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CDE Topical Report

Operational Experience on Common-Cause Failures due to External Environmental Factors

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NUCLEAR ENERGY AGENCY

Nuclear Energy Agency

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NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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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 Nuclear Energy Agency (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, from their respective backgrounds in research, development and engineering, to its activities. It has regard to the exchange of information between member countries and safety R&D programmes of various sizes in order 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 in order 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 also considers the safety implications of scientific and technical developments of future reactor technologies and designs. Further, the scope for the Committee includes 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 Nuclear Energy Agency (NEA) member countries initiated the International Common-cause Failure Data Exchange (ICDE) project in 1994. In 1997, the NEA Committee on the Safety of Nuclear Installations (CSNI) formally approved the carrying out of this project within the NEA framework; since then the project has successfully operated over eight consecutive terms, with the current ninth term being 2023-2026.

The purpose of the ICDE project is to allow 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 events, most countries do not experience enough CCF events to perform meaningful analyses. Data combined from several countries, however, yield sufficient data 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 by reports that are distributed without restrictions. It is not the aim of those 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 (2000), "Collection and Analysis of Common-Cause Failure of Centrifugal Pumps", www.oecd-nea.org/jcms/pl_16434.
- NEA (2001), "Collection and Analysis of Common-Cause Failure of Emergency Diesel Generators", www.oecd-nea.org/jcms/pl_17470.

- NEA (2001), "Collection and Analysis of Common-Cause Failure of Motor-Operated Valves*", www.oecd-nea.org/jcms/pl_17516.
- NEA (2002), "Collection and Analysis of Common-Cause Failure of Safety Valves and Relief Valves", www.oecd-nea.org/jcms/pl_17748.
- NEA (2002), "Proceedings of ICDE Workshop on the Qualitative and Quantitative Use of ICDE Data", www.oecd-nea.org/jcms/pl_17508.
- NEA (2003), "Collection and Analysis of Common-Cause Failure of Check Valves", www.oecd-nea.org/jcms/pl_17948.
- NEA (2003), "Collection and Analysis of Common-Cause Failure of Batteries", www.oecd-nea.org/jcms/pl_17978.
- NEA (2008), "Collection and Analysis of Common-Cause Failure of Switching Devices and Circuit Breakers", www.oecd-nea.org/jcms/pl_18524.
- NEA (2008), "Collection and Analysis of Common-Cause Failure of Level Measurement Components", www.oecd-nea.org/jcms/pl_18568.
- NEA (2012), "ICDE General Coding Guidelines – Updated Version", www.oecd-nea.org/jcms/pl_19122.
- NEA (2013), "Collection and Analysis of Common-Cause Failure of Centrifugal Pumps", www.oecd-nea.org/jcms/pl_19250.
- NEA (2013), "Collection and Analysis of Common-Cause Failure of Control Rod Drive Assemblies", www.oecd-nea.org/jcms/pl_19274.
- NEA (2013), "Collection and Analysis of Common-Cause Failure of Heat Exchangers", www.oecd-nea.org/jcms/pl_19648.
- NEA (2015), "ICDE Workshop - Collection and Analysis of Common-Cause Failures Due to External Factors", www.oecd-nea.org/jcms/pl_19670.
- NEA (2017), "ICDE Workshop - Collection and Analysis of Emergency Diesel Generator Common-Cause Failures Impacting Entire Exposed Population", 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", www.oecd-nea.org/jcms/pl_19852.
- NEA (2019), "ICDE Project Report: Summary of Phase VII of the International Common-Cause Data Exchange Project", www.oecd-nea.org/jcms/pl_19902.
- NEA (2020), "ICDE Topical report: Collection and Analysis of Common-Cause Failures due to Plant Modifications", www.oecd-nea.org/jcms/pl_36527.
- NEA (2022, "ICDE Topical Report: Provision against Common-Cause Failures by Improving Testing", www.oecd-nea.org/jcms/pl_75196.
- NEA (2022), "ICDE Topical Report: Collection and Analysis of Multi-Unit Common-Cause Failure Events", www.oecd-nea.org/jcms/pl_75202.
- NEA (2022), "ICDE Topical Report: Collection and Analysis of Intersystem Common Cause Failure Events", www.oecd-nea.org/jcms/pl_69830.

This report was approved by the Committee on the Safety of Nuclear Installations on 3 December 2020 during its 68th session (NEA, 2020), and prepared for publication by the NEA.

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List of abbreviations and acronyms

ASAMPSA	Advanced Safety Assessment Methodologies: Extended PSA
CCCG	Common-cause component group
CCF	Common-cause failure
EDG	Emergency diesel generator
I&C	Instrumentation and control
ICDE	International Common-Cause Failure Data Exchange
PRA	Probabilistic risk assessment
PSA	Probabilistic safety assessment

Note: The acronyms from the ICDE general coding guideline [1] are presented in Annex C.

Organisations

ANVS[1]	Autoriteit Nucleaire Veiligheid en Stralingsbescherming (Authority for Nuclear Safety and Radiation Protection, Netherlands)
CNSC	Canadian Nuclear Safety Commission (Canada)
CSN[2]	Consejo de Seguridad Nuclear (Spain)
CSNI	Committee on the Safety of Nuclear Installations (NEA)
ENSI	Eidgenössisches Nuklearsicherheitsinspektorat (Federal Nuclear Safety Inspectorate, Switzerland)
GRS	Gesellschaft für Anlagen- und Reaktorsicherheit (Germany)
IRSN	Institut de Radioprotection et de Sûreté Nucléaire (France)
KAERI[2]	Korea Atomic Energy Research Institute (Korea)
NRA	Nuclear Regulatory Authority (Japan)
NEA	Nuclear Energy Agency
NRC	Nuclear Regulatory Commission (United States)
OECD	Organisation for Economic Co-operation and Development
ONR[2]	Office for Nuclear Regulation (United Kingdom)

1. New participant for the updated version of this report.
2. CSN, Consejo de Seguridad Nuclear (Spain), KAERI, Korea Atomic Energy Research Institute (Korea) and ONR, Office for Nuclear Regulation (United Kingdom) participated in the development of the first published version, NEA (2015).

SSM	Swedish Radiation Safety Authority (Sweden)
STUK	Finnish Centre for Radiation and Nuclear Safety (Finland)
UJV	Nuclear Research Institute (Czechia)

Executive summary

This report presents a study performed on a set of common-cause failure (CCF) events within the International Common-cause failure Data Exchange (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 (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 over-represented, by 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), with foreseen environmental aspects contributing significantly. An equally large share of the events was 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:

- Biological infestation is often a slow developing failure mechanism. It is important to ensure adequate procedures for 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 a very important aspect, especially during periods when marine growth occurs.
- Hazards related to debris can be avoided in some case 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. In addition, 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 is recommended with consideration of operational experience from events triggered or caused by, for example, freezing effects or the blockage of air/ventilation intakes. In addition, in events during periods of low sea or river temperatures, the importance of monitoring systems dependent on the water intake is paramount.
- 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 hazard PRAs and to support the identification of possible external factors that may have low frequencies but large consequences.

1. Introduction

In the light of the Fukushima Daiichi Nuclear Power Plant accident, a workshop on common-cause failure (CCF) events due to external factors was performed during the International Common-cause Failure Data Exchange (ICDE) steering group meeting in April 2012. The result was published by the Nuclear Energy Agency (NEA) Committee on the Safety of Nuclear Installations (CSNI) in 2015 [3]. In April 2019, a second workshop was performed that included additional identified external factor events, resulting in this updated report. The results of the workshops may serve as input for an in-depth review of the methods and assumptions used in external hazards probabilistic risk assessments (PRA). This report summarises the workshop results and presents an overview of the exchange among several participating countries of CCF data of failures due to external factors. The objectives of this report are:

- To describe the data profile of the ICDE events due to external factors;
- To develop qualitative insights in the nature of the reported events, expressed by event causes, coupling factors and corrective actions; and
- To develop the failure mechanisms and phenomena involved in the events, their relationship to the event causes, and possibilities for improvement.

Chapter 2 presents the identification process of events. Chapter 3 describes the developed classification of the events. Chapter 4 presents an overview of the included events with their event parameters. Chapter 5 contains the engineering insights about the CCF events, supported by the failure mechanism descriptions. Chapter 6 provides a summary and conclusions. References can be found at the end of the report before the annexes.

The ICDE project was organised to exchange CCF data among participating countries. A brief description of the project, its objectives and the participating countries is given in Annex A. Annex B and Annex C present the definition of common-cause failures and the ICDE event definitions [1]. Annex D presents the workshop form that was used in the event analysis.

Annex E presents the concluded failure mechanism descriptions for the event set according to the external factor classification. All tables and conclusions presented in this report are based on the analysis of this event set. From the event analysis, the ICDE aims at providing lessons learnt from actual events and thereby contribute with operating experience feedback.

Other international activities related to the Fukushima Daiichi accident are summarised by the STG-FUKU (NEA Senior-level Task Group on the Impacts of the Fukushima Daiichi Nuclear Power Plant Accident) in [4]. The report outlines the actions that the NEA and its member countries took. Also, key messages and their implications for ensuring high levels of nuclear safety are summarised.

2. Identification of 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 (conditions).

The goal of identification was to identify events due to external factors like storms, hurricanes, extreme outdoor temperatures, excessive algae growth, extreme tide levels and accumulation of sand, as well as combinations of such factors. The preparation started with a brainstorming exercise performed by the ICDE project's operating agent, where the method on how to identify interesting events at the workshop was discussed. It was concluded that the description texts in the ICDE database should be searched for related keywords as well as events with the associated event cause and/or coupling factor. Consequently, the brainstorming resulted in many possible keywords related to events due to external environmental factors. The following keywords were used to identify potential events.

weather	flood
freezing	moisture
freeze	earthquake
environment	eels
pollution	damp
debris	foam
clog	rain
sludge	storm
snow	wind
mussel	sand
lightning	tide

The same events were found for several keywords. In addition, events that were coded with event cause "abnormal environmental stress" and/or coupling factor "environmental external" were also considered.

In the first workshop, 43 external factor events were analysed. In the second workshop, 21 more events were included and analysed, resulting in a total of 64 events. The observation period for these identified events spans from 1977 through 2015. However, the participating countries may have different observation periods for their submitted data. Most of the events and observation years were between 1990 and 2010.

3. Classification of events

For classification of external factor events, the external hazards groups from [2] are used, i.e. "natural" and "man-made". The natural hazards are grouped into the following subgroups.

- Seismotectonic hazards (earthquake)
- Flooding and hydrological hazards
- Meteorological events [5]: extreme values of meteorological phenomena
  a. high or low temperature of air or of cooling water
  b. persistent drought and effects on cooling water supply
  c. high winds including tornado
  d. high or low humidity
  e. snow
  f. icing, freezing, etc.
  g. torrential rain, hail
  h. lightning
  i. related effects like salt deposits at oceanic sites, dust and sand, missiles (such as wind induced missiles), etc.
- Meteorological events: rare meteorological phenomena
- Biological hazards/infestation [5]
  a. encrustation/blockage by mussels
  b. large quantities of algae, jellyfish or fish
  c. large quantities of foliage, grass or weed as flotsam
  d. large quantities of biological flotsam due to a flooding event
  e. microbiologically induced corrosion.
- Geological hazards
- Forest fire

External man-made hazards are grouped into the following subgroups: industrial accidents, military accidents, transportation accidents, pipeline accidents and other man-made external events [2].

Other interesting classification aspects are the hazard duration, hazard predictability (e.g. predictable by weather forecast or unpredictable) and hazard progression (rapidly or gradually) [2].

4. Overview of database content

This chapter presents an overview of the data set, which comprises 64 external factor events. Tables are presented exhibiting the event count for each event parameter (component type, event cause, coupling factor, corrective action, CCF root cause, detection method and event severity). The event parameters are defined in the ICDE general coding guidelines [1], see Annex C.

To put the percentages in context, two values are given. “Percent” is the percentage in relation to the subset of events which was analysed in the workshop. “Relative occurrence” is the occurrence factor of the event parameter in relation to the complete ICDE database content.

It is worth stressing that all relative occurrences need to be interpreted carefully since the statistical certainty is not always high. This is especially important for the event codes with only a few events reported since the relative occurrence can differ significantly if another event is added/removed with that specific event code.

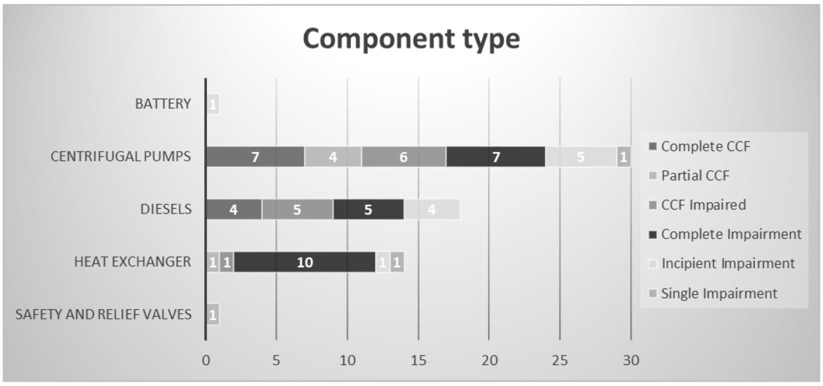
4.1. Component type and event severity

Table 4.1 and Figure 4.1 show the distribution of the events by component type and event severity. The components most susceptible to failures due to external factors are centrifugal pumps, followed by emergency diesel generators (EDG) and heat exchangers. As for relative occurrence, heat exchangers are significantly over-represented, meaning that heat exchangers are more susceptible to external factors than other components. The most common event severity category was “complete impairment” (34%). The relative occurrence of complete CCFs is high, almost a factor two higher compared to the complete ICDE database. It is also noteworthy that these two mentioned severities mean that all components in the CCF group are affected.

Table 4.1. Distribution of component types and event severities

Component type	Complete CCF	Partial CCF	CCF impaired	Complete impairment	Incipient impairment	Single impairment	Total	Percent	Relative occurrence
Battery					1		**1**	**2%**	40%
Breakers							**0**	**0%**	-
Centrifugal pumps	7	4	6	7	5	1	**30**	**47%**	210%
Check valves							**0**	**0%**	-
Control rod drive assembly							**0**	**0%**	-
Emergency diesel generators	4		5	5	4		**18**	**28%**	220%
Fans							**0**	**0%**	-
Heat exchanger		1	1	10	1	1	**14**	**22%**	720%
Level measurement							**0**	**0%**	-
Motor operated valves							**0**	**0%**	-
Safety and relief valves		1					**1**	**2%**	10%
Total	**11**	**6**	**12**	**22**	**11**	**2**	**64**	**100%**	-
Percent	**17%**	**9%**	**19%**	**34%**	**17%**	**3%**	**100%**		
Relative occurrence	**190%**	**70%**	**70%**	**180%**	**70%**	**150%**			

Figure 4.1. Distribution of component types and event severities



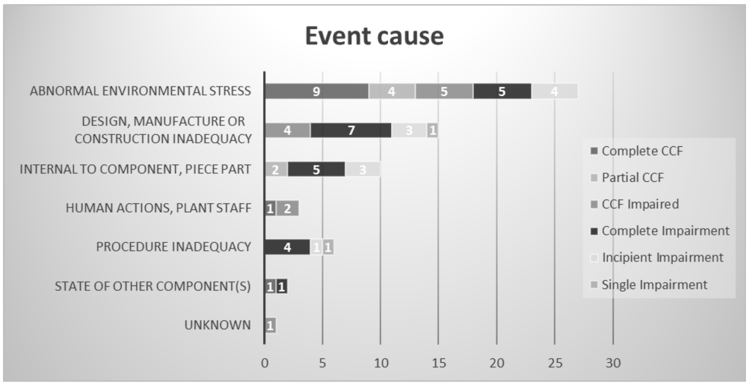
4.2. Event cause

Table 4.2 and Figure 4.2 show the distribution of the events by event causes. The major observed event causes are "abnormal environmental stress" (42%) and "design, manufacture or construction inadequacy" (23%). Many of the events with "abnormal environmental stress" event causes involve debris, algae or mussels causing pumps, heat exchangers or the diesel's coolers to fail due to clogging. As expected, the relative occurrence of abnormal environmental stress is significantly over-represented.

Table 4.2. Distribution of external factor event causes

Event cause	Complete CCF	Partial CCF	CCF Impaired	Complete Impairment	Incipient Impairment	Single Impairment	Total	Percent	Relative occurrence
Abnormal environmental stress	9	4	5	5	4		**27**	**42%**	910%
Design, manufacture or construction inadequacy			4	7	3	1	**15**	**23%**	80%
Human actions, plant staff	1		2				**3**	**5%**	50%
Internal to component, piece part		2		5	3		**10**	**16%**	70%
Maintenance							**0**	**0%**	-
Procedure inadequacy				4	1	1	**6**	**9%**	70%
State of other component(s)	1			1			**2**	**3%**	50%
Other							**0**	**0%**	-
Unknown			1				**1**	**2%**	40%
Total	**11**	**6**	**12**	**22**	**11**	**2**	**64**	**100%**	**-**

Figure 4.2. Distribution of external factor event causes



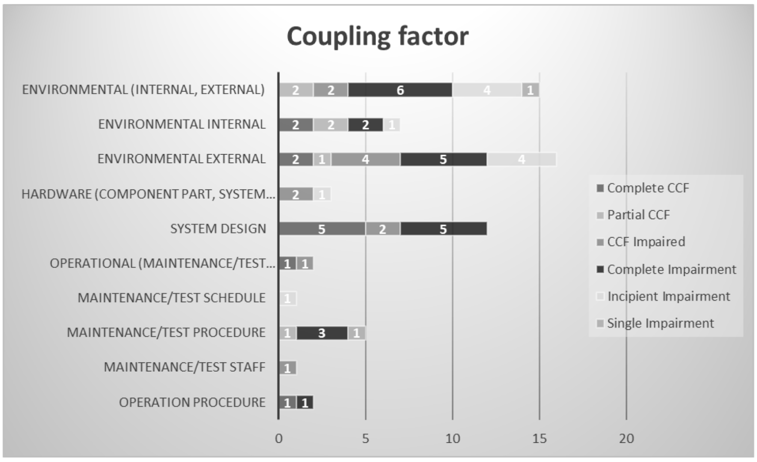
4.3. Coupling factor

Table 4.3 and Figure 4.3 show the distribution of the failure events by coupling factor. The dominant coupling factor category group is as expected “environment”, which accounts for almost 59% of the events due to external factors and the relative occurrence is again significantly over-represented. The most common coupling factors are “environment external”, “environmental” and “system design”. Many of the events with “environment external” coupling factors involve extreme outdoor temperature affecting several components and causing multiple failures. Examples are low outdoor temperature causing non-operable diesel generators due to too cold diesel oil temperatures respectively high outdoor temperatures causing extreme algae growth and clogging of heat exchangers.

Table 4.3. Distribution of external factor coupling factors

Coupling factor	Complete CCF	Partial CCF	CCF Impaired	Complete Impairment	Incipient Impairment	Single Impairment	Total	Percent	Relative occurrence
Environmental (internal, external)		2	2	6	4	1	**15**	**23%**	920%
Environmental External	2	1	4	5	4		**16**	**25%**	1 130%
Environmental Internal	2	2		2	1		**7**	**11%**	150%
Hardware (component part, system configuration, manufacturing quality, installation/configuration quality)			2		1		**3**	**5%**	20%
Hardware Design							**0**	**0%**	-
Hardware Quality Deficiency							**0**	**0%**	-
System Design	5		2	5			**12**	**19%**	250%
Operational (maintenance/test (M/T) schedule, M/T procedure, M/T staff, operation procedure, operation staff)	1		1				**2**	**3%**	40%
Maintenance/test Procedure		1		3		1	**5**	**8%**	60%
Maintenance/test Schedule					1		**1**	**2%**	20%
Maintenance/test Staff			1				**1**	**2%**	30%
Operation Procedure	1			1			**2**	**3%**	230%
Operation Staff								**0%**	-
Total	**11**	**6**	**12**	**22**	**11**	**2**	**64**	**100%**	-

Figure 4.3. Distribution of external factor coupling factors



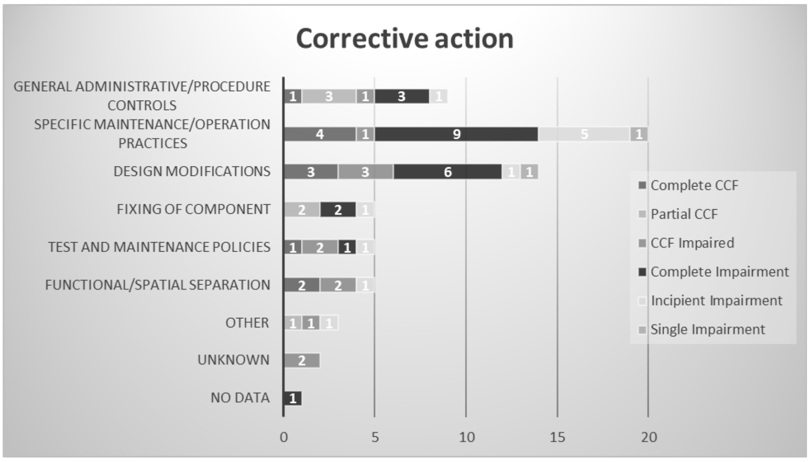
4.4. Corrective action

The distribution of the events for corrective actions is shown in Table 4.4 and Figure 4.4. A broad distribution of corrective actions is observed, but most common are “specific maintenance/operation practices”, followed by “design modifications”. As for the relative occurrence, the “functional/spatial separation” is slightly over-represented.

Table 4.4. Distribution of external factor corrective actions

Corrective action	Complete CCF	Partial CCF	CCF Impaired	Complete Impairment	Incipient Impairment	Single Impairment	Total	Percent	Relative occurrence
General administrative/procedure controls	1	3	1	3	1		**9**	**14%**	90%
Specific maintenance/operation practices	4		1	9	5	1	**20**	**31%**	130%
Design modifications	3		3	6	1	1	**14**	**22%**	100%
Fixing of component		2		2	1		**5**	**8%**	60%
Test and maintenance policies	1		2	1	1		**5**	**8%**	70%
Diversity							**0**	**0%**	-
Functional/spatial separation	2		2		1		**5**	**8%**	240%
Other		1	1		1		**3**	**5%**	100%
Unknown			2				**2**	**3%**	250%
No Data				1			**1**	**2%**	110%
Total	**11**	**6**	**12**	**22**	**11**	**2**	**64**	**100%**	-

Figure 4.4. Distribution of external factor corrective actions



4.5. CCF root cause

The root cause is "the most fundamental reason for an event or adverse condition, which if corrected will effectively prevent or minimise the recurrence of the event or condition.[3]" By combining the coded information for the (apparent) event cause, the corrective action and the coupling factor, insights regarding the CCF root cause of the events can be gained. The combination of the event parameters provides individual root cause aspects, which are combined into one CCF root cause. The possible CCF root cause aspects are:

- deficiencies in the design of components or systems (Design);
- deficiencies in procedures (Procedures);
- deficiencies in human actions (Human actions).

In addition to these three basic aspects, the supporting aspects "environmental" and "unknown" are used in case of events due to external factors or events, which are not completely coded. It is distinguished if all three aspects of an event are identical (e.g. 3 x Design) or if there is a predominant and a contributing root cause aspect (e.g. 2 x design and 1 x procedure). Details on how the CCF root cause aspects are determined are given in the ICDE general coding guideline [1]. The results of the CCF root cause assignment are given in Table 4.5 and Figure 4.5. For about 31% of the events, the concluded CCF root cause was solely or predominant design, where environmental aspects significantly contributed. An equally large share of the events was determined to be "environmental trigger" events, i.e. events with a non-foreseen environmental cause.

Table 4.5. Distribution of external factor CCF root causes

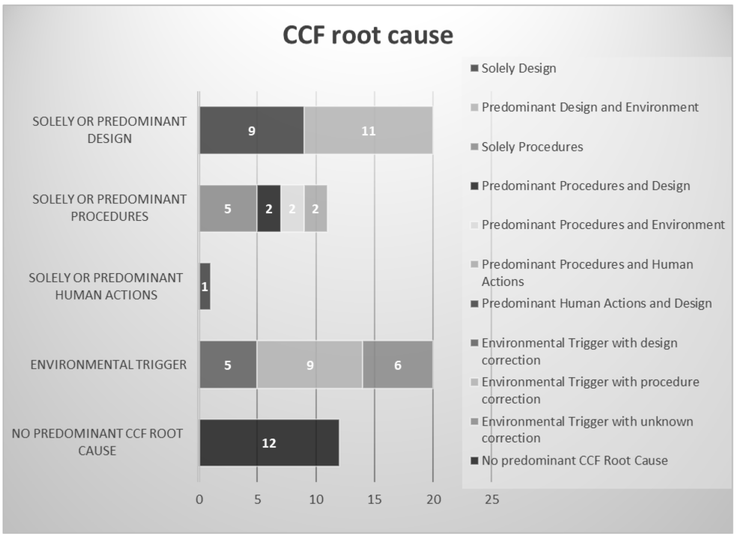
CCF root cause	Total	Percent
Solely or predominant design	**20**	**31%**
Solely design	9	14%
Predominant design and environment	11	17%
Solely or predominant procedures	**11**	**17%**
Solely procedures	5	8%

3. See [9] for more details

Table 4.6. Distribution of external factor CCF root causes (Continued)

CCF root cause	Total	Percent
Predominant procedures and design	2	3%
Predominant procedures and environment	2	3%
Predominant procedures and human actions	2	3%
Solely or predominant human actions	**1**	**2%**
Predominant human actions and design	1	2%
Environmental trigger	**20**	**31%**
Environmental trigger with design correction	5	8%
Environmental trigger with procedure correction	9	14%
Environmental trigger with unknown correction	6	9%
No predominant CCF root cause	**12**	**19%**
Total	**64**	**100%**

Figure 4.5. Distribution of external factor CCF root causes



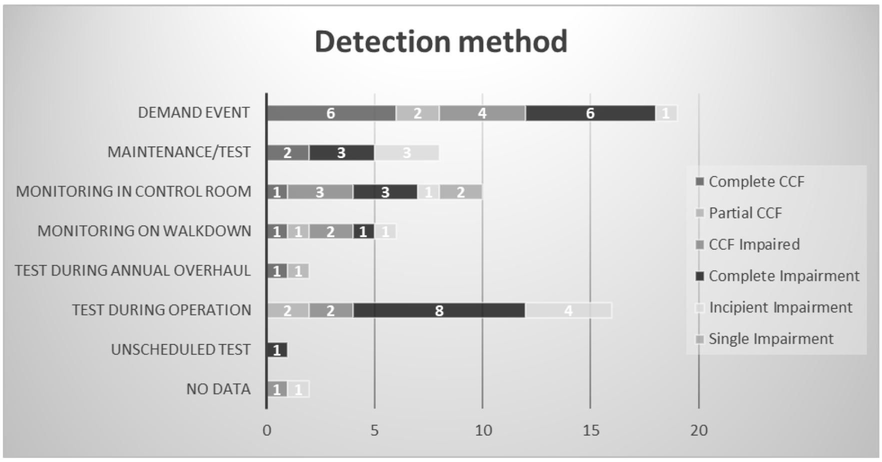
4.6. Detection method

Table 4.6 and Figure 4.6 contain the distribution of the events due to external factors by detection method. The most common detection method was "demand events", i.e. the event occurred when the components were demanded by the safety system. This is not unexpected since the event set involves events related to external factors, which many times result in a demand of the system. For example, an external factor causes a transient and at the same time degradation of the system, and this system is demanded following a transient. In addition, the high number of demand events suggests that these types of "external failures" may be difficult to detect in periodic tests. Moreover, if grouping the detection methods into "test" (includes normal tests, i.e. test during operation and test during annual overhaul) and "not test", it can be seen that 72% of the events are not detected by normal tests.

Table 4.7. Distribution of external factor detection methods

Detection method	Complete CCF	Partial CCF	CCF impaired	Complete impairment	Incipient impairment	Single impairment	Total	Percent
Demand event	6	2	4	6	1		**19**	**30%**
Monitoring in control room	1		3	3	1	2	**10**	**16%**
Monitoring on walkdown	1	1	2	1	1		**6**	**9%**
Maintenance/test	2			3	3		**8**	**13%**
Detection method	**Complete CCF**	**Partial CCF**	**CCF impaired**	**Complete impairment**	**Incipient impairment**	**Single impairment**	**Total**	**Percent**
Test during operation		2	2	8	4		**16**	**25%**
Test during annual overhaul	1	1					**2**	**3%**
Test during laboratory							**0**	**0%**
Unscheduled test				1			**1**	**2%**
Unknown							**0**	**0%**
No data			1		1		**2**	**3%**
Total	**11**	**6**	**12**	**22**	**11**	**2**	**64**	**100%**

Figure 4.6. Distribution of external factor detection methods



5. Engineering aspects of the collected events

This section contains an engineering review of the events due to external factors. The analysis was based on questions listed in the workshop form, see Annex D. In all, 64 events are included in the statistics in the following sections. The engineering aspects of the event analysis consist of:

- What happened
  - environmental triggers, causes and their failure effects;
  - failure mechanism descriptions;
  - interesting event categories.
- What can be done to prevent the event from happening again
  - main areas of improvement;
  - lessons learnt.

5.1. Assessment basis

Failure mechanism description

The failure mechanism is 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. It is derived from the event description and should preferably consist of one sentence.

External factor classification

The external factor events were grouped according to Chapter 3.

Hazard duration, hazard predictability and hazard progression

When studying external factors, different aspects of the hazard itself are interesting. Aspects to consider are hazard duration, hazard predictability (e.g. predictable by weather forecast or unpredictable) and hazard progression (rapidly or gradually).

Areas of improvement

The areas of improvement address what could prevent the event from happening again. They can be considered as lessons learnt from the event analysis and identify possible defences to prevent the occurrence of CCFs.

Interesting event categories

The marking of interesting events in the ICDE database consists of pointing out interesting and extraordinary CCF event records such as subtle dependencies with specific codes and descriptions. These records are important dependency events that are useful for the overall operating experience and can be used as input for the stakeholders to develop defences against CCFs. Several areas may be relevant for a single event.

5.2. External factor classification

Based on the classification presented in Chapter 3, the external factor events could be seen as environmental triggers and divided into two main categories, weather-related events and non-weather events. Then, depending on the type of trigger, a further sub-division of the events into the following environmental causes was possible:

- Flooding and hydrological hazards:
  - high/low seawater/river water level (e.g. low tide);
  - underwater debris (e.g. accumulation of sand causing wear or clogging).
- Meteorological events:
  - high/low air temperature (e.g. the build-up of ice plugs);
  - rainfall or snowfall (e.g. block air intake due to heavy snowfall).
- Biological infestation (e.g. mussels or algae in water intake or airborne particles/pollution, which leads to clogging).
- Other.

The results are summarised in Table 5.1. Annex E presents the concluded failure mechanism descriptions according to the external factor classification. Table 5.2 shows the affected system function as an additional engineering aspect.

Table 5.1. Classification of external factors

External factor classification	Complete CCF	Partial CCF	CCF impaired	Complete impairment	Incipient impairment	Single impairment	Total	Percent
Non-weather related	**8**	**5**	**4**	**18**	**10**	**1**	**46**	**72%**
Biological	7	1	1	10	5	1	25	39%
Flooding and hydrological hazards		4	3	8	4		19	30%
Man-made - pollution (sandblasting)	1						1	2%
Potential Seismic					1		1	2%
Weather-related	**3**	**1**	**8**	**4**		**1**	**17**	**27%**
Flooding and hydrological hazards			4			1	5	8%
Meteorological - temperature	2	1	4				7	11%
Meteorological - snow				2			2	3%
Meteorological - winds	1						1	2%
Meteorological - rain				2			2	3%
Audit					**1**		**1**	**2%**
Meteorological - temperature					1		1	2%
Total	**11**	**6**	**12**	**22**	**11**	**2**	**64**	**100%**

Table 5.2. Affected system by external factors

Safety function	System	Component type	Failure effect (clogging, wear, etc.)	Environmental cause	Count of CCF event
Primary reactor systems	**Primary coolant (pumps and associated materials, loop piping, ...)**	Pumps	**Loss of oil pump board**	Rain water	1
	Steam generator, Boiler, Steam drum	SRV	**Faulty actuator**	Low temperature	1
Primary reactor systems Total					**2**
Essential reactor auxiliary systems	**Auxiliary and emergency feedwater**	Pumps	**Clogging**	Mussels and mud	1
			Pump diesel fuel problems	Moisture build-up	1
	Emergency core cooling (core spray or RHR, CVCS participation)	Pumps	**Freezing**	Low temperature	1
Essential reactor auxiliary systems Total					**3**
Essential service systems	**Component cooling water (including reactor building closed cooling water)**	Heat exchanger	**Clogging**	Clams	4
				Eels	1
				Foreign material	1
				High water level, foliage and seaweed.	1
				Marine growth	1
				Mussels	1
				Mussels and algae	1
	Containment spray and ice condensers	Heat Exchanger	**Clogging**	Clams	1
				Marine growth	1
				Mussels	1
				Shellfish	1
	Essential raw cooling or service water	Pumps	**Wear**	Sand	10
			Clogging	Debris	2
				Debris from flooding	2
				Jellyfish	2
				Sand	3
				Seaweed	2
			Freezing	Low temperature	2
			Flooding	High seawater level (Storm tide)	1
			Inadequate cooling	High temperature	1
			Tripping of pumps	Low sea water level (low tide)	1
Essential service systems Total					**40**
Electrical systems	**DC power**	Battery	**Cracks in batteries**	Potential earthquake	1
	Emergency power generation and auxiliaries (includes fuel oil supply)	Diesels	**Blocked air intake**	Snow	2
			Clogging	Debris	2
				Fish	2
				Mussels	5
				Water pollution	1
			Corrosion	Rain water	1
			Freezing	Low temperature	1
			Insufficient greasing	Low temperature	1
			Loss of air supply	Pollution (man-made)	1
			Loss of off-site power	High winds	1
			Low oil temperature	Low temperature	1
Electrical systems total					**19**
Total					**64**

Weather-related events

The weather-related events concerned mainly meteorological phenomena including temperature and snow or rain. Some events were due to debris from flooding.

Most of the meteorological events are predictable by weather forecast. The hazard duration of extreme weather varies a lot and, depending on the severity of the weather, the hazard can progress gradually or rapidly.

In case of flooding, the amount of debris and its potential effect on the plant and systems can be difficult to predict. The hazard durations of such events are short and the progression is generally rapid. For example, clogging due to debris can build up gradually or occur quickly.

As for the event severity, the weather-related events involved different degrees of severity, with three events resulting in a complete CCF. In most cases, all components in the CCF groups were affected.

Non-weather-related events

The non-weather related events cover 72% of the event set and consist almost entirely of events related to the water intake, with environmental causes related to biological infestation or underwater debris/sediments (mainly sand). Sediments, such as sand, affect components gradually and in some cases this is detected in time before complete failure of the components occurs. Sand can result in wear of component parts and in some events even clogging.

The non-weather related events are much harder to predict. Some analysis is done in the system design process, and most biological infestation is predictable, e.g. when algae bloom. However, while the impact of underwater debris such as sand is expected in many cases, the effect on the components may be difficult to assess. The degradation or failure of components will occur slowly over time, but when, for example, a heat exchanger clogs and fails, the effect is direct.

Many of the non-weather-related events are slow and can be avoided through ageing management, surveillance of components and maintenance programmes.

5.3. Areas of improvement

Improvements to mitigate biological infestation

Biological infestation is often a slow-developing failure mechanism. Potential improvements involve:

- the installation of mussel strainers;
- improvements in the procedures for cleaning strainers, tubes and plates, and the addition of backflush capability;
- improvements to the monitoring capability (e.g. control of flow rate and temperature conditions).

Improvements to mitigate non-weather related flooding and hydrological hazards

Hazards related to debris can be avoided in some case with an improved design of strainers. However, it can be difficult to create sufficient defences against clogging due to heavy debris.

For the large portion of the events related to degradation due to sand intrusion in the system, the potential improvements involve the following:

- improved monitoring of sand in the system suction lines;
- a system design change to use a pond, rather than raw river water, to reduce sand in the system intake;
- improvement of components, especially the strainers;
- maintenance, design and operational practices.

Improvements to mitigate meteorological effects

Potential improvements to mitigate the classified meteorological events involve:

- system design changes (e.g. improved piping to avoid freezing effects, improved air/ventilation intakes and leak tightness of buildings);
- procedural and operational measures and instructions;
- improved monitoring, especially for the events related to low sea or river temperatures.

5.4. Interesting event categories

Table 5.3 presents the statistics for each interesting event code defined in the ICDE general coding guidelines. An event can be assigned to more than one code.

Table 5.3. Applied interesting event codes

Interesting CCF event codes	**No. of events**
Complete CCF	11
CCF outside planned test	6
Component not-capable	1
Multiple defences failed	0
Sequence of multiple CCF failure mechanisms	0
Multiple systems affected	1
Common-cause initiator	8
Safety culture	3
Multi-unit CCF	20
No code applicable	32
Total codes	**82**

The insights from the applied interesting event codes are:

- Multi-unit CCF: A total of 20 events were marked as multi-unit CCFs. The high portion of multi-unit events is not unexpected since many events involve issues related to biological infestation and underwater debris in the water intake, which is often shared between units. A detailed analysis of multi-unit aspects is addressed in another ICDE topical report, see [6].
- Complete CCF: This event code sums up all the complete CCFs. It is noteworthy that the share of complete CCFs is relatively high compared to the complete ICDE database.
- Common-cause initiator: Eight events were marked as common-cause initiators (CCI), Table 5.4. Four of these events involved two multi-unit events affecting both units with a biological infestation (build-up of fish/jellyfish) and resulted in a complete CCF. The other three events were weather-related.

Table 5.4. CCI events

Component type	CCF root cause	Failure mechanism description	Event Id
Centrifugal pumps	Predominant design and environment	Build-up of jellyfish at intake led to air ingress into the suction lines and failure of both pumps.	15416 15528
Diesels	Solely design	EDG failed due loss of cooling caused by ice forming in the service water pump column (environmental conditions).	15484
	Solely design	The turbo of diesel generator units were replaced. Misjudgment of the new turbo wall inserts lead to an unanticipated resonance induced vibration resulting in fatigue failure of compressors impeller blade.	9073 9103
	Predominant procedures and human actions	Severe winds led to loss of grid + 2 diesels were mistakenly shut down + electrical supply switched back from DG to grid without resetting reactor shutdown system + no training when loss of grid + reactor shutdown causing complete failure of 2 diesels.	15395
	Environmental trigger with design correction	A large school of fish impinging on the intake screens of the essential service water systems caused screens to fail and caused the clogging of EDG heat exchangers. EDGs were declared inoperable due to loss of cooling.	16371 16372
Heat exchanger	Predominant design and environment	A very high water level of the river combined with a high amount of foliage and grass led to clogging of the tube sides of service water heat exchangers.	15950
	Solely procedures	When a plate screen was dismounted, eels were sucked into the intake that led to clogging of 3 out of 4 heat exchangers for the residual heat cooling and diesel generator cooling.	15964

- CCF outside planned test: Six events were marked as interesting due to the fact that they occurred outside planned tests. One event of special interest was detected through an audit at the plant. An investigation revealed that in case of prolonged high air temperature, the cooling water in the alternate cooling tower would not be able to provide sufficient cooling (outside design basis). A detailed analysis of testing inadequacies is addressed in another ICDE topical report, see [7].
- Safety culture: Three events were marked as interesting from a safety culture perspective. One event involved a faulty switch that prevented activation of the freeze protection system during low outside temperature and led to ice plugs in the suction line to both pumps. This protection system had previously been revised after problems with it, but these actions were unsuccessful. In addition, the administrative controls did not sufficiently recognise the safety significance of this protection system. In addition, ineffective communication between operations and maintenance personnel prevented a thorough evaluation.

6. Summary and conclusions

This report covers 64 ICDE events that were reviewed with respect to the degree of failure (expressed as event severity), the event parameters and the CCF root causes.

The goal of the workshop was to review operational plant experiences of external factor events, such as storms, hurricanes, extreme air temperatures, excessive algae growth, extreme tide levels, accumulation of sand and combinations of such factors. The classification and analysis of the external factor events was based on the hazard groups in [2], i.e. external, natural and man-made.

Summary of database content:

- 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 over-represented in this study compared to the overall ICDE database.
- The main observed event causes are "abnormal environmental stress" (42%) and "design, manufacture or construction inadequacy" (23%). The "abnormal environmental stress" is significantly over-represented, by a factor of nine compared to the complete ICDE database.
- The dominant coupling factor category group is, as expected, "environment." It accounts for almost 59% of the events due to external factors and is again significantly over-represented.
- A broad range of corrective actions is observed, but the most common are "specific maintenance/operation practices".
- For about 31% of the events, the concluded CCF root cause was solely or predominantly design, where environmental aspects contributed significantly. An equally large share of the events was determined to be "environmental trigger" events, i.e. events with a non-foreseen environmental cause.
- The most common detection method was "demand events", i.e. the event occurred when the components were demanded by the safety system. This is not unexpected since the event set involves events related to external factors, which can easily result in a demand of the system.

Summary of the engineering aspects:

- The non-weather related events cover 72% of the event set and consist almost entirely of events related to the water intake, with environmental causes related to biological infestation or underwater debris/sediments (mainly sand).
- The weather-related events concern mainly different meteorological phenomena including temperature and snow or rain. In addition, some events were due to debris from flooding.
- Some events were not detected by regular tests and the observed impairments could have developed into more severe failures if not detected. Here, increased monitoring was one of the most common types of operational improvements.
- The recurrence of some kinds of events indicates that taking action upon operating experience feedback sometimes takes too long.

- Since many of the events due to external factors involve seawater problems, important hardware improvements involve system design changes of the water intake. In addition, improved cleaning of strainers was found to be important.

Lessons learnt from the engineering aspects:

- Biological infestation is often a slow developing failure mechanism. It is important to ensure adequate procedures for the cleaning of strainers, tubes and plates, and the addition of a backflush capability. In addition, the monitoring capability (e.g. control of flow rate and temperature conditions) is important, especially during periods of marine growth.
- Hazards related to debris can be avoided in some case with an improved design of the strainers. However, sufficient defences against clogging from heavy debris are difficult to achieve.
- For a large part of the events related to degradation due to sand intrusion in the system, monitoring in combination with maintenance and operational practices may have detected the degradation before components failed. In addition, an adequate ageing management programme could have prevented several of the events.
- Biological infestation and debris in the water intake is 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 is recommended, with consideration of operational experience from events triggered or caused by, for example, freezing effects or the blockage of air/ventilation intakes. In addition, events that occurred during periods of low sea or river temperatures show the vital importance of monitoring systems dependent on the water intake.

The results of this analysis may serve as input for an in-depth review of the methods and assumptions used in external hazards PRAs. The initial revision of this report [3] was motivated by the reassessment of external hazards among the international community after the Fukushima Daiichi Nuclear Power Plant accident; see the PSAM 11 paper [8] and the ASAMPSA project (Advanced Safety Assessment Methodologies, http://asampsa.eu/). It is important to continue to identify potential external hazards. The aim of this research is to identify possible "external events" that may have low frequencies but large consequences or that may result from combinations of different impacts not yet considered in current external hazard PRAs.

References

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[5] IRSN (2016), "Selecting Initiating Events for an Extended PSA Report", ASAMPSA_E-WP 30- D30.3-2016-13/IRSN/PSN-RES-SAG 16-101, Institut de radioprotection et de sûreté nucléaire, Fontenay-aux-Roses.

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Annex A. Overview of the ICDE project

Background

Common-cause failure (CCF) events can significantly impact the availability of safety systems of nuclear power plants. In recognition of this, CCF data are being systematically collected and analysed in several countries. A serious obstacle to the use of national qualitative and quantitative data is that the criteria and interpretations applied in the collection and analysis of events and data differ between countries. A further impediment is that descriptions of reported events and their root causes and coupling factors, which are important to the assessment of the events, are usually written in the native language of the countries where the events were observed.

To overcome these obstacles, the preparation for the International Common-cause Data Exchange (ICDE) project was initiated in August of 1994. Since April 1998, the NEA has formally operated the project, following which the project was operated over eight consecutive terms from 1998 to 2022. The current phase started in 2023 and is due to run until the end of 2026. The member countries under the current 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), Sweden (SSM), Switzerland (ENSI) and the United States (NRC).

More information about the ICDE project can be found on the NEA website: www.oecd-nea.org/jcms/pl_25090. Additional information can also be found at the website https://projectportal.afconsult.com/ProjectPortal/icde.

Scope of the ICDE project

The ICDE project aims to include all possible events of interest, comprising complete, partial and incipient CCF events, called "ICDE events" in this report. The project covers the key components of the main safety systems, including centrifugal pumps, diesel generators, motor operated valves, power operated relief valves, safety relief valves, check valves, main steam isolation valves, heat exchangers, fans, batteries, control rod drive assemblies, circuit breakers, level measurement and digital instrumentation and control (I&C) equipment.

Data collection status

Data are collected in an MS.NET based database implemented and maintained at ÅF, Sweden, the appointed ICDE operating agent. The database is regularly updated. It is operated by the operating agent following the decisions of the ICDE steering group.

ICDE coding format and coding guidelines

Data collection guidelines have been 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 general coding guidelines and in the component-specific guidelines. Component-specific guidelines are developed for all analysed component types as the ICDE plans evolve [1].

Protection of proprietary rights

Procedures for protecting confidential information have been developed and are documented in the Terms and Conditions of the ICDE project. The co-ordinators in the participating countries are responsible for maintaining proprietary rights. The data collected in the database are password protected and are only available to ICDE participants who have provided data.

Annex B. Definition of common-cause events

In the modelling of common-cause failures in systems consisting of several redundant components, two kinds of events are distinguished:

- Unavailability of a specific set of components of the system, due to a common dependency (for example, on a support function). If such dependencies are known, they can be explicitly modelled in a PSA.
- Unavailability of a specific set of components of the system due to shared causes that are not explicitly represented in the system logic model. Such events are also called "residual" CCFs. They are incorporated in PSA analyses by parametric models.

There is no rigid borderline between the two types of CCF events. There are examples in the PSA literature of CCF events that are explicitly modelled in one PSA and are treated as residual CCF events in other PSAs (for example, CCF of auxiliary feedwater pumps due to steam binding, resulting from leaking check valves).

Several definitions of CCF events can be found in the literature, for example in NUREG/CR-6268, Revision 1 "Common-Cause Failure Data Collection and Analysis System: Event Data Collection, Classification, and Coding":

"Common-Cause Failure Event: 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."

A CCF event consists of component failures that meet four criteria: (1) two or more individual components fail, are degraded (including failures during demand or in-service testing), or have deficiencies that would result in component failures if a demand signal had been received; (2) components fail within a selected period of time such that success of the probabilistic risk assessment (PRA) mission would be uncertain; (3) components fail because of a single shared cause and coupling mechanism; and (4) components fail within the established component boundary.

In the context of the data collection part of the ICDE project, the focus will be on CCF events with total as well as partial component failures that exist over a relevant time interval[4]. To aid in this effort. the following attributes are chosen for the component fault states, also called impairments or degradations:

- Complete failure of the component to perform its function.
- Degraded ability of the component to perform its function.
- Incipient failure of the component.
- Default: component is working according to specification.

Complete CCF events are of particular interest. A "complete CCF event" is defined as a dependent failure of all components of an exposed population where the fault state of each of its components is a "complete failure to perform its function" and where these fault states exist simultaneously and are the direct result of a shared cause. Thus, in the ICDE project, we are interested in collecting complete CCF events as well as partial CCF events. The

4. Relevant time interval: two pertinent inspection periods (for the particular impairment) or, if unknown, a scheduled outage period.

ICDE data analysts may add interesting events that fall outside the CCF event definition but are examples of recurrent - eventually non-random - failures. With a growing understanding of CCF events, the relative share of events that can only be modelled as "residual" CCF events is expected to decrease.

Annex C. ICDE general coding guidelines[5]

Event cause

In the ICDE database, the event cause describes the direct reason for the component's failure. For this project, the appropriate code is the one representing the common-cause, or if all levels of causes are common-cause, the most readily identifiable cause. The following coding was suggested:

C State of other components. The cause of the state of the component under consideration is due to the state of another component.

D Design, manufacture or construction inadequacy. This category encompasses actions and decisions taken during the design, manufacture or installation of components, both before and after the plant is operational. Included in the design process are the equipment and system specification, material specification and initial construction that would not be considered a maintenance function. This category also includes design modifications.

A Abnormal environmental stress. This represents causes related to a harsh environment that is not within component design specifications. Specific mechanisms include chemical reactions, electromagnetic interference, fire/smoke, impact loads, moisture, radiation, abnormally high or low temperature, vibration load and severe natural events.

H Human actions. This represents causes related to errors of omission or commission on the part of plant staff or contractor staff. This category includes accidental actions and failure to follow procedures for construction, modification, operation, maintenance, calibration and testing. This category also includes deficient training.

M Maintenance. All maintenance not captured by H – human actions or P – procedure inadequacy.

I Internal to component or piece part. This deals with the malfunctioning of internal parts of the component. Internal causes result from phenomena such as normal wear or other intrinsic failure mechanisms. It includes the influence of the environment on the component. Specific mechanisms include corrosion/erosion, internal contamination, fatigue and wear out/end of life.

P Procedure inadequacy. Refers to ambiguity, incompleteness or error in procedures for the operation and maintenance of equipment. This includes inadequacy in construction, modification, administrative, operational, maintenance, test and calibration procedures. This can also include administrative control procedures such as change control.

O Other. The cause of event is known, but does not fit in one of the other categories.

U Unknown. The cause of the component state cannot be identified.

Coupling factor

The ICDE general coding guidelines [1] define coupling factor as follows: "The coupling factor field describes the mechanism that ties multiple impairments together and identifies the influences that created the conditions for multiple components to be affected."

[5] The coding names and descriptions in this annex were drawn from [1].

For some events, the event cause and the coupling factor are broadly similar, with the combination of coding serving to give more detail as to the causal mechanisms. Selection is made from the following codes:

H Hardware (component, system configuration, manufacturing quality, installation, configuration quality). Coded if none of or more than one of HC, HS or HQ applies, or if there is not enough information to identify the specific ‘hardware’ coupling factor.

HC Hardware design. Components share the same design and internal parts.

HS System design. The CCF event is the result of design features within the system in which the components are located.

HQ Hardware quality deficiency. Components share hardware quality deficiencies from the manufacturing process. Components share installation or construction features, from initial installation, construction or subsequent modifications

O Operational (maintenance/test (M/T) schedule, M/T procedures, M/T staff, operation procedure, operation staff). Coded if none or more than one of OMS, OMP, OMF, OP or OF applies, or if there is not enough information to identify the specific ‘maintenance or operation’ coupling factor.

OMS M/T schedule. Components share maintenance and test schedules. For example, the component failed because maintenance procedure was delayed until failure.

OMP M/T procedure. Components are affected by the same inadequate maintenance or test procedure. For example, the component failed because the maintenance procedure was incorrect or calibration set point was incorrectly specified.

OMF M/T staff. Components are affected by maintenance staff error.

OP Operation procedure. Components are affected by inadequate operations procedure.

OF Operation staff. Components are affected by the same operations staff personnel error.

E Environmental, internal and external.

EI Environmental internal. Components share the same internal environment. For example, the process fluid flowing through the component was too hot.

EE Environmental external. Components share the same external environment. For example, the room that contains the components was too hot.

U Unknown. Sufficient information was not available in the event report to determine a definitive coupling factor.

Detection method

The ICDE general coding guidelines [1] suggest the following coding for the detection method for each failed component of the exposed population:

MW Monitoring on walkdown

MC Monitoring in control room

MA Maintenance/test

DE Demand event (failure when the response of the component(s) is required)

TI Test during operation

TA Test during annual overhaul

TL Test during laboratory

TU Unscheduled test

U Unknown

Corrective action

The ICDE general coding guidelines [1] define corrective action as follows. The corrective actions field "describes the actions taken by the licensee to prevent the CCF event from re-occurring". The defence mechanism selection is based on an assessment of the event cause and/or coupling factor between impairments. Selection is made from the following codes:

A General administrative/procedure controls.

B Specific maintenance/operation practices.

C Design modifications.

D Diversity. This includes diversity in equipment, types of equipment, procedures, equipment functions, manufacturers, suppliers, personnel, etc.

E Functional/spatial separation. Modification of the equipment barrier (functional and/or physical interconnections). Physical restriction, barrier or separation.

F Test and maintenance policies. Maintenance programme modification. The modification includes item such as staggered testing and maintenance/ operation staff diversity.

G Fixing component

O Other. The corrective action is not included in the classification scheme.

CCF root cause

For each event, the event cause, the corrective action and the coupling factor are assigned to one of the three basic CCF root cause aspects listed below:

- *Deficiencies in the design of components or systems (D):* This category comprises all events where safety-relevant components or systems were not available or otherwise impaired due to deficiencies in the design. This although they were operated and maintained procedurally correct and under circumstances (ambient temperature, fluid temperature, pressure, etc.) within the expected limits. In general, these events require changes to hardware as corrective action.
- *Procedural or organisational deficiencies (P):* This category comprises all events where a) wrong or incomplete procedures were applied and followed and b) events which happened because of organisational deficiencies of one or more of the involved entities (utilities, subcontractors, TSO, regulating bodies, etc.). In general, these events require changes to procedures or organisational improvements as corrective action.
- *Deficiencies in human actions (H):* This category comprises all events, which happened because of erroneous human actions. Corrective actions for these events may involve training measures, further improvements of procedures and instructions or organisational improvements (e.g. more personnel).

The CCF root causes are further discussed in the ICDE general coding guidelines [1].

Event severity

The severity category expresses the degree of severity of the event based on the individual component impairments in the 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	The event does not contain multiple impairments. Only one component impaired. No CCF event.

Interesting CCF event categories

Interesting CCF event codes	**Description** ***Purpose***
Complete CCF **(1)**	Event has led to a complete CCF. *This code sums up all complete CCFs, for any component type.*
CCF Outside planned test **(2)**	The CCF event was detected outside of normal periodic and planned testing and inspections. *The code gives information about test efficiency when CCFs are observed by other means than ordinary periodic testing – information about weaknesses in the defense-in-depth level 2.*
Component not-capable **(3)**	The event revealed that a set of components was not capable of performing its safety function over a long period of time. *The code gives information about a deviation from deterministic approaches when it is revealed that two or more exposed components would not perform the licensed safety function during the mission time.*
Multiple defences failed **(4)**	Several lines of defence failed *More than one line of defence against CCF failed, e.g. in the QA processes of the designer, manufacturer, TSO and utility during construction and installation of a set of components.*
NO LONGER USED **CCF new failure mechanism (5)**	The event revealed an unattended or not foreseen failure mechanism. *The code gives information about a new CCF event revealed and a new failure mechanism not earlier documented in the licensing documentation or operating history.*

Interesting CCF event codes	**Description** ***Purpose***
Sequence of multiple CCF failure mechanisms (6)	Events with a sequence of multiple CCF failure mechanisms. *The code gives information about incidents that revealed that during the event sequence more than one CCF failure mechanism was observed. The code focuses on the sequence of failures in the observed CCF failure mechanisms, regardless of how many common cause component groups (CCCGs) were affected.*
NO LONGER USED **CCF causes modification (7)**	The event causes major modification *The code gives information about a CCF event revealed that has led to or will lead to a major plant or system or component modification*.
Multiple systems affected (8)	Events where a single CCF failure mechanism affected multiple systems. *This code indicates events where a single CCF failure mechanism affected components in more than one different system or affected more than one different safety function. In most cases, these events are Cross Component Group CCFs (X-CCF).*
Common-cause initiator (9)	A dependency event originating from an initiating event of type common-cause initiator (CCI) – a CCF event that is at the same time an initiator and a loss of a needed safety system. *The code gives information about an event with direct interrelations between the accident mitigation systems through common support systems. An event of interest, for example, to PSA analysts and regulators.*
Safety culture (10)	The reason why the event happened originates from safety culture management. Understanding, communication and management of requirements have failed. *The code gives information about CCF events that have occurred that can be said to have originated from management and safety culture factors.*
Multi-unit CCF (11)	CCF affecting a fleet of reactors or multiple units at one site *The code gives information about CCF events that have occurred and affected several plants at a site. The events have to originate from a common event cause.*
No code applicable (12)	Indicates that the event has been analysed but the event is not considered to be highlighted and therefore none of the codes is applicable.
Other remarkable events (13)	Other remarkable events not covered by the other codes but worth to noting. *The code gives information, for example, about an important new CCF failure mechanism not earlier documented in the licensing documentation or operating history, or about a CCF event that has led to or will lead to a major plant or system modification.*
Questionable coding (14)	Indicates that there are comments on the event coding in the analyst comment field.

Interesting CCF event codes	**Description** ***Purpose***
Shutdown and decommissioning (15)	Events with a special interest for plants planning for permanent shut-down or decommissioning state. *This code indicates events where CCF phenomena were observed that might be of special interest for non-power operation modes. It should not be used for components like the EDGs where the importance in all plant states is obvious.*

Annex D. Workshop form

Main areas of improvement

- Can any areas of improvement be identified in order to prevent the event from happening again?
- What could have prevented the event from developing into a more severe event (i.e. complete or partial CCF event)? Try to continue the sentence "Much happened because…"

Examples of conclusions:

- The event developed slowly during plant operation, creating degraded or fault conditions of components. Much happened because of incomplete operating and maintenance procedures.
- Area of improvement: Ensuring comprehensive work control.
- Area of improvement: Better planning of tests/maintenance.
- Area of improvement: Comprehensively prescribing the steps of testing required in the re-qualification of components or systems after maintenance, repair or backfitting work.

Lessons learnt

- Can any general lessons be drawn regarding the event?
- Do the less severe events (CCF impaired or complete impairment) contain any specific factor or defence preventing it from being a more severe event (i.e. complete or partial CCF event)? Try to continue the sentence "Nothing happened because…"

Examples of conclusions:

- Nothing happened because of the chosen testing technique.
- The types of failures are extremely random, which indicates difficulties in identifying specific important defence factors. Hence, nothing happened because of luck.
- General lesson: High redundancy is an effective defence against complete CCF. However, complete CCF cannot be prevented by high redundancy.
- General lesson: The higher the degree of redundancy, the more it takes human inadvertent action to fail the system.

Other aspects of interest

- Have you found any new failure modes, unusual failure mechanisms or unusual ways of operation of value for the overall operating experience of the respective component?
- Are there any other findings that are not yet taken into account in the coding guideline for the respective component?
- At which operational mode was a failure discovered?

- Does the event report give enough qualitative information about the system configurations, technical specification demands or other important elements?

Comment on event coding

- Have you found any uncertainties regarding the event coding?
- Are there any other findings that concern the coding of the event?

Annex E. Failure mechanism descriptions

Classification and event severity	Total	Failure mechanism description
Biological	**25**	
Complete CCF	2	A large school of fish impinging on the intake screens of the essential service water systems caused screens to fail and caused the clogging of EDG heat exchangers. EDGs were declared inoperable due to loss of cooling.
Complete CCF	1	Algae growth in the shared fuel tank led to failure to run the diesel driven pumps.
Complete CCF	2	Build-up of jellyfish at intake led to air ingress into the suction lines and failure of both pumps.
Complete CCF	2	Ingress of seaweed led to air in suction path that caused failure of both pumps.
Partial CCF	1	Marine growth led to reduced flow and clogging of heat exchanger tubes.
CCF impaired	1	Sludge movement in the sea water channel led to reduced heat capacity of sea water heat exchangers for two diesel generators.
Complete impairment	1	Debris (clam shells and ferrous materials) led to clogging of heat exchangers.
Complete impairment	4	Debris (clam shells) led to clogging and degradation of the heat exchangers.
Complete impairment	1	Marine growth and dirt at the intake of the essential service water system degraded both pumps.
Complete impairment	1	Missing (too late) addition of biocides in the intake water after the winter caused degradations of the heat exchangers.
Complete impairment	1	Mussel growth led to clogging and degraded heat exchangers.
Complete impairment	1	Mussels and other biological debris led to clogging and degradation of the two heat exchangers.
Complete impairment	1	Shellfish led to clogging and degradation of both heat exchangers.
Incipient impairment	1	Debris (mussels and algae) led to clogging and degradation of the heat exchangers.
Incipient impairment	1	Mussels were clogging the heat exchangers, which led to high temperatures and frequency swings of the diesel generators.
Incipient impairment	1	Sludge movement in the sea water channel led to reduced heat capacity of sea water heat exchangers for three diesel generators.
Incipient impairment	2	Sludge movement in the sea water channel led to reduced heat capacity of sea water heat exchangers for two diesel generators.
Single impairment	1	When a plate screen was dismounted, eels were sucked into the intake, which led to clogging of 3 out of 4 heat exchangers for the residual heat cooling and diesel generator cooling.
Flooding and hydrological hazards	**24**	
Partial CCF	1	Cooling lost to 2 out of 4 pumps due to clogging by sand.
Partial CCF	1	Foreign material in suction path led to damage of pump shaft coupling of two pumps.
Partial CCF	1	Motor cooler plugged by sand caused loss of two out of four RHRSW pumps.

Classification and event severity	**Total**	**Failure mechanism description**
Partial CCF	1	Pump impeller wear due to sand in the suction path resulting in high pump rotation and high pump motor current.
CCF impaired	1	A high coefficient for low tide led to tripping of the pump.
CCF impaired	1	A very high water level of the river combined with a high amount of foliage and grass led to clogging of the tube sides of service water heat exchangers.
CCF impaired	1	Broken impeller blades of auxiliary service water pumps due to wear in a sand-containing medium.
CCF impaired	1	Design error resulted in too large gap between radial bearing and shaft-enclosing tube permitted sand from the river to get into the grease-lubricated bearing and damage the bearing.
CCF impaired	1	Overtemperature of diesel due to dirt deposition on heat exchanger due to high iron content of well water. Depending on circumstances, river or well water is used.
CCF impaired	2	Two out of three service water pump bearing oil coolers plugged by heavy debris from flooding.
Complete impairment	1	Foreign material (sandy lake water) in suction path degrading the seal water supply to the pumps.
Complete impairment	1	Foreign material clogs heat exchanger tubes due to strainer/screen degradation.
Complete impairment	2	Improper strainer assembly, which led to stress on welds and damaged strainer basket in combination with cross-connection of strainers and caused clogging of both heat exchangers that supply the two diesel generators with cooling water.
Complete impairment	4	Pump impeller wear due to sand in the suction path.
Incipient impairment	1	Debris in the intake structure reduced the flow rate and led to failure of two pumps.
Incipient impairment	2	Pump impeller wear due to sand in the suction path.
Incipient impairment	1	Wear of pump internals due to sand entrained in suction path.
Single impairment	1	Flooding due to corroded bolting of seal plates led to failure of the pump.
Man-made - pollution (sandblasting)	**1**	
Complete CCF	1	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 of the diesel generators.
Meteorological - Rain	**2**	
Complete impairment	1	Leakage of a coolant pipe due to corrosion caused by rainwater penetration into the EDG building.
Complete impairment	1	Rain water ingress due to open ventilation louvres led to degraded function of the pumps.
Meteorological - Snow	**2**	
Complete impairment	2	Unusual weather conditions with very dense snowing and high wind speed in the direction of the walls caused partial blocking of the combustion air filter to the diesel generators.

Classification and event severity	**Total**	**Failure mechanism description**
Meteorological - Temperature	**8**	
Complete CCF	1	Faulty switch prevented activation of the heat system during low outside temperature, which led to ice plugs in the suction line to both pumps.
Complete CCF	1	Suction lines blocked by ice led to failure of all four pumps.
Partial CCF	1	Three atmospheric steam dump valves (ASDV) failed to stroke open on testing due to defective booster relay. Several weeks out of service and low ambient temperature might have contributed to the failure.
CCF impaired	1	EDG failed due to loss of cooling caused by ice forming in the service water pump column (environmental conditions).
CCF impaired	1	Freezing of service water piping in the intake bay led ice plugs in the suction lines causing a failure and degradation of two pumps.
CCF impaired	1	Improper greasing of fuel oil pump motor bearings rendered pumps inoperable during extremely cold weather conditions.
CCF impaired	1	Low sump oil temperature due to cold weather and non-functioning sump heater led to excessive run-up times of two diesel generators.
Incipient impairment	1	An audit discovered that the alternate cooling tower was inadequate (insufficient cooling) in case of high outdoor temperatures.
Meteorological - Winds	**1**	
Complete CCF	1	Severe winds led to loss of grid + 2 diesels were mistakenly shut down + electrical supply switched back from DG to grid without resetting reactor shutdown system + no training when loss of grid + reactor shutdown causing complete failure of 2 diesels.
Potential seismic	**1**	
Incipient impairment	1	Inadequate manufacturing quality led to crack indication in casings of battery cells.

Glossary

Common-cause failure event: 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.

CCF root cause: The CCF root cause is the most fundamental reason for the observed common-cause failure. It is derived by combining the coded information from the event cause, the corrective action and the coupling factor depending on the coding. The possible CCF root cause aspects are deficiencies in the design of components or systems, procedural or organisational deficiencies, or deficiencies in human actions.

Coupling factor: The coupling factor describes the mechanism that ties multiple impairments together and identifies what created the conditions for multiple components to be affected.

Corrective action: The corrective action describes the actions taken by the licensee to prevent the CCF event from re-occurring. The defence mechanism selection is based on an assessment of the event cause and/or coupling factor between the impairments.

Defence: Any operational, maintenance and design measures taken to diminish the probability and/or consequences of common-cause failures.

Detection method: The detection method describes how the exposed components were detected.

Event cause: In the ICDE database, the event cause describes the direct reason for the component's failure. For this project, the appropriate code is the one representing the common-cause, or if all levels of causes are common-cause, the most readily identifiable cause.

Event severity: The severity category expresses the degree of severity of the event based on the individual component impairments in the exposed population. The *severe events* include the categories complete CCF and partial CCF. The *less severe events* include the categories CCF impaired and complete/incipient/single impairment.

Failure mechanism: Describes the observed event and the influences leading to a given failure. Elements of the failure mechanism could be a deviation or degradation or a chain of consequences. It is derived from the event description.

Hazards: Hazards can be divided into external or internal, natural or man-made. External hazards originate from sources located outside the site of the nuclear power plant. Internal hazards originate from the sources located on the site of the nuclear power plant, both inside and outside plant buildings. Natural hazards are defined as those hazards that occur in nature and whose magnitude or frequency man has little or no control over. Man-made hazards are hazards originating from any kind of human activity, whether accidental or due to malicious acts. [2]

Biological infestation: Refers to marine growth, such as encrustation/blockage by mussels, large quantities of algae, jellyfish or fish, large quantities of foliage, grass or weeds as flotsam, or large quantities of biological flotsam due to a flooding event.

Meteorological effects: Refers to weather-related events. These can include, for example, a high or low temperature of the air or cooling water, a persistent drought and its effect on cooling water supply, high winds including tornadoes, high or low humidity, snow, icing and freezing.

Flooding and hydrological hazards: Refers to a high/low seawater/river water level (e.g. low tide) or underwater debris (e.g. accumulation of sand causing wear or clogging).

ICDE event: Refers to all events accepted into the ICDE database. This includes events meeting the typical definition of CCF event (as described in Annex B). ICDE events also include less severe events, such as those with an impairment of two or more components (with respect to performing a specific function) that exists over a relevant time interval and is the direct result of a shared cause.

Interesting CCF event categories: Marking of events as interesting via event codes. The idea of these codes is to highlight a small subset of ICDE events that are in some way "extraordinary" or provide "major" insights.