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ICDE PROJECT REPORT: COLLECTION AND ANALYSIS OF COMMON-CAUSE FAILURE OF CHECK VALVES

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ICDE Project Report: Collection and Analysis of Common-Cause Failure of Check Valves

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PREFACE

The purpose of the International Common Cause Data Exchange (ICDE) Project is to allow multiple countries to collaborate and exchange Common Cause Failure (CCF) data to enhance the quality of risk analyses that include CCF modelling. Because CCF events are typically rare 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.

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.

The qualitative insights gained from the analysis of CCF events are made available by reports that are distributed without restrictions. It is not the aim of those reports to provide direct access to the CCF raw data recorded in the ICDE databank. The confidentiality of the data is a prerequisite of operating the project. The ICDE database is accessible only to those members of the ICDE Project Working Group who have actually contributed data to the databank.

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

ACKNOWLEDGEMENT

The following persons have significantly contributed to the preparation of this report by their personal effort: Klaus Theiss (HSK), Philippe Hessel (CNSC), Wolfgang Werner (SAC). In addition, the support by ICDE steering group has been an important contributor to the success as well as the effort of the various ICDE liaison persons in all participating countries.

CONTENTS

EXECUTIVE SUMMARY

This report documents a study performed on the set of Common Cause Failure (CCF) events of Check Valves (CVs). The events studied here were derived from the International CCF Data Exchange (ICDE) database. Organizations from Canada, Finland, France, Germany, Netherlands, Sweden, Switzerland and the United States contributed with data to this data exchange.

This study examines 94 CCF events of CVs reported in the ICDE database by tabulating the data and observing trends. The database contains general information about event attributes like root cause, coupling factor, detection method and corrective action taken. As part of this study, most of these events were reviewed in more detail and characterized by failure cause and failure symptom categories.

The study itself begins with an overview of the entire data set in chapter 5. Charts are provided for each of the abovementioned event attributes. This chapter forms the baseline for chapter 6. The intention of chapter 6 is to give the reader a deeper qualitative insight in the database content beyond that obtained from using the event coding only. Chapter 7 contains the summary of the study results and the conclusions derived from.

Approximately 8% of all ICDE events of CVs were complete CCFs (all redundant components had failed). The number of partial CCF events (at least two of the redundant components failed) accounted for 24%. In the remaining 68% of the ICDE events, less than two components had failed completely, and the other components of the observed group only suffered from small defects, incipient degradation or were not affected at all. However, it was found that for more than 75% of the ICDE events the causal factors had a high probability to be shared by all the redundant components.

88 of the 94 reported ICDE events were reviewed in some more detail in Section 6 of this report with respect to failure causes, failure symptoms and failure mechanism. All events classified with a low "shared cause factor" were screened out for that review.

The most common failure mode of CVs is "failure to close" (includes internal leaking). Deficiencies in operation were responsible for about 50% of the failure causes, mainly due to "deficient maintenance procedures". In several cases test and maintenance intervals were too long, which prevent timely detection of the failure mechanism. The other 50% of failure causes were mainly due to "deficiencies in design of hardware".

Two dominant failure symptoms have been identified: valve movement impeded by deposition of dirt or oxidation products and valve leakage due to disk/seat surface degradation. Other failure symptoms are disk/seat misalignment and problems with loose or broken piece parts. The dominant failure mechanism are mechanical wear, (in particular disk/seat surface degradation causing the valve to leak), and chemical wear (in particular corrosion products impeding valve movement).

ACRONYMS

CCCG	COMMON CAUSE COMPONENT GROUP
CCF	Common Cause Failure
CSNC	Canadian Nuclear Safety Commission
CV	Check Valve
HSK	Hauptabteilung für die Sicherheit der Kernanlagen, Switzerland
ICDE	International Common Cause Failure Data Exchange
IRS	Incident Reporting System
NEA	Nuclear Energy Agency
OECD	Organization for Economic Cooperation and Development
PSA	Probabilistic Safety Assessment
SAC	Safety Assessment Consulting

ICDE Project Report

Collection and Analysis of Common-Cause Failures of Check Valves

1. INTRODUCTION

This report presents an overview of the exchange of CCF data of CVs among several countries. The objectives of this report are:

- to describe the data profile in the ICDE database for check valves and to develop qualitative insights in the nature of the reported events,
- to characterise the CCF events of interest by failure categories and failure symptoms,
- to illustrate possibilities for improvement.

The ICDE Project was organized to exchange CCF data among countries. Therefore a brief description of the project, its objectives, and the participating countries are presented in Section 2. Sections 3 and 4 provide the general boundary conditions for data collection including a definition of common cause failure and a description of the CV and its sub-components. The data review begins with an overview of the database presented in Section 5 and ends with engineering insights gained from the data review presented in Section 6.

2. 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 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 ICDE project is operated under the umbrella of the OECD/NEA whose representative for this purpose is the Secretariat for Principal Working Group 1 (PWG1). The ICDE project member countries and their sponsoring organizations are:

Canada:	CSNC
Finland:	STUK
France:	IPSN
Germany:	GRS
Japan:	NUPEC
Korea:	KAERI
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 and partial CCF events called “ICDE events” in this report. The project covers the key components of the main safety systems of Nuclear Power Plants, including centrifugal pumps, diesel generators, motor operated valves, power operated relief valves, safety relief valves, check valves, reactor protection system circuit breakers, batteries and transmitters.

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

2.4 Reporting and Documentation

All reports and documents related to the ICDE project are issued as public CSNI reports and they may be accessed through the OECD NEA web site [1].

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 [2].

2.7 Protection of Proprietary Rights

IRS procedures for protecting confidential information have been adopted. The coordinators 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

Two kinds of dependent events are identified when modeling common-cause failures in systems consisting of redundant components:

- 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 modeled 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 modeled 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 instance, according to NUREG/CR-6268" [3] a Common-Cause Event is defined as follows:

> "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 (degraded or incipient) component failures. To include all events of interest, an ICDE event is defined as follows:

> "Impairment[a] of two or more components (with respect to performing a specific function) that exists over a relevant time interval[b] 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.

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[a] 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

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

COMPONENT DESCRIPTION

4.1 General Description of the Component

The function of the CV is

- to establish or isolate flow to or from the fluid system,
- to form a conditional boundary (i.e., one direction) between high pressure and low pressure sections of a system during static conditions.

By design, the CV will open to allow flow when the low pressure section has experienced a pressure increase (e.g., pump start). The CV is operated by system pressure overcoming gravity.

The CV is comprised of a valve with its internal piece-part components. Typically, there is no capability to open, close or block these valves. However, some CVs can also be moved by manual, motor or hydraulic force. Furthermore some CVs are “air-testable” which should not affect normal component operation and, in some cases, the air supply is turned off during operation as a precaution. No power is normally required for valve operation.

CVs are typically installed in system areas like pump discharge, pump suction or system inter- or cross-connection. CV data were collected for the following systems especially:

- Reactor Core Isolation
- Auxiliary and Emergency Feedwater
- Residual Heat Removal
- Emergency Core Cooling
- Service Water
- Component Cooling Water

4.2 Component Boundaries

The main component of a CV is the valve itself. For the purpose of this study, the boundaries will encompass the valve body, including valve internals (e.g., disk, spring) and in the case of CVs driven additionally by external forces the valve operators.

4.3 Event Boundary

Successful operation of a CV is defined as opening or remaining closed in response to direct system pressure differential, and re-closing (in case of opening) when pressure differential is reduced to zero or reversed. Subsequent failures to re-seat completely are defined as a failure to close event. If the CV is driven additionally by external forces prevention of successful operation by a malfunction of valve operators is considered.

5. OVERVIEW OF DATABASE CONTENT

Organizations from Canada, Finland, France, Germany, Netherlands, Sweden, Switzerland and the United States contributed with CCF data for CVs to this data exchange. Ninety four (94) ICDE events were reported from Nuclear Power Plants [Pressurized Water Reactor, Boiling Water Reactor, and CANDU]. The data span a period from 1977 through 2000. The data are not necessarily complete for each country through this period.

Table 5-1 summarizes, by failure mode and impact of failure, the reported ICDE events. Seven of the reported ICDE events are complete CCF events. Complete CCF events are ICDE events in which all components of the CCCG fails completely due to the same cause and within a short time interval. A further subclass of ICDE events are partial CCF events having at least two components completely failed. In comparison to the number of the complete CCF events the number of partial CCF events is more than three times higher. From Table 5-1 it is obvious that the most common failure mode of CVs is "failure to close". This result is in line with the experience gained from the assessment of independent failures of CVs.
The remaining sixty-four (64) ICDE events are CCF events in which less than two components failed completely. All other components of the observed group have the impairment attribute "degraded ability" or "incipient failure" or were not affected. However more than 75% of the ICDE events are assigned to the shared cause factor category "high". The shared cause factor allows the analyst to express his degree of confidence how far multiple failures or impairments resulted from the same cause.

Event Reports received Failure mode	Total	Impact of Failure	
		Partial	Complete
Failure to Open	17	11	2
Failure to Close	36	11	5
External Leaking	4	0	0
Failure to Remain Closed/Internal Leaking	35	1	0
No proper interpretation	2	0	0
Total	94	23	7

Table 5-1. Summary statistics of CV data

The following charts illustrate the distribution of important attributes defined in the general coding guidelines [2] to describe the nature of the events reviewed by the analysts.

Figure 5-1 shows the distribution of analyzed events by root cause. The dominant root cause "internal to component" (I) accounts for 54% of the events while "design" (D) accounts for 27% of the events. The root cause "internal to component" refers to malfunction of parts internal to the CV, resulting from phenomena such as wear or other intrinsic failure mechanism (see more detailed analysis in Section 6 of this report).

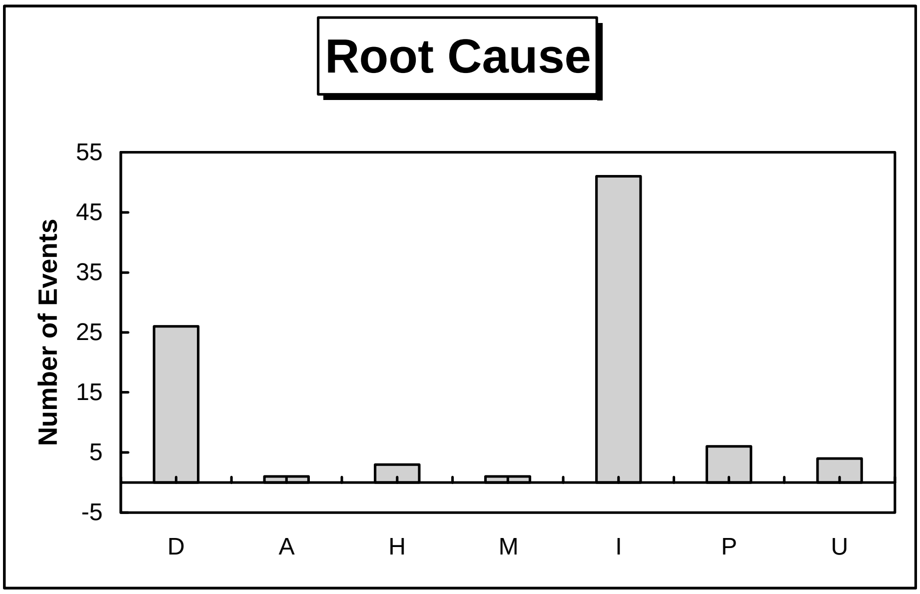

Figure 5-1 Root cause distribution

Figure 5-2 shows the coupling factor distribution for the events. The dominant coupling factor categories are "maintenance/test schedule" (OMS) which accounts for 33 % of the events and "hardware design" (HC) which accounts for 27 % of the events.

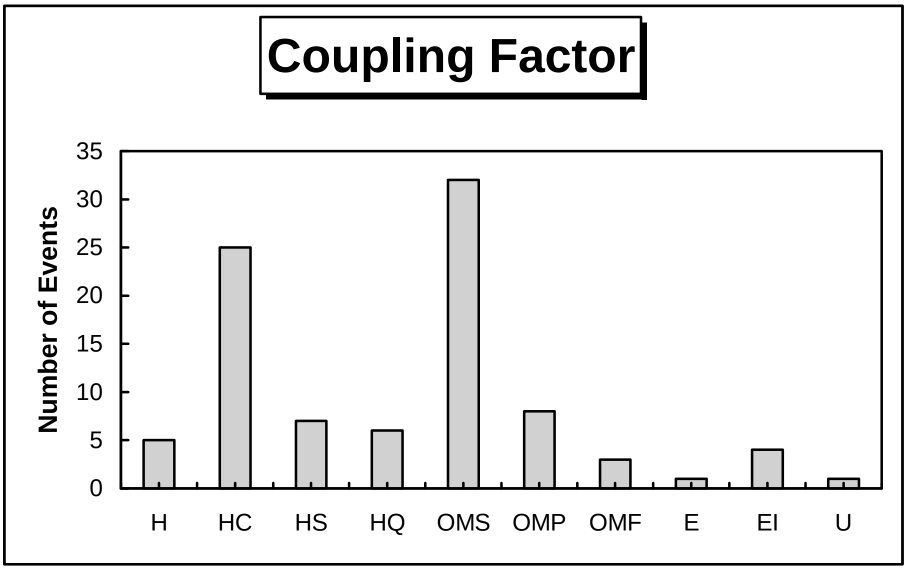

Figure 5-2 Coupling factor distribution

Figure 5-3 shows the distribution of corrective actions taken after detection of the respective CCF events. Test and maintenance policies (F) rank highest, accounting for 38 % of the corrective actions. Specific maintenance/operation practice (B) rank next, followed by administrative/procedural actions (A) and design modification (C).

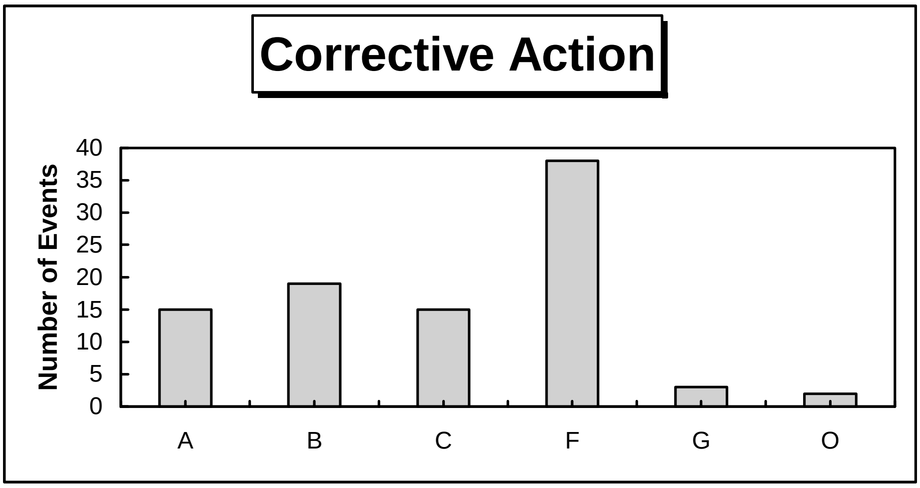

Figure 5-3 Corrective action distribution

Figure 5-4 shows the distribution of how the CCF events were discovered or detected. Testing (TA) accounts for 43%, maintenance (MA) accounts for 23%, and monitoring (MW) accounts for 17%. It is obvious that most of the events were detected during planned actions. Detection of five of the seven complete CCF events during annual overhaul indicates that test intervals were too long to identify the CCF mechanism in time.

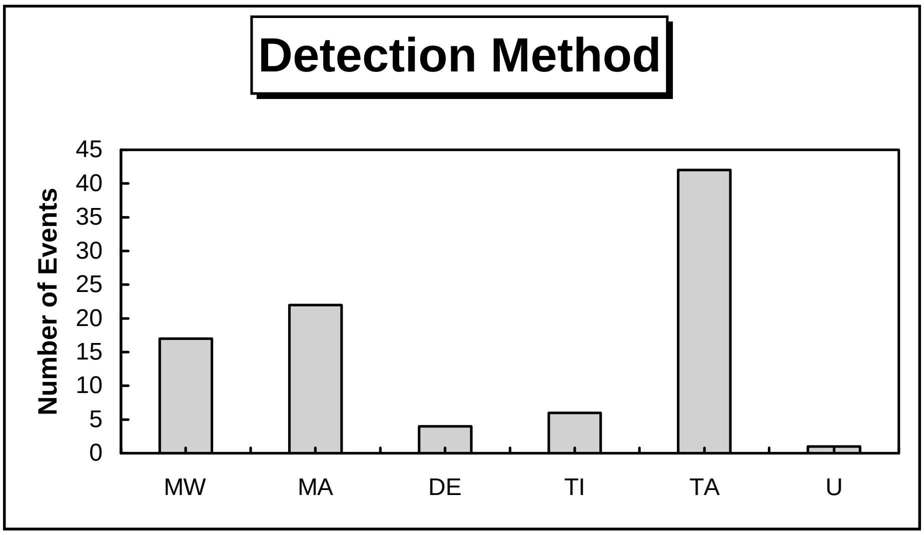

Figure 5-4 Detection method distribution

6. ENGINEERING ASPECTS OF THE CCF EVENTS

The intention of this chapter is to provide the reader with a deeper qualitative insight in the database content beyond that obtained from using the database coding only (as performed in Section 5 of this report). All events classified with a low "shared cause factor" were screened out because the degree of confidence about multiple failures resulting from the same cause is low. As a result of the screening process 88 of the 94 reported ICDE events were reviewed in more detail with respect to failure causes and failure symptoms. In a second step the review was confined to complete and partial CCF events as defined in Section 5 of this report.

6.1 Failure Cause and Failure Symptom Categories

Failure cause categories are defined by combining the event attributes "root cause" and "coupling factor" logically in order to describe the CCF process entirely. The coupling factor indicates the mechanism necessary for affecting multiple components within in a small time window whereas the root cause is the initiator. Two principle failure cause categories are defined:

1) Deficiencies in operation

This group comprises all ICDE events characterized by a human error related root cause or a human error related coupling factor. Three subcategories have been identified as being important:

O1 Deficient or erroneous procedures for maintenance and/or testing

O2 Insufficient work control after maintenance

O3 Human performance error during maintenance

2) Deficiencies in design, construction, manufacturing

This group comprises all ICDE events characterized by a hardware related root cause and a hardware related coupling factor. Two subcategories have been identified as being important:

D Deficiency in design of hardware

C/M Deficiency in construction or manufacturing of hardware

Failure symptom categories are derived directly from the event descriptions. The following failure symptom categories have been identified as being important:

B1 Movement of the valve is impeded by deposition of dirt, deposition of oxidation products or other chemical reaction products, insufficient lubrication

B2 Valve is leaking due to degradation of the valve seat/valve disk surface

B3 Full closure of the valve is prevented by misalignment of valve seat/valve disk

B4 Movement of the valve is impeded by deformation of valve internals

B5 Movement of the valve is impeded by loose or broken screw, bolts, hinges etc.

B6 Others

The above mentioned categories are used for the classification of the 88 ICDE events. It should be noted that CCF events of different types of CVs are recorded in the ICDE database (see Section 4.1). Definition of the failure symptom categories does not distinguish between CCF caused by internal parts or by valve operators.

6.2 Qualitative Insights

The categorization of the ICDE events is presented by using the matrices shown in Tables 6.1 and 6.2. Table 6.1 summarizes the results of the categorization of the above mentioned 88 ICDE events. Additionally the matrix contents the relative contribution of failure mechanism identified as being most important (*italic print)*. The following insights can be derived from table 6.1:

1) Dominant failure causes

- Deficiencies in operation are responsible for 50% of the failures, mainly due to failure cause category O1 "deficient maintenance/test procedures".
- The other 50% of failure causes are design, construction, manufacturing deficiencies, mainly due to failure cause category D "deficiencies in design of hardware".

It is interesting to mention that for 54% of the ICDE events assigned to the hardware related failure cause categories it was decided by the operator to improve the maintenance procedures instead of backfitting the affected component. In several cases environmental impact such as mechanical or chemical wear had been misjudged by the designer when specifying the maintenance procedures. These examples illustrates that a distinction between human related and hardware related failure in many cases is not possible.

2) Dominant failure symptoms

B1 Valve movement impeded by deposits of dirt or oxidation products, lacking lubrication accounts for 30% of the failure symptom categories.

B2 Valve leaking due to disk/seat surface degradation accounts for 25% of the failure symptom categories.

B3 Full closure of valve prevented by disk/seat misalignment degradation accounts for 19% of the failure symptom categories.

B5 Valve movement impeded by loose/broken screws, bolts, hinges etc. accounts for 12% of the failure symptom categories.

3) Dominant failure mechanism

Mechanical wear (35%, in particular disk/seat surface degradation causing the valve to leak) and chemical wear (25%, in particular corrosion products impeding valve movement) are dominant.

It appears that a significant portion of the events caused by mechanical or chemical wear could have been avoided by shorter test and maintenance intervals.

Table 6.1 Categorization of ICDE CV events with shared cause factor "Medium" or "High"

	Failure Symptom Categories						
Failure Cause Categories	**B1** Valve movement impeded by deposits of dirt or oxidation products, lacking lubrication	**B2** Valve leaking due to disk/surface degradation	**B3** Full closure of valve prevented by disk/seat misalignment	**B4** Valve movement impeded by deformation of valve internals	**B5** Valve movement impeded by loose/broken screws, bolts, hinges etc.	**B6** Others	**Total**
Deficiencies in operation (root cause <u>or</u> coupling factor are human related failures)	8	18	8	3	4	-	45
O1 Deficient maintenance/test procedures	7 *75 % chemical wear*	13 *85 % mechanical wear*	6 *70 % mechanical wear*	2	3 *75 % inadequate torque*	-	31
O2 Insufficient re-qualification and/or work control, after maintenance	1	5	1	-	-	1	8
O3 Operator performance error during maintenance	-	3	1	1	1	-	6
Design, construction, manufacturing deficiencies (root cause <u>and</u> coupling factor are hardware related failures)	17	3	8	2	6	6	43
D Deficiencies in design of hardware	16 *85 % chemical wear*	2	3	2)	5 *70 % mechanical wear*	4	32
C/M Deficiencies in construction or manufacturing of hardware	1	2	5 *75 % mechanical wear*	-	1	2	11
Total	25	25	16	5	10	7	88

Table 6.2 summarizes the results of the categorization of the reported CCF events with more than one component failed completely in dependence of failure cause category and degree of CCF. The number of complete CCF events is put in brackets. Additionally the distribution of failure symptoms is shown.

Table 6.2 Categorization of complete and partial CCF CV events

Failure Cause Category	**Number of completely failed CVs per Event**				
	Two	Three	Four	Five	Total
Deficiencies in operation					
O1 Deficient maintenance/test procedures	4	2 (1)	2 (2)		8 (3)
O2 Insufficient re-qualification and/or work control, after maintenance	(1)				(1)
O3 Operator performance error during maintenance	1				1
Design, construction, manufacturing deficiencies					
D Deficiencies in design of hardware	8 (1)	6	3 (2)	1	18 (3)
C/M Deficiencies in construction, manufacturing of hardware	2				2
Total	16 (2)	8 (1)	5 (4)	1	30 (7)
Distribution of failure symptoms	B1: 44%, B2: 18% B3: 18% B4: 7% B5: 14%	B1: 64% B5: 12% B6: 24%	B1: 80% B5: 20%	B1: 100%	B1: 57% B2: 10% B3: 10% B4: 3% B5: 13% B6: 7%

The following insights can be derived from Table 6.2:

- The highest number of completely failed CVs is five. Valve movement was impeded by deposits of oxidation products in this case.
- The number of CCF events strongly decreases with increasing number of completely failed CVs.
- The dominant failure cause for partial CCF events is deficiency in design. This result is somewhat different to that presented before.
- The dominant failure symptom category is B1 "Valve movement impeded by deposits of dirt or oxidation products, insufficient lubrication". Its relative contribution increases with the number of completely failed CVs.

7. SUMMARY AND CONCLUSIONS

Ninety-four (94) ICDE events of CVs were reported from Nuclear Power Plants. The overview of the database content in Section 5 of this report shows that 30 of the 94 ICDE events involve two or more completely failed components. In seven cases all components of the CCCG failed. The most frequent common cause failure mode of CVs is "failure to close". This result is in line with the experience gained from the assessment of independent failures of CVs.

88 of the 94 reported ICDE events were reviewed in more detail in Section 6 of this report with respect to failure causes, failure symptoms and failure mechanism. All events classified with a shared cause factor "low" were screened out for this review.

Deficiencies in operation were responsible for about 50% of the failure causes, mainly due to failure cause category O1 "deficient maintenance procedures". In several cases, test and maintenance intervals were too long to detect a failure mechanism before it had affected multiple components. The other 50% of failure causes were mainly due to failure cause category D "deficiencies in design of hardware". The operators had taken procedure related corrective actions in consequence of 78% of the ICDE events. This portion indicates the importance of reviews and improvements of existing operating procedures in order to enhance the plant-specific CCF defenses.

Two failure symptoms were identified as dominant:

- valve movement impeded by deposition of dirt or oxidation products, and
- valve leakage due to disk/seat surface degradation.

Similar to this observation two dominant dominant failure mechanism were found:

- mechanical wear, mostly disk/seat surface degradation causing the valve to leak, and
- chemical wear, mostly corrosion products impeding valve movement.

Taking into account complete and partial CCF events only the highest number of CVs failed completely was five. The number of CCF events strongly decreases with increasing number of completely failed CVs. This trend demonstrates that a higher degree of redundancy can be an effective defense against CCF. The dominant failure symptom category is B1 "Valve movement impeded by deposits of dirt or oxidation products, insufficient lubrication". Its relative contribution increases with the number of completely failed CVs.

8. REFERENCES

[1] OECD/NEA's web site: hppt://www.nea.fr. ICDE project documentation, 1995-1998

[2] ICDE Coding Guidelines (ICDE CG00), 2002

[3] 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.