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NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

ICDE PROJECT REPORT ON COLLECTION AND ANALYSIS OF COMMON-CAUSE FAILURES OF CENTRIFUGAL PUMPS

SEPTEMBER 1999

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

– to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
– to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
– to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996) and the Republic of Korea (12th December 1996). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full Member. NEA membership today consists of 27 OECD Member countries: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Portugal, Republic of Korea, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The Commission of the European Communities also takes 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, as well as
– 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 safety and regulation of nuclear activities, radioactive waste management, 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.

In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

The NEA Committee on the Safety of Nuclear Installations (CSNI) is an international committee made up of scientists and engineers. It was set up in 1973 to develop and co-ordinate the activities of the Nuclear Energy Agency concerning the technical aspects of the design, construction and operation of nuclear installations insofar as they affect the safety of such installations. The Committee's purpose is to foster international co-operation in nuclear safety amongst the OECD Member countries.

CSNI constitutes a forum for the exchange of technical information and for collaboration between organisations which can contribute, from their respective backgrounds in research, development, engineering or regulation, to these activities and to the definition of its programme of work. It also reviews the state of knowledge on selected topics of nuclear safety technology and safety assessment, including operating experience. It initiates and conducts programmes identified by these reviews and assessments in order to overcome discrepancies, develop improvements and reach international consensus in different projects and International Standard Problems, and assists in the feedback of the results to participating organisations. Full use is also made of traditional methods of co-operation, such as information exchanges, establishment of working groups and organisation of conferences and specialist meeting.

The greater part of CSNI's current programme of work is concerned with safety technology of water reactors. The principal areas covered are operating experience and the human factor, reactor coolant system behaviour, various aspects of reactor component integrity, the phenomenology of radioactive releases in reactor accidents and their confinement, containment performance, risk assessment and severe accidents. The Committee also studies the safety of the fuel cycle, conducts periodic surveys of reactor safety research programmes and operates an international mechanism for exchanging reports on nuclear power plant incidents.

In implementing its programme, CSNI establishes co-operative mechanisms with NEA's Committee on Nuclear Regulatory Activities (CNRA), responsible for the activities of the Agency concerning the regulation, licensing and inspection of nuclear installations with regard to safety. It also co-operates with NEA's Committee on Radiation Protection and Public Health and NEA's Radioactive Waste Management Committee on matters of common interest.

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Requests for additional copies of this report should be addressed to:

Nuclear Safety Division
OECD Nuclear Energy Agency
Le Seine St-Germain
12 blvd. des Iles
92130 Issy-les-Moulineaux
France

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ICDE Project Report

Collection and Analysis of Common-Cause Failures of Centrifugal Pumps

1. GENERAL BACKGROUND

Several member countries of OECD/NEA decided to establish the International Common-Cause Failure Data Exchange (ICDE) Project to encourage multilateral co-operation in the collection and analysis of data relating to Common-Cause Failure (CCF) events.

The project was initiated in August 1994 in Sweden and was discussed at meetings in both Sweden and France in 1995. A coding benchmark exercise was defined which was evaluated at meetings held in Germany and in the US in 1996. Subsequently, the exchange of centrifugal pump data was defined; the first phase of this exchange was evaluated at meetings in Switzerland and in France in 1997.

The pilot activity was financially supported by SKI, Sweden, from its initiation to March 1998, and partly by GRS, Germany, from initiation to December 1995. As of April 1998, the project is formally operated by OECD/NEA.

The ICDE project is operated under the umbrella of OECD/NEA whose representative for this purpose is the Secretariat for PWG1.

The member countries and the sponsoring organisations are:

- Canada : AECB
- Finland : STUK
- France : IPSN
- Germany : GRS
- Spain : CSN
- Sweden : SKI
- Switzerland : HSK
- United Kingdom : NII
- United States : NRC

Other countries have recently expressed their interest to participate.

2. ICDE PROJECT

2.1 Objectives of the ICDE Project

The objectives of the ICDE Project are:

- to collect and analyse CCF events in the long term so as to better understand such events, their causes, and their prevention,

- to generate qualitative insights into the root causes of CCF events which can then be used to derive approaches or mechanisms for their prevention or for mitigating their consequences,

- to establish a mechanism for the efficient feedback of experience gained on CCF phenomena, including the development of defences against their occurrence, such as indicators for risk based inspections.

For terms and conditions for project operation, see [1].

2.2 Scope of the ICDE Project

The ICDE Project is envisaged as including all possible events of interest, comprising complete, partial and incipient CCF events, called "ICDE events" in the following.

The Project covers the key components of the main safety systems, like centrifugal pumps, diesel generators, motor operated valves, power operated relief valves, safety relief valves, check valves, RPS circuit breakers, batteries and transmitters.

In the long term, a broad basis for quantification of CCFs could be established, if the participating organisations wish to do so.

2.3 Reporting and Documentation

All reports and documents related to the ICDE project can be accessed through the OECD/NEA web site [2].

2.4 Data Collection Status

Data are collected in an MS ACCESS based databank implemented and maintained at ES-Konsult, Sweden, by NEA appointed clearinghouse. The databank is regularly updated. The clearinghouse and the project group operate it.

2.5 ICDE Coding Format and Coding Guidelines

An ICDE coding format was developed for collecting the ICDE event data for the ICDE database. Definition and guidance is provided in the ICDE coding guidelines [3].

2.6 Protection of Proprietary Rights

IRS procedures for protecting confidential information are adopted. The co-ordinators in the participating countries are responsible for maintaining proprietary rights. The data collected in the clearinghouse database are password protected and are only available to ICDE participants who have provided data.

3. DEFINITION OF COMMON CAUSE EVENTS AND ICDE EVENTS

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

a) 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.

b) 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 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 "Common Cause Failure Data Collection and Analysis System, Vol. 1, NUREG/CR-6268":

Common-Cause 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.

Data collection in the ICDE project comprises complete as well as potential CCF. To include all events of interest, an "ICDE event" is defined as follows:

ICDE Event: Impairment[1] of two or more components (with respect to performing a specific function) that exists over a relevant time interval[2] and is the direct result of a shared cause.

The ICDE data analysts may add interesting events that fall outside the ICDE event definition but are examples of recurrent - eventually non random - failures.

With growing understanding of CCF events, the relative share of events that can only be modelled as "residual" CCF events will decrease.

4. OBJECTIVES OF THE CENTRIFUGAL PUMP REPORT

Objectives of the centrifugal pump report are:

- to describe the data profile in the ICDE data base for centrifugal pumps and to develop qualitative insights in the nature of the reported ICDE events, expressed by root causes, coupling factors and corrective actions,
- to develop the failure mechanisms and phenomena involved in the events, their relationship to root causes, and possibilities for improvement

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[1] *Possible attributes of impairment are:*

- *complete failure of the component to perform its function (Complete CCF)*
- *degraded ability of the component to perform its function*
- *incipient failure of the component*
- *component is working according to specification (default)*

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

5. DESCRIPTION OF THE COMPONENT

Operating experience and probabilistic safety studies of nuclear power plants consistently show influence of common-cause failures of pumps (mostly centrifugal pumps) on plant safety. For this reason, centrifugal pumps were chosen for the first data exchange in the ICDE project.

In the context of the ICDE data collection, a pump includes the driver and the breaker(s). The exact component boundaries to be applied are shown in Figure 1 of Appendix B. Table 1 of Appendix B shows the categorisation of pumps according to mass flow and pressure range and the correspondence of the six categories to important stand-by and operational systems of nuclear power plants.

The failure modes “failure to start” (FS), defined as failure before reaching nominal operating conditions, and “failure to run” (FR), defined as failure after having reached nominal operating conditions, are considered.

The basic set for pump data collection is the “common-cause component group”, (CCCG: set of identical components in a system, performing the same function).

5.1 Content of Database

Presently (December 1998), data for centrifugal pumps are collected in the clearinghouse data bank. Organisations from Finland, France, Germany, Sweden, Switzerland and the United States have contributed data to this first data exchange. 125 ICDE events were reported from 84 plants (60 PWR plants and 24 BWR plants).

The following tables and graphical illustrations provide statistical summaries of several important characteristics of the received data. The database will be updated with new entries when data is available from other countries.

Table 5.1-1. Summary statistics of centrifugal pump data

Reports received on	affecting group size				Total
	2	3	4	others	
ICDE events	40	29	41	15	125
Failure to run	24	15	25	7	71
Failure to start	16	14	16	8	54
Stand-by systems	39	17	15	-	71
Operational systems, also intermittent	1	12	26	15	54
Complete CCFs[3]	14	3	2	-	19
Failure to run	4	-	1	-	5
Failure to start	10	3	1	-	14
Stand-by systems	14	1	1	-	16
Operational systems, also intermittent	-	2	1	-	3
Common-cause component group records[4]	396	163	171	63	793

[3] All components of CCCGs completely failed

[4] Number of sets of CCCGs (CCCG is a set of identical components in a system, performing the same function)

Table 5.1-2 Distribution of ICDE events among systems

System	ICDE events
Containment spray and ice condensers	8
Essential raw cooling or service water	50
Auxiliary and emergency feedwater	18
Emergency core cooling (including core spray, RHR, CVCS)	26
Component cooling water (including reactor building closed cooling water)	3
Residual heat removal (PWR and BWR, except ECC functions)	15
Standby liquid control (BWR)	4
Emergency power generation and auxiliaries (including supply of fuel and lubrication oil)	1
Total	125

The total observation time exceeds 5000 CCCG[5] years, with roughly equal distribution between CCCG sizes 2, 3 and 4. (Set of 2,3 or 4 centrifugal pumps per system)

Graphical illustrations on the following pages show how:

- Root causes[6],
- coupling factor[7] attributes, and
- corrective actions[8]

are distributed among failure to run and failure to start and, within these classes, among group sizes. The numbers supporting the graphical displays are shown in tables in Appendix A.

The information provided on corrective actions is not always clear: in most cases, “corrective action” describes measures taken by the licensee to prevent the problem from re-occurring. In some cases, however, the codes “design modifications”, “diversity” and “functional/spatial separation” describe actions that could be taken to avoid the CCF problem, but nothing is said about the actions taken. These latter cases were not included in the presented statistics.

[5] CCCG: “Common Cause Component Group” (Set of identical components in a system performing the same function)

[6] The root cause is the most basic reason the components failed

[7] The coupling factor describes the mechanism that ties multiple failures together and identifies that the influences that created the conditions for multiple components to be affected.

[8] Is here actions taken by the licensee.

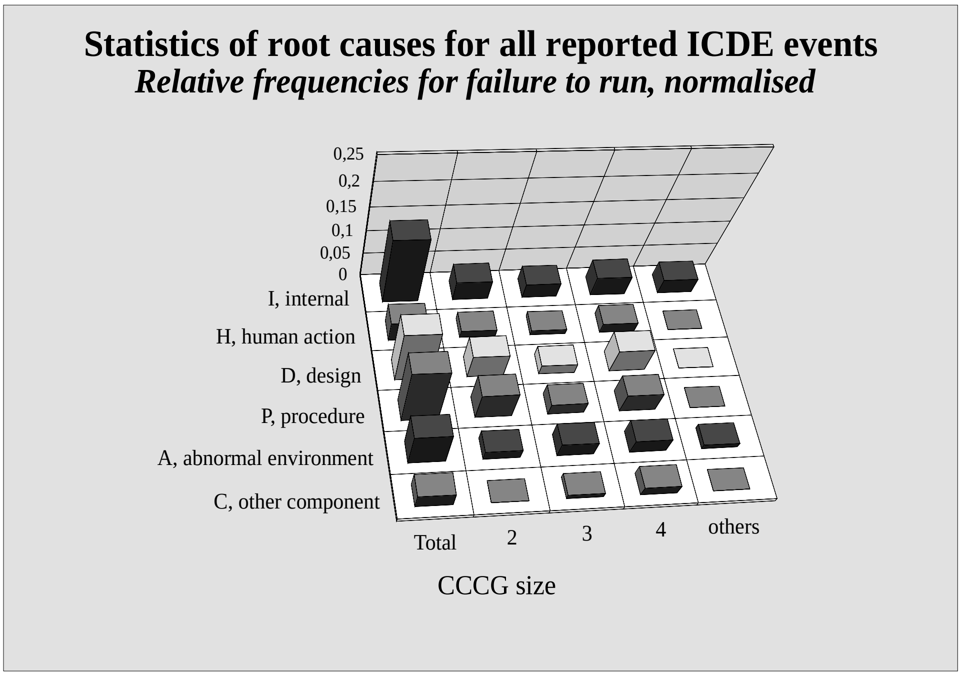

Figure 5.1-1. Relative frequencies of occurrence of root causes for all ICDE events with failure to run, normalised to total number of reported ICDE events, 125

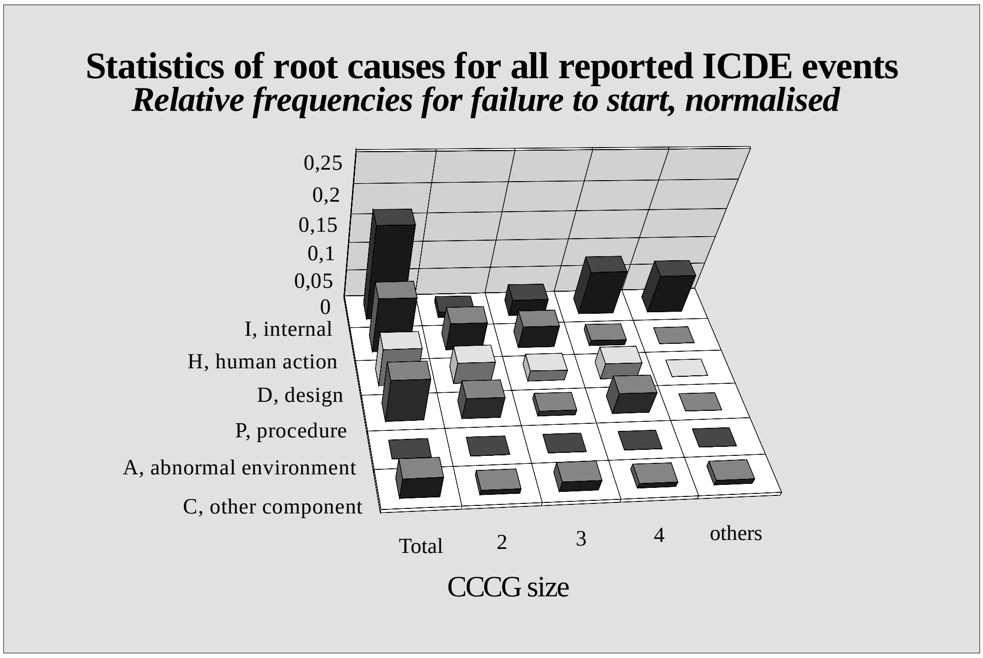

Figure 5.1-2. Relative frequencies of occurrence of root causes for all ICDE events with failure to start, normalised to total number of reported ICDE events, 125

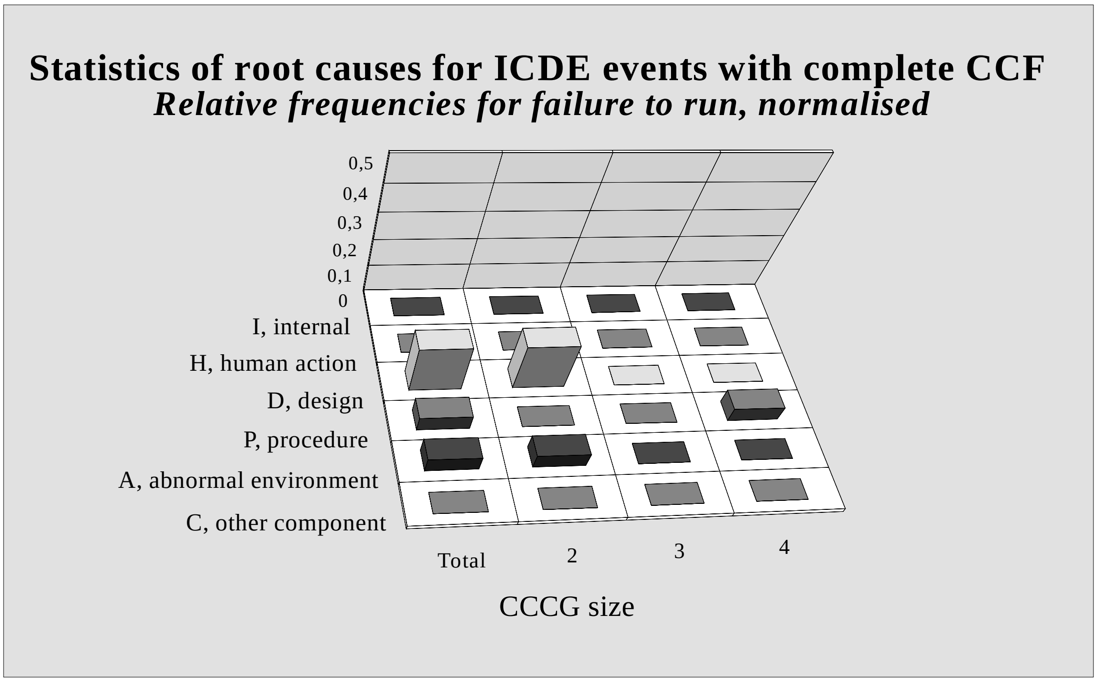

Figure 5.1-3. Relative frequencies of occurrence of root causes for ICDE events with complete failure to run, normalised to number of ICDE events with complete failure, 19.

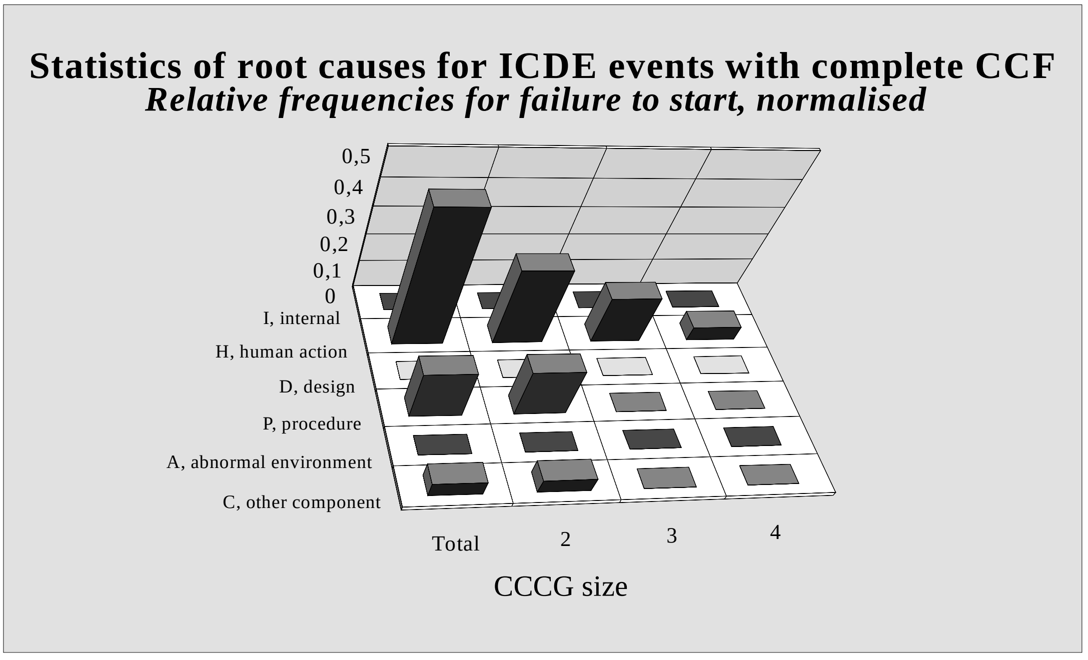

Figure 5.1-4. Relative frequencies of occurrence of root causes for ICDE events with complete failure to start, normalised to number of CCF events with complete failure, 19.

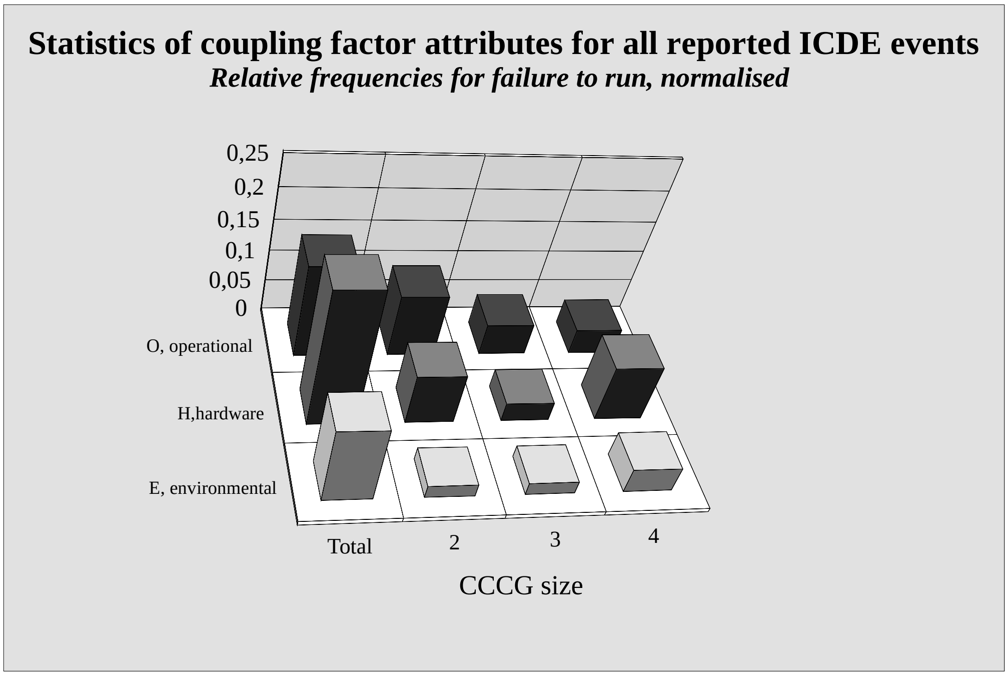

Figure 5.1-5. Relative frequencies of occurrence of coupling factor attributes for all reported ICDE events with failure to run, normalised to number of reported ICDE events, 125

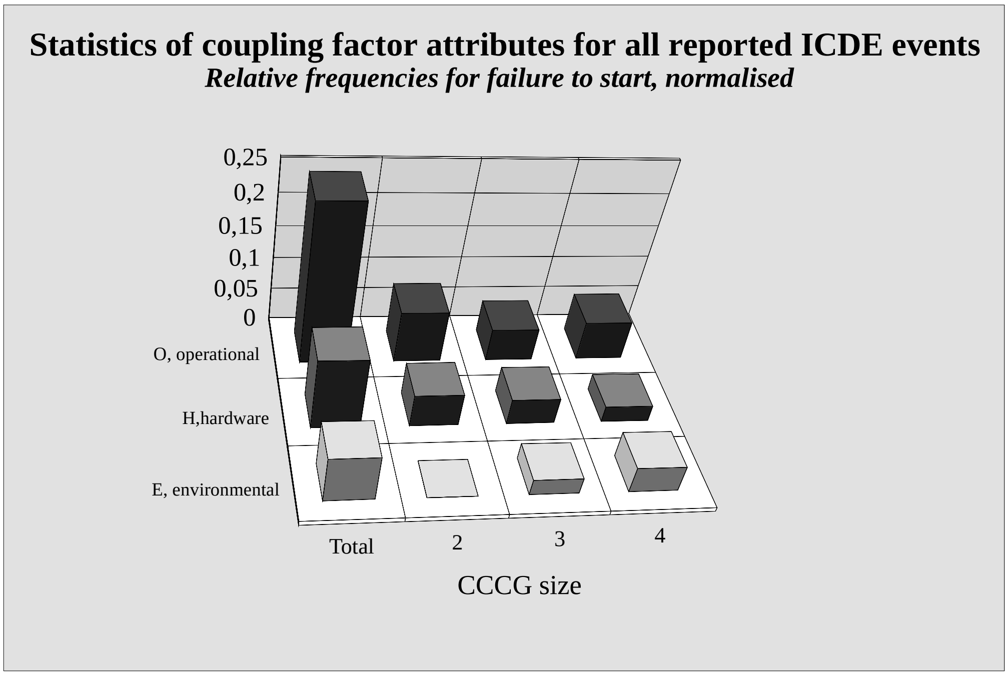

Figure 5.1-6. Relative frequencies of occurrence of coupling factor attributes for all reported ICDE events with failure to start, normalised to number of reported ICDE events, 125

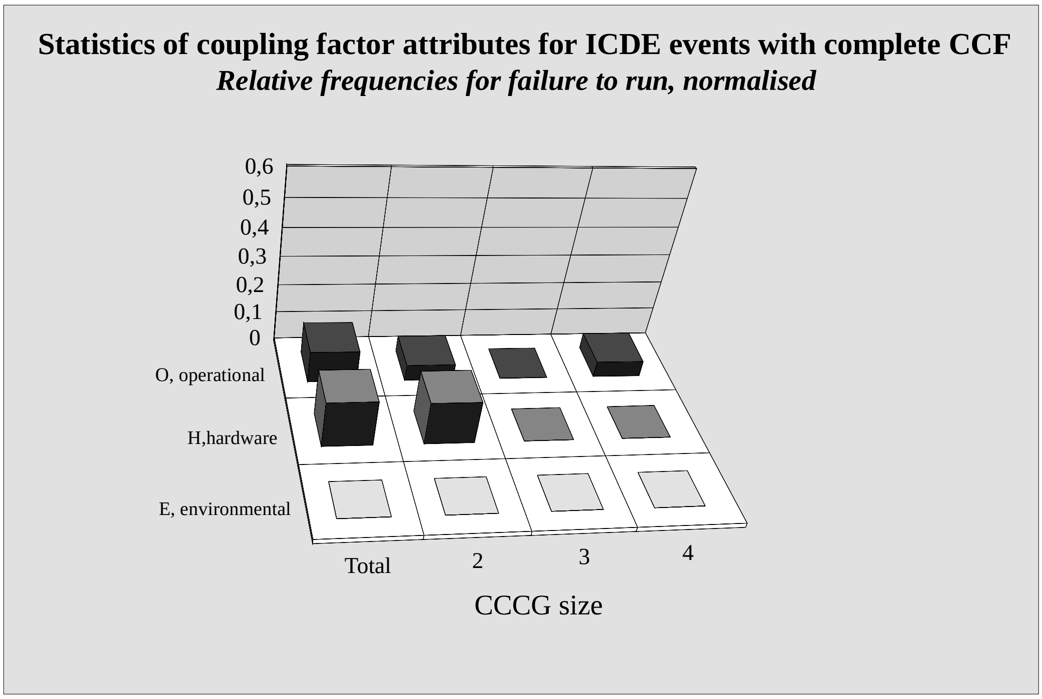

Figure 5.1-7. Relative frequencies of occurrence of coupling factor attributes in ICDE events with complete failure to run, normalised to number of ICDE events with complete CCF, 19.

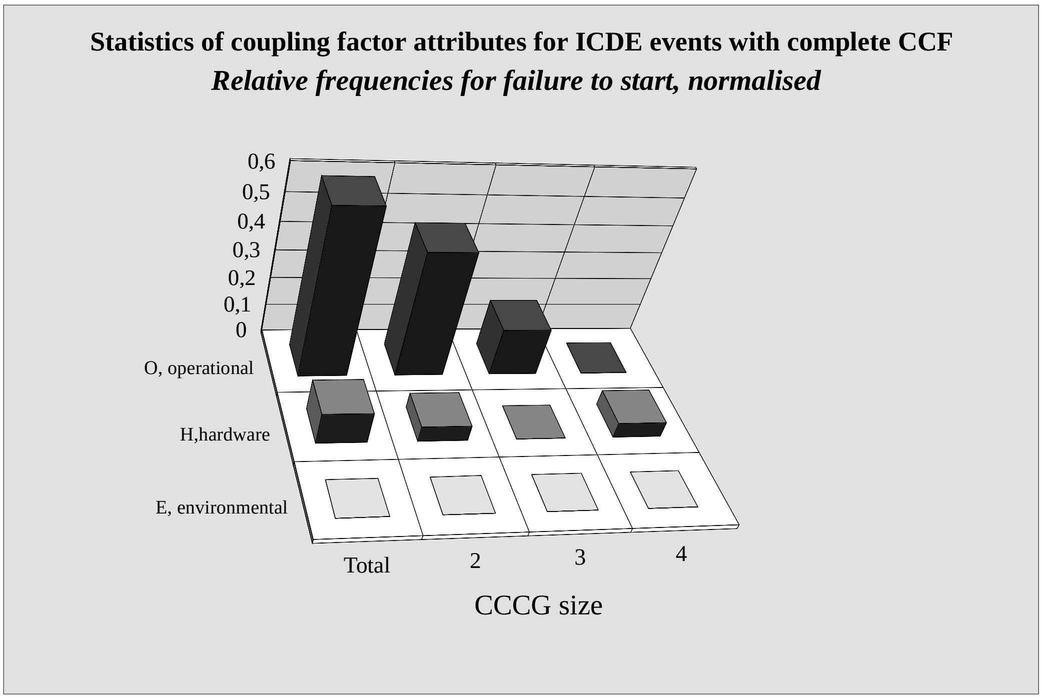

Figure 5.1-8. Relative frequencies of occurrence of coupling factor attributes in ICDE events with complete failure to start, normalised to number of ICDE events with complete CCF, 19.

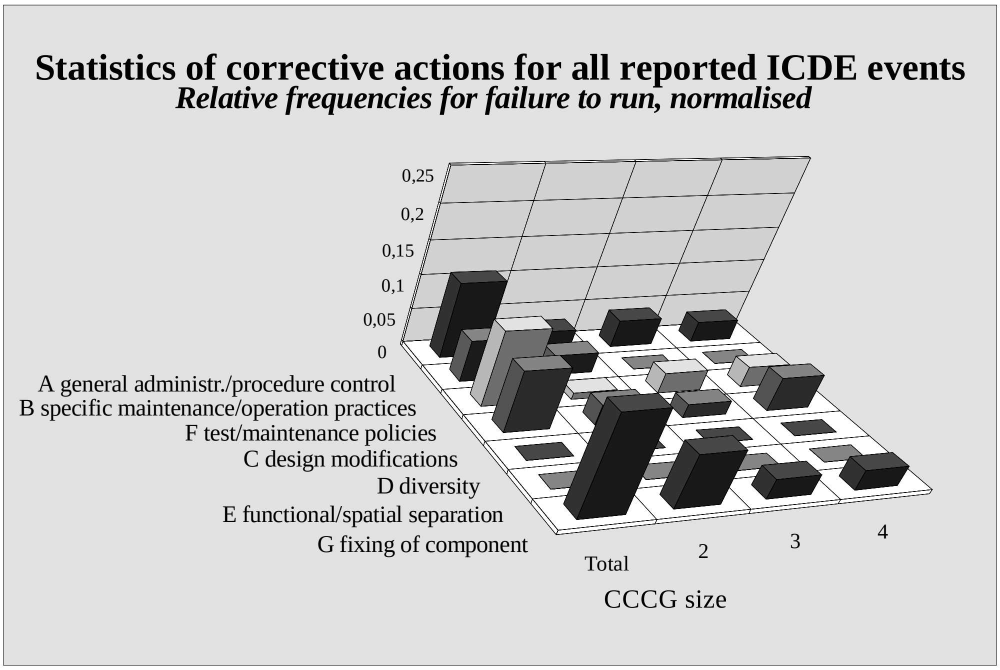

Figure 5.1-9. Relative frequencies of corrective actions reported for all ICDE events with failure to run, normalised to number of reported ICDE events, 125.

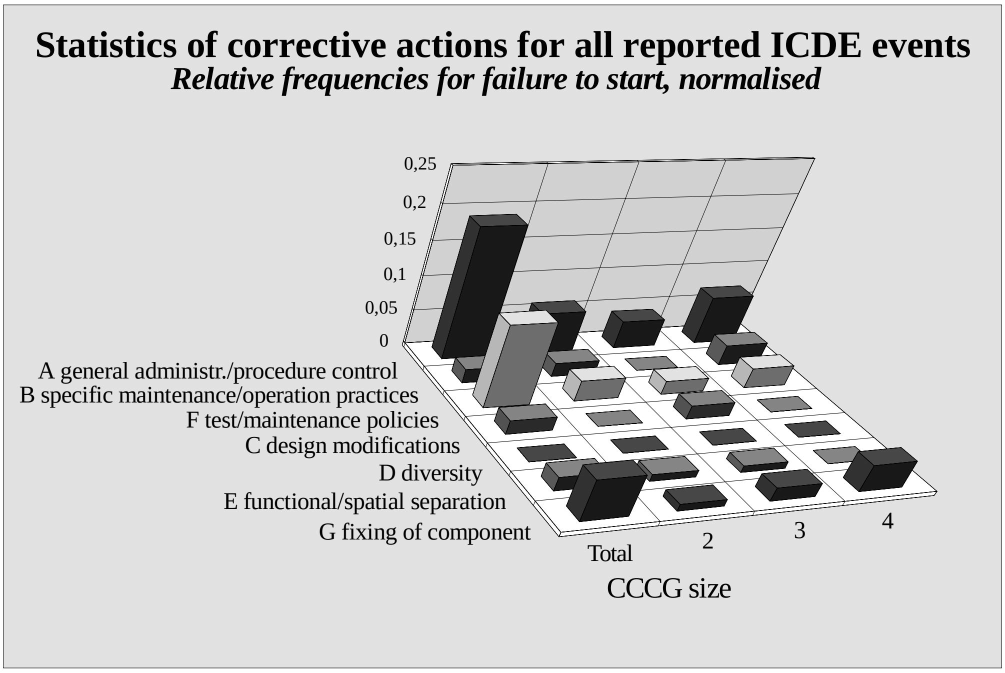

Figure 5.1-10. Relative frequencies of corrective actions reported for all ICDE events with failure to start, normalised to number of reported ICDE events, 125.

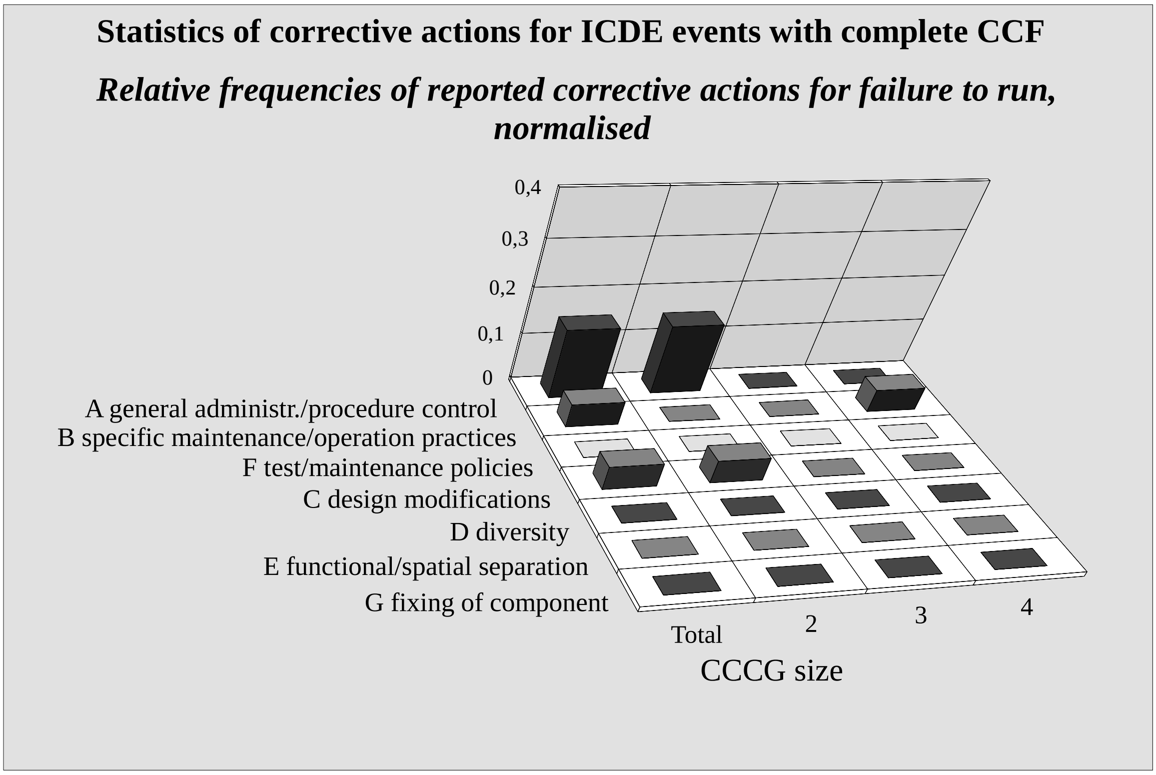

Figure 5.1-11. Relative frequencies of corrective actions reported for ICDE events with complete failure to run.

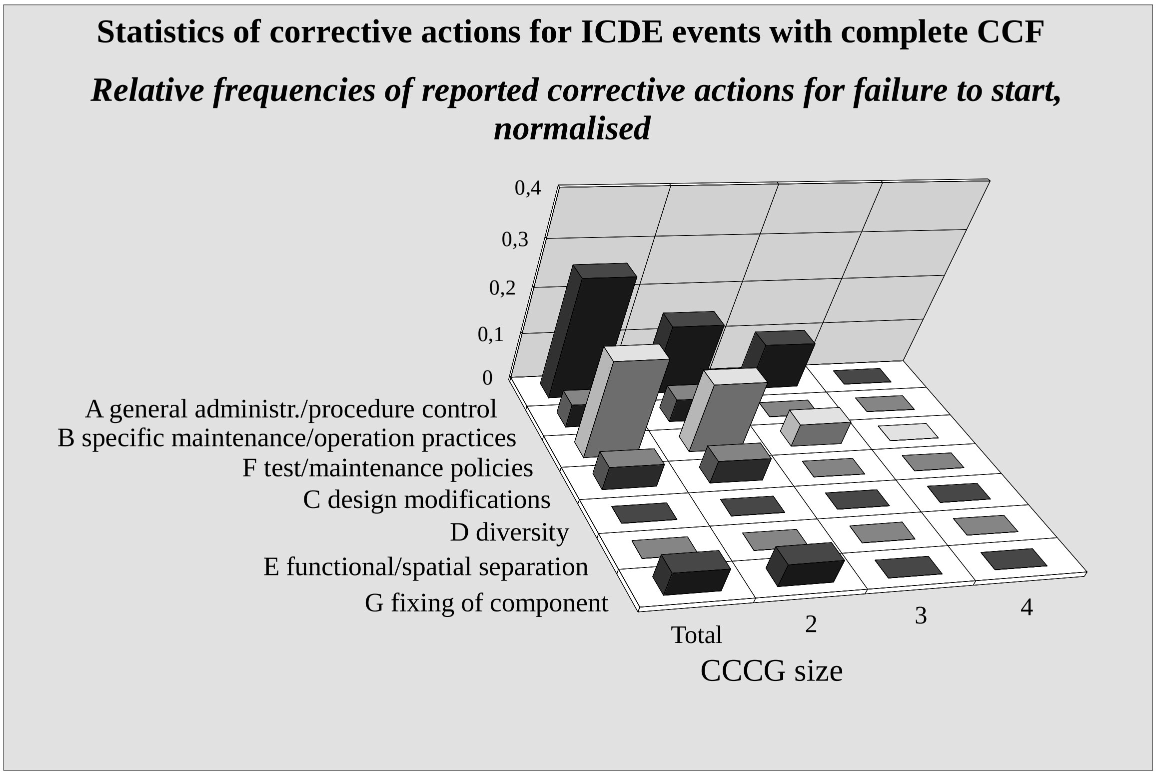

Figure 5-12 Relative frequencies of corrective actions reported for ICDE events with complete failure to start.

6. QUALITATIVE ANALYSIS OF CENTRIFUGAL PUMP EVENT RECORDS

This section contains a qualitative analysis of the centrifugal pump data. The data are characterised by root causes, coupling factors, and corrective actions. Some general assessments are made. Finally the failures are categorised by failure mechanism, and
engineering aspects of the failures are discussed with respect to the failure mechanisms.

6.1 Root Causes

For root causes the following observations are made:

- For all reported ICDE events, most root causes fall in the categories:
  - Internal
  - Design
  - Procedures
  - Human action.

  All other root causes are relatively unimportant.

- For the reported ICDE events that have led to complete CCFs, the dominant root cause contributions are from:
  - Human action
  - Procedures
  - Design.

  All other causes are relatively unimportant.

6.2 Coupling Factor Attributes

The following observations are made regarding the coupling factors observed in the pump failure events.

- For all reported ICDE events, coupling factor attributes fall in the categories (in the indicated order):
  - Operational
  - Hardware
  - Environmental.

- The reported ICDE events that have led to complete CCFs are in the categories (in the indicated order):
  - Operational
  - Hardware.

6.3 Corrective Actions

For corrective actions observed in the pump failure data, the following observations are made:

- For all reported ICDE events, the most frequent corrective measures are on the human actions and procedures side in the categories:
  - general administrative/procedure control,
  - test/maintenance/operation practices,
  - specific maintenance/operation practices consisting of improvement of maintenance, testing and operation rules.

- Corrective actions on the hardware side are less numerous. Most of them are in the category “fixing of components”. There are relatively few corrective actions in the category “design modifications” and “functional spatial separation”. Adding “diversity” is mentioned as a possibility for preventing CCF events, but not as an action taken.

- For the ICDE events reported to have led to complete CCFs, there is a disparity between measures on the human actions and procedures side and on the hardware side. Nearly all corrective measures are directed at improving:
  - General administrative/procedure control
  - Test/maintenance/operation practices
  - Very few are related to hardware improvements.

6.4 Assessment

The following general observations are made with respect to the pump failure events:

- Among all reported ICDE events, more than two thirds of the root causes are related to hardware problems, and more than half of the corrective actions concern the human actions and procedures side.

- Among the ICDE events leading to complete CCF, human action related root causes are dominant. In line with this, the majority of corrective actions concerns the human actions and procedures side, but very few of the reported corrective actions address hardware issues.

6.5 Analysis of Failure Mechanisms

The pump failure events were sorted by failure mechanism. The failure mechanisms fell into the following broad categories:

- Suction problems
- Mechanical problems
- Lubrication problems
- Valve problems
- Leakage problems
- Breaker problems, and
- Control, power supply, regulation problems, and system alignment.

The following table presents a summary of these failure mechanisms reported in the ICDE event reports.

Failure mechanism	Total ICDE events	Complete CCF
Suction problems		
– foreign objects in suction path	14	
– gas in suction path	4	
– suction source depleted or of inadequate physical property	8	2
Mechanical problems		
• Impeller		
– mechanical wear (7 caused by foreign material)	11	
– adjustment	5	
– loosened	1	
• Other parts (4 caused by foreign material)	14	1
Lubrication problems	15	1
Valve problems	4	2
Leakage	9	
Spraying and flooding	3	
Breaker problems	13	4
Control, power supply, regulation problems, system alignment	22	7
Others	2	2
Total	125	19

Background information on failure mechanisms is given in Appendix C.

CCFs are events which significantly reduce the function of mitigating systems. It is of primary concern that operating experience is used to reduce the number of common cause events. Below is a listing of actions suggested to prevent the recurrence of the observed CCF events.

- Possibilities for improvement of suction problems:
  - About 35% of the problems could be corrected by improved design of suction screens, by adding redundancy/diversity to the raw water inlet piping and by providing backflushing possibilities. Also, the provision of settling tanks could have reduced the amount of fine grain particles, like sand, in the suction paths.
  - About 30% of the problems could be corrected by improved source tank instrumentation (water level measurement, water temperature measurement).
  - About 30% of the problems could be corrected by improved operational, test and maintenance procedures.

- Possibilities for improvement of mechanical problems:
  - Nearly one half of the mechanical wear problems could be corrected by the provision of settling tanks designed to reduce the amount of fine grain particles, like sand, in the suction paths.

- Possibilities for improvement of lubrication problems:
  - 60% of the problems could be corrected by better procedures and controls/maintenance practices. Improvements should assure adequate quality and quantity of lubricant.
  - 30% of the problems could be corrected by design modifications, directed at surveying oil level, oil and bearing temperature.

- Possibilities for improvement leakage problems:
  - 80% of the problems could be corrected by better procedures and controls/maintenance practices.

- Possibilities for improvement of control, power supply, regulation problems:
  - More than 75% could be corrected by better procedures and controls/maintenance practices.

7. CONCLUSIONS

The procedure to collect Common Cause Failures for Pump events has been established. The basis for better understanding of such events is now available to the participating organisations.

The database is a source for qualitative insights to root causes and failure mechanisms for preventing recurrence of events. The data were collected for a five year period. The database will be updated as more countries are delivering data.

125 ICDE events have been reported, 19 of which were complete CCFs.

Root causes, coupling factor attributes and corrective actions were distributed as follows among the events with complete failure:

- root causes: 70% human actions and procedural deficiencies, 20% hardware related,
- coupling factor attributes: 66% operational, 33% hardware related,
- corrective actions taken: >70% administrative/procedure controls, maintenance, operation and testing practices

Human performance plays an important role for most of the identified complete CCFs.

Most of the events leading to complete failure involve human error; they could be corrected by better procedures and control/maintenance practices.

8. REFERENCES

1. International common-cause failure data exchange (ICDE) project, terms and conditions. OECD/NEA, 1998.
2. OECD/NEA’s web site: http://www.nea.fr ICDE project documentation, 1995-1998.
3. ICDE coding guidelines (NEA/SEN/SIN/WG1(98)3).

Appendix A, Table 1 (corresponds to figures 0-1 and 0-2)

Frequencies of occurrence of root causes in the reported ICDE event records

Root cause	Total	CCCG size			
		2	3	4	others
I, internal to component	39	6	7	14	12
FR	18	5	4	5	4
FS	21	1	3	9	8
H, human actions	17	7	5	5	-
FR	5	2	1	2	-
FS	12	5	4	3	-
D, design	25	12	6	6	1
FR	14	6	2	6	-
FS	11	6	4	-	1
P, procedure	24	11	4	9	-
FR	15	7	3	5	-
FS	9	4	1	4	-
A, abnormal environmental stress	9	2	3	3	1
FR	9	2	3	3	1
FS	-	-	-	-	-
C, state of other component	7	1	3	2	1
FR	3	-	1	2	-
FS	4	1	2	-	1

Appendix A, Table 2 (corresponds to figures 0-3 and 0-4)

Frequencies of occurrence of root causes in ICDE events with complete CCF.

Root cause	Total	CCCG size		
		2 CC	3 CCC	4 CCCC
I, internal to component	-	-	-	-
FR	-	-	-	-
FS	-	-	-	-
H, human actions	9	5	3	1
FR	-	-	-	-
FS	9	5	3	1
D, design	4	4	-	-
FR	4	4	-	-
FS	-	-	-	-
P, procedure	4	3	-	1
FR	1	-	-	1
FS	3	3	-	-
A, abnormal environmental stress	1	1	-	-
FR	1	1	-	-
FS	-	-	-	-
C, state of other component	1	1	-	-
FR	-	-	-	-
FS	1	1	-	-

Appendix A, Table 3 (corresponds to figures 0-5 and 0-6)

Frequencies of occurrence of coupling factor attributes in the reported ICDE events.

Coupling factor attribute	Total	CCCG Size		
		2	3	4
O, operational	58	22	12	13
FR	27	12	6	5
FS	31	10	6	8
H, hardware	41	16	9	14
FR	27	10	4	11
FS	14	6	5	3
E, environmental	24	2	6	14
FR	15	2	3	9
FS	9	-	3	5

Appendix A, Table 4 (corresponds to figures 0-7 and 0-8)

Frequencies of occurrence of coupling factor attributes in ICDE events with complete failure.

Coupling factor attribute	Total	CCCG Size		
		2 CC	3 CCC	4 CCCC
O, operational	13	9	3	1
FR	2	1	-	1
FS	11	8	3	-
H, hardware	6	5	-	1
FR	3	3	-	-
FS	3	2	-	1
E, environmental	-	-	-	-
FR	-	-	-	-
FS	-	-	-	-

Appendix A, Table 5 (corresponds to figures 0-9 and 0-10)

Frequencies of reported corrective actions in the ICDE event.

Corrective action	Total	CCCG size		
		2	3	4
A - general administrative/ procedure controls	38	11	10	13
FR	14	4	5	4
FS	24	7	5	9
B - specific maintenance/operation practices	10	6	-	4
FR	8	4	-	4
FS	2	2	-	-
F - test and maintenance policies	28	6	7	8
FR	13	2	4	4
FS	15	4	3	4
C - design modifications	14	3	5	6
FR	11	3	2	6
FS	3	-	3	-
D - diversity	-	-	-	-
FR	-	-	-	-
FS	-	-	-	-
E - functional/spatial separation	2	1	1	-
FR	-	-	-	-
FS	2	1	1	-
G - fixing of component	27	11	6	7
FR	19	10	4	4
FS	8	1	2	3

Appendix A, Table 6 (corresponds to figures 0-11 and 0-12)

Frequencies of corrective actions reported for ICDE events with complete failure.

Corrective action	Total	CCCG size		
		2	3	4
A - general administrative/ procedure controls	8	6	2	-
FR	3	3	-	-
FS	5	3	2	-
B - specific maintenance/operation practices	2	1	-	1
FR	1	-	-	1
FS	1	1	-	-
F - test and maintenance policies	4	3	1	-
FR	-	-	-	-
FS	4	3	1	-
C - design modifications	2	2	-	-
FR	1	1	-	-
FS	1	1	-	-
D - diversity	-	-	-	-
FR	-	-	-	-
FS	-	-	-	-
E - functional/spatial separation	-	-	-	-
FR	-	-	-	-
FS	-	-	-	-
G - fixing of component	1	1	-	-
FR	-	-	-	-
FS	1	1	-	-

In several event reports, no taken corrective actions were reported.

Appendix B

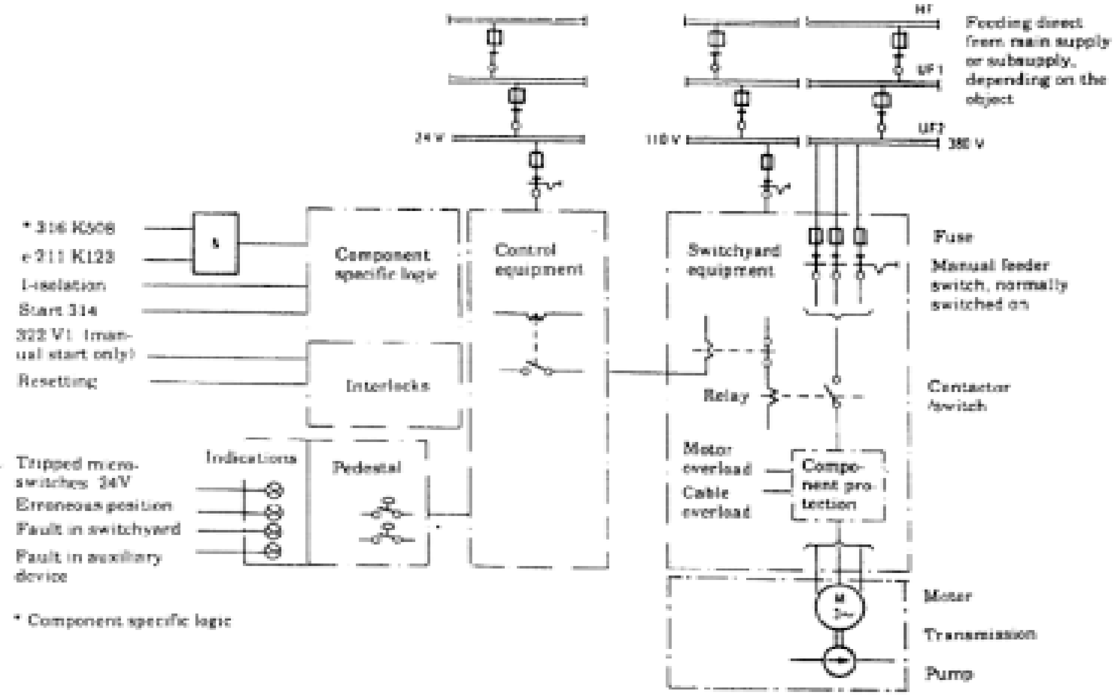

Figure 1. Component boundary of centrifugal pump

Appendix B:
Table 1, Pump categories and examples of corresponding systems

	<75 kg/s Small Flow	>75 kg/s Large Flow
0.2-2 MPa Low pressure	Centrifugal pumps, Low pressure Small flow, horizontal and vertical CP- LS -OP- operational (T-book Table 1) CP- LS -Int- intermittent CP- LS -SB- Standby CP- LS -TD- turbine driven	Centrifugal pumps, Low pressure Large flow, horizontal and vertical CP-LL-OP- operational (T-book Table 2), (T-book Table 3) CP-LL-Int- intermittent (T-book Table 5a) CP-LL-SB- Standby CP-LL-TD- turbine driven (T-book Table 9)
Example system	Cooling and cleaning system for spent fuel Service water system Heating system	Salt water system Secondary cooling system System for contaminated waste water, ion exchanger Refuelling water storage Service water system Residual heat removal system (PWR) Containment spray system LP Safety injection system BWR LP Core spray system BWR
2-8 MPa Medium pressure	Centrifugal pumps, Medium pressure Small flow, horizontal and vertical CP-MS-OP- operational CP-MS-Int- intermittent CP-MS-SB- Standby (T-book Table 7) CP-MS-TD- turbine driven (T-book Table 9)	Centrifugal pumps, Medium pressure Large flow, horizontal and vertical CP-ML-OP- operational CP-ML-Int- intermittent CP-ML-SB- Standby (T-book Table 8) CP-ML-TD- turbine driven
Example system	Auxiliary feed-water system PWR Emergency (Auxiliary) feed-water system BWR Residual heat removal system (TVO)	HP Safety injection system BWR
8-20 MPa High pressure	Centrifugal Pumps, High pressure Small flow, horizontal and vertical CP-HS-OP- operational CP-HS-Int- intermittent CP-HS-SB- Standby (CP-HS-TD- turbine driven)	Centrifugal pumps, High pressure Large flow, horizontal and vertical CP-HL-OP- operational CP-HL-Int- intermittent (T-book Table 5b) CP-HL-SB- Standby CP-HL-TD- turbine driven
Example system	Chemical and volume control, boron recycle and thermal regeneration systems (PWR)	HP Safety injection system (PWR) Chemical and volume control, boron recycle and thermal regeneration systems (PWR)

Appendix C:

Verbal presentation of failure mechanisms for centrifugal pump ICDE events.

C.1 Suction problems

- 26 ICDE events,
- Among them: 2 complete CCF events.

Specific failure mechanisms:

- 14 events were caused by foreign objects in the suction path; thereof,
  - 8 events affected operational systems (SWS, ESWS, RSWS, CCW, seal water system, lube oil cooling system),
  - 6 events affected stand-by systems (ECCS AFW),

  Failure modes statistics:
  - 10 events were failures to run, 4 events were failure to start

  - Most of the problems with operational systems were due to insufficient protection of the intake section, permitting foreign material like sand, mud, marine growth, plastic material or other large objects being introduced in the suction path or obstructing the intake.
  - Most stand-by system problems resulted from deficient procedures and controls, permitting foreign objects to be left in tanks or in the suction paths following maintenance work, or were caused by the use of inadequate material, for example for coating of tanks.

- 8 events were caused by depletion of the suction source or by too high temperature of the suction source; thereof,
  - 3 events affected operational systems (SWS).
  - 5 events affected stand-by systems (SBLC, CS, and AFW). 2 of these events were complete CCFs in two-train SBLC systems.

  Failure modes statistics:
  - 6 events were failures to run; 2 events were failure to start.
  - Most of the problems involved degraded or disabled measurement of water level or water temperature resulting from inadequate design, inadequate modifications testing or deficient procedures and controls.

- 4 events were caused by gas, air or steam in suction path.
  - All 4 events affected stand-by systems (ECCS, AFW, and CVCS).

  Failure modes statistics:
  - 1 event was failure to run; 3 events were failures to start.
  - The problems were caused by inadequate design or construction, in combination with deficient maintenance and test procedures, allowing gas or air being introduced in the suction path, or leaking check valves causing steam binding of pumps.

- Possibilities for improvement:
  - About 35% of the problems could be corrected by improved design of suction screens, by adding redundancy/diversity to the raw water inlet piping and by providing backflushing possibilities. Also, the provision of settling tanks could have reduced the amount of fine grain particles, like sand, in the suction paths.
  - About 30% of the problems could be corrected by improved source tank instrumentation (water level measurement, water temperature measurement).
  - About 30% of the problems could be corrected by improved operational, test and maintenance procedures.

C.2 Mechanical problems

- 31 ICDE events,
- Among them, 1 complete CCF event.

Specific failure mechanisms:

- 25 mechanical wear problems were reported. Thereof, 11 concerned the pump impeller, 14 concerned other parts of the pump (mostly bearings, shafts and couplings).
  - 20 events affected operational systems
  - 5 events affected stand-by systems. Thereof, 1 event was a complete CCF of 2 emergency diesel generator fuel pumps, caused by broken pins in the motor-pump coupling.

  Failure modes statistics:
  - 13 events were failures to run, 11 events were failures to start, and 1 event was external leakage.
  - 11 of the mechanical wear problems were caused by foreign objects in the suction path, mostly fine grain abrasive particles.
  - 5 events involved misadjustment of the pump impeller
  - 1 event involved a loosened pump impeller.
  - Most reported mechanical problems were self-revealing by noise, vibrations, high temperature, and could be detected early enough to prevent development to serious CCF events.

- Possibilities for improvement:
  - Nearly one half of the mechanical wear problems could be corrected by the provision of settling tanks designed to reduce the amount of fine grain particles, like sand, in the suction paths.

C.3 Lubrication problems

- 15 ICDE events
- Among them, 1 complete CCF event.

Specific failure mechanisms:

- 11 events were caused by insufficient quantity of the lubricant (leaks at pump bearings, broken sight glasses, leaks due to corrosion of oil cooler piping)
  - 8 events affected operational (also intermittent) systems
  - 3 events affected stand-by systems.

Failure modes statistics:
- All events were failures to run

- 4 events were caused by insufficient quality of the lubricant (air, sediments, water in lubricant, incompatible mixture of lubricants).
  - All events affected operational (also intermittent) systems.
  - All events were failure to run.

- Possibilities for improvement:
  - 60% of the problems could be corrected by better procedures and controls/maintenance practices, directed at assuring adequate quality and quantity of lubricant.
  - 30% of the problems could be corrected by design modifications, directed at surveying oil level, oil and bearing temperature.

C.4 Valve Problems

- 4 ICDE events
- Among them 2 complete CCFs

  - 1 event affected operational systems,
  - 3 events affected stand-by systems.

Failure mode statistics:
- 3 events were failures to start, 1 event was failure to run.

Affected functions:
- defective solenoid start valve (for diesel driven pump): 25%
- inhibition of operation due to faulty valve position surveillance: 50%
- inhibition of operation due to closed discharge flow control valves: 25%

C.5 Leakage problems

- 9 ICDE events

  - 2 events affected operational systems,
  - 7 events affected stand-by systems.

Failure mode statistics:
- 8 events were failures to run, and 1 event was failure to start.
- 55% of the events were seal and gasket problems.
- Most of the mechanical problems (piping, weld, rupture) were self-revealing, and could be detected early enough to prevent development to serious CCF events.

- Possibilities for improvement:
  - 80% of the problems could be corrected by better controls and maintenance practices.

C.6 Breaker problems

- 13 ICDE events
- Among them 4 complete CCFs (all a direct result of human error)
  - 4 events affected operational systems,
  - 9 events affected stand-by systems.

  Failure modes statistics:
  - 12 events were failures to start, 1 event was failure to run.

  Affected functions:
  - 45%: breaker mechanics,
  - 45%: control power, calibration, electrical alignment.

- Possibilities for improvement:
  - 80% of the problems could be corrected by better procedures and controls/maintenance practices.

C.7 Control, power supply, regulation problems, system alignment.

- 22 ICDE events
- Among them 7 complete CCFs (all a direct result of human error)
  - 4 events affected operational systems,
  - 18 events affected stand-by systems.

  Failure mode statistics:
  - 13 events were failures to start, 9 events were failures to run.

  Affected functions:
  - 38%: power supply (defective connectors),
  - 33%: control devices,
  - 24%: system alignment,
  - 5%: regulation.

- Possibilities for improvement:
  - More than 75% could be corrected by better procedures and controls/maintenance practices.