as well as different component types. Prominent examples for such CCF events affecting multiple OPs are so-called asymmetrical faults in the on-site power system of nuclear power plants, as they have been observed.

Thorough analysis of operational experience from nuclear power plants suggests that there are numerous obvious or hidden dependencies between the individual OPs such as common maintenance teams and procedures, piece parts that are used in multiple OPs, shared cooling water, superordinate I&C, or internal and external factors that may affect multiple OPs simultaneously.

Even though X-CCF are rare events (only a fraction of all failure events are CCF events and only a fraction of all CCF events are X-CCF events) it is worth analysing such events in depth since they have the potential to cause severe impairments of the plant's safety system.

# 3. Data collection principles and guidelines

Data collection guidelines were developed during the project and are continually revised. They describe the methods and documentation requirements necessary for the development of the ICDE databases and reports. The format for data collection is described in the generic coding guideline and in specific component guidelines (see Section 3.2).

*Definition of observed population:* Set of similar or identical components that are considered to have a potential for failure due to a common cause. A specific OP contains a fixed number of components. Sets of similar OPs form the statistical basis for calculating common cause failure rates or probabilities. [1]

Data collection in the ICDE Project is basically based on observed populations that are handled in the database with "observed population records" (or "OP-records") and CCF events that are handled with CCF event records (or ICDE event records). In most cases, the OP-records comprise the redundant, identical components of a system, all performing the same function. Thus, they are equal to the common cause component groups (CCCGs) explicitly modelled in many probabilistic safety analyses (PSAs), such as the parallel pumps in a multi-train safety injection system.

*Definition of common cause events:* 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. [1]

ICDE data collection also includes potential CCF events, or ICDE events, which include the impairment of two or more components (with respect to performing a specific function), which occurs over a relevant time interval and is the direct result of a shared cause.

## 3.1. Quality assurance

The data collection and qualitative analysis shall result in quality assured data recorded in databases with consistency verification performed within the project.

The ICDE activity defines the formats for collection of CCF event experience in a quality assured and consistent database. This task includes the development of a set of coding guidelines describing the methods and documentation requirements necessary for the development of the ICDE databases. For more details, see Section 3.2.

The data are collected according to the internal processes of the participating organisations and checked according to their internal quality assurance programmes. The event information provided by the participating organisations is intended to be analysed within the scope of the project; it is not intended that the event data be changed unless the events undergo a review by the responsible national co-ordinator.

The ICDE steering group prepares publicly available reports containing insights and conclusions from the analysis performed whenever major steps of the project have been completed. The ICDE steering group assists the appointed lead person in reviewing the project report. Otherwise, the work follows the quality assurance plans and external review is provided by the Working Group on Operating Experience (WGOE) and the CSNI in sequence.

## 3.2. General coding guidelines

The general coding guidelines for the ICDE Project give explanations on the ICDE general coding format. The guidelines reflect experience with the data format and with the collected data. For each component analysed in the ICDE Project, separate coding guidance is provided in the appendices, specifying details relevant to the respective components.

Some of the most central coding elements for the ICDE event collection are:

- Failure mode: The function the components failed to perform.
- Root cause: The most basic reason for a component failure, which, if corrected, could prevent recurrence. The identified root cause may vary depending on the defensive strategy adopted against the failure mechanism. In general, the root causes are not based on a formal full scope root cause analysis.
- Coupling factor: The mechanism that ties multiple impairments together and identifies the influences that created the conditions for multiple components to be affected.
- Shared cause factor: Allows the analyst to express a degree of confidence about the multiple impairments resulting from the same cause.
- Time factor: A measure of the "simultaneity" of multiple impairments. This can be viewed as an indication of the strength-of-coupling in synchronising failure times.
- Corrective action: The action taken by the licensee to prevent the CCF event from re-occurring. The defence mechanism selection is based on an assessment of the root cause and/or coupling factor between the impairments.
- Detection method: Describes how the exposed components were detected.
- Component impairment: Expresses the degradation of the individual components. Some or all components are exposed to a common cause mechanism but may be affected differently: some may fail completely, some may be degraded, while others remain unaffected. The suffered impairment is described by the component impairment vector. The degradation scale of failure is complete (C), degraded (D), incipient (I) or working (W).

## 3.3. Component coding guidelines

Component-specific guidelines are developed for all analysed component types as the ICDE plans evolve. The ICDE general coding guidelines [1] include component coding guidelines for centrifugal pumps, motor-operated valves, emergency diesel generators, safety valves/relief valves, check valves, batteries, level measurement, switching devices and circuit breakers, control rod and drive assemblies.

For each component type included in the ICDE, a component-specific coding guideline is developed, defining the component boundaries, event boundary, system types (with corresponding international reporting system for operating experience [IRS] system coding), coding rules and exemptions, functional fault modes, and minimum time periods of exchange.

**Component boundary**

The component boundary encompasses the set of subcomponents or piece parts that are considered to form the component. The component boundary may be comprised of different pieces of equipment located in different locations. The component boundaries of the different component types are defined and described in the corresponding component coding guidelines.

**Event boundary**

The event boundary is component-specific and describes the mission of the component. For example, for EDGs, it is defined as any condition that does not permit the EDG to start or supply motive force/electrical power in the event of loss of coolant or loss of offsite

power. The mission for a centrifugal pump is to maintain the water inventory in the primary system, or to maintain cooling flow in the primary or secondary system or in support systems. Failure of the centrifugal pump to perform its mission occurs if a pump that is required to be running to allow injection or cooling flow fails to start or fails to run.

## 3.4. Failure analysis guideline

Following the collection of data and ICDE event coding for components, the ICDE steering group initiates and performs the failure analysis assessment. The development of failure analysis provides:

- Transparency and reproducibility between component reports and the database. It is further expected that the opportunity to find new perspectives and to engage in new development of data analysis will increase as the database content is extended with failure analysis.
- Detailed analyses of failure mechanism sub-categories that will provide valuable insights for improving defences against the occurrence of CCF events.
- Additional aspects when conducting workshops.

The failure analysis elements provide efficient support and transparency to the writing of component or topical reports. The work procedure shall support the ICDE SG when analysing events for the reports where an approach has been developed to perform a failure analysis focused on failure mechanisms. Failure mechanisms should be considered as consequences of the failure cause.

Coding should be done on the available information even if the information in the event description is sparse. However, there should be awareness that the coding could have been different if more details had been available. When several consequences are observed in a chain, implying that several sub-categories can be assigned to the event, the first or most important mechanism should be chosen. The codes are a result of work performed by the ICDE steering group.

The failure analysis elements are:

- Failure mechanism description: A history describing the observed events and influences leading to a given failure. Elements of the failure mechanism could be a deviation or degradation, or a chain of consequences derived from the event description.
- Failure mechanism category and sub-category: Component-type-specific observed faults or non-conformities that have led to the ICDE event; a failure mechanism category is a group of similar failure mechanism sub-categories.
- Failure cause category: The codes for failure causes are not component dependent; however, they are dependent on root cause and coupling factor. It is the coupling factor that identifies the mechanism that ties together multiple failures and the influences that created the conditions for multiple components to be affected. The root cause alone does not provide the information required for identifying failure cause categories. There are six failure cause categories that are distributed over two types of groups: deficiencies in operation and deficiencies in design, construction and manufacturing.

Severity category classification: The severity classification is an important part in the failure analysis since it correlates the observed event's failure mechanism with a severity degree, i.e. the impact of the failure mechanism. The severity category expresses the degree

of severity of the event based on the individual component impairments (C, D, I, W), as described in Section 3.2, in the observed/exposed population. The categories are:

- Complete CCF: All components in the group are completely failed (i.e. all elements in impairment vector are C; time factor high and shared cause factor high).
- Partial CCF: At least two components in the group are completely failed (i.e. at least two C in the impairment vector, but not complete CCF; time factor high and shared cause factor high).
- CCF impaired: At least one component in the group is completely failed and others affected (i.e. at least one C and at least one I or one D in the impairment vector, but not partial CCF or complete CCF).
- Complete impairment: All components in the exposed population are affected; no complete failures but complete impairment; only incipient degraded or degraded components (all D or I in the impairment vector).
- Incipient impairment: Multiple impairments but at least one component working; no complete failure; incomplete but multiple impairments with no C in the impairment vector.
- Single impairment: No multiple impairments, with only one component impaired; no CCF event but considered interesting by the ICDE data analyst.

# 4. Insights from data collection and event analysis

Data collection is a continuous process and several event analyses have been performed and published. This chapter presents the status of the data collection, some insights from the specific component analysis and the topical analyses. In addition, failure mechanisms and failure cause are presented for the most severe events, i.e. complete CCFs.

## 4.1. Data collection overview

An overview of the database content[1] with the number of CCF events and the number of complete[2] and partial[3] CCF events for each component type is given in Table 4.1.

### Table 4.1. Data collection overview

| Component type | CCF Events | Percentage | Complete CCF | Partial CCF | Phase 8[4] |
|---|---|---|---|---|---|
| Centrifugal pumps | 444 | 21.5% | 47 | 44 | 45 |
| Diesels | 348 | 16.8% | 33 | 21 | 112 |
| Safety and relief valves | 296 | 14.3% | 22 | 44 | 25 |
| Motor-operated valves | 194 | 9.4% | 10 | 37 | 22 |
| Control rod drive assembly | 180 | 8.7% | 4 | 27 | 7 |
| Level measurement | 169 | 8.2% | 9 | 32 | 15 |
| Check valves | 118 | 5.7% | 12 | 26 | 1 |
| Breakers | 116 | 5.6% | 6 | 29 | 6 |
| Battery | 87 | 4.2% | 5 | 2 | 10 |
| Heat exchanger | 58 | 2.8% | 4 | 1 | 3 |
| Fans | 32 | 1.5% | 3 | 0 | 0 |
| Main steam isolation valves | 13 | 0.6% | 1 | 4 | 3 |
| Cross-component CCF | 5 | 0.2% | 0 | 0 | 5 |
| Digital I&C | 4 | 0.2% | 2 | 0 | 0 |
| Inverters | 4 | 0.2% | 2 | 0 | 4 |
| Total | 2 068 | 100% | 160 | 267 | 258 |

1. As of February 2022.

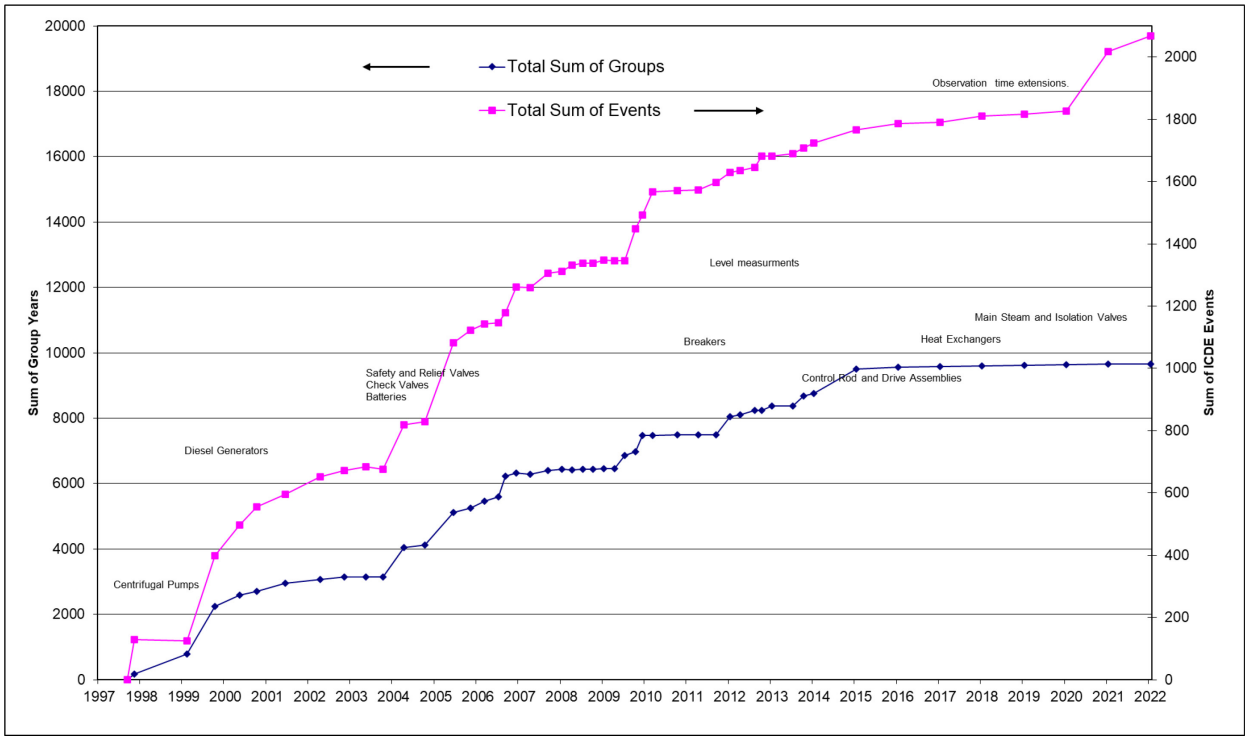
2. Complete CCF: A common-cause failure in which all redundant components are failed simultaneously as a direct result of a shared cause (i.e. the component impairment is "complete failure" for all components and both the time factor and the shared cause factor are "high").

3. Partial CCF: A complete failure of at least two components, but not all the exposed population, where these fault states exist simultaneously and are the direct result of a shared cause.

4. Data collected 2018-2022.

The chronological sequence of the data collection is shown in Figure 4.1. The graph shows how new component types were added over time as well as the continuous data collection for the existing component types.

**Figure 4.1. ICDE data collection progress**




## 4.2. Failure mechanisms and failure causes of complete CCF

Events with "complete CCFs" are of particular interest for CCF analysis because they often result in a complete loss of a safety function with a high risk that nuclear safety goals are endangered. Therefore, it is interesting to analyse what factors led to such complete CCFs (i.e. what the "failure cause" was) and what can be done to prevent complete CCFs in the safety system of nuclear power plants.

The following observation can be made:

- Averaged over all components, almost 60% of all complete CCF events involve human failure, e.g. procedure inadequacy, insufficient maintenance and faulty actions by plant personnel and contractors.

With the use of failure mechanism identification and descriptions (see Section 3.4), some exemplary complete CCF ICDE events can be described. The selected events focus on the identified failure mechanisms and failure causes and include a variety of components.[5]

5. To comply with the ICDE terms and conditions, no plant names, systems codes, dates, etc. are included in the event descriptions.

| Component type | Failure mechanisms and failure causes |
|---|---|
| • Centrifugal pump | – Maintenance work on main cooling water pumps led to loss of all reactor coolant water pumps due to changed flow conditions in the common water intake for the pumps during the test. The maintenance procedure had been modified before the event occurred. As corrective action, the procedure was withdrawn and revised once again. |
| | – Erroneous modifications to the auxiliary feed water system (AFWS) start logic caused all pumps in the component cooling system (CCW) not to start on demand. The event is assessed as a potential intersystem dependency since these systems were sharing the same electrical cubicle. The event would have been prevented by separate sheets of drawings for each system, but it is difficult to defend from this type of event. An improved process for work preparations and better-quality assurance (QA) of documentation would also have helped. |
| • Emergency diesel generator | – An error in the test procedure disabled the automatic start function of all EDGs during testing of a turbine-driven emergency power supply. The knowledge and safety awareness of the personnel performing the test led to a fast discovery of the faulty state. Better QA of test procedures would have prevented the event from happening. A lesson learnt was that a test may cause problems in another system that is tested. |
| | – Pollution of the air supply due to sandblasting outside the diesel building led to scoring in the sleeves of the cylinders and to high pressure in the motors in EDGs. An implementation of pressure instrumentation could have prevented the event. Also, verification of operability after maintenance could be improved. |
| • Level measurement | – Both level transmitters were replaced without updating the calibration procedure so the transmitters could not monitor the tank level in the chemical and volume control system (CVCS) correctly. The performed functional test could not detect this fault because the test could only check the level measurement by simulating draining the tank. A functional test with draining of the tank could have prevented the event. |
| | – The three level transmitters of the pressuriser did not fulfil their function during emergency conditions because they were not connected to the uninterrupted power supply as designed. During the plant modification, they had been connected to the wrong power supply. A better testing procedure after the plant modification could have prevented the event. |

| Component type | Failure mechanisms and failure causes |
|---|---|
| • Safety and relief valve | – Wrong settings for safety relief valves were detected at two groups of valves at a twin-unit site, one in each unit. The reason for the wrong settings was incorrect engineering judgement and identical maintenance actions that were applied for all valves, which resulted in a complete CCF (correlation factor; human and organisation) of two groups of safety valves. As a corrective action, it was proposed to introduce a process to ensure completeness, quality and validity of maintenance procedures e.g. by an independent verification of the used input data and calculations. |
| • Motor-operated valves | – Design modifications of the logic of the containment isolations were erroneously not applied for a group of motor-operated valves in the residual heat removal system. Because of this, containment isolation would not have been available for the plant shutdown phase as required in the technical specifications. The design should have been reviewed and tested for all plant modes, and the testing of the modification during plant shutdown should have been performed. Diverse maintenance teams would increase the possibility of identifying such failures. |

## 4.3. Component analysis

A component analysis presents an overview of the entire data set of a specific component type. The data are not necessarily complete for each country, but all available approved data are used. The overview includes information about the event parameters' root cause, coupling factor, observed population (OP) size, corrective action, degree of failure, affected subsystem, and detection method. The degree of failures is based on defined severity categories which are used in the assessment. Charts and tables are provided exhibiting the event count for each of these event parameters.

The component analysis also includes analysis of engineering aspects of the events, which presents a qualitative assessment of the collected data. Events are analysed with respect to failure mechanisms and failure cause categories through use of an assessment matrix.

The objectives of the component analysis are:

- to describe the data profile for the component type in question;
- to develop qualitative insights into the nature of the reported events, expressed by root causes, coupling factors and corrective actions; and
- to develop the failure mechanisms and phenomena involved in the events, their relationship to the root causes, and possibilities for improvement.

Public final reports for centrifugal pumps, diesel generators, motor-operated valves, safety and 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 [2]-[11]. Older versions of the component reports for motor-operated valves [4], safety and relief valves [5] and batteries [7] have been updated during phase 8.

### *4.3.1. Data profile*

The data profile presents an overview of the collected component's data set, including the event count and the total observation period; see Figure 4.2 and Figure 4.3. The events are examined by tabulating the data and observing trends. Once trends are identified, individual events are reviewed for insights. For example, the updated diesel report [3] includes 224 CCF events spanning a period from 1977 through 2012.

**Figure 4.2. ICDE observation and event data**

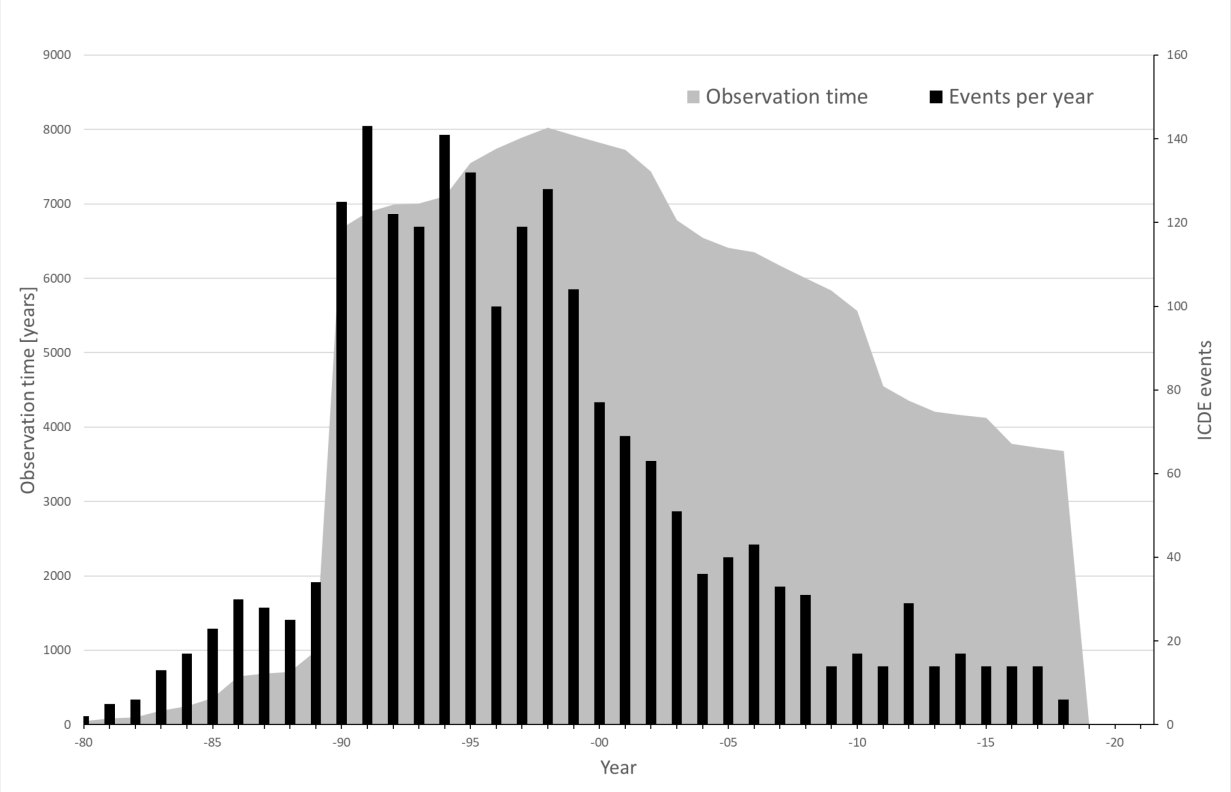
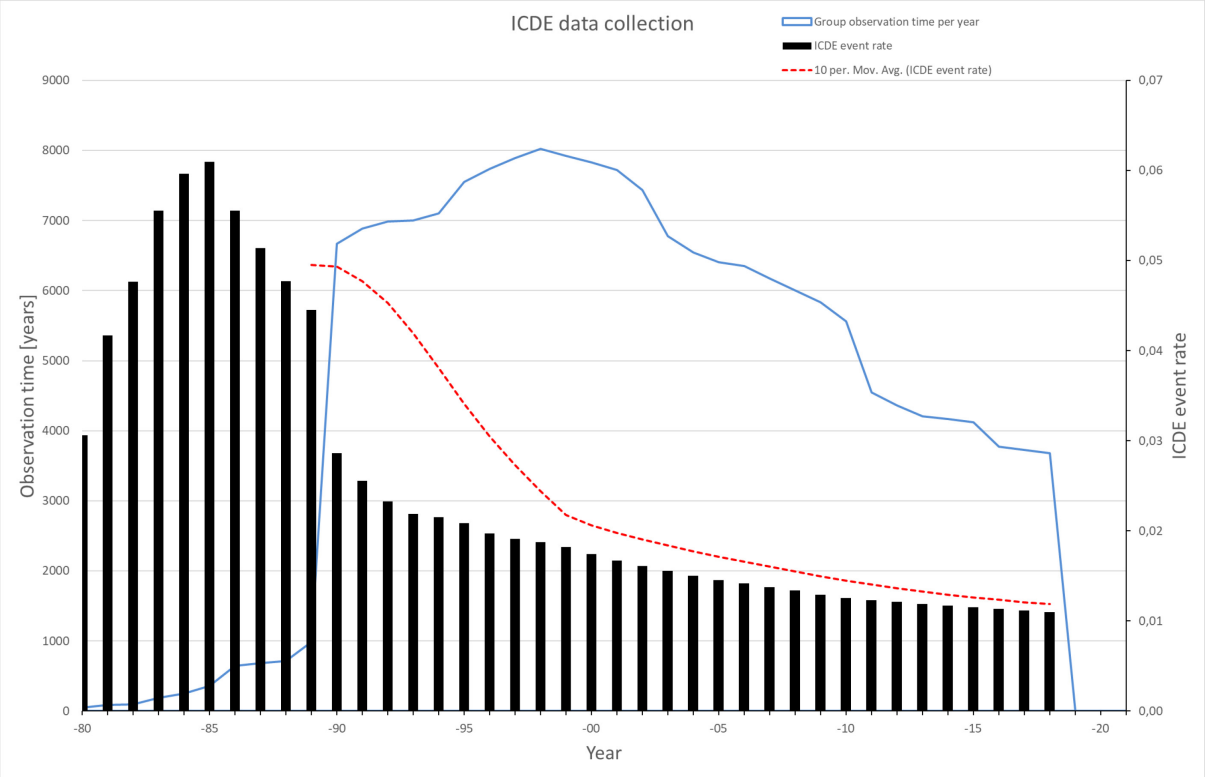


**Figure 4.3. ICDE data event rate**




### *4.3.2. Failure mechanism categories and failure phenomena*

Failure mechanism categories are defined in an iterative process based on the observed events. The final list of categories can also be looked upon as a summary description of the event observation. Examples of concluded failure mechanism categories from the updated diesel report are:

- Engine damage or problems, such as:
  - Starting air or air supply valve/distributor damage, damage of rotating or stationary parts (bearings, high pressure in crankcase, etc.), combustion chamber problems (e.g. cylinder, piston, fuel injection nozzle and pump damage), coupling damage (between engine and generator), combustion/charging air problems (e.g. air intake, turbocharger damage)
- Compromised ancillary systems, such as:
  - Cooling water (missing or low water pressure, temperature, leakage), lubrication (missing lube oil or low lube oil pressure, bad quality, or wrong temperature of lube oil), compromised air intake or cooling of ventilation, fuel (quantity, quality, leakage)
- Electrical failures, such as:
  - Alternator damage, breaker/relay failure, other electrical damage (e.g. of cables, cabinets)
- Deficient control and deficient protective cut-out (I&C problems), such as:
  - Defective or unsuited piece part, misadjusted setpoints, inadvertent actuation of protective cut-out or fire protection system

- Misalignment, such as:
  - Faulty subcomponent, faulty system configuration/operator control actions, faulty logic

### *4.3.3. Qualitative insights*

The component analysis is finally concluded into insights and lessons learnt, based on the data review and observed failure mechanisms. Examples of such observations are taken from the updated diesel report. The following notable observations were made.

- The most frequently occurring causes of emergency diesel generator failures are design errors related to design, manufacture or construction inadequacy.
- Events with failure causes related to deficiencies in operation tend to include a higher proportion of severe failures.
- Maintenance/testing was the main way of detecting problems with the diesels, followed by unknown detection methods and testing during operation. The share of demand events is low compared with other components.
- The most common diesel generator failure mechanism category is comprised ancillary systems, with many failures involving cooling water or fuel supply systems.
- I&C failures are more likely than other types of failure mechanisms to result in severe CCF events that completely fail multiple components in a group.
- Ten percent of the reported ICDE diesel generator events are complete CCF events. This is the most severe failure category, with complete failure of all diesels in the common cause component group.
- Fifty diesel generator CCF events have been marked as impacting multiple reactor units.

## 4.4. Topical analysis

The ICDE steering group has developed a work procedure for topical analysis, which supports the analysis of events. The work procedure includes the failure analysis elements (as presented in Section 3.4). The procedure aims to capture insights for possible improvements and defences for the topic in question. The defences try to identify aspects that prevented the event from developing into a complete CCF. The improvements identify areas that could be improved to prevent the event from happening again. Topical analyses have been performed for the following topics:

- External factors [12] (64 events)
- Diesels all affected [13] (143 events)
- Plant modifications [14] (53 events)
- Improving testing [15] (59 events)
- Multi-unit events [16] (87 multi-unit events)
- Intersystem dependencies [17] (25 intersystem events)
- Pre-initiator HFE [18] (51 events)

For the topical analyses, the findings and conclusions are presented in the following sections.

### *4.4.1. Common cause failures due to external environmental factors*

This report presents a study performed on a set of CCF events within the ICDE Project. The topic of the study was "external factor events". An external factor event is a CCF event or CCF fragility (impairment) related to external or environmental factors, or an event directly caused or triggered by such factors (e.g. weather or environmental conditions).

The report is mainly intended for designers, operators and regulators to provide insights into the type of external factor events in the ICDE database. The insights can give valuable experience to support and improve the external event modelling in probabilistic risk assessment (PRA) models and provide CCF data for quantification purposes.

The report summarises the results of two data analysis workshops performed by the ICDE steering group, presents CCF defence aspects, and includes in total 64 external factor events spanning an observation period from 1977 through 2015. The data analysis included an assessment of the event parameters: event cause, coupling factor, corrective action, CCF root cause, event severity and detection method.

The most noteworthy aspects of the event parameters are:

- The major observed event cause is "abnormal environmental stress" (42%) and it is relatively overrepresented with a factor of nine compared to the complete ICDE database, i.e. abnormal environmental stress is more commonly seen in an external factor event. However, since this report is for external factors, the event causes for all other events covered are indirect environmental effects related to external factors (58%).
- For about 31% of the events, the concluded CCF root cause was solely or predominantly design (deficiencies in the design of components or systems), where foreseen environmental aspects contributed significantly. An equally large share of the events were determined to be "environmental trigger" events, i.e. events with a non-foreseen environmental cause.

The engineering analysis addressed the "cause" or "trigger" of the external factor event, expressed by different hazard groups and classification of their causes and areas of improvement to prevent the events from happening again.

The lessons learnt from the engineering aspects analysis of the external factor events and the resulting recommendations are as follows:

- The components most susceptible to failures due to external factors are centrifugal pumps, followed by emergency diesel generators and heat exchangers. As for relative occurrence, heat exchangers are significantly overrepresented compared to the complete ICDE database.
- Biological infestation is often a slow developing failure mechanism, but it can be an important aspect during periods or outbreaks. It is important to ensure adequate procedures for the cleaning of strainers, tubes and plates, and to have a backflush capability. Also, the monitoring capability (e.g. control of flow rate and temperature conditions) is an important aspect, especially during periods when marine growth occurs.

- Hazards related to debris can be avoided in some cases with an improved design of strainers. However, sufficient defences to avoid clogging due to heavy debris are difficult to achieve.
- For a large portion of the events related to degradation due to sand intrusion in the system, monitoring in combination with maintenance and operational practices may result in detection of degradation before failure of the components. Also, an adequate ageing management programme could have prevented several events.
- Biological infestation and underwater debris in the water intake are likely to affect multiple units since the intake is often shared between the units.
- To mitigate meteorological effects, a careful evaluation of the system design with consideration of operational experience from events triggered or caused by, for example freezing effects, blockage of air/ventilation intakes is recommended. Also, during periods of low sea or river temperatures, monitoring systems dependent on the water intake are vital.
- No experience from seismic events exists in the ICDE data except for one event that relates to a suspected seismic fragility.

The results of this analysis may serve as input for an in-depth review of the methods and assumptions used in external hazards PRA and to support the identification of possible external factors that may have low frequencies but large consequences.

### *4.4.2. Common cause failures affecting all exposed diesel generators*

The scope of the "diesels all affected" topic was to identify failure mechanisms that can impact all diesels in an exposed population, so-called "all affected" diesel failures (in total 142 events). "All affected" diesel failures involve events where all diesels in an exposed population either failed or were degraded or showed an incipient impairment due to the same cause. The scope aimed to get broader insights in failure mechanisms that are potentially able to lead to complete common cause failures of emergency diesel generators. This topical analysis is complete, and the report has been published [13]. One part of the analysis is to try to identify areas of improvement to prevent the event from happening again with use of so-called "improvement categories". An event can be assigned to multiple categories:

a) Design of system or site;

b) Design of component;

c) Surveillance of component;

d) Maintenance or testing of component;

e) Operation of component;

f) Management system of plant[6]

The most assigned category was "maintenance or testing of component" (34%). Many of these events involve improper re-installations or re-assemblies after testing/maintenance. Suitable prevention of this kind of failure would mean improved test/maintenance procedures, which would include checks after completion of test/maintenance. Approximately 15% of the events were concluded with this type of prevention. Also, the improvement category "design of component" was common among the events (28%).

6. QA of vendor, spare parts management, training of personnel, sufficient resources/staff, etc.

Improper design of different piece parts such as cooling pipes, three-way-valves (gap rod/valve) and exhaust damper linkage seems to be the problem for many events.

Among the events (16%) that were assigned to “management system of plant”, improved QA of the vendor was pointed out several times. Evidence was found that “QA of vendor” not only involves quality assurance of the actual product but also that the product information delivered together with the product must be sufficient.

For the category “design of system or site”, the observed design errors included corrosion in cooling pipes due to penetration of rainwater because of a non-leak-proof EDG building or inadequate vibration tolerant design leading to cracks in the cooling system.

In the category “surveillance of component”, blockage in heat exchanger tubes (primarily corrosion) and unusual high oil consumption that led to low oil level and stopping of the engine was observed. Monitoring the flow in cooling pipes, the oil consumption and the diesel fuel supply can be an appropriate improvement.

An example in the category “operation of component” was an event where the high iron content of well water led to dirt deposition on the heat exchanger and an overly high temperature of the diesel engine. One lesson learnt from this event is that controlling the water chemistry of the cooling water is important.

### *4.4.3. CCFs due to plant modifications*

The topical analysis report “CCFs due to plant modifications” [14] evaluates CCF events that occurred due to modifications, backfitting and/or replacements. However, there were no CCF events identified that were related to modifications resulting from a regulatory backfit, i.e. relating to new or amended regulatory requirements or regulations.

The share of complete CCFs (22%) is significantly larger than the share of complete CCFs in the whole database, which is only about 10%. A time-separated implementation of modifications of modified components could reduce the possibility of all components being affected by an unanticipated erroneous modification.

For the severe events (complete or partial CCF), I&C modifications were most common. Several problems relate to modified protection devices of the main components (e.g. protection relays, contacts and wiring). This finding also underlines the importance of a complete and thorough system evaluation including a full-featured test programme after modifications.

The following generic insights and recommendations can be given regarding the question on how to prevent CCF events due to modifications:

- Modifications to the safety systems of a nuclear power plant have the potential to cause CCFs, especially CCFs that affect all redundant components at once.
- A stringent, comprehensive planning of the intended modifications should be performed, including the assessment of possible interactions on the system-level.
- A comprehensive post-modification testing programme should be developed and implemented.
- Modifications of settings, testing procedures and maintenance procedures (change of lubrication, grease, etc.) should be comprehensively tested after the modification.
- If possible, modifications in redundant trains should not be implemented simultaneously to increase the chance of identifying problems by testing.

- Modifications to I&C systems and protection devices should be performed with special care.
- CCFs due to the modification of subcomponents are mostly related to the design of the subcomponent itself and can be prevented by the owner completing a thorough design evaluation and review of the manufacturers.

For some events, these defences prevented all components from failing. For other events, the failures slowly developed over time and were detected before developing into complete failures.

### *4.4.4. Provision against CCFs by improving testing*

The main objective of the topical report "Provision against CCFs by improving testing" [15] was to study CCF events where fault states or impairments could not be detected in normal recurrent tests because the scope of the tests was insufficient or no appropriate tests existed. The report is mainly intended for designers, operators and regulators to widen their understanding of reducing CCF risks by improving testing and to give insights into relevant failure mechanisms.

It summarises the results of two data analysis workshops performed by the ICDE steering group and presents CCF defence aspects for provision against CCFs by improving testing.

The analysis included an assessment of the event parameters; event cause, coupling factor, detection method, corrective action and event severity. The following noteworthy observations can be made.

- The most common component types were emergency diesel generators, centrifugal pumps and safety relief valves. Level measurements contribute with several severe events.
- The most common CCF root cause was procedure deficiencies (58%).
- Inadequacies in testing have been observed in all investigated aspects of testing. They are: extent of test, QA of test, performing the test and verification of operability.
- The most common area to find test inadequacies is in the QA of testing.
- No event was identified to have been caused by inadequate test intervals.

The most common areas of improvement were testing procedure, maintenance procedure and management of plant.

The lessons learnt from the engineering aspects analysis of improving testing events are:

- It is important to have a process for quality assurance of procedures to ensure the completeness, adequacy and validity of tests.
- When performing a test, it is important to verify the equipment, ensure a high degree of training of the personnel performing the test, and to have a strong safety culture to prevent deviations from procedures, especially in the verification of the work performed.
- Verification of operability after test, maintenance activities and modifications are essential, especially after maintenance, to prevent latent failures and the occurrence of CCFs.
- The actual defences that prevented events from becoming complete CCFs show that experience feedback from other units and previous similar events can be a

successful way to detect latent failures in time, even when ordinary testing does not identify the failure mechanism.

### *4.4.5. Multi-unit CCF events*

The main objective of the topical report "Multi-Unit CCF Events" [16] was to study CCF events that occurred at multiple units at the same site. The report is mainly intended for designers, operators and regulators to improve their understanding of multi-unit CCF events and to give insights into relevant failure mechanisms.

The observed multi-unit events were classified as: internal factors (shared design or organisational factor), external factors (physical, external or environmental connection), or fleet CCF events (same or similar events occurring at multiple sites). The analysis included an assessment of the event parameters: event cause, coupling factor, detection method, corrective action, CCF root cause and multi-unit event severity. The following noteworthy observations can be made.

- Multi-unit events were observed for a wide range of component types. Emergency diesel generators and centrifugal pumps accounted for more than 50% of the events.
- The most common CCF root cause (nearly 60%) for multi-unit CCF events was deficiency in the design of components and systems. Hence design is significantly overrepresented compared to the total observed CCF event population.
- Events with observed environmental deficiencies were caused by harsh environmental conditions, such as severe weather or abnormal debris in a raw water source, that usually require design improvements to prevent reoccurrence.
- About 10% of the events were complete multi-unit CCF events.

The conclusion from the engineering aspects of the multi-unit CCF events were:

- A total of 57 events were dependent through internal factors, where 27 of these events were correlated to "identical design" (for example, same design of components/systems, operating environment, or installation) and 17 were correlated by "organisational aspects" (mainly by test and maintenance procedures).
- Feasible defence strategies for the internal multi-unit CCF events are well-functioning testing procedures, maintenance procedures, operating experience feedback, skilled personnel, etc. Adequate and robust system/component design is the fundamental defence against complete CCFs. Also, some failures were slowly developing in time and could be detected before developing into complete CCFs.
- A total of 14 events were dependent through external factors, with ten of these events correlated to "shared structures, systems and components (SSCs)" (for example, units with shared water intake channel). Four of the nine complete CCFs were caused by shared SSCs.
- A feasible defence strategy against external multi-unit CCF events is "design of system or site", which can include a better design of the water intake: adding back-flushing capability or cleaning strainers. Also, improved surveillance/maintenance is a feasible defence to detect problems before the components fail.
- The multi-unit CCF events identified can provide useful insights to inform multi-unit probabilistic safety assessment (MUPSA) modelling. The external factor events can provide insights relevant to the modelling of physical connections and dependencies across unit boundaries. The internal factor events can provide

insights relevant to the need for defining new CCF groups by combining common cause component groups across units at the site.

### *4.4.6. Intersystem dependencies*

The goal of the "CCF intersystem dependency event" topic [17] was to analyse events where a single CCF failure mechanism affects multiple systems; that is, events where a single CCF failure mechanism affected components in more than one different system or affected more than one different safety function.

The topical report includes 25 intersystem events involving a total of 33 ICDE events affecting more than one different system (or safety function).

For classification of intersystem dependency events, two parameters were considered: the degree of failure and degree of simultaneity. The level of intersystem dependency impairment (severity) is determined by assessing how multiple systems were affected and degraded. The "simultaneity" (time factor) of the intersystem events is determined by the timeframe between detections of the intersystem events. By combining these, the following classification was concluded.

- *Actual intersystem dependency.* Failures affecting multiple systems with a high time factor. Observed event(s) show evidence of multiple systems affected.
- *Partial/incipient intersystem dependency*. Failures/impairment affecting multiple systems with a low time factor. Observed event(s) show evidence of multiple systems affected by a similar problem (failure mechanism), e.g. same subcomponent.
- *Potential intersystem dependency.* Failures in one system only, but other systems could have been affected due to the nature of the failure mechanism. Observed event(s) show evidence of potential intersystem dependency.
- *Inter-CCCG dependency.* Failures of multiple common cause component groups (CCCGs) in only one system with no indications that other systems might have also been affected. These are not ordinary intersystem events but are nonetheless of interest since they involve dependencies between CCCGs, which are not specifically modelled in a probabilistic risk assessment (PRA).

Intersystem dependency events were observed for a wide range of component types. Centrifugal pumps, motor-operated valves, diesels and breakers were most common, with 76% of events involving these component types. The most noteworthy observation was that the most common CCF root cause was "solely or predominant design" (72%). However, for the more severe events, i.e. complete CCF and complete impairment, procedure deficiency was the dominant CCF root cause.

The analysed events show evidence of internal and external intersystem CCF events, and inter-CCF group events. Thus, intersystem dependencies need to be addressed for all types of potential system dependencies. The lessons learnt from the engineering aspects analysis of the intersystem CCF events, and the resulting recommendations are as follows:

- Intersystem CCFs are rare events (the 25 events correspond to about 1.4% of all CCF events in the ICDE database and about 1.9% of the complete CCFs, i.e. ~0.02 in an intersystem β-factor model), yet their existence and their risk significance should not be overlooked.
- The observed intersystem dependency events cover a wide range of component types, systems and failure mechanisms. Thus, there are no component types that

are especially vulnerable or robust against intersystem CCFs, i.e. no trend can be observed in the data.

- Highly redundant component types, such as safety and relief valves (SRV) and control rods and drive assemblies (CRDA), were not observed among the events (these components are not intersystem systems by design).
- The modification of component protection devices (overcurrent, torque, etc.) should be performed with great care. If possible, only one system redundancy should be modified until sufficient operating experience is gathered to ensure its adequacy.
- Maintenance or modification activities in one system resulting in a CCF in another system were observed. Close attention should be paid when planning maintenance or modification activities to ensure that the activities do not affect other systems.
- Diversity on the component level does not ensure diversity on piece part level in different systems. For example, the same type of breaker is used in multiple systems and is vulnerable to a CCF mechanism.
- Thus, intersystem dependencies could exist on a lower component level that is normally not considered in a PRA. Due to the risk significance, intersystem dependencies should be considered accordingly when performing a PRA, while also considering the rarity of these events and defences that could prevent or mitigate their occurrence.

### *4.4.7. Pre-initiator human failure events*

The goal of the "pre-initiator human failure event (HFE)" topic [18] was to analyse events that may impact the availability of components in accident-preventing/mitigating systems and are caused by inappropriate actions or human inactions, such as misalignments and miscalibrations.

The topical report includes 51 common cause pre-initiator HFEs. All the included events were complete CCFs. The event set also includes important intersystem HFEs and multi-unit HFEs.

The engineering analysis of pre-initiator HFEs addressed:

- The involved act that determines the "cause" or "trigger" of the human failure event. The resulting acts are mainly: corrective or preventive maintenance (e.g. improper installation), modification or replacement, surveillance testing, operation, and other/unknown actions.
- The performance shaping factors (PSFs) that impact the pre-initiator HFEs. The involved PSFs considered in the event analysis were written work plans, procedures, training, complexity and number of steps, reliance on memory, ergonomics and the task environment.
- The latency of the event until failure or detection of degraded component state. The latency of the HFEs was divided into three levels: low (no latency or latency of a few minutes or hours), medium (latency of days or months) or high (latency of months or unknown).

Pre-initiator HFEs were observed for a wide range of component types. Centrifugal pumps, followed by emergency diesel generators (EDGs), motor-operated valves (MOVs) and safety and relief valves (SRVs) were the most common component types: 77% of events involved these types. The event causes human actions (26%) and procedures (24%) were

almost equally common. The most common coupling factor was operational followed by maintenance/test procedure. The most common corrective action was general administrative/procedure controls. For about 75% of the events, the concluded CCF root cause was deficiencies in procedures. Also, almost 50% of all events had all three root cause aspects related to procedures. The most common detection method was monitoring in the control room, followed by testing during operation and the annual overhaul. Also, eight demand events were observed.

The conclusions drawn from the analysis of pre-initiator HFEs, related to engineering aspects, are listed below.

- The most common acts were corrective/preventive maintenance followed by surveillance testing.
- The most common type of PSF was procedures, followed by training and written work plans.
- About 55% of the events had high latency, including several latent events only detected by demand.
- The most common plant state was outage followed by at power.
- About 18% of the HFEs were marked as safety culture issues.

For the low latency events, all possible PSFs were observed. The PSF related to "written work plans" was only observed for corrective/preventive maintenance acts. The PSF "procedure" was observed for all types of acts.

For the medium, high or unknown latency events, the PSF "procedure" was very common among the more latent events. Also, the PSF "ergonomics" was not observed. In addition, the PSFs "complexity and number of steps", "reliance on memory" and "the task environment" were not observed to the same extent as for the low latent events.

The analysis also identified possible defences/improvements for the HFEs that could have prevented all components from failing. These possible defences mainly include improvements in the surveillance of the components, better maintenance or test procedures and different types of improvement to the management system of the plant.

The lessons learnt from the engineering aspects analysis of the pre-initiator HFEs and the resulting recommendations are as follows:

- Deficiency in the procedure was the main CCF root cause for the complete common cause pre-initiator HFEs (74%). However, faulty human actions are often involved in the procedures and therefore the procedure itself is not a sufficient defence to avoid HFEs. Factors such as training of personnel, safety culture and plant management have an important role to prevent HFEs.
- The most important PSFs were procedure, training and written work plan, with emphasis on the adequacy of the procedure itself but also on the planning of the work as well as the training of the personnel.
- The analysed complete HFEs show the importance of:
  - Quality assurance of procedures, e.g. ensuring the scope, adequacy and know-how of the procedures. Plant management plays an important role in ensuring this through training of personnel, QA of processes and safety culture.
  - Adherence to procedures and written work plans in a safe manner. For example, tests should not be conducted in the wrong operational mode or simultaneously.

  - Verification of operability after maintenance work (installations, modifications and replacements) and after testing (ensuring the correct positions of breakers, switches, etc.).
- The pre-initiator HFEs from the ICDE database provide valuable insights into dependencies since many of these dependencies are not typically modelled in an HRA.

# 5. Envisaged use and further development of ICDE

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

Maybe the most important generic lesson is that it is worth forming specialised data exchange projects like the ICDE. National efforts are the key to the success of any project that relies on operating experience. The success of the ICDE has been a precursor to several similar types of projects, among which are the Component Operational Experience, Degradation and Ageing Programme (CODAP) for pipe failure events and the Fire Incidents Records Exchange project (FIRE) for nuclear power plant fire events.

In conclusion, it can be said that the ICDE Project has fulfilled its objectives for phase VIII (2019–2022) quite well. The following sections outline the methods by which these qualitative and quantitative objectives were fulfilled.

## 5.1. Data collection and coding guidelines

Data collection and data exchange for "standard" component types continues as part of the general ICDE operation.

The data collection of "new" component types (digital I&C, inverters, cross-component group CCF events) has just started. The planned data collection of these components will make it possible to identify failure mechanisms, failure causes and possible defences against occurrences of CCF events.

Coding guidelines [1]

The general coding guidelines for the ICDE are presented with explanations and appendices for each analysed component. The guide reflects the present experience with the already completed data collection. New component types are added in case a participating country is interested. As data collection continues, new needs and interests may arise for further development of the ICDE guidelines.

A part of the general coding guideline is the failure analysis. The failure analysis is performed by the ICDE Project participants during dedicated workshop sessions. The failure analysis assessment allows the ICDE participants to perform an in-depth review of the event data from all the participating countries. This failure analysis approach helps the ICDE group develop common insights and trends across the entire data population. These evaluations have revealed insights that would otherwise not have become evident. The failure analysis codes are a result of work performed by the ICDE steering group and further analysis will lead to more insights about the collected data.

## 5.2. Qualitative analysis

Failure analysis presentation

A list of the failure mechanism descriptions can be an easy, yet efficient, way to summarise the types of failures for a certain scope of events. A central part of the specific component type report is the presentation of the relationship between failure mechanism categories and failure cause categories (matrices with failure mechanism categories and failure cause categories). They could provide valuable insights for improving defences against the occurrence of CCF events.

Component and topical analysis

As presented in Sections 4.3 and 4.4, the ICDE Project has several analyses ongoing in parallel. The qualitative analyses will continue and result in insights and lessons learnt about the collected data. This work is part of one of the objectives of ICDE Project phase VIII to generate qualitative insights into CCF events to prevent them or mitigate their consequences.

The reports in preparation [14-18] are as follows:

- *ICDE Topical Report: Collection and Analysis of Common-Cause Failures due to Plant Modifications.*
- *ICDE Topical Report: Provision against Common-Cause Failures by Improving Testing.*
- *ICDE Topical Report: Collection and Analysis of Multi-Unit Common-Cause Failure Events.*
- *ICDE Topical Report: Intersystem Dependencies.*
- *ICDE Topical Report: Pre-Initiator Human Failure Events (HFEs).*

Future component and topical analysis

The topical analyses that are in the initial phase are:

- safety culture;
- proof of concept for quantification of CCF parameters;
- cross-component CCF events (pending additional data collection); and
- digital I&C CCF events (pending additional data collection).

Other interesting topics that have been up for discussion are grease/lubrication issues.

In general, component-specific insights would be derived; however, for several failure mechanism categories/sub-categories, cross-component-type insights could also be obtained if failure mechanism categories/sub-categories are common to several components.

Problems with lubricants are predominantly caused by errors in operation, mainly deficient maintenance procedures and overly long maintenance intervals. By improving maintenance procedures and reducing maintenance intervals, the occurrence rate of such events could be significantly reduced. More detailed analyses could provide recommendations for maintenance intervals and procedures to be applied to piece parts and to used lubricants that are identified as being critical by the collected data on failure mechanism sub-categories. An important parameter to be considered in this context would be the degree of impairment associated with the events.

Other failure mechanism sub-categories to be examined in detail could include:

- bearing problems in diesels and centrifugal pumps;
- degraded or broken moving parts in diesels and centrifugal pumps;
- wrong set points in all types of valves, breakers and level measurement devices;
- misadjusted seat/disk configurations in all types of valves; and
- broken, bent or otherwise degraded mechanical parts in all types of valves and breakers.

This cross-component-type of failure analysis can improve the search for CCF defences and decrease the occurrence of CCF events.

## 5.3. Quantitative analysis

The general frequency of an ICDE event in an observed population (CCF component group) is approximately 0.015/year (or <2E-6/h). The ICDE data collection provides a structure and basis for component-specific quantification of CCF rates and probabilities. However, several precautions must be respected to avoid over- or underestimation. The precautions to consider are:

- Completeness of the CCF event set and observation periods: It is important to determine whether the provided set of CCF events covers the whole available national CCF experience, and whether the group year observation estimate in relation to the reported event data set is correct.
- Event interpretation with respect to PSA failure combinations: Depending on the used CCF model, a transformation of the data, for example into an "event impact vector", is necessary for quantitative CCF parameter estimation.
- Applicability of CCF events: To achieve quality assurance of the data inputs of the analyses, the events shall be analysed and reviewed in a team review. Individual specific assessment is necessary to decide whether to take the event into account or not.
- Applicability of observed populations: Component groups and events shall be divided and grouped to ensure that the quantification is made on a homogeneous set of data. This means that the data set should be divided based on homogeneity issues, but only to such extent that the data sets do not become too scarce.
- Parameter estimation methodology: Different methods are used for quantitative CCF parameter estimations. Independently of the choice of methods, several characteristics need to be considered as some features of the method may have a high impact on the CCF parameter estimation results.

An example of a quantitative application has been carried out with use of ICDE MOV, pump, diesel generator and battery data. This application demonstrates the use of the ICDE database and examines the applicability of the ICDE data for quantification. Carrying out application examples for other component types can further demonstrate the applicability of the collected ICDE data for quantification. Several national applications have also been performed based on the ICDE data.

## 5.4. Additional information

More information about the ICDE Project may be obtained by visiting:

- The NEA website: www.oecd-nea.org/jointproj/icde.html,
- The CSNI reports web page: www.oecd-nea.org/nsd/docs/indexcsni.html,
- The Operating Agent website: https://projectportal.afconsult.com/ProjectPortal/icde.

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