Unclassified **NEA/CSNI/R(2001)10**

Organisation de Coopération et de Développement Economiques
Organisation for Economic Co-operation and Development **27-Jul-2001**

English text only

NEA/CSNI/R(2001)10
Unclassified

NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

ICDE Project Report: Collection and Analysis of Common-Cause Failures of Motor Operated Valves

February 2001

English text only

JT00111244

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– 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.

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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.

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The 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 the programme of work. It also reviews the state of knowledge on selected topics on 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 on technical issues of common interest. It promotes the co-ordination of work in different Member countries including the establishment of co-operative research projects 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 meetings.

The greater part of the CSNI's current programme is concerned with the 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 nuclear fuel cycle, conducts periodic surveys of the reactor safety research programmes and operates an international mechanism for exchanging reports on safety related nuclear power plant accidents.

In implementing its programme, the 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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ICDE Project Report: Collection and Analysis of Common-Cause Failures of Motor Operated Valves

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February 2001

ABSTRACT

This report documents a study performed on the set of common cause failures (CCF) of motor operated valves (MOV). The data studied here were derived from the International CCF Data Exchange (ICDE) database, to which several countries have submitted CCF event data. The purpose of the ICDE is to allow multiple countries to collaborate and exchange CCF data to enhance the quality of risk analyses that include CCF modeling. 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, yields sufficient data for more rigorous analyses. This report is the result of an in-depth review of the MOV events and presents several insights about them. The objective of this document is to look beyond the CCF parameter estimates that can be obtained from the CCF data, to gain further understanding of why CCF events occur and what measures may be taken to prevent, or at least mitigate the effect of MOV CCF events. The report presents details of the ICDE project, a quantitative presentation of the MOV events, and a discussion of some engineering aspects of the events.

CONTENTS

EXECUTIVE SUMMARY

This study examined 87 events in the International CCF Data Exchange (ICDE) database by tabulating the data and observing trends. Once trends were identified, individual events were reviewed for insights.

The database contains information developed during the original entry of the events that was used in this study. This information includes root cause, coupling factor, exposed population size, and corrective action. As part of this study, these events were reviewed again and additional categorizations of the data were included. Those categories included the degree of failure, affected subsystem, and detection method.

This study begins with an overview of the entire data set (Section 6). Charts and tables are provided exhibiting the event count for each of these event parameters. This section forms the baseline for the MOV component.

Section 7 contains charts that demonstrate the distribution of the same events further refined by failure mode (fail-to-open, fail-to-close and internal leakage) for each event parameter. Each of these charts is replicated with the further distinction that only those events classified as partial or complete are included. Distinctions are drawn as these parameters shift.

Section 8 contains the results of an analysis on failure cause categories. For this, the events have been analysed and characterised regarding the human error aspects and the technical aspects of the observed failure.

Especially this approach focuses on root causes of common cause failures. So there are errors in the calculation during design that caused false stroke forces. Wearing is a widespread effect. The subcomponent "limit switch" caused also a substantial amount of CCF. Failures on locking out during maintenance actions were also conspicuous. There are further failure effects that caused CCF in not such a large and determinant scope. For example appeared in the study the selection of unsuited service media (mostly lubricants), the selection of improper materials, and assembly faults.

ACRONYMS

CCCG	common cause component group
CCF	common cause failure
ECCS	emergency core cooling system
ICDE	International Common Cause Failure Data Exchange
IRS	Incident Reporting System
LOCA	loss-of-coolant accident
MOV	motor operated valve
NEA	Nuclear Energy Agency
OECD	Organisation for Economic Cooperation and Development
PRA	probabilistic risk assessment
PSA	probabilistic safety assessment
RPS	reactor protection system
WGOE	Working Group on Operating Experience

ICDE Project Report
Collection and Analysis of Common-Cause Failures of Motor Operated Valves

1. INTRODUCTION

This report presents an overview of the exchange of motor operated valves (MOV) common cause failure (CCF) data among several countries. The objectives of this report are the following:

- *To describe the data profile in the ICDE database for motor operated valves and to develop qualitative insights in the nature of the reported events, expressed by root causes, coupling factors, and corrective actions; and*

- *To develop the failure mechanisms and phenomena involved in the events, their relationship to the root causes, and possibilities for improvement.*

The ICDE Project was organized to exchange CCF data among countries. A brief description of the project, its objectives, and the participating countries is contained in Section 2. Section 3 presents a definition of common cause failure. Section 4 presents a description of the motor operated valve and a short description of the subcomponents that comprise it. An overview of the data is presented in Section 5. Section 6 contains a description of the data by failure mode and also a comparison of complete CCF events with all of the events collected in this effort. Section 7 discusses the events by root cause, and Section 8 summarizes the events by subsystem. A summary and conclusions are presented in Section 9.

2. ICDE PROJECT

This section contains information about the ICDE Project.

2.1 Background

Several member countries of OECD/NEA established the ICDE Project to encourage multilateral co-operation in the collection and analysis of data relating to 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 USA 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 ICDE project is operated under the umbrella of the OECD/NEA whose representative for this purpose is the Secretariat for the Working Group for Operating Experience.

The ICDE project member countries and their sponsoring organisations are:

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

2.2 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.*

2.3 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 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, reactor protection system (RPS) circuit breakers, batteries and transmitters.

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

2.4 Reporting and Documentation

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

2.5 Data Collection Status

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

2.6 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 are provided in the ICDE coding guidelines [3].

2.7 Protection of Proprietary Rights

Incident Reporting System (IRS) procedures for protecting confidential information have been 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 identified:

- 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, and 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 feed-water pumps due to steam binding, resulting from leaking check valves).

Several definitions of CCF events can be found in the literature, for example, "Common Cause Failure Data Collection and Analysis System, Vol. 1, NUREG/CR-6268": [4]

- 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.

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[1] Possible attributes of impairment are the following:

- *Complete failure of the component to perform its function*
- *Degraded ability of the component to perform its function*
- *Incipient failure of the component*

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

4. COMPONENT DESCRIPTION

4.1 General Description of the Component

This family of valves is comprised of those emergency core cooling system (ECCS) valves that are motor operated and are used for the purpose of establishing or isolating flow to or from the primary system. The systems for which motor operated valve (MOV) data were collected are:

– *auxiliary feedwater*

– *high pressure safety injection*

– *low pressure safety injection (residual heat removal)*

– *refuelling water storage tank*

– *containment spray*

– *pressurizer power operated relief valve block valves*

– *high pressure coolant injection/reactor core isolation cooling*

– *low pressure coolant injection (residual heat removal)*

– *isolation condenser*

– *essential service water system*

The following component types are distinguished:

- MOV Ball valve
- MOV Gate valve
- MOV Globe valve
- MOV Butterfly valve
- MOV General type

One of the primary "PRA missions"for an MOV is to allow flow of water into the primary system following a LOCA or to prevent water from leaving the primary containment system in the event of a LOCA. Some of the systems for which MOV data were reviewed serve dual purposes (low pressure injection and residual heat removal), such that the flow paths are used during normal plant evolutions. Failure of the MOV to perform its PRA mission occurs if a valve that is required to be open to allow injection or cooling fails to open, or if a valve that is required to close to isolate secondary parts of the ECCS after a LOCA fails to close.

4.2 Component Boundaries

The component for this study is the MOV, comprised of a valve with its internal piece-part components and a motor operator. The operator includes the circuit breaker, power leads, and other local protective devices, open/close limit switches, torque switches, and the motor. The control circuit that induces a close or open signal to an MOV is not included within the MOV boundary if it also controls other component functions, such as other valve actions, pump starts and functions modeled in PRA, (the schematic diagram in figure 4.1 shows the generic component boundaries for MOVs).

4.3 Subcomponent Descriptions

This section contains a brief description of each of the subcomponents that comprise the motor operated valve. These descriptions are intended only to provide a general overview of the most common MOVs.

4.3.1 Valve

The valve subcomponent includes the housing, the seals, the packing, the disk, and the seat.

4.3.2 Actuator

The actuator includes the gear, the clutch, and the stem.

4.3.3 Motor

The electrical motor provides motive force to open or close the valve.

4.3.4 Limit and torque switches

The limit and torque switches provide information about the position of the valve. This information is used to indicate the position of the valve and to stop the motor after actuation of the valve. Limit and torque switches are part of the component protection system.

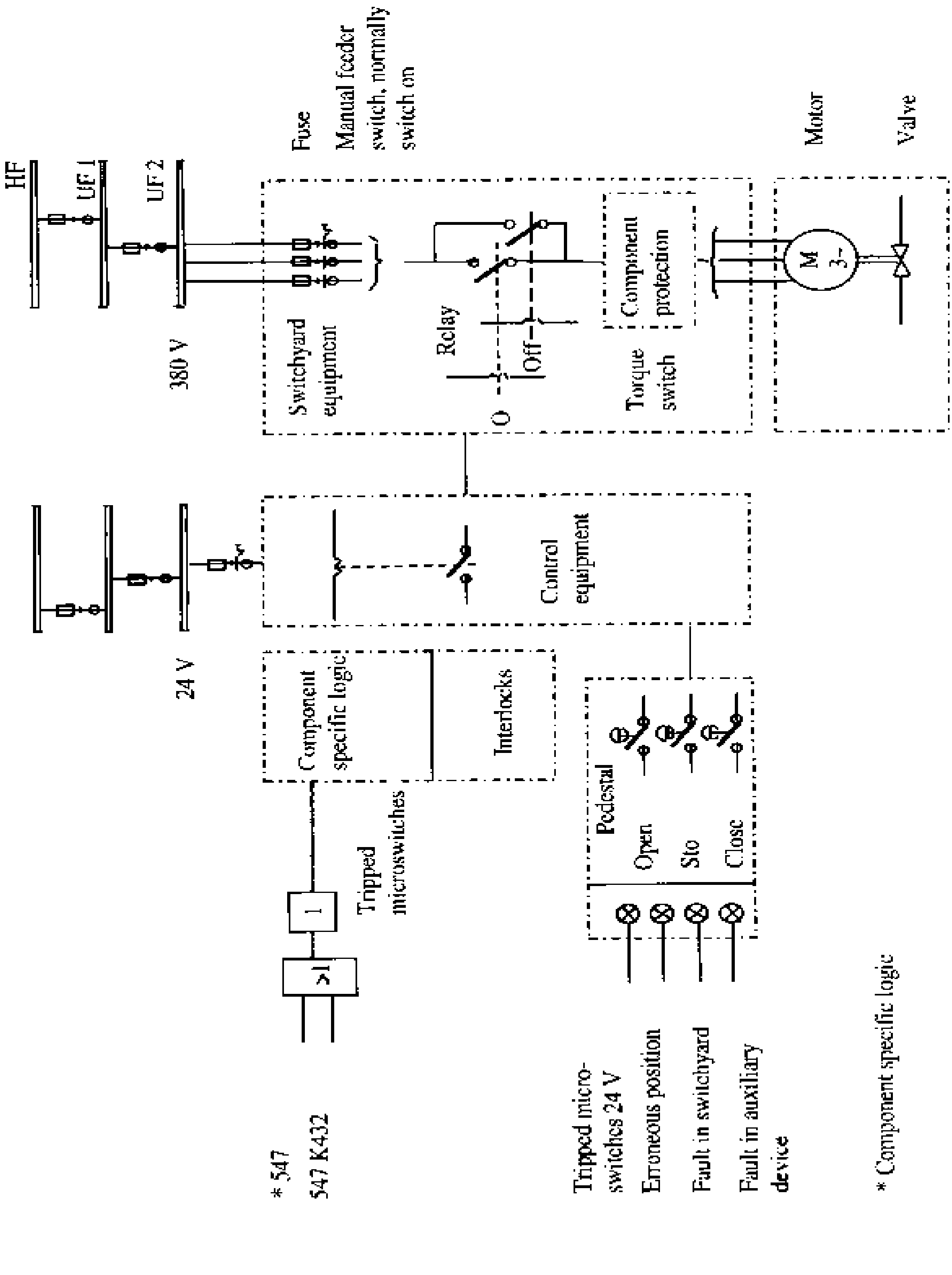
4.3.5 Power supply

The power supply consists of the switchyard equipment, including the contactor or switch, and the fuses.

4.3.6 Component specific logic and control equipment

The component specific logic and control equipment functions to start, stop, and provide operational control and protective trips for the MOV.

Figure 4-1. Generic component boundaries of motor operated valves



4.4 Event Boundary

The main “PRA mission” for an MOV is to allow flow of water into the primary system following a LOCA or to prevent water from leaving the primary containment system in the event of a LOCA.

Some of the systems for which MOV data were reviewed serve dual purposes (low pressure injection and residual heat removal), such that the flow paths are used during normal plant evolutions. Failure of the MOV to perform its PRA mission occurs if a valve that is required to be open to allow injection or cooling flow fails to open, or if a valve that is required to close to isolate secondary parts of the ECCS after a LOCA fails to close.

5. MOV EVENT COLLECTION AND CODING GUIDELINES

5.1 Basic Unit for ICDE Event Collection

The basic set for MOV data collection is the "exposed population" (EP: set of components exposed to the same failure cause). The number of valves in an exposed population depends on the specific failure identified in the event analysis.

In general the exposed population shall be in the same system for the components identified but could be modified depending on the linkage of CCF events by failure mechanism or causal factors.

The elements of the exposed population will normally have similar test intervals. Similar in this context means a factor of not more than 2 between minimum and maximum.

The determination of the exposed population is left to the event reviewer and the reviewer's knowledge of the relation of system design, operation and testing.

5.2 Time Frame for ICDE Event Exchange

The minimum period of exchange covered a period of 5 years for each plant.

5.3 Coding Rules and Exceptions

1. In general, the definition of the ICDE event given in section 2 of the General ICDE Coding Guidelines applies.

2. Some reports discuss only one actual failure, and do not consider that the same cause will affect other MOVs, despite the licensee replaces the failed component on all MOVs as a precautionary measure. This type of event is coded as incipient impairment (0.1) of the components that did not actually fail.

3. Inoperability due to seismic or electrical separation criteria violations will not be included, unless an actual failure has occurred.

4. Inoperability due to administrative actions, that would not cause the valve to fail to function, is not included as failures. An example is a surveillance test not performed within the required time frame.

5. Failure of the electrical operator without coincident failure of the manual operator is considered a MOV failure.

6. Failure of the MOV to cycle in the required time (as opposed to mission time) will not be considered a failure, either CCF or independent, if the MOV reached its intended state.

5.4 Functional Fault Modes

The following functional fault modes were used to analyze MOV data:

1. Failure to open (FO)

2. Failure to close (FC)

3. Internal Leakage (IL)

4. External Leakage (EL)

6. OVERVIEW OF DATABASE CONTENT

CCF data for the MOV component have been collected. Organisations from Finland, France, Germany, Sweden, Switzerland and the United States contributed data to this data exchange. Eighty-seven (87) ICDE events were reported from nuclear power plants (pressurised water reactors and boiling water reactors). One event was reported twice, the original record and an update. Therefore only the updated record was included in the study. These 86 events are used only in the failure mode summary. Five events are reported two times in the database. Each of these events was reported for two failure modes -- "failure to open" and "failure to close." These events are only counted once for the statistical analyses, except the failure mode analysis. Thus, the total number of events for the study is 81 events.

Table 6-1 summarizes, by failure mode, the MOV ICDE events used in this study. Complete CCF events are CCF events in which each component fails completely due to the same cause and within a short time interval. Due to the low number (5) of observed complete CCF events no further detailed statistical analysis of this particular subclass of ICDE events is done in this study. A further subclass of ICDE events are partial CCF events having at least two completely failed components. This subclass contains 24 events and includes the complete CCF events.

Regarding the coded failure modes, there seems to be no rigid borderline between "failure to close" and "internal leakage" events. Looking at the verbal event descriptions, some of the "failure to close" events might also have been coded as "internal leakage" events and vice versa.

Table 6-1. Summary statistics of MOV data.

Event reports received	Total	Degree of Failure Observed	
		Partial	Complete
ICDE events			
Failure to open	38	14	3
Failure to close	34	8	1
External leakage	1	1	1
Internal leakage	9	0	0
No failure mode	4	1	0
Total	86	24	5

Table 6-2 summarizes the root causes of the analysed events. Figure 6-1 shows the distribution of CCF events by root cause. Design, Manufacture or Construction inadequacy accounts for about 31 percent of the events. An example is a failure of valves as a result of an improper friction factor. Internal Parts of the valves accounts for about 30 percent. In this group are for instance events by failure due to weak valve stems. Other important contributions are Procedure, accounting for 13 percent (e.g. lack of lubricant because of missing instructions), and Human Actions, accounting for 12 percent (e.g. incorrect torque switch setting).

Table 6-2. Root causes distribution

ICDE Code	Number of events	Percent
Abnormal stress	3	~4
Components not modeled in PSA	1	~1
Design etc.	25	~31
Human actions	10	~12
Internal parts	24	~30
Maintenance not captured by human	1	~1
Others	6	~7
Procedure	11	~13
Total	81	

Table 6.3 summarizes the coupling factors of the analysed events, and Figure 6-2 shows this distribution. The dominant coupling factor, Operational Procedure or Staff, accounts for 38 percent of the events. The systematic wrong setting of limit switches is an example of an event belonging to this group. Hardware (component part) accounts for 26 percent and Hardware Design for 17 percent. The other coupling factors are equally distributed. An event revealing inadequate actuators to achieve minimum required closing thrusts is an example of a coupling factor in the hardware group. An example for a coupling factor "hardware design" is the occurrence of some stems or stem nuts where the thread was worn out.

Table 6-3. Coupling factors distribution

ICDE Code	Number of events	Percent
Environmental	2	~2
Hardware	21	~26
Hardware design	14	~17
Hardware quality	1	~1
Maintenance	3	~4
Procedure	5	~6
Operational	31	~38
Operation staff	2	~2
Operation procedure	2	~2
Total	81	

Table 6-4 summarizes the corrective actions and Figure 6-3 shows the distribution of identified possible corrective actions for CCF events analyzed. The dominant corrective action, administrative/ procedural control, accounts for 41 percent. Example events of this group are the revision of procedures to avoid prematurely locking of valves during plant shutdown, a revision of procedures to avoid excessive torque on valves by hand wheel, and recalculation of incorrectly calculated torque switch set-point. Maintenance program modifications each account for 21 percent of the corrective actions. Specific maintenance and design modification account for 11 percent. The remaining events are about equally distributed among the remaining actions (fixing components, additional diversity, others).

Table 6-4. Corrective actions

ICDE Code	Number of events	Percent
Administrative control	33	~41
Specific maintenance	9	~11
Design modification	9	~11
Diversity	5	~6
Test	17	~21
Fixing of component	4	~5
Other	4	~5
Total	81	

Table 6-5 summarizes the number of exposed components (here called exposed size) in the exposed population. Figure 6-4 shows the distribution of the events by exposed size. The exposed size ranges from 2 to 27. Two exposed sizes are dominant: four valves (28%) and eight valves (27%). The exposed size of two valves accounting for 13 percent and six valves for 19 percent. The others sizes are equally distributed.

Table 6-5. Exposed component

Exposed Size	Number of events	Percent
2	11	~13
3	3	~4
4	23	~28
5	1	~1
6	15	~19
8	22	~27
10	1	~1
15	1	~1
17	1	~1
24	1	~1
27	2	~2
Total	81	

Table 6-6 and Figure 6-5 summarize the detection method of the analyzed events. Only 13 events were discovered during an actual demand. Thirteen events were discovered as a result of monitoring in the control room. Five events were discovered in the course of maintenance. Most of the CCF events (61 %) were discovered during tests. The term "test" includes all types of tests (e.g., tests during annual overhauls, tests during operation, and unscheduled tests).

Table 6-6. Detection method

ICDE code	Number of events	Percent
Demand event	13	~16
Maintenance/test	5	~6
Monitoring in control room	13	~16
Test	49	~61
Unknown	1	~1
Total	81	

Table 6-7 and Figure 6-6 summarize the distribution of the affected subcomponents of the analyzed events. In this group, the total number of the events is 83 (two events involve two subcomponents [actuator/power supply and actuator/valve]). The dominant subcomponents are the limit/torque switch accounting for 30 percent and valve (housing, disk) accounting for 35 percent. The actuator accounts for 16 percent, and the power supply for 13 percent.

Table 6-7. Affected subcomponent

Subcomponent	Number of events	Percent
Actuator	13	~16
Control equipment	2	~2
Limit/torque switch	25	~30
Motor	3	~4
Power supply	11	~13
Valve	29	~35
Total	83	

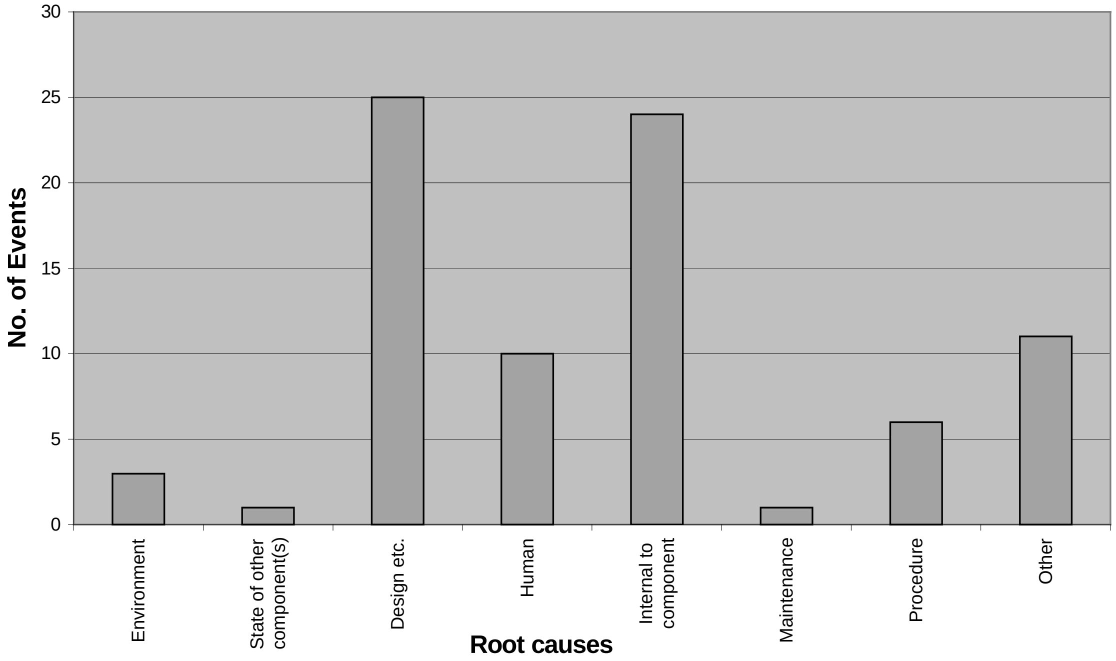


Figure 6-1. Root cause distribution

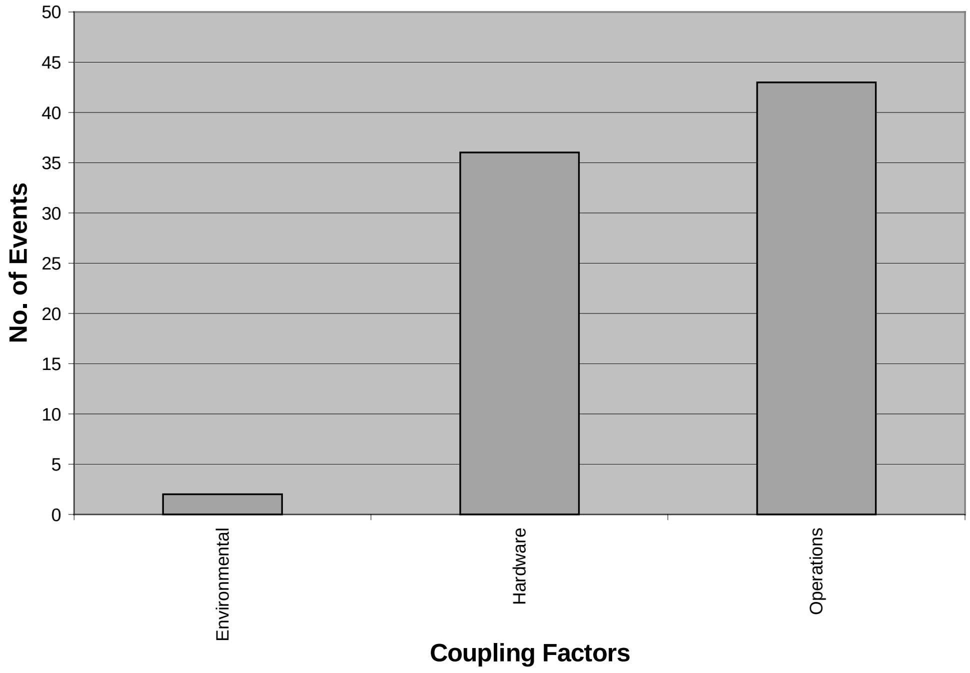


Figure 6-2. Coupling factors distribution

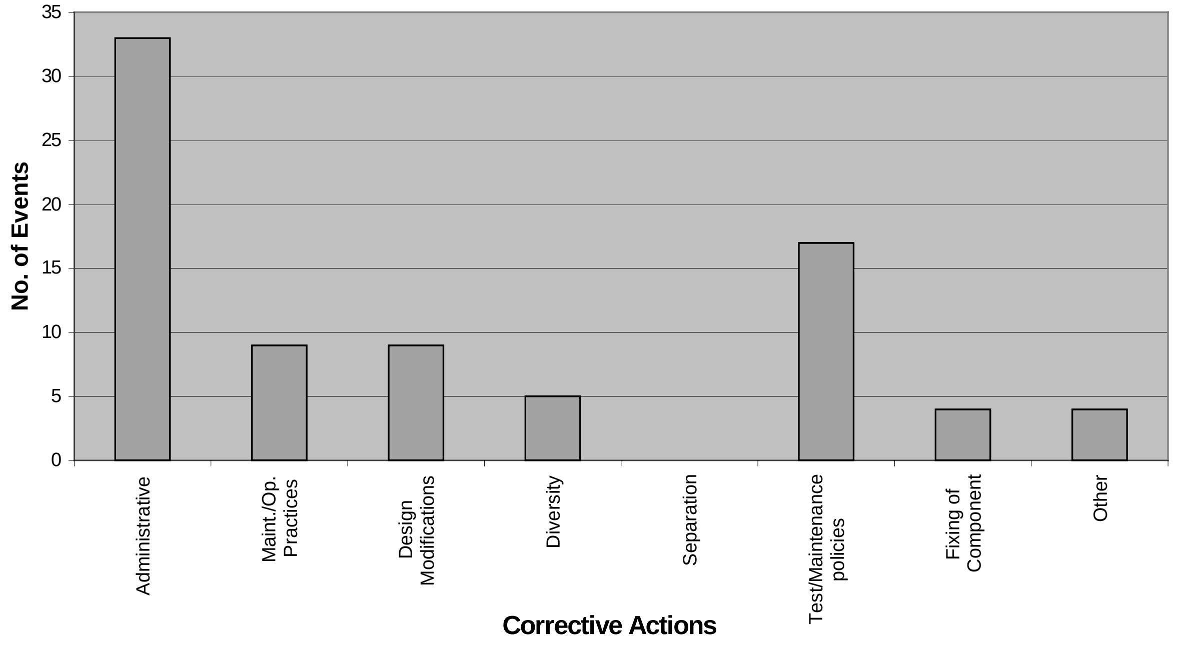


Figure 6-3. Corrective action distribution

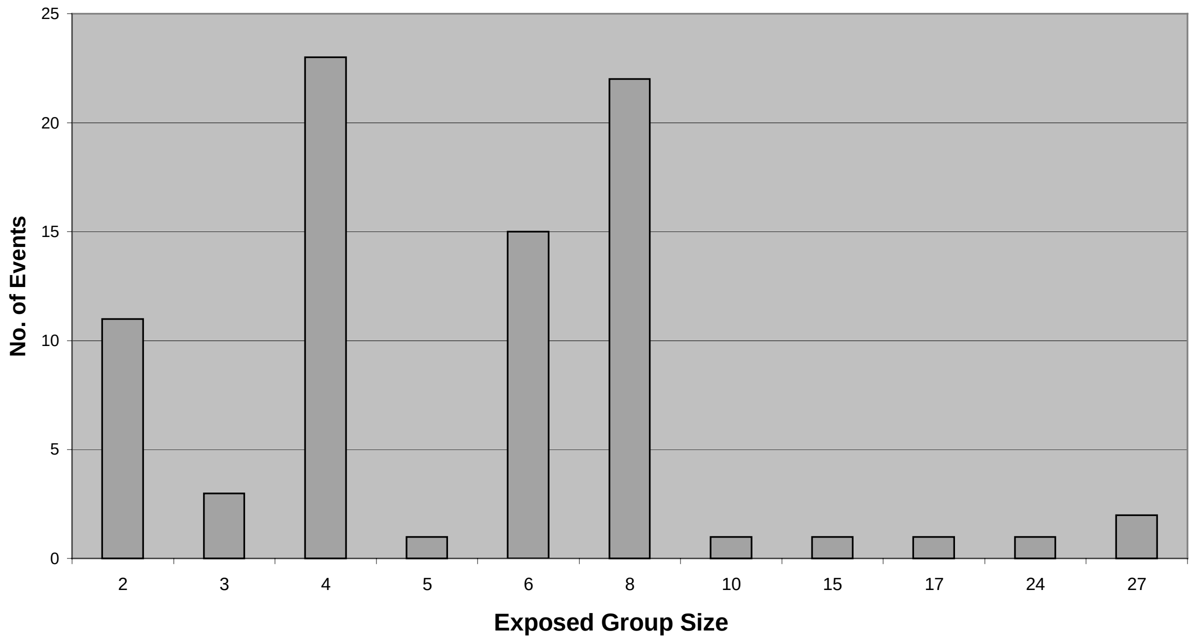


Figure 6-4. Exposed group size distribution

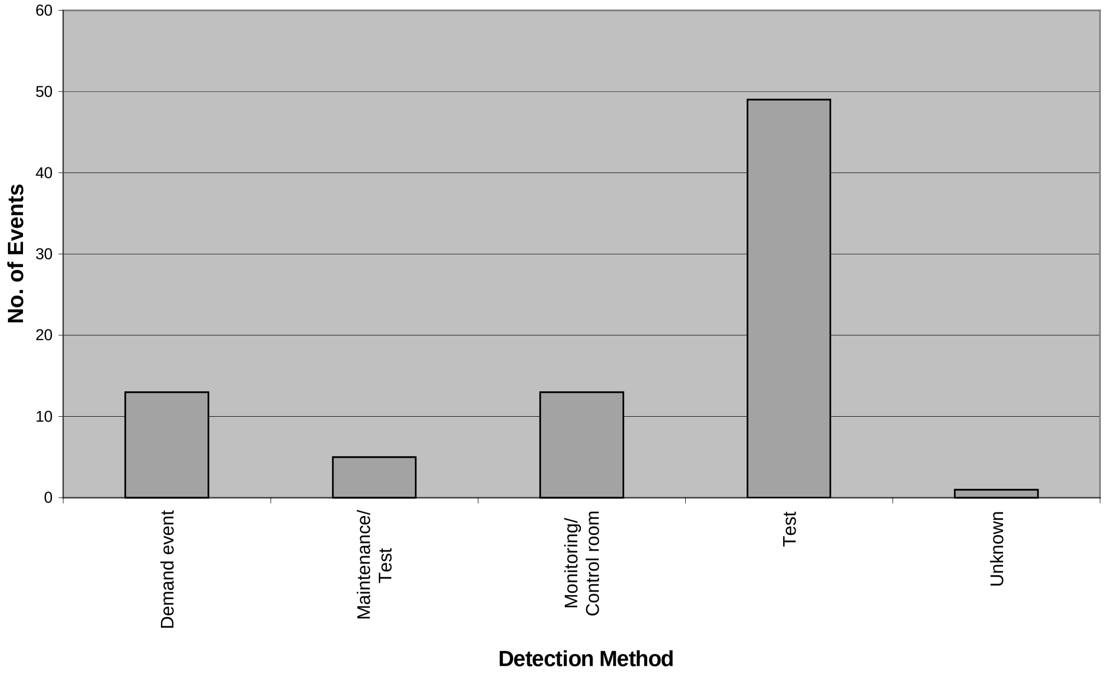


Figure 6-5. Detection method distribution

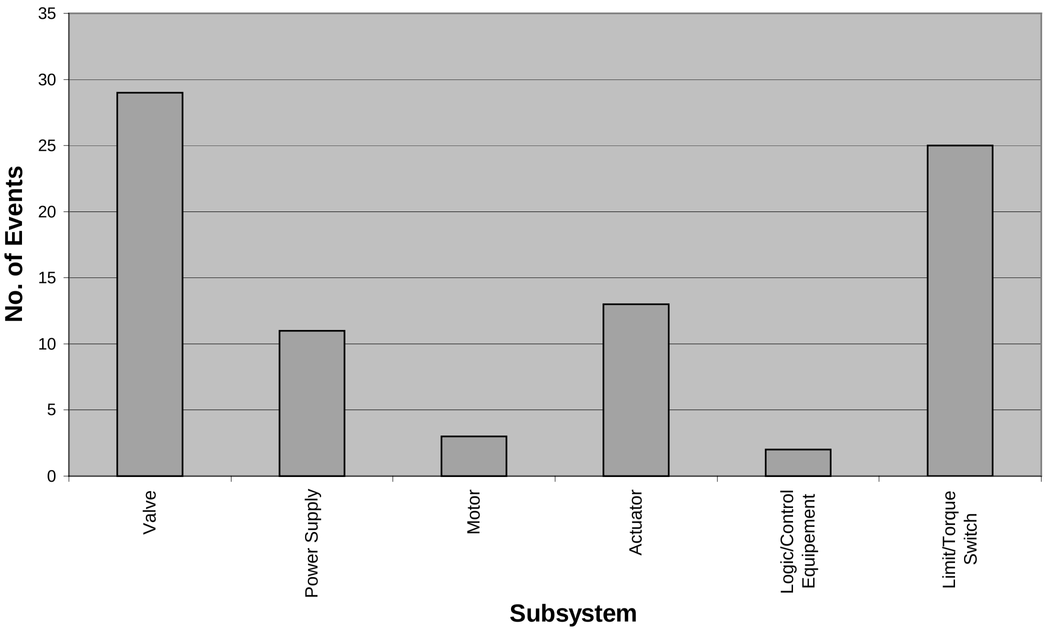


Figure 6-6. Subsystem distribution

7. OVERVIEW OF EVENTS BY FAILURE MODE AND DEGREE OF FAILURE

This section discusses the CCF events by failure mode and contrasts the distributions of partial CCF events with the distributions of the total group. A discussion of degree of failure is included in Section 6. Due to the low number (5) of events with failure modes “external leakage” and “no failure mode indicated,” these events are not included in the analysis in this section. As this section discusses events by failure mode, the five events that are coded both for failure to open and failure to close are counted separately. Thus, the analysis in this section covers 81 ICDE events.

Table 7-1 summarizes the number of events by root cause and failure mode. Figures 7-1 and 7-2 show the root cause distributions for all CCF events and the distribution of partial CCF events by failure mode. The Design root cause contribution and the Internal to Component/Piece Part contribution are the most important in the total group. Other major contribution comes from the human actions root cause and from the procedure inadequacy root cause. Examples of the root causes are given in Section 6. In the group of partial CCF events, these four root causes are nearly equally distributed. However, the composition between failure to open and failure to close shifts a little to more failure to open events in the partial CCF group. There are no internal leakage events in the partial CCF group.

Table 7-1. Root cause distribution for all ICDE events

Failure Mode	Root Cause	Number of events	Number of partial CCF
Failure to close	Abnormal Environmental Stress	3	2
	State of other components	1	1
	Design, manufacture or construction inadequacy	11	2
	Human actions	4	1
	Internal to component, piece part	9	0
	Maintenance	0	0
	Other	2	0
	Procedure inadequacy	4	2
Failure to open	Abnormal Environmental Stress	0	0
	State of other components	1	0
	Design, manufacture or construction inadequacy	11	5
	Human actions	5	4
	Internal to component, piece part	10	3
	Maintenance	1	0
	Other	5	0
	Procedure inadequacy	5	0
Internal leakage	Human actions	1	0
	Internal to component, piece part	7	0
	Procedure inadequacy	1	0

Table 7-2 summarizes the events by coupling factor and failure mode. Figures 7-3 and 7-4 show the distributions of CCF events for coupling factors for all events and partial CCF events by failure mode. In both group of events the operations coupling factor group is dominant, followed by the hardware coupling factor group. The environmental coupling factor group has no importance. The hardware coupling factor group has the same importance as the operations coupling factor in the failure to open mode for all events. In the internal leakage failure mode operations coupling factor is the only one.

Table 7-2. Coupling factor on failure mode

Failure Mode	Coupling factor	Number of events	Number of partial CCF
Failure to close	Environmental	2	1
	Hardware	13	3
	Operations	19	4
Failure to open	Hardware	19	6
	Operations	19	8
Internal leakage	Operations	9	0

Table 7-3 shows the number of events by corrective action and failure mode. Figures 7-5 and 7-6 show the distributions of CCF events for corrective actions for all events and partial CCF events by failure mode. The most important corrective action identified in this study is general administrative/procedure control. A second important corrective action concerns test and maintenance policies in the all events group whereas this corrective action has no importance in the partial CCF group. The dominance of the general administrative/procedure control and test and maintenance policies corrective action in the failure to close mode is stronger as in the failure to open mode. In the internal leakage failure mode test and maintenance policies corrective actions appear slightly more important than the general administrative/procedure control corrective actions.

Table 7-3. Corrective action on failure mode

Failure Mode	Root Cause	Number of events	Number of partial CCF
Failure to close	Administrative	18	5
	Maintenance/operation practices	2	1
	Design modifications	1	0
	Diversity	1	1
	Test/Maintenance policies	9	0
	Fixing of components	1	0
	Other	2	1
Failure to open	Administrative	15	7
	Maintenance/operation practices	6	3
	Design modifications	5	2
	Diversity	4	
	Test/Maintenance policies	3	1
	Fixing of components	2	1
	Other	3	0
Internal leakage	Administrative	3	0
	Maintenance/operation practices	1	0
	Test/Maintenance policies	5	0

Table 7-4 shows the number of events by subcomponent and failure mode. Figures 7-7 and 7-8 show the distributions of CCF events for subcomponent for all events and complete CCF events by failure mode. There is no significant difference in the distributions for the failure-to-open and failure-to-close failure modes for the actuator, control equipment, limit/torque switch, and motor. For the power supply failure mode failure to open is dominant, whereas for valve failure mode failure to close is dominant. As can be expected failure mode internal leakage is only attributed to the subcomponent valve. The distribution of failure modes does not shift for the group of partial CCF events. Most important subcomponents for partial CCF events are the subcomponents actuator, limit/torque switch, and power supply.

Table 7-4. Affected subcomponent by failure mode

Failure mode	Subcomponent	Number of events	Number of partial CCF
Failure to close	Actuator	7	4
	Limit switch	14	2
	Motor	1	1
	Power supply	2	1
	Valve	11	1
Failure to open	Actuator	6	2
	Control equipment	1	1
	Limit switch	16	3
	Motor	2	1
	Power supply	9	6
	Valve	5	2
Internal leakage	Valve	9	0

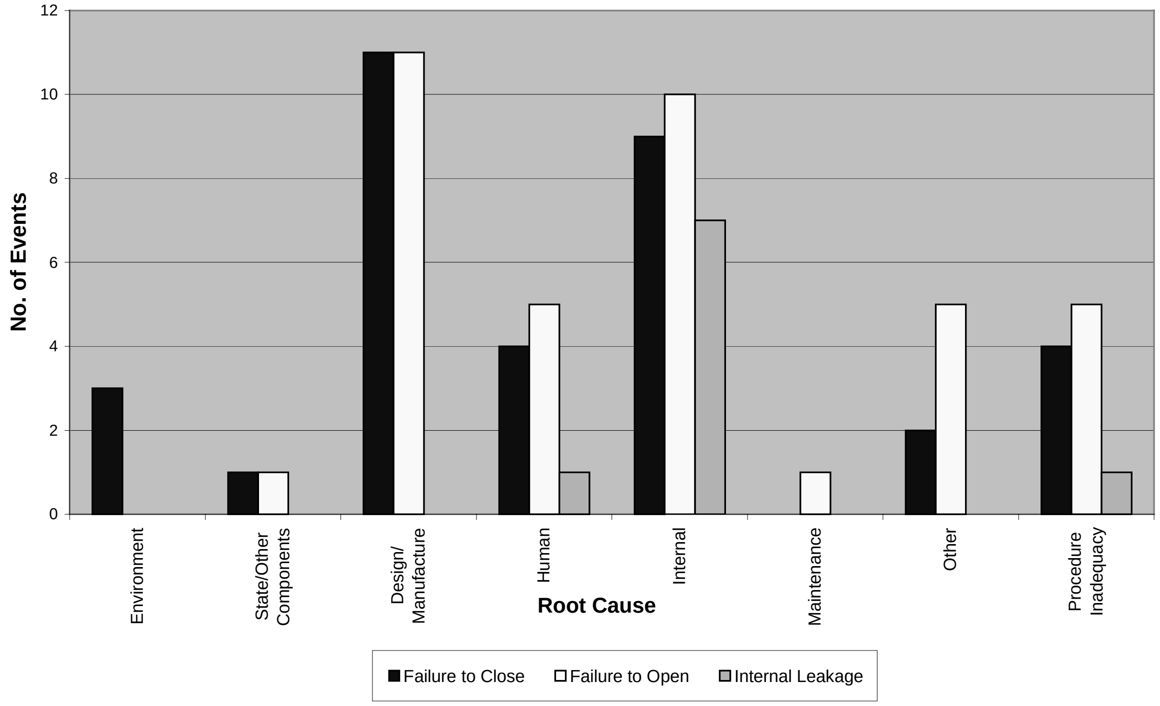


Figure 7-1. Root cause distribution for all ICDE events

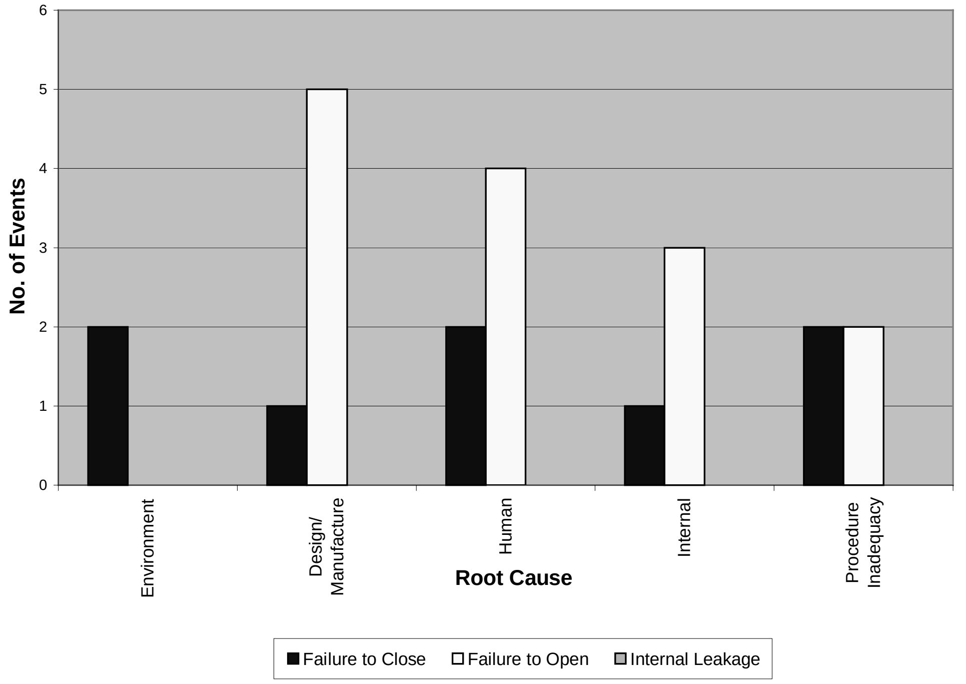


Figure 7-2. Root cause on failure mode for partial CCF

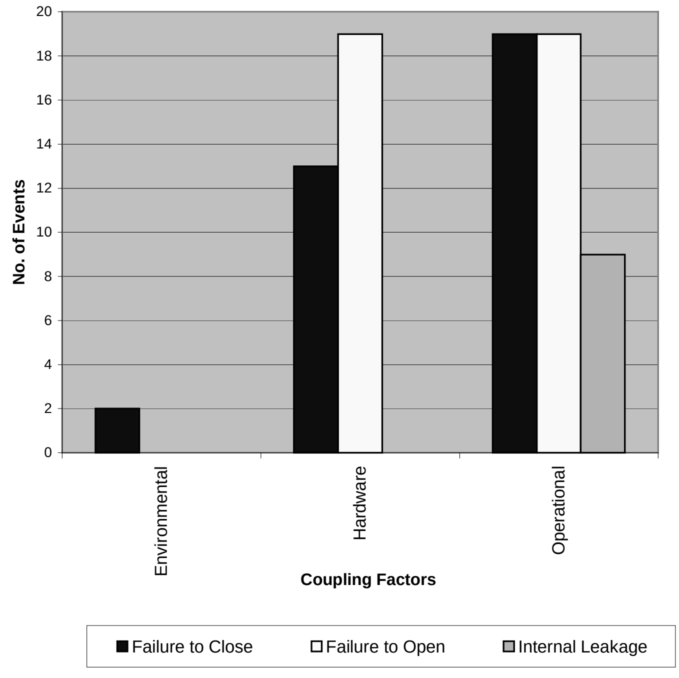


Figure 7-3. Coupling factor on failure mode for all ICDE events

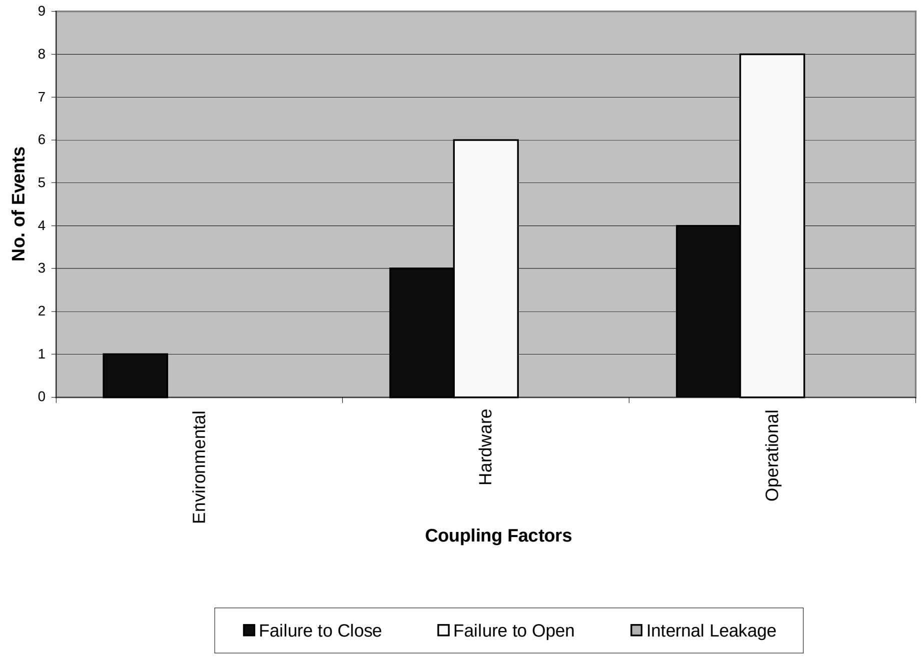


Figure 7-4. Coupling factor on failure mode for partial CCF events

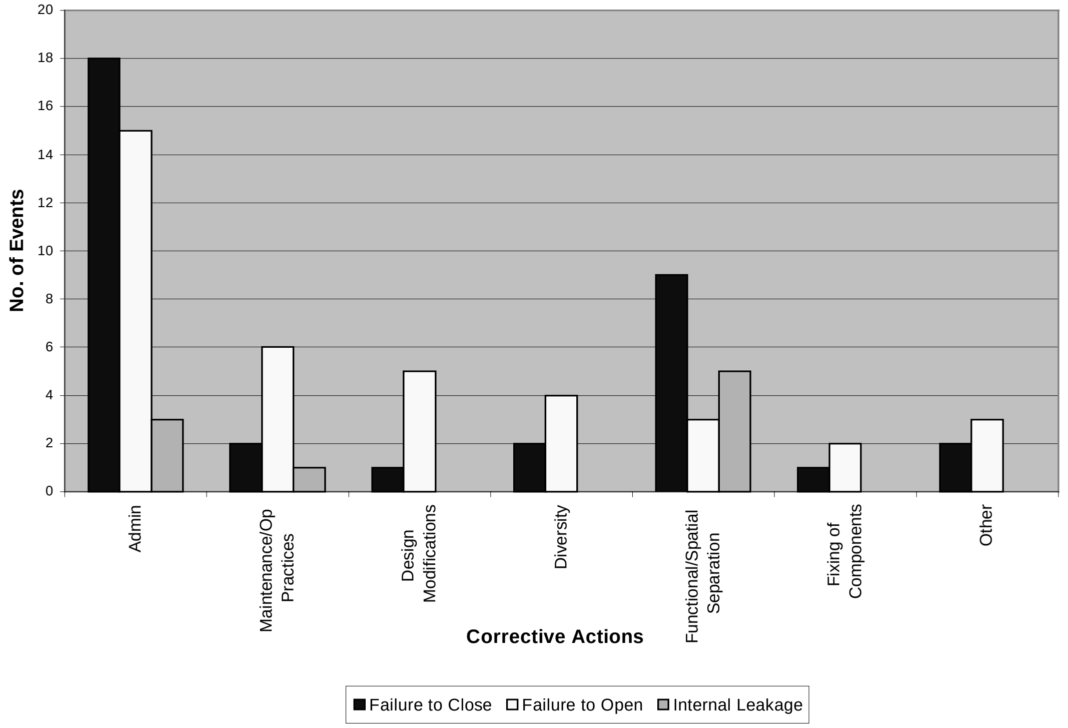


Figure 7-5. Corrective action on failure mode for all CCF events

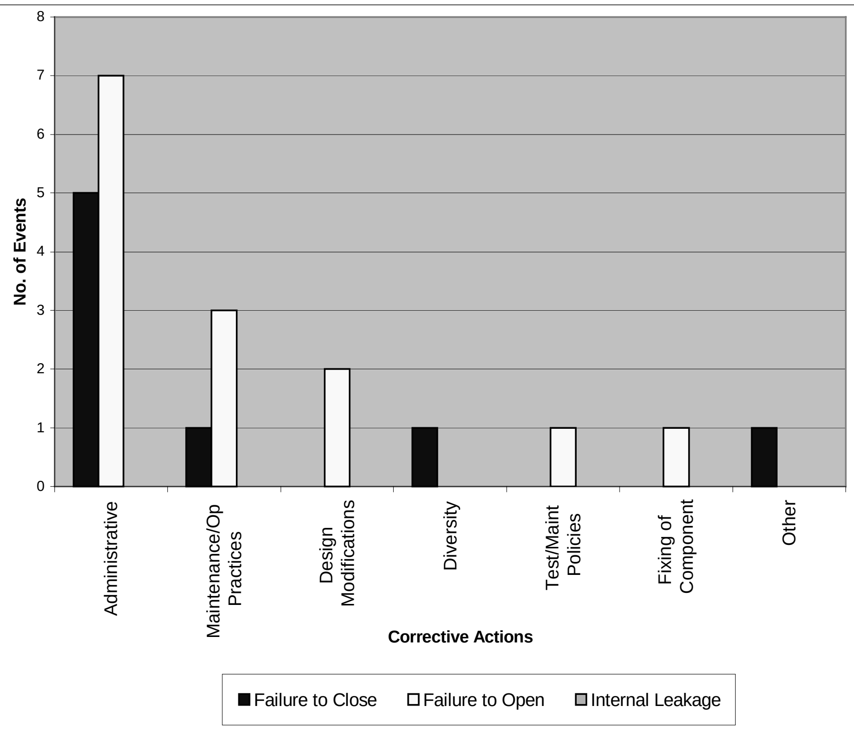


Figure 7-6. Corrective action on failure mode for partial CCF events

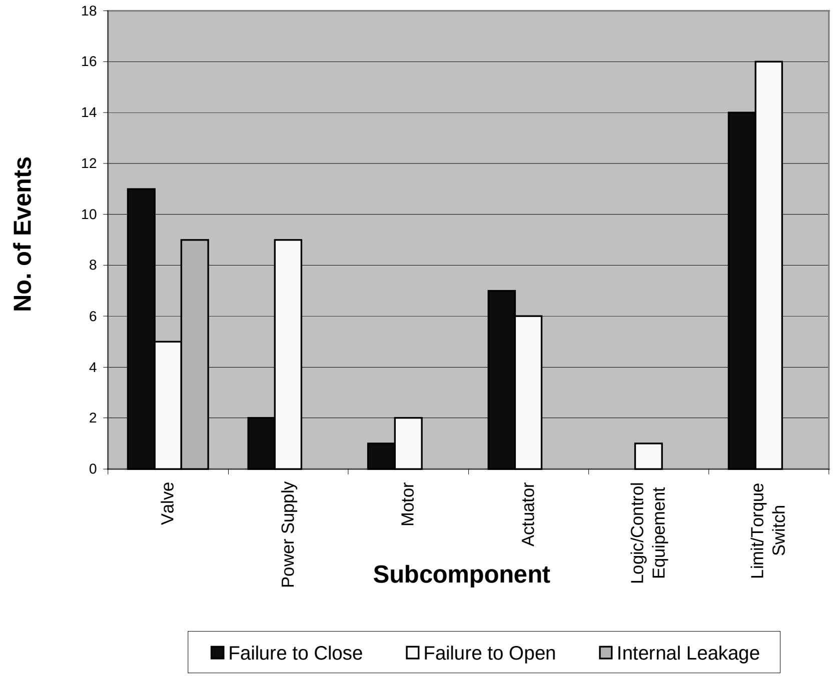


Figure 7-7. Affected subcomponent on failure mode for all CCF events

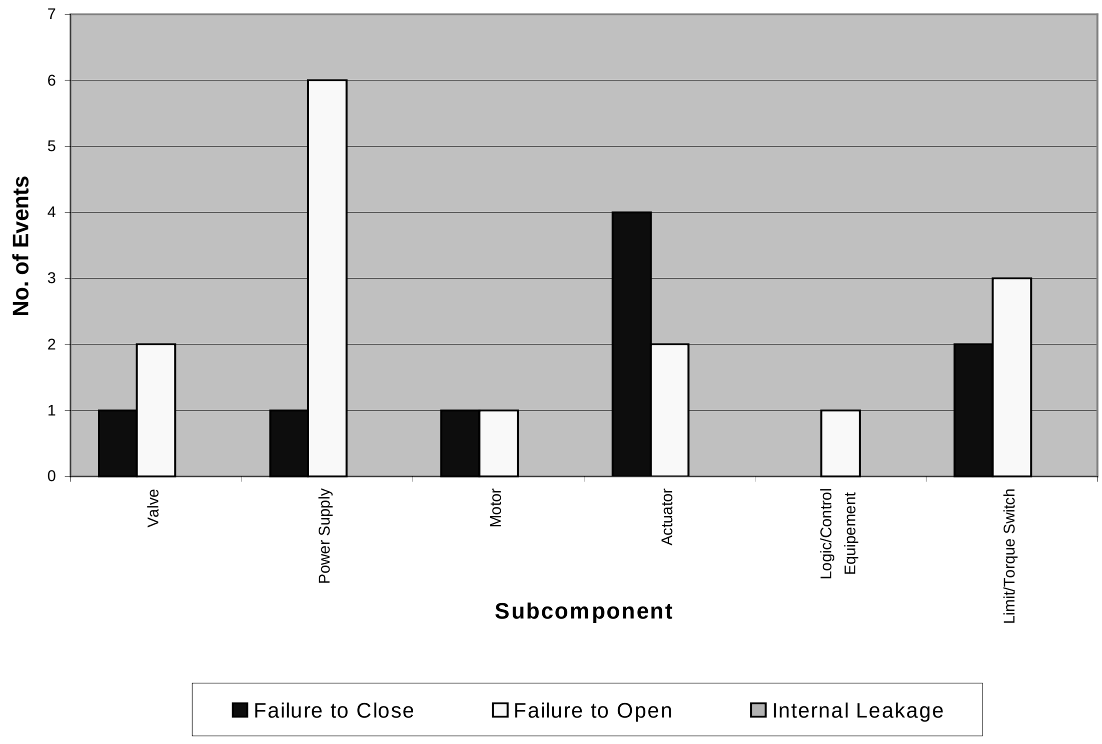


Figure 7-8. Affected subcomponent on failure mode for partial CCF events

8. FAILURE CAUSE CATEGORIES

The 81 ICDE events reported for MOVs from nuclear power plants have been analysed and characterised regarding the human error aspects and the technical aspects of the observed failures. For this purpose a further coding system with respect to fault categories was introduced. This coding system has a strong structure. Categorising of the events follows a decision tree. Categorising is done separately for human error aspects and technical fault aspects. Within the assessment of the technical fault aspects operating medium influences and technical effects are separately treated.

Human actions are determinative in view of the root causes of all events. That means every technical fault can be connected to a human error. The point of time and the circumstances of the human error can be very manifold. For instance, it is possible that during the design of an MOV a potential force remains unconsidered and the detection of this construction respectively dimension error has an effect only years afterwards. In this case, beside the technical effect on a subcomponent making the component MOV unavailable, the human error during design has to be considered as a failure cause.

By connecting the above described grouping of events by technical and human cause categories and the knowledge about the affected subcomponents it is possible to focus on failure centres and their causes.

This approach of evaluating events was created during handling of the MOV events. Of cause, not all available descriptions of the events are appropriate for a comprehensive, deep failure analysis regarding this human error analysis pattern. Even licensee event reports, which often were taken as the basis for the ICDE event reports, are frequently not expressive enough. So there are many events for which it is not possible to assign clearly human errors regarding the created categories.

The classification of the events was done during one workshop of the ICDE working group. The basis of the classification was the event description and coding in the ICDE database. The analysis shows that more than 50 % of the events could be assigned either to human error categories or to technical fault categories. For about 30 % of the events both human errors and technical faults have been identified.

8.1 Human error aspects

Events were classified according to the following classification scheme:

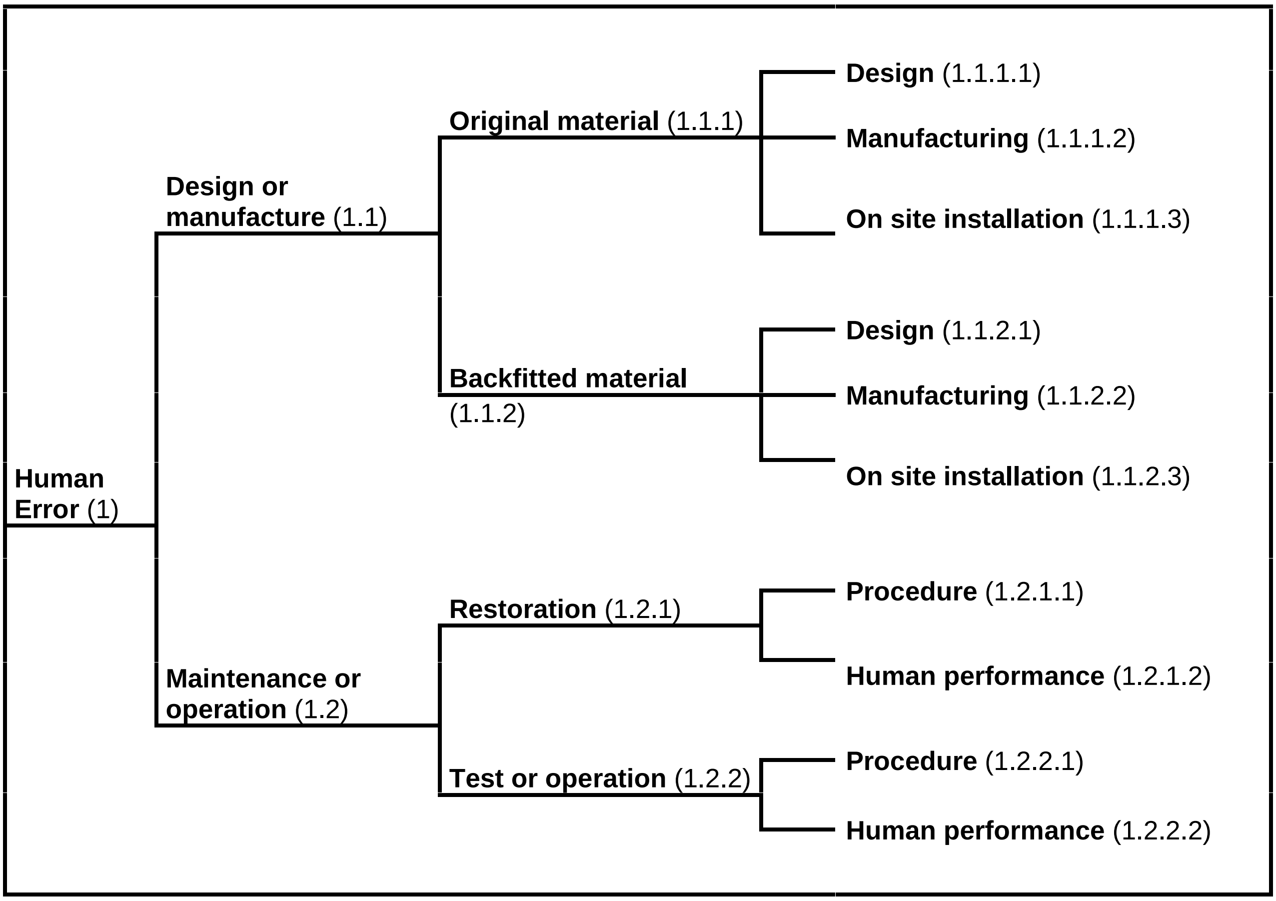


Table 8.1 shows a summary of the human error aspects of MOV events as reported in the ICDE event reports.

Table 8-1. Summary of human error aspects

Type of error	N° of events	Classification	Failure Mode	Subcomponent
Design error of original materials	12	1.1.1.1	FC=5 FO=5 N.F=2	Actuator=3 Limit/torque switch=3 Motor=1 Valve=5
Design error of backfitted material	5	1.1.2.1	FO=5	Actuator=1 Limit/torque switch=3 Valve=1
Maintenance or operation procedure error during restoration	6	1.2.1.1	FC=3 FO=1 EL=1 IL =1	Limit/torque switch=2 Valve=4
Maintenance or operation human performance error during restoration	2	1.2.1.2	FO=1 IL =1	Limit/torque switch=1 Valve=1
Maintenance or operation procedure error during test	8	1.2.2.1	FC=2 FO=6	Actuator=1 Control equipement=1 Limit/torque switch=4 Power supply=2
Maintenance or operation human performance error during test	12	1.2.2.2	FC=5 FO=7	Actuator=1 Limit/torque switch=4 Power supply=5 Valve=2

The most likely causes are design/manufacture inadequacy of original materials (12 events) and human error during tests (12 events). The CCF events are about equally distributed among the other causes, with exception of the error group human performance during restoration, which accounts for only 2 events.

8.1.1 Design error of original materials

Design error of original materials accounts for 15 percent of all events analyzed. Of these 12 events, 5 were failure to close, 5 were failure to open and 2 events were no failure mode included. Concerning the subcomponent distribution, 3 events were concerned with the actuator, 5 were concerned with the valve (housing, seals, and disk), 3 were concerned with limit/torque switch and one was with the motor. Most of these events revealed that false data were used for design calculation.

8.1.2 Design error of backfitted material

Design error of backfitted materials accounts for about 6 percent of 81 events analyzed. All 5 events were failure to open. The subcomponents involved were 3 events with limit/torque switch, one event with valve and one with actuator. An example for this group are events caused by the choice of an improper pinion key material leading to sheared motor pinion keys.

8.1.3 Maintenance or operation procedure error during restoration

This type accounts for about 7 percent of 81 events analyzed. From these 6 events, 3 were failure to close, 1 was failure to open, 1 was external leakage and 1 was internal leakage. The subcomponent distribution is 4 events involved with valve (housing, seals, and disk) and 2 with limit/torque switch. It should be noted that the only one event in the MOV database notified as an external leakage is in this group. The cause of the body to bonnet leak of this event was due to improper installation of the retaining ring.

8.1.4 Maintenance human performance error during restoration

Only two events were notified for this type of failure classification. One of them was failure to open tied to the limit/torque switch and the other was valve internal leakage due to an inadequate mounting of valve disks.

8.1.5 Maintenance or operation procedure error during test

Procedure error during test accounts for about 10 percent of 81 events. Of these 8 events, 2 were failure to close and 6 were failure to open. Concerning the subcomponent distribution, 4 events were concerned with an incorrect setting of torque limit switches, 1 was involved with control equipment, 1 was involved with the actuator and 2 were with the power supply. Observed failure mechanisms were e.g. lack of regular maintenance or failures in locking procedures.

8.1.6 Maintenance or operation human performance error during test

Human performance error during test accounts for 15 percent of all events analyzed. Of these 12 events, 5 were failure to close and 7 were failure to open. The subcomponent involved were power supply (5 events, e.g. locking failure), limit/torque switch (4 events, e.g. not correctly adjusted limit switches), valve (2 events, e.g. unsuitable grease or contact spray) and actuator (1).

8.2 TECHNICAL FAULT ASPECTS OF MOV CCF

This section contains an analysis of technical fault categories. Within the assessment of the technical fault aspects operating medium influences and technical effects are separately treated. The medium group contains media that causes technical faults. Both working medium (mostly water) and service medium (including lubricants and electric current) are considered in this branch. That most technical faults appear in connection with damage or material destruction of elements is used for grouping the events regarding their technical effect.

Events were classified according to the following classification scheme:

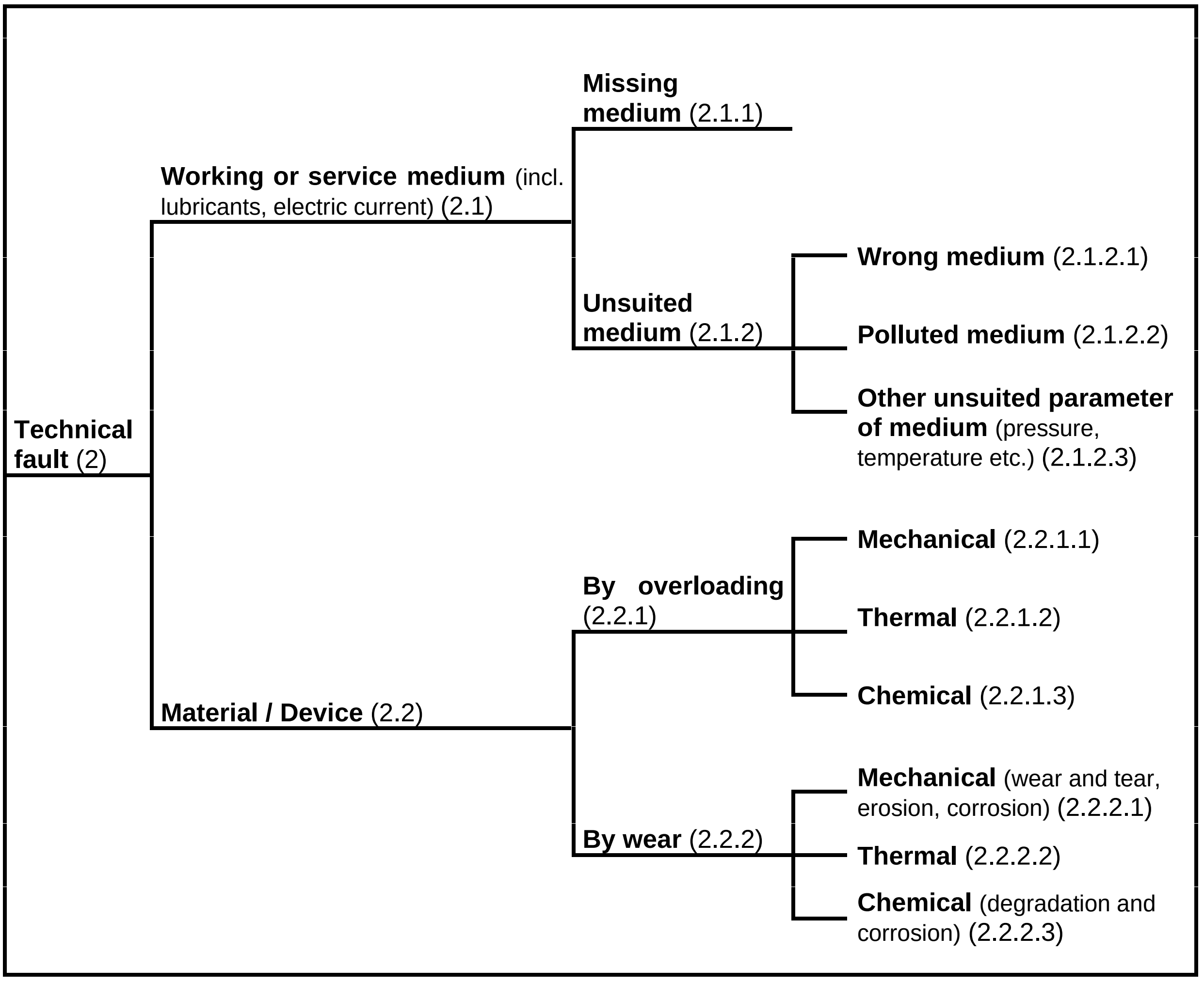


Table 8-2 shows a summary of the technical fault aspects of MOV events as reported in the ICDE event reports.

Table 8-2. Summary of technical fault aspects

Type of fault	Number of events			Classifi-cation	Failure mode	Subcomponent
Working or service medium fault	13			2.1	FC=6 FO=4 FC and FO=2 IL=1	Actuator=3 Limit/torque swi.=4 Power supply=2 Valve=4
missing medium		0		2.1.1		
unsuited medium		13		2.1.2	equals 2.1	equals 2.1
wrong medium			4	2.1.2.1	FC=2 FO=1 FC and FO=1	Limit/torque=1 Power supply=2 Valve=1
polluted medium			1	2.1.2.2	FO=1	Limit/torque=1
other unsuited parameter			8	2.1.2.3	FC=4 FO=2 FC and FO=1 IL=1	Actuator=3 Limit/torque=2 Valve=3
Material or device fault	57			2.2	FC=22 FO=21 FC and FO=4 IL=7 N.F.=3	Actuator=10 Control equipm.=1 Limit/torque=18 Motor=2 Power supply=6 Valve=20
by overloading		22		2.2.1	FC=8 FO=11 N.F.=3	Actuator=5 Control equipm.=1 Limit/torque=8 Motor=1 Power supply=1 Valve=6
mechanical			20	2.2.1.1	FC=8 FO=10 N.F.=2	Actuator=5 Limit/torque=7 Motor=1 Power supply=1 Valve=6
thermal			1	2.2.1.2	FO=1	Limit/torque=1
chemical			0	2.2.1.3		
by wear		35		2.2.2	FC=14 FO=10 FC and FO=4 IL=7	Actuator=5 Limit/torque=10 Motor=1 Power supply=5 Valve=14

mechanical			27	2.2.2.1	FC=11 FO=7 FC and FO=3 IL=6	Actuator=4 Limit/torque=7 Motor=1 Power supply=3 Valve=12
thermal			2	2.2.2.2	FO=1 IL=1	Power supply=1 Valve=1
chemical			2	2.2.2.3	FC=1 FC and FO=1	Actuator=1 Limit/torque=1

In total, for 60 events technical fault aspects of the observed failure have been identified. For 10 of them both working or service medium faults and material or device faults have been identified. The most likely causes are material or device faults (57 events). Nearly all of these events were due to mechanical problems, either by mechanical overloading (20 events) or by mechanical wear (27 events). Among the 13 events showing working or service medium faults, all events were due to unsuited medium.

8.2.1 Operating medium influences

The failure cause of 13 events can be related to operating medium. There are no events that are unequivocally caused by missing medium. The use of unsuited medium is the only failure cause in this group. In detail, there are four events caused by influence of wrong medium, one event caused by a polluted medium and eight further events that are caused by other unsuited parameters of the medium.

Affected subcomponents in this group are valve (4 events), limit/torque switch (4 events), actuator (3 events), and power supply (2 events).

Classification examples

Wrong medium:	An event was caused by the use of unsuitable grease for the bearings of the valve stem.
Polluted medium:	Failed valve operation due to dirty contacts on the valve operator limit switch.
Other unsuited parameters of the medium:	Lubricant not suited for high system temperatures.

8.2.2 Technical effects

60 events appeared with damages or material destruction of elements.

Overloading caused 22 of these events. (The term overloading describes a mechanical, thermal or chemical influence of a force or many forces on a subcomponent that is under-dimensioned for this kind of effect. The appearance of this force is often not considered during the design. The duration of the influence of the effect is far shorter than the planned lifetime of the subcomponent and appears often only sporadically)

This group is mainly formed by events caused by mechanical overloading (20). There is one event caused by thermal and no event that is caused by chemical overloading. The precise classification of one event was not possible. About 25 % of the events in the mechanical overloading group showed some kind of under-dimensioning leading to insufficient operating thrust under design basis conditions.

Affected subcomponents in this group are limit/torque switch (7 events), valve (6 events), actuator (5 events), motor (1 event), and power supply (1 event).

Thirty-five events were caused by wear. (The term wear describes a mechanical, thermal or chemical influence of a force or many forces on a subcomponent that is under-dimensioned for this kind of effect. The appearance of this force is mostly considered in the design. The duration of the influence of the effect is often long lasting and does in general not consist of countable single events.) In detail there are 28 events caused by mechanical wear, two events by thermal and two events by chemical wear. The precise classification of four events was not possible.

Affected subcomponents in the mechanical wear group are valve (12 events), limit/torque switch (7 events), actuator (4 events), power supply (3 events) and motor (1 event). About 70 % of the valve events due to mechanical wear lead to internal leakage. Nearly half of the limit/torque switch events were due to set-point drift.

Classification examples

Mechanical overloading:	An event that is caused by a sheared motor pinion key and can be attributed to improper key material.
Thermal overloading:	Pressure locking
Mechanical wear:	Reopening of valves after closure caused by reduced friction between screw and stem nut below self locking due to frequent actuation during tests.
Thermal wear:	Worn out valve seats due to cyclic fatigue
Chemical wear:	Oxidation on torque switch contacts

9. SUMMARY AND CONCLUSIONS

This study examined 81 events in the ICDE database by tabulating the data and observing trends. Once trends were identified, individual events were reviewed for insights.

The database contains information developed during the original entry of the events that was used in this study. This information includes root cause, coupling factor, detection method ,size, and corrective action. As part of this study, these events were reviewed again and additional categories of the data were included. Those categories included the degree of failure, the affected subcomponent, the kind of human failure, and the kind of technical failure.

This study begins with an overview of the data set. Charts and tables are provided which show the event count for the event parameters. There are charts that demonstrate the distribution of the events further refined by failure mode, root causes, coupling factors, corrective actions, number of exposed components, detection method, and affected subcomponents. There are charts that demonstrate the distribution of events even further refined into groups of the total group and partial CCF events.

Testing is the dominant mode for detecting common cause failures. The used term "test" summarized all kind of tests like tests during annual overhauls, tests during operation, and unscheduled tests.

The report contains a further grouping according to a decision tree that shows the distribution of the same events further refined by kind of human and technical failures. The analysis shows that more than 50 % of the events could be assigned either to human error categories or to technical fault categories. For about 30% of the events, both human errors and technical faults have been identified.

This approach especially focuses on root causes of common cause failures. So there are errors in the calculation during design that caused false stroke forces. Wearing is a widespread effect. The subcomponent "limit switch" caused also a substantial amount of CCF. Failures on locking out during maintenance actions were also conspicuous. There are further failure effects that caused CCF in not such a large and determinant scope. For example appeared in the study the selection of unsuited service media (mostly lubricants), the selection of improper materials, and assembly faults.

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10. REFERENCES

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4. Marshall, F. M., D. M. Rasmuson, and A. Mosleh, 1998. *Common Cause Failure Data Collection and Analysis System, Volume 1—Overview*, U.S. Nuclear Regulatory Commission, NUREG/CR-6268, INEEL/EXT-97-00696, June.