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Organisation de Coopération et de Développement Economiques
Organisation for Economic Co-operation and Development

**07-Nov-2002**

**English text only**

**NUCLEAR ENERGY AGENCY**
**COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS**

NEA/CSNI/R(2001)8
Unclassified

# PROCEEDINGS OF THE ICDE WORKSHOP ON QUALITATIVE AND QUANTITATIVE USE OF ICDE DATA

**Held in Stockholm, Sweden on 12-13 June 2001**

*The complete version in only available in pdf format.*

**JT00134794**



English text only

**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), Korea (12th December 1996) and the Slovak Republic (14 December 2000). 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 28 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, Slovak Republic, 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 Committee on the Safety of Nuclear Installations (CSNI) of the OECD Nuclear Energy Agency (NEA) is an international committee made up of senior 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 among the OECD Member countries.

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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**OECD Nuclear Energy Agency (NEA)**
**Committee on the Safety of Nuclear Installations (CSNI)**
**Working Group on Operating Experience (WGOE)**

# *ICDE SEMINAR AND WORKSHOP*

*ON*

# QUALITATIVE AND QUANTITATIVE USE OF ICDE DATA

**12-13 June 2001**

At Scandic Hotel, Slussen. Stockholm City
*Guldgränd 8, 10465 Stockholm*

**(Metro station Slussen, close to the Old Town)**

# *PROGRAMME*

**Hosted by**

**SKI, Swedish Nuclear Power Inspectorate**
**Stockholm, Sweden**

| | |
|---|---|
| 8.30 – 9.10 | Opening remarks<br>SKI, NRC, OECD/NEA |

**Qualitative Insights**
*Chairman : Dave Roberts*

| | |
|---|---|
| 09.15 – 09.45 | Use of CCF insights in inspection and maintenance<br>*P. Baranovsky (NRC)* |
| 09.45 – 10.15 | Generic insights from data collected in the ICDE project. How can the findings best be conveyed for inspection and maintenance<br>*W. Werner (SAC*) |
| 10.45 – 11.15 | Qualitative insights from ICDE data.<br>*D. Roberts/I. Morris (NII)* |

**Quantification: Event Interpretation**
*Chairman : Albert Kreuser*

| | |
|---|---|
| 12.30 – 13.00 | Quantitative assessments and applicability of CCF events. Use of data for other plants<br>*A. Kreuser (GRS)* |
| 13.00 –13.30 | Impacts vectors – construction and linkage of CCF data to CCF quantification<br>*T. Mankamo (Avaplan)* |
| 13.30 – 14.00 | Models assumptions and estimation technique with the focus on the role of ICDE in the future<br>*J. Vaurio (Fortum)* |
| 14.15 – 14.45 | Possible Improvement of ICDE guidelines according to influences from KOLA NPP dependency analysis.<br>*G Johansson (ES-Konsult)* |
| 14.45 – 15.15 | CCF Analysis in PSA at IPSN. Overview of methodology used for modelling CCFs in PSA<br>*J. Tirira (IPSN)* |
| 15.15 – 15.45 | CCF Analysis in progress at EdF. Overview of EdF involvement in qualitative CCF analysis, e.g. control rod application<br>*Dominique Vasseur (EdF)* |

**Quantification: Models parameters**
*Chairman : Dale Rasmuson*

| | |
|---|---|
| 15.45 – 16.15 | Parameter estimation within the activities of the Nordic CCF Group<br>*G. Johansson (ES-konsult)* |
| 16.15 – 16.45 | An analysis of piping degradations and failures as the root cause of common cause failure mechanisms in redundant safety systems<br>*B.O.Y. Lydell (ERIN)* |
| 16.45 – 17.15 | The use of the data in quantification in safety analysis<br>*D. Rasmuson (NRC)* |
| 17.15 – 18.00 | Sum-up and discussions about the presentations the first day<br>All session leaders, Lennart Carlsson, participants |

## *Wednesday, June 13, 2001*
## Workshop

**********

**Group 1 - Qualitative insights**
**Groups 2 – Quantitative insights / Guidelines**
**Group 3 – Parameter estimations**

**********

**Summary and Conclusions of workshop**
***Chairman : P. Baranovsky***
***Group leaders: 1, 2, 3***
***And workshop participants***

## *Thursday, June 14, 2001*
## ICDE meeting

**********

**According to the ordinary ICDE agenda**

## *Friday, June 15, 2001*
## ICDE meeting

**********

***According to the ordinary ICDE agenda***

# 1. INTRODUCTION

Common-cause-failure (CCF) events can significantly impact the availability of safety systems of nuclear power plants. In recognition of this, CCF data are systematically being collected and analysed in several countries, e.g. in Germany, France, Sweden and the United States

A serious obstacle to the use of national qualitative and quantitative data collections by other countries is that the criteria and interpretations applied in the collection and analysis of events and data differ among the various countries. A further impediment is that descriptions of reported events and their root causes, which are important to the assessment of the events, are usually written in the native language of the countries where the events were observed.

Preparation for ICDE project was initiated in August of 1994. Swedish and US Nuclear Power Inspectorates (SKI and NRC) identified the need to establish an international project aiming at collection and analysis of CCF data for key components of the main safety systems at for world's nuclear power plants and further exchange of these data between participating countries. Since April 1998, the OECD/NEA has formally operated the project. The Phase II with an agreement period 2000-2002 will be continued with a new phase. The agreement for the phase III covers the period 2002-2005.

As for the end of phase II data collection, analysis and exchange have been performed for centrifugal pumps, diesel generators, motor-operated valves, safety & relief valves, check valves and batteries. Final reports for centrifugal pump, diesel generators motor-operated valves and safety relief valves have been developed.

Member countries, which formed the ICDE Working Group under the Phase II Agreement of OECD/NEA and the organisations representing them in the project group, were as of 2001:

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

The objective with the ICDE activity is to provide a framework for a multinational co-operation in order to:

- to generate qualitative insights on root causes of CCF events that can be used to derive provisions for preventing CCF events, or for mitigating their consequences, should they occur.

- to establish an international working group on a long term basis which will collect and analyse CCF events

- to generate the framework for efficient experience feedback on CCF phenomena and on defence against CCF

Closely related to the ICDE project, a workshop was organised by the Committee on the Safety of Nuclear Installations (CSNI) of the OECD Nuclear Energy Agency (NEA) in June 2001 in Stockholm. The idea was to discuss the qualitative and quantitative insights gained in collecting and using CCF data. The workshop was hosted by the Swedish Nuclear Power Inspectorate SKI, and it gathered a large audience of researchers, regulators and industry representatives. The findings of the discussions and the papers of the workshop are presented in these proceedings.

## 2. PROPOSALS AND INSIGHTS FROM THE DISCUSSION GROUP 1

**Task: To consider what improvements could be made to assist in the production of qualitative information and the production of qualitative reports.**

There was a discussion about the limitations of the ICDE database in terms of the quality and scope of information and difficulties encountered when attempting to sort and analyse data.

The following proposals were made for changes to the Database and information supplied to the Database.

1. Coded fields should be searchable. Currently not all the coded fields in the ICDE database are searchable, which makes the analysis very difficult.

2. There should be additional guidance i.e. standard definitions for Coded Field terms. This would remove ambiguity and increase the accuracy of the field. Not all coded values of fields are defined in the coding guidelines.

3. Change the field C13 from "OTHER" to "CODING JUSTIFICATION" to include information on corrective action and preventative action. It is not always obvious why a record has been coded the way it has and this information is often very useful in understanding the nature of the event.

4. Consider having ICDE Coding Guidelines in the Database as a "POP-UP" text to aid coding during data input. This would be useful to the input stage of the process to ensure that the guidelines are accurately followed. The downside of this is that cost of maintaining the help files for each database particularly if the ICDE change a generic coding guideline.

5. In Database Fields C5 and C7, provide more guidance on what information should be supplied. Expand the bullet points as to what is expected under the headings in the guidelines to include a good definition and description of the possible inputs to these fields.

6. If possible, include more information on Direct and Root causes. Root causes are often missed and represent the most useful information when considering actions that would prevent or have mitigated this CCF.

7. The date when information was entered (not only the event date) should be accessible. This can be an automatic field. This will be useful in understanding what has changed in the database since the last release.

8. Group State Information to be accessible from the Database to include "ALL FAILED", "NONE FAILED" and "AT LEAST ONE FAILED". When doing analysis on the data a useful categorisation is to consider the degree of impact on the system. Since the data records the state of each component and different reactors may use, two three, four or more train systems, it is very difficult to automatically identify when complete systems have failed. For example a search of CC

would reveal when two train systems have completely failed but not three or four train systems. This change would therefore enable the analysis to be considerably less onerous.

9. Provide completed component databases to each country as a master not a replica. Since the databases are transmitted as a replica they have considerably more fields than are required for analysis (since they include fields to control replication). They are also write protected which prevents the analyst from adding fields for analytical purposes and writing queries and reports. Making Master databases the default end product would make the analysis process easier.

## 3. PROPOSALS AND INSIGHTS FROM THE DISCUSSION GROUP 2

### Task: To consider improvements of the ICDE database for Quantitative insights and Guidelines

The participants analysed some example records (Observed Population Records (CCCG) and CCF Event Records) of the ICDE database. The aim of the analysis was to find out whether there are proposals for further improvement of the database and the quality of information stored in it. The analysis resulted in the following recommendations for coding guides and database:

a) Recommendations, which are easy to implement and which do not affect the database structure

- Homogenise format of print outputs for "CCCG Records" and "CCF Event Records" for the different component databases
  - use accurate names of fields, e.g. for G6 - number of components in Observed population C4 - number of exposed components
  - C4 is missing in print output from MOV database (event records)
- Add a sequential number in GO Identifier for CCCG records to allow for unique CCCG records within one system and one type of component if several clearly distinguishable subsets exist
- Change word "failure" to "impairment" in all Coding Guides, e.g. for field C14 (time factor), C10 (coupling factor), C11 (shared cause factor), C12 (corrective actions)
- Restrict observed populations to one system in General Coding Guide (page 8, G 1)

Remark: General Coding Guides: table of content is missing C14

b) Recommendations, which need major effort:

- Improve existing items in check list of field C 05 (Event description) in General Coding Guide
  - add examples
  - describe expressions like "conditioning event", "trigger event"
- Coding is sometimes not consistent with event descriptions, therefore
  - make codes simpler for "Root Cause", "Coupling Factor", "Corrective Action": reduce number of choices for each field or introduce hierarchical codes
  - check: which codes are really used
- Move subcomponent classification from analysis part to data collection part
  - add description of boundaries of subcomponents in coding guide (component specific ones)

Observation: in some CCCG records parts of or all statistical information is missing.

# 4. PROPOSALS AND INSIGHTS FROM THE DISCUSSION GROUP 3

## Task: Suggestions for improvements in the database for Quantification purposes

1. The ICDE Database should provide information needed for the quantification methods used in the participating countries.

   - All fields should be complete.
   - Database should be quality assured

   SUGGESTIONS TO IMPROVE THE DATABASE:

   a) Add a field to the Database to distinguish between a CCF event and an interesting event

   b) Add a field to the Database to identify complete CCF events.

   c) Make sure each field is coded (Unknown versus an empty field). There should not be any empty fields.

2. Developing a "pseudo plant-specific" Database

   - Need to develop guidance on "tailoring" events for the target plant (e.g., use of the applicability factor, guidance on evaluating CCF defences).
   - Need to perform an empirical study of mapping up and down to verify the concepts
   - Need to assess the role of demand-based versus time-based estimates in risk-informed decision making.
   - Need to develop guidance on the "amount" of data needed for a "good" estimate.
   - Need to develop guidance on the estimation of impact vectors and how to treat the uncertainty in them.

3. Survey of Quantification Methods

   - ICDE should conduct a survey of countries to see what CCF quantification methods they use. This should include the following:

     Description of the method
     Parameters to be estimated
     Input data required
     How the ICDE Database compares with the data needs
     What CCF methods are used for high redundancy configurations

   - A controlled benchmark exercise should be performed

4. Use of Different Databases for Single Events and CCFs

   - ICDE needs to develop guidance on the proper way to use data from different databases.
   - ICDE needs to develop guidance on how to augment an existing CCF database with CCF data from another CCF database.

5. Qualitative CCF Insights

6. Other Comments

   - Each country should share their experiences with providing information to the utilities.
   - There are inconsistent definitions in the General Coding Guidelines (e.g., observed population, use of term “degraded failure”).

## 5. LIST OF PARTICIPANTS

| | |
|---|---|
| Mr. Philip HESSEL | Atomic Energy Control Board, Canada |
| Mr. Tuomas MANKAMO | Avaplan Oy, Finland |
| Mr. Kalle JÄNKÄLÄ | Fortum, Finland |
| Mr. Jussi VAURIO | Fortum, Finland |
| Mr. Risto HIMANEN | TVO, Finland |
| Mr. Jari PESONEN | TVO, Finland |
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| Mr. C. BONNET | EDF DPN, France |
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| Mr. Dave ROBERTS | Nuclear Installations Inspectorate, UK |
| Mr. Pat BARANOWSKY | NRC, USA |
| Mr. Dale RASMUSON | NRC, USA |
| Mr. Bengt LYDELL | RSA, USA |
| Dr. Wolfgang WERNER | Werner Safety Assessment Consulting, Germany |
| Mr. Lennart CARLSSON | OECD Nuclear Energy Agency, France |

# 6. PRESENTATIONS

## Qualitative Insights

- Use of CCF insights in inspection and maintenance
  *P. Baranovsky (NRC)*
- Generic insights from data collected in the ICDE project. How can the findings best be conveyed for inspection and maintenance
  *W. Werner (SAC)*
- Qualitative insights from ICDE data.
  *D. Roberts/I. Morris (NII)*

## Quantification: Event Interpretation

- Quantitative assessments and applicability of CCF events. Use of data for other plants
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- Impacts vectors – construction and linkage of CCF data to CCF quantification
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## Quantification: Models parameters

- Parameter estimation within the activities of the Nordic CCF Group
  *G. Johansson (ES-konsult)*
- An analysis of piping degradations and failures as the root cause of common cause failure mechanisms in redundant safety systems
  *B.O.Y. Lydell (ERIN)*
- The use of the data in quantification in safety analysis
  D. Rasmuson (NRC)

# Using CCF insights in Risk-Informed Inspection[1]

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Washington, D.C. 20555-0001 USA

Recently the U. S. Nuclear Regulatory Commission (USNRC) shifted to a more risk-informed reactor oversight process (ROP) that includes a risk-informed inspection program. In that inspection program, risk insights from probabilistic risk assessments (PRAs) performed as part of the individual plant examination (IPE) program and risk-based analysis of reactor operating experience are being factored into the risk planning and implementation process. Quantitative risk information is being used to set inspection schedules and identify the risk-significant scope of items to be inspected including specific component features and failure mechanisms. An important element of risk involves susceptibility to common-cause failure (CCF). The primary use of CCF data has been to estimate parameters for use in quantitative risk and reliability analysis applications. This paper provides a concept for integrating CCF insights of a general nature as well as the use of detailed data for plant specific tailoring of inspection plans.

The steps in this process involve:

1. Understanding the risk-informed inspection program including overall, regional, and plant-specific inspection planning.

2. Identifying where additional risk information could enhance the inspection process and how it could be used.

3. Conceptually organizing risk information and supporting sources to feed into the inspection process. This includes identifying risk-important scenarios, dominant contributors and the risk-important functional requirements of the equipment and associated operator actions.

4. Identifying applicable generic and plant-specific insights and related risk-based reactor operating experience information, and specifically, common-cause failure insights and data.

5. Delineating the specific CCF information that will be used in the inspection planning process.

6. Extracting and organizing CCF data to match inspection planning categories and plant specific features: design, test & maintenance, operations & procedures.

7. Developing inspection plans that incorporate specific aspects of CCF data for each system and component within the plant-specific inspection scope.

This approach provides a risk focus to inspection planning that is consistent with the USNRC's significance determination process (SDP), and therefore, more likely to result in risk-significant findings.

[1] This paper was prepared (in part) by an employee of the United States Nuclear Regulatory Commission. It presents information that does not currently represent an agreed-upon staff position. USNRC has neither approved nor disapproved its technical content.

# Using CCF Insights in Risk-Informed Inspection

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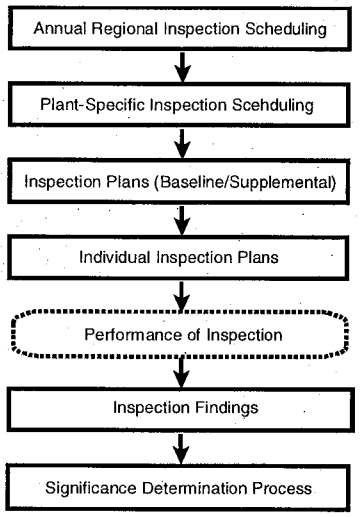
**U.S. Nuclear Regulatory Commission**
**Washington, D.C. 20555-0001**



## Objectives

- To provide a conceptual approach for incorporating CCF insights in the risk-informed inspection process in:
  - Scheduling of inspections
  - Scope of inspection plans
  - Identification of specific inspection items

## Risk-Informed Inspection Process Overview

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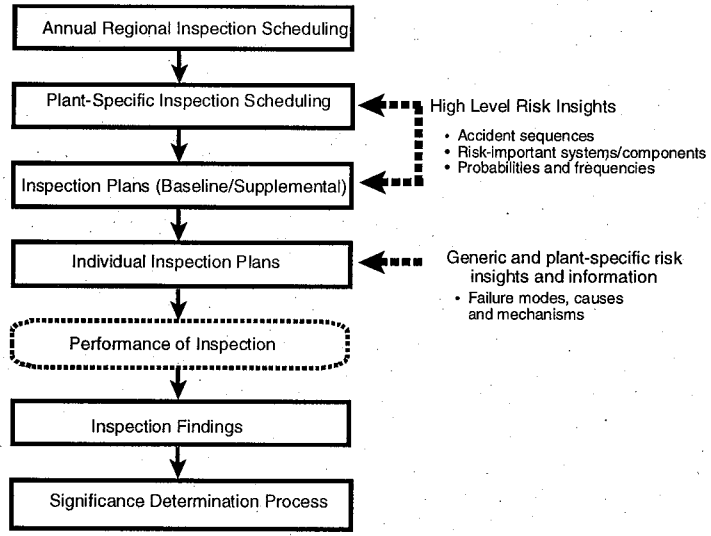
## Risk-Informing the Inspection Process (1)

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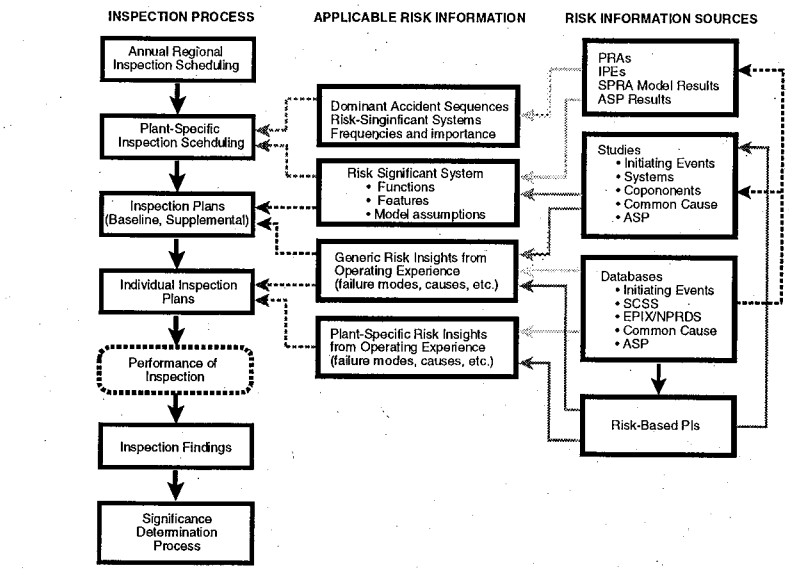
## Risk-Informing the Inspection Process (2)






## High Level Risk Insights

Dominant Accident Sequences

Risk-Singificant Systems

Important Components and Operator Actions

Accident Sequence Precursors

Description

Frequency

Reliability

Importances

Trends

Data Souces

# Risk-Significant System Information

- Select System
- Identify/describe risk-significant system function/mission
- Identify risk-significant features
  - Success criteria, mission phases
  - Design and operating features and procedures
  - Interfaces and external factors
- Identify risk-significant equipment and operator actions

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# Reactor Operating Experience Information

| Operating Experience Studies | Generic Insights | Plant-Specific Insights | Detailed Data and Event Information |
|---|---|---|---|
| Systems | • Trends<br>• Dominant contributors to system unreliability<br>• Causes | • Plant-specific system unreliability<br>• Plant-specific events | Access to databases to obtain information about detailed events and data |
| Components | • Trends<br>• Industry failure probability<br>• Failure causes | | Access to RADS, EPIX, and SCSS |
| Common-Cause Failures | • Trends<br>• Failure causes<br>• Subcomponents or subsystems | • Subsystem or subcomponent causes<br>• Specific CCF events<br>• Plant-specific CCF events | Access to the CCF Database |
| Accident Sequence Precursors | • Trends<br>• Event characteristics | • Related ASP events<br>• Plant-specific ASP events | Access to the ASP Database |

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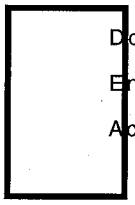
# CCF Information

- Component identification
- Risk-significant function
- Component description and boundary

Failure modes
Failure causes
Failure detection
Other insights (mechanisms)



Dominant contributors
Engineering description
Access to raw data

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# Inspection Planning

- Organize CCF data insights by inspection category
  - Design (D)
  - Test/maintenance (T/M)
  - Operations/procedures (O/P)
- Review source data to identify most applicable inspection areas to specific plants
- Identify specific aspects of D, T/M , O/P to be inspected for each component

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## Inspection Planning (cont.)

- Evaluate risk/safety significance of potential negative or deficient findings of inspection items
  - Relate to risk-significant safety function
  - Risk significant features
- Adjust specific inspection plan to emphasize the most risk-significant deficiencies

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Werner Safety Assessment Consulting

# Generic Insights from Data Collected in the ICDE Project

## How Can the Findings be Best Conveyed to Inspection and Maintenance

## 1 Abstract

The CCF data collected in the clearing house data bank of the ICDE Project have been analysed with respect to complete common cause failure of redundant systems and the major contributions to such events.
The analysis showed that the vast majority of complete CCFs involve human errors. Consequently, the event descriptions of the complete CCFs have been screened to identify typical scenarios of human error involvement and to quantify their frequencies of occurrence. Due to lack of detail of the event description this was possible only on a high level.
The assessment has led to several recommendations aimed at

- improving operation, maintenance and testing procedures,
- improving the requalification process,
- intensifying operator training,
- introducing ergonomically better designs.

## 2 General Statistical Information

### 2.1 Collected components, number of received event reports

Data have been collected for the components

- centrifugal pumps
- emergency diesel generators
- motor operated valves
- safety and relief valves
- check valves (preliminary)

Table 1 shows the number of ICDE events, and the number of complete CCFs[1] reported to the clearing house for the individual components.

**Table 1. Number of reported ICDE events and ICDE events with complete CCF**

| Component | ICDE events | ICDE events with complete CCF |
|---|---|---|
| centrifugal pumps | 134 | 21 |
| emergency diesel generators | 118 | 18 |
| motor operated valves | 90 | 5 |
| safety and relief valves | 149 | 17 |
| check valves (preliminary) | 95 | 7 |
| Total | 586 | 68 |

### 2.2 Population considered in this report

The most critical complete CCFs are those with the characteristic "H" both for shared cause factor and time factor. The investigations in this report pertain only to the elements of the population having this characteristic. This restriction eliminates 130 ICDE events, among them 3 events with complete CCF, from the total population summarised in table 1, leading to the figures shown in table 2.

[1] Complete CCF: the component impairment vector contains only "Cs"

**Table 2. Number of reported ICDE events and ICDE events with complete CCF**

| Component | ICDE events with shared cause factor and time factor "H" | ICDE events with complete CCF, and shared cause factor and time factor "H" |
|---|---|---|
| centrifugal pumps | 87 | 21 |
| emergency diesel generators | 83 | 18 |
| motor operated valves | 57 | 5 |
| safety and relief valves | 134 | 14 |
| check valves (preliminary) | 73 | 7 |
| Total | 434 | 65 |

## 3 Complete CCFs Observed in the Population

### 3.1 Main causes for complete CCF and principal scenarios of complete CCF events

**Definitions**

Events causing a redundant system to be unable to perform its function are of prime interest in the ICDE Project. Normally, this situation exists if all redundant components of the system are completely failed, i.e. if the component impairment vector contains only "C"s. As for the causes for complete CCF, distinction is made between human error involvement, and purely technical reasons for failure. Human error involvement means that the failure is either

- caused by human actions, maintenance or procedural problems as described by the root cause
- or that the influences that created the conditions for multiple components to be failed result from maintenance or operations procedure deficiencies, as described by the coupling factor. In terms of root cause and coupling factor attributes, human error involvement is given if
- the root cause is H or M or P combined with any coupling factor, or
- any root cause is combined with coupling factors MS, MT, MF, OP or OF.

Following this definition, the events collected in the ICDE databank have been categorised in the two categories (1) human error involvement and (2) others (technical faults).

Table 3 shows that complete CCFs are dominated by human error involvement. The table also shows the principal scenarios associated with the events and their reported frequencies of occurrence.

Check valves are not included in the table, as not all data have yet been received for this component.

**Table 3. Summary of complete CCFs with human error involvement and principal scenarios**

| Scenario | all components except CV Complete CCF | | | | | |
|---|---|---|---|---|---|---|
| | CC | CCC | CCCC | 6-10 fold | higher | all |
| absence/insufficiency of testing after maintenance/repair/backfitting work (mostly undetected misalignment) | 5 | 2 | 2 | 1 | 0 | 10 |
| operator error due to deficient/incomplete procedures for testing/maintenance, insufficient work control | 14 | 2 | 4 | 1 | 0 | 21 |
| operator error of commission (wrong valve manoeuvring, wrong switch/breaker positioning) | 5 | 2 | 1 | 1 | 0 | 9 |
| others | 3 | - | - | - | 0 | 3 |
| total (second number: all complete CCFs) | 27⊂ 39 (70%) | 6⊂ 8 (75%) | 7⊂ 8 (88%) | 3⊂ 3 (100%) | 0 | 43⊂ 58 (75%) |

The information in table 3 must be seen in conjunction with the number of systems of certain multiplicity, as given in the event reports and summarised in table 4.

**Table 4. Number of systems of given multiplicity**

| multiplicity | 2 | 3 | 4 | 6-10 | >10 |
|---|---|---|---|---|---|
| no. of ICDE events | 117 | 67 | 112 | 91 | 85 |

Except for multiplicity 3, the number of reported ICDE events is about evenly distributed on multiplicities

## 4 Message to Inspection and Maintenance

### 4.1 What defences had failed in the observed "complete CCF" events?

The considered population contains 361 ICDE events, of which 186 (51%) involve human errors.
58 complete CCFs have been reported for all multiplicities, of which 43 (75%) involve human errors.
39 complete CCFs have been reported for multiplicity 2, of which 27 (70%) involve human errors.
19 complete CCFs have been reported for multiplicities between 3 and 10, of which 16 (85%) involve human errors.
For multiplicity >10 (only for MOVs and SRVs), no complete CCF is reported.

The figures in the bottom line of table 3 clearly show:

- high redundancy is an effective defence against complete CCF.
- if there is a complete CCF in a redundant system, the relative share of human error involvement increases with the number of redundant components of a system (but the frequency of occurrence of complete CCF decreases with the number of redundant components). In essence: the higher the degree of redundancy, the more it takes human action to fail the system.
- A very important line of defence against complete CCF are detailed and comprehensive procedures for testing and maintenance, and attentive and comprehensive work control. Deficiency and incompleteness of procedures lead the operators to act inappropriately. Together with insufficient work control this turns out to be the most prominent cause for complete CCF.
- Another important item is comprehensive testing after maintenance, repair or backfitting of components (requalification of equipment). Human errors during requalification and organisational problems like deficient documentation and communication are important causes for complete CCF. Valves and electrical equipment were identified as particularly vulnerable to requalification errors.
- Third in importance are operator errors of commission, i.e. the operator incorrectly applies a correct procedure

### 4.2 Main areas for improvement

The last three bullets already contain recipes for improvements:

- Scrutinising existing operation, maintenance and testing procedures for deficiencies creating the potential for CCF of redundant systems, ensuring comprehensive work control.
- Comprehensively prescribing the steps of testing required in the requalification of components or systems after maintenance, repair or backfitting work.
- Intensifying operator training, introducing ergonomically better designs, introducing more key locks.

A limitation of the presented analysis lies in the absence of sufficient detail in many of the event descriptions. It is recommended to initiate a study aimed at more detailed examination of the outlined problems.

UK Contribution to the ICDE
by Ian Morris - WS Atkins, Bristol

# International Common Cause Failure Data Exchange

## CCF Quantification Study

*Dave Roberts*
*Nuclear Installations Inspectorate*
*United Kingdom*

*Ian Morris*
*WS Atkins*
*United Kingdom*

## Future Areas Of Work On Quantification

*1) Analysis Of Data To Determine*

*A. Statistic l Significance*
*B. Levels Of Confidence*

*2) Reactor Application - PSA Analysis For:*
*A. Diesels*
*B. SRVs*

*Comparison Of ICDE Derived Data With Assumed PSA Figures*

*3) Could Identify Important Information To Collect For Quantification And PSA Application*

UK Contribution to the ICDE
by Ian Morris - WS Atkins, Bristol

## CCF Quantification Study

*This work consists of two parts:*

- *Comparison with PSA models*
  - *fail-to-start and fail-to-run ratios*
  - *UPM defences and factors that stopped CCFs developing*
- *Human Factors Review*
  - *root causes and defences that were in place or have been breached*
  - *additional defences that may have mitigated CCF*
  - *compare with current HF approaches to determine if any lessons or enhancements can be made*

## CCF Quantification Study

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- *Review against Human Factors Models*
  - *identify root causes and defences that were in place or have been breached*
  - *identify additional defences that may have mitigated CCF*
  - *compare with current HF approaches to determine if any lessons or enhancements can be made*

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## Comparison with PSA Models

### Data Baseline

- Diesel Database contained 96 true CCF events
- None of the 96 CCFs were revealed as a result of a demand
- Events have been categorised as fail-to-start or fail-to-run
- Due to the wide range of impact on plant, the CCFs have been normalised using a Conditional Factor

## Comparison with PSA Models

### Conditional Factors

The Conditional Factors (CF) have been defined as follows:

CF = 1 - CCF would incapacitate all DGs if a demand were to occur

CF = 0.1 - CCF has only incapacitated one DG at a time, and would only prevent the Group if affecting other DGs at the same time

CF = 0.01 - if CCF has only been incipient and would need to occur and affect all DGs at the same time

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by Ian Morris - WS Atkins, Bristol

## Comparison with PSA Models

*Start vs Run Failures (from Data):*

| | Reports (R) | R with CF=1.0 | Summed RxCF |
|---|---|---|---|
| Start | 47 | 12 | 14.50 |
| Run | 49 | 5 | 7.42 |
| Start/Run | 0.96 | 2.40 | 1.95 |
| Total | 96 | 17 | 21.92 |

*We will be comparing this number with the PSA equivalent.*

## Comparison with PSA Models

*PSA Model:*

*For Heysham 2, Failure to Start is 1.14E-2/dem*

*For runs <4hours (as most tests will be), failure to run is 1.71E-3/hr*

*Assuming 4 hour run gives S/R of 1.67*
*This is close to the 1.95 derived from the data.*

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by Ian Morris - WS Atkins, Bristol

## Comparison with PSA Models

### Review of the Data - Significant defences:

*A review indicates that the only significant factor that provides defence against the CCF events affecting all DGs in a Group is redundancy.*

*Redundancy allows potential CCFs to occur over time but be detected by testing before all trains are affected.*

## Comparison with PSA Models

### Review of the Data - causes of CCF

| Cause | No. of events (N) | % of Total | NxCF | % of Total |
|---|---|---|---|---|
| Design/Understanding | 47 | 48.96% | 8.84 | 40.31% |
| Operation/Maintenance | 24 | 25.00% | 7.17 | 32.69% |
| Hazards (Int/Ext) | 16 | 16.67% | 5.47 | 24.94% |
| Component failure | 7 | 7.29% | 0.25 | 1.14% |
| Auxiliary system failure | 2 | 2.08% | 0.2 | 0.91% |
| Totals | 96 | | 21.93 | |

*Design being the most common reflects there is no, or very little diversity inherent in installed Diesel Generators*

## Comparison with PSA Models

### Review of the Data - causes of CCF

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| Totals | 96 | | 21.93 | |

*Although only half as many events, when Conditional Factor is applied they are almost equalised, indicating that they have a much higher potential for promptly jeopardising all trains of the DG system.*

## Comparison with PSA Models

### Review of the Data - causes of CCF

| Cause | No. of events (N) | % of Total | NxCF | % of Total |
|---|---|---|---|---|
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| Totals | 96 | | 21.93 | |

*Hazards also have a high potential for promptly jeopardising all trains. Based on NxCF, internal hazards are the most significant, in these cases better separation would have prevented the failure.*

UK Contribution to the ICDE
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## Human Factor Review

The review has highlighted lessons can be learned in:

- Failures of claimed defences
- Selection of Scenarios for assessment
- Event Recording

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## Human Factor Review

*Data Baseline*

*Total of 96 records in database*

*29 were established as having a human factors element (by search on 'human action', 'procedure inadequacy' and 'maintenance')*

*7 events resulted in complete CCFs (16 in total in database)*

## Human Factor Review

*Failures of claimed defences*

*Strong Defences may not be as strong as we like to think*

*An example from the database...*

*Changing bulk fuel tanks over has several defences*

- *Valves are locked off*
- *Valves need dedicated keys*
- *Procedures are in place*
- *The valves are labelled*

} *Strong Defence*

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## Human Factor Review

### Failures of claimed defences

Strong Defences may not be as strong as we like to think

An example from the database...

Changing bulk fuel tanks over has several defences

- Valves are locked off — Mindset/safety culture made him continue
- Valves need dedicated keys
- Procedures are in place — Procedures inadequate?
- The valves are labelled — Not maintained - difficult to read

## Human Factor Review

### Failures of claimed defences

Strong Defences may not be as strong as we like to think

An example from the database...

Changing bulk fuel tanks over has several defences

- Valves are locked off
- Valves need dedicated keys
- Procedures are in place
- The valves are labelled

This resulted in a Complete CCF

## Human Factor Review

*Failures of claimed defences*

- *The event was found in a routine over-speed test*

*Lessons?*

*Independent checks - useful admin control*

*Best of all - require a return to service test if possible*
*this should be consistent with nature of work and may be more onerous than the routine tests e.g. under-speed test*

## Human Factor Review

*Selection of scenarios for assessment*

*HF assessments are not undertaken when work is:*

- *not seen as safety significant*
- *not invasive*
- *simple*

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## Human Factor Review

*Selection of scenarios for assessment*

*7 HF related Complete CCFs*

*4 of which were caused by minor/simple tasks*
*e.g. painting, cleaning*

*The majority of tasks associated with the events would not normally be subject to a human factors assessment*

## Human Factor Review

*Selection of scenarios for assessment*

*Observations:*

*IT HF assessment of complex tasks is good*

*? Are procedures for simple tasks written by different people to complex procedures - e.g. does the author understand the safety case? Are there enough warnings of what the risks are?*

*? Is the way in which tasks are identified for HF assessment appropriate?*

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## Human Factor Review

*Selection of scenarios for assessment*

*Two Examples:*

"..when cleaning the control room desk, the cleaner (a contractor) pushed without meaning it on buttons that tripped the 2 emergency diesel generators..."

"...investigation revealed paint overspray on the d/g 1a exciter commutator ring. A second start of d/g 1a was attempted, a failure occurred due to an unsuccessful loading attempt... paint was noted on the back side of the fuel rack pivot points for d/g..."

## Human Factor Review

*Event Recording*

*In the majority of the events recorded*

- *the direct cause was identified - e.g. bolts were incorrectly torqued*
- *the real root cause was not evident - why they were incorrectly torqued*

*It is by understanding the real root cause that lessons can be learned.*

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## Human Factor Review

### Event Recording

*How can this be improved?*

*By ensuring a specialist investigates the event.*

- *If it is HF related, the event should be reviewed and described by an HF specialist*
- *If it is design related, it should be reviewed and described by an appropriate engineer*

## Conclusions

### PSA-Data Review

*Fail-to-Start and Fail-to-Run occur in similar ratios to the PSA prediction*

*The only significant defence identified was redundancy*

*Due to the number of Design CCFs, little inherent diversity exists in installed DG systems*

*Operations/maintenance CCFs have a much higher potential for promptly jeopardising DG systems*

*Internal Hazards are significant, but can be defended against by separation*

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## *Conclusions*

*Human Factors Review*

*Strong defences may not be as strong as we think*
- *use return to appropriate service test if possible*

*More of the complete CCFs relate to simple tasks than complex ones*
- *a change to which tasks to assess?*
- *a change to how procedures are written?*

*Root Cause normally missed in event description*
- *a change to the way events are investigated?*

# Quantitative Assessments and Applicability of CCF Events – Use of Data for Other Plants

## ICDE Seminar and Workshop on Qualitative and Quantitative Use of ICDE Data

Dr. Albert Kreuser

GRS Köln

**12-13 June 2001, Stockholm**

Reliability data for common cause failures (CCF) of redundant components have to be determined on the basis of CCF events which were derived from operation experience. Due to the sparse number of observed CCF events, operation experience from one plant or one system is in general not sufficient to generate quantitative CCF data. Therefore, it is necessary, to put together large statistical populations of sets of "similar" components from different plants and different systems. An important criterion for forming such populations is the "component type". This leads to the generation of CCF data for specific types of components, like "circulating pumps", "emergency diesel generators", "motor operated valves", "check valves", "safety/relief valves" or "batteries". Depending on the amount of observed CCF events, further sub-divisions are possible, e.g. "circulating pumps" in specific systems or "motor operated valves" in specific construction features like "globe valves", "gate valves" or "butterfly valves".

Statistical methods for generating reliability data for populations of components are based on the assumption, that a population is homogeneous. That means, an observed failure event at one component is equally probable at each of the other components of the population.

On putting together CCF populations of sets of "similar" components a "sufficient" degree of homogeneity of these components has to be regarded. There should be, e.g., the same requirements for quality and quality control for components in one population. This may be reached e.g. by limiting a population to include only components in safety relevant systems, which have comparable requirements regarding design, construction, maintenance programs and maintenance practices.

Nevertheless, in the end there will be residual inhomogenities in a population which are larger than the inhomogenities in populations for determining reliability data for independent failures. These inhomogenities can be different operating conditions, different media, system parameters, specific construction details etc..

Consequently, if an observed CCF failure mechanism in one set of components is strongly influenced by one of these inhomogeneous features, than this CCF event appears under special " boundary conditions" which may be different in another set of components from the same populations.

Therefore, there must exist a method to assess and quantify the differences in the "boundary conditions" between the set of components where a CCF event was observed and another set of components for which CCF reliability data are generated. This is called, here, assessment of applicability of CCF events for other plants and systems.

The presentation shows what information from the ICDE database is needed for such assessments and which parameters of CCF models may be influenced by an assessment of applicability. Furthermore, first ideas about a systematic way for assessing applicability are presented. Finally, an outlook is given on requirements for further development of methods for assessing applicability and improvements of the ICDE database.

These recommendations can be summarised as follows:

- There is a need for methods to assess applicability, as:
  - Guidance for building populations of "sufficiently similar" groups of components,
  - Definition of plant specific, plant state specific, system and component group specific boundary conditions which allow to modify assessment parameters for single CCF events,
  - Guidance for estimation of modified parameters like applicability factor.
- The structure of the ICDE database is sufficient.

- There are open questions to ICDE, as:
  - Is quality of existing descriptions of technical features of components sufficient?
  - Is there sufficient detail in verbal descriptions of boundary conditions of observed ICDE events?
  - Is check list sufficient in ICDE general coding guidelines – field C5: Event description?
  - What other requirements result from practice of assessment of applicability in other countries?

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Nevertheless, in the end there will be residual inhomogenities in a population which are larger than the inhomogenities in populations for determining reliability data for independent failures. These inhomogenities can be different operating conditions, different media, system parameters, specific construction details etc..

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# Problem areas in determining CCF data

- Due to sparse number of CCF events:
  Need for forming large statistical populations of sets of "similar" components

- Consequence: Observed CCF events in one set of components are equally probable in each other set of same population

- This means: In general, full applicability of each event within population

- Problem area:
  Some CCF events happened under special "boundary conditions" like operating conditions or technical details which may not exist for component groups to be assessed in PSA fault tree

- Task: assessment of differences in boundary conditions between observed CCF event and PSA component group

- This is called "assessment of applicability"

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# Information needed from ICDE database /1/

- Detailed technical description of failed components
  - general features - in "Observed Population Identification Record" (CCCG Record)
  - specific features which are relevant for understanding the observed failure mechanism and causes – in "ICDE Event Record" (Field C5: Event description)
- Boundary conditions of observed CCF event (in Field C5)
  - system operating on demand, system in standby
  - influences or causes introduced by test and maintenance activities or by external events
  - method of discovery
  - if detected by test: type of test and test interval
  - operative action
  - any special circumstances, environmental conditions
  - operational state of the plant at the time the CCF event was discovered

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# Information needed from ICDE database /2/

- Description of failure mechanism
  - development in time
  - important system parameters (if applicability for other systems is needed) like
    - quality of medium
    - temperature influence

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# Quantification of applicability assessment

- Quantification of CCF is done using models like alpha factor, beta factor, BFR, coupling model...
- Input parameters derived from observed CCF events for each population
- Assessment of applicability: event specific parameters have to be adjusted to component group quantified
- Adjustable event specific parameters
  - applicability factor: if probability of occurrence of observed CCF mechanism seems to be different in component group quantified
  - impairment vector (impact vector): if degree of expected damages would be different in component group quantified
  - time to detect failure: if test program for quantified component group contains different types of tests, it has to be decided, which test (and associated test interval) would detect the observed CCF mechanism

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# Questions to be answered for each CCF event:

- Are there special possibilities to detect a certain failure, so that the occurrence of the observed CCF seems to be lower?
  - this would lead to a applicability factor lower than 1 for the event
- If the observed failure mechanism is slowly developing in time: are there special possibilities for early detection of this failure reducing the degree of impairment?
  - this would lead to a modification of the impairment vector for the event
- Does the observed CCF concern a very specific component part or a very specific operating condition of the components which do not exist nor does a similar component part/ operating condition exist in the assessed components?
  - this would lead to a applicability factor 0 for the event (exclusion)

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# Examples

- If CCF events detected during start up tests after revision outage are applied for CCF quantification of full power state:
  probability has to be estimated for not detecting the failure with the start up tests in the plant to be assessed.
  Leads to an applicability factor smaller than 1 (but full applicability for plant states before start up test)

- CCF events due to polluted medium (e.g. service water) applied for "clean" systems.
  Leads to an applicability factor smaller than 1

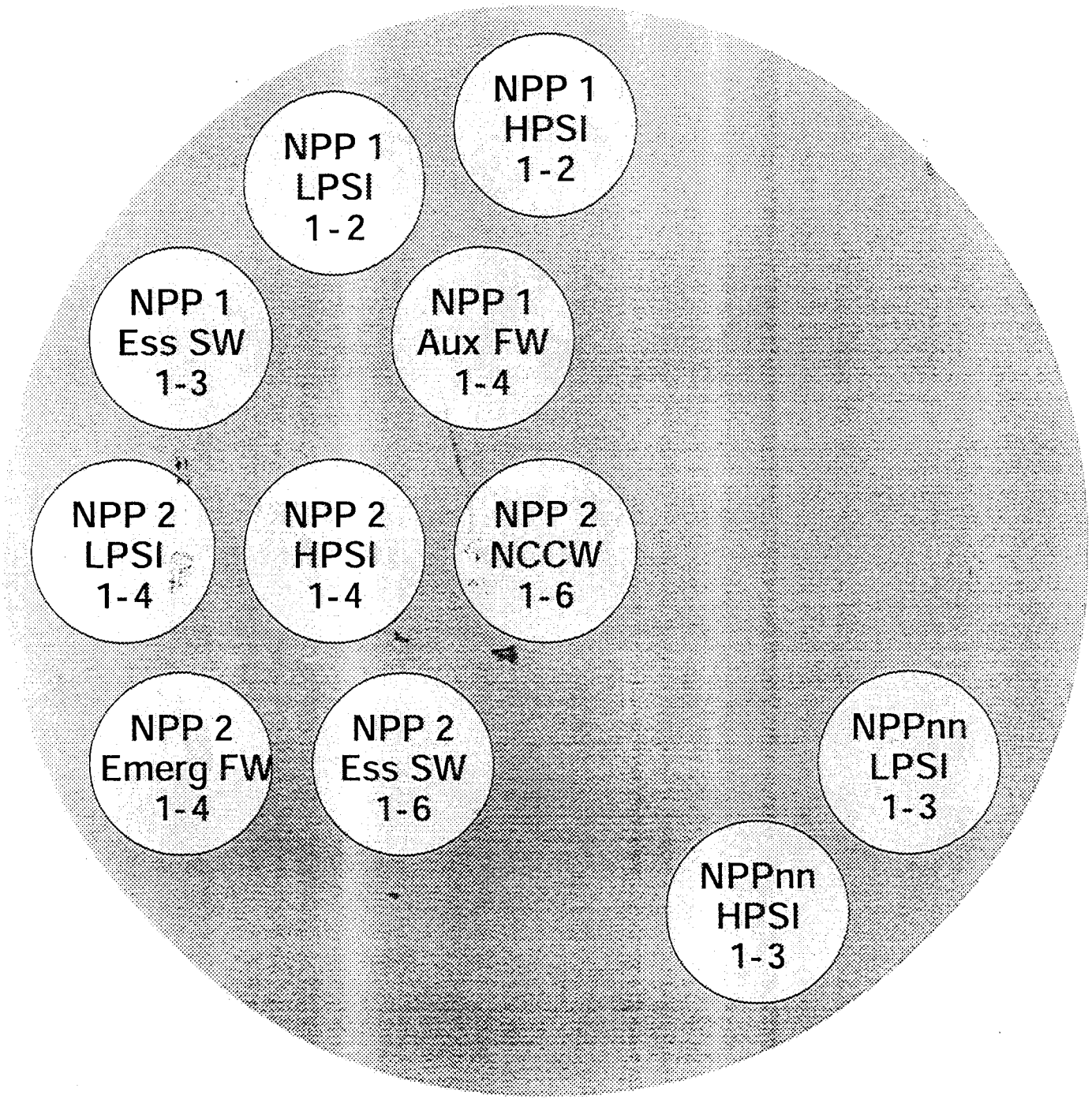
- CCF events with total CCF of tightness of check valves where tightness is not permanently surveyed.
  May lead only to failure of single or few components if permanent surveying equipment exists:
  modification of impairment vector

GRS

# Conclusion

- Methods needed to assess applicability
  - Guidance for building populations of "sufficiently similar" groups of components
  - Definition of plant specific, plant state specific, system and component group specific boundary conditions which allow to modify assessment parameters for single CCF events
  - Guidance for estimation of modified parameters like applicability factor
- Structure of ICDE database is sufficient
- Open questions to ICDE
  - Is quality of existing descriptions of technical features of components sufficient?
  - Is there sufficient detail in verbal descriptions of boundary conditions of observed ICDE events?
  - Is check list sufficient in ICDE general coding guidelines – field C5: Event description
  - What other requirements result from practice of assessment of applicability in other countries?

# Population of Sets of Components Example: Circulating Pumps



ICDE Seminar and Workshop on
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# Impact Vectors – Construction and Linkage of CCF Data to Quantification

Tuomas Mankamo, Avaplan Oy

This presentation will discuss the basic definition of impact vector and steps of construction. The linkage to the direct estimation of multiple failure probabilities and to the parameter estimation of CCF models is described. Despite of its central role to utilize the statistical information of potential CCF events the impact vector method is still undeveloped in many practical features. Instructions with a spectrum of example cases are being prepared in the Nordic CCF Analysis Group [NAFCS-PR03]. A basic description of the method is presented, for example, in [NUREG/CR-5485].

## 1 Impact vector concept

The impact vector describes the outcome of a demand placed on a group of components, which constitute a Common Cause Component Group (CCCG). In a CCCG of size 'n' the impact vector has 'n+1' elements:

$$\mathbf{v} = [\, v_0, v_1, v_2, \ldots, v_n \,], \text{ alternative notation: } v(m|n) \qquad (1)$$

Basically, the impact vector describes the impact of failure mechanisms at each test or demand cycle (TDC). The impact can range from fully intact state to actual multiple failure state of order 'm' that is represented by impact vector:

$$v(m|n) = 1 \text{ and } v(k|n) = 0 \text{ for } k \neq m \qquad (2)$$

During a part of the cycles the components can be detected as degraded, not completely failed, but nevertheless having a significant conditional probability of simultaneous failure given that an actual demand would occur. Another example of event pattern that is complicated to interpret is detecting component failures spread over time but still within a short interval meaning that there was a chance of multiple failure. The description of these fuzzy cases is the justification of impact vector method, which provides a consistent way to generally express the component failure and degradation information for the purpose of estimating multiple failure probabilities. The general form of impact vector describes how the demand outcome probability is distributed over different order of failure states:

$$0 \le v(m|n) \le 1 \text{ and } \sum_{m=0}^{n} v(m|n) = 1 \qquad (3)$$

An impact vector represents the outcome of each test or demand. The observed number of demands is denoted as 'ND' and correspondingly the observation period is divided into same number of TDCs. Summing up the observed impact vectors produces a sum impact vector:

$$v_{sum}(m|n) = \sum_{i=1}^{ND} v_i(m|n) \qquad (4.a)$$

with the normalization condition

$$\sum_{m=0}^{n} v_{sum}(m|n) = ND \qquad (4.b)$$

It should be emphasized that the number of component demands is 'n*ND'. It must also be strongly emphasized that impact vector is always connected to the size of CCCG. The impact vectors over CCCGs of different size cannot be directly summed together. Integrating statistics in these regards requires special mapping up/down procedure.

In the degradation and other potential failure cases the component state index - also called as component impairment or degradation value $d_k$ - can fall anywhere in the range (0,1). There is no universal one-to-one correspondence between the impact vector and component degradation values, see a more thorough discussion in [CR_ImpV2]. Anyway, they are fundamentally connected. The assessment of component degradation values is easier, and they can be useful in the impact vector construction, e.g. constructing upper and lower bound impact vector.

A multiple failure is in most cases due to a clear shared cause or an identical combination of causes, i.e. an actual CCF in its defined meaning. However, also other types of multiple failures can coincidentally occur, i.e. components can have different failure causes. A larger event statistics use to contain at least so called "independent" double failures. The wording "independent" is, however, idealized. Namely, there can be underlying shared causes such as decreased quality of maintenance even to failures which seem to be different (e.g. different parts in the components can be affected). Due to possible non-visible dependence (which is strictly taken never possible to be declared excluded) the "coincident" multiple failures must not be excluded from the event analysis aimed at quantification. The impact vector can be constructed following the same rules for any multiple failure or multiple degradation event.

## 2 Construction of impact vectors

The construction of impact vectors contains following steps:

1. Definition of TDCs over the observation period
2. Impact vectors for single failure cycles
3. Impact vectors for multiple failure/degradation cycles
4. Counting failure-free cycles
5. Creating sum impact vector
6. Integration of sum impact vectors of different CCCGs (optional)
7. Output to probability estimation

The basic method for impact vector construction uses alternative hypotheses about the possible status of the components at a given demand condition, taking into account the preceding operational history and other pertinent information. The chances for actual failure have to be assessed with respect to real demand condition, which may be more challenging than periodic test condition. Table 1 presents an example, which has been discussed in more detail and developed further in [T314_TrC].

Table 1 Example derivation of sum impact vector: electromagnetic pilot valves of BWR safety/relief valves of Olkiluoto 1 and 2 [T314_TrC].

| Event | Hypo-thesis | Weight | Impact vector 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Element sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OL1/85 | 1 | 0.5 | | | 2 | | | | | | | | | 2 |
| 2xFO + 2xFO | 2 | 0.5 | 1 | | | | 1 | | | | | | | 2 |
| | Net | | 0.5 | | 1 | | 0.5 | | | | | | | 2 |
| OL2/85 | 1 | 0.8 | | | | 1 | | | | | | | | 1 |
| 3xFO + 7xNO | 2 | 0.15 | | | | | | | | 1 | | | | 1 |
| | 3 | 0.05 | | | | | | | | | | | 1 | 1 |
| | Net | | | | | 0.8 | | | | 0.15 | | | 0.05 | 1 |
| Single FO | | | | 5 | | | | | | | | | | 5 |
| Success | | | 26 | | | | | | | | | | | 26 |
| Sum impact vector | | | 26.5 | 5 | 1 | 0.8 | 0.5 | 0 | 0 | 0.15 | 0 | 0 | 0.05 | 34 |

The hypotheses constitute alternative interpretations of the event. The weights represent analyst's prediction or belief about the chances of the different hypotheses to be true. The net impact vector for the event is obtained as weighted average over the hypothesis-specific impact vectors.

It is quite usual that the detected failures of a CCF mechanism are distributed over consecutive TDCs, with potential to simultaneous failure. In such a situation it is advisable to construct a joint (sum) impact vector covering the concerned TDCs. Compare to OL1/85 event in Table 1 representing a CCF case spread over two TDCs. It should be pointed out that the sum of the elements in a joint impact vector equals to the number of covered TDCs.

NUREG/CR-5485 suggest to construct the impact vector from component degradation values treating them as independent failure probabilities. The assumption of independence is, however, not generally valid, see the more thorough discussion in [CR_ImpV2]. Of course, there may be some cases where the assumption of independent component degradations is reasonable. This requires proven randomness of the failure mechanisms, which should be well explained because strong or at least moderate dependence is usually to be expected for the remaining operability margin in the multiple degradation case, where the components are already affected by a CCF mechanism. The impact vector constructed with the independent component degradations can be useful information, because it represents a lower bound.

## 3 Connection to CCF quantification

As pointed out the sum impact vector represents the failure statistics arranged according to failure multiplicity. The estimation of multiple failure probabilities is straightforward, given that the statistics is sufficient. For example, the probability of some m out of n components failing, while the other n-m survive at demand, can be estimated in the following way (using the sum impact vector for the observed population):

$$\langle pes(m \mid n) \rangle = \frac{v(m \mid n)}{ND} \qquad (5)$$

This represents in fact so called Direct Estimation Method, a basic alternative to quantify CCFs (or generally multiple failures).

Similarly, the sum impact vector constitutes a general way of representing failure statistics for many parametric CCF models. For example, Alpha Factors are estimated in the following way:

$$\langle \alpha(m|n) \rangle = \frac{v(m|n)}{\sum_{k=1}^{n} v(k|n)} \qquad (6)$$

## 4 Concluding remarks

Due to its importance as general tool for the estimation of multiple failure probabilities and CCF model parameters better procedures for the impact vector method needs to developed, regarding also the use of the CCF event data processed and stored in ICDE database. The needed development work is started in the Nordic CCF Analysis Group.

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# Impact Vectors - Construction and Linkage of CCF Data to Quantification

- *Impact Vector Concept*
- *Construction Steps*
- *Connection to CCF Quantification*

To be presented by Tuomas Mankamo, Avaplan Oy
ICDE Seminar and Workshop on
Qualitative and Quantitative Use of ICDE Data
12-13 June 2001, Stockholm

CCF Projects\ICDE\Stockholm2001\ImpVe-Slides.ppt, Slide 1, 04.06.2001

Avaplan Oy – Impact Vector Method – ICDE Seminar, Stockhom 2001

## Impact Vector Concept

***Impact vector presents the outcome of a test or demand placed on a Common Cause Component Group (CCCG)***

***A multiple failure of order 'm' corresponds to impact vector:***

$$v(m \mid n) = 1 \text{ and } v(k \mid n) = 0 \text{ for } k \neq m$$

CCF Projects\ICDE\Stockholm2001\ImpVe-Slides.ppt, Slide 2, 04.06.2001

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## Generalized Impact Vector

***The general form of impact vector describes potential failure cases, e.g. including degraded component states:***

$$0 \le v(m \mid n) \le 1 \text{ and } \sum_{m=0}^{n} v(m \mid n)$$

***- describes how the outcome probability is distributed over different multiplicity***

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## Sum Impact Vector

***The failure statistics of a CCCG over an observation period is presented by the sum of impact vectors:***

$$v_{sum}(m \mid n) = \sum_{i=1}^{ND} v_i(m \mid n), \text{ with } \sum_{m=0}^{n} v_{sum}(m \mid n) = ND$$

***ND is the total number of test/demand cycles (TDCs) in the observation period***

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## Component Degradation Values

*Component Degradation (Impairment) Values $d_k$ present the outcome of a demand for each individual component separately.*

*There is no one-to-one correspondence*

$$d_k \not\Leftrightarrow v(mln)$$

*Assumption of independent component degradations is not generally valid to construct impact vector – can be used to produce lower bound assessment*

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## Coincidental Multiple Failures

*For quantitative analysis general types of multiple failures should be covered, not only straight CCFs with a clear shared cause.*

*Failures due to (partially) different causes can be dependent, e.g. because of not directly visible maintenance shortcomings.*

*The same rules of impact vector construction applies to all multiple failures*

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# Construction of Impact Vectors

1. *Definition of TDCs over observation period*
2. *Impact vectors for single failure cycles*
3. *Impact vectors for multiple failure/degradation cycles*
4. *Counting failure-free cycles*
5. *Creating sum impact vector*
6. *Integration of sum impact vectors of different CCCGs (optional)*
7. *Output to probability estimation*

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# Example of Sum Impact Vector: Electromagnetic Pilot Valves of BWR Safety/Relief Valves, Olkiluoto 1 and 2

| Event | Hypo-thesis | Weight | Impact vector 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Element sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OL1/85 | 1 | 0.5 | | | 2 | | | | | | | | | 2 |
| 2xFO + 2xFO | 2 | 0.5 | 1 | | | | 1 | | | | | | | 2 |
| | Net | | 0.5 | | 1 | | 0.5 | | | | | | | 2 |
| OL2/85 | 1 | 0.8 | | | | 1 | | | | | | | | 1 |
| 3xFO + 7xNO | 2 | 0.15 | | | | | | | | 1 | | | | 1 |
| | 3 | 0.05 | | | | | | | | | | | 1 | 1 |
| | Net | | | | | 0.8 | | | | 0.15 | | | 0.05 | 1 |
| Single FO | | | | 5 | | | | | | | | | | 5 |
| Success | | | 26 | | | | | | | | | | | 26 |
| Sum impact vector | | | 26.5 | 5 | 1 | 0.8 | 0.5 | 0 | 0 | 0.15 | 0 | 0 | 0.05 | 34 |

CCF Projects\ICDE\Stockholm2001\ImpVe-Slides.ppt, Slide 8, 04.06.2001

## CCF Event of Electromagnetic Pilot Valves, Olkiluoto 1, 1985

| Component | | Test/demand cycles | | | | | |
|---|---|---|---|---|---|---|---|
| | | 85-06-24 | 85-09-11 | 85-10-10 | 85-11-17 | | |
| 1 | V179 | | | | | | |
| 2 | V180 | | | F | F | | |
| 3 | V181 | | D | F | | | |
| 4 | V182 | | F | | | | |
| 5 | V183 | | | | | | |
| 6 | V184 | | | | | | |
| 7 | V185 | | F | | | | |
| 8 | V186 | | | | | | |
| 9 | V187 | | D | | | | |
| 10 | V188 | | | | | | |
| | | ... | Startup tests | Trans-ient | Additio-nal test | Additio-nal test | ... |

**Syntax:**

F = Failed

D = Degraded

Blank = Intact

CCF Projects\ICDE\Stockholm2001\ImpVe-Slides.ppt, Slide 9, 04.06.2001

Avaplan Oy – Impact Vector Method – ICDE Seminar, Stockhom 2001

## Using Hypothesis Method: Electromagnetic Pilot Valves, Olkiluoto 1, 1985

| Hypothesis | Weight | TDC | Impact vector 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Element sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. As occurred | 0.5 | 1 | | | 1 | | | | | | | | | 1 |
| | | 2 | | | 1 | | | | | | | | | 1 |
| 2. Four components fail at later demand | 0.5 | 1 | 1 | | | | | | | | | | | 1 |
| | | 2 | | | | | 1 | | | | | | | 1 |
| Net impact vectors | | 1 | | | 0.5 | | | | | | | | | 0.5 |
| | | 2 | 0.5 | | 0.5 | | 0.5 | | | | | | | 1.5 |
| Sum impact vector over TDC1 andTDC2 | | | 0.5 | | 1 | | 0.5 | | | | | | | 2 |

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Avaplan Oy – Impact Vector Method – ICDE Seminar, Stockhom 2001

## Connection to Probability Estimation

***Direct estimation of multiple failure probability is straightforward from the sum impact vector, e.g.***

$$\langle \mathrm{pes}(m \mid n) \rangle = \frac{v(m \mid n)}{ND}$$

for

$\mathrm{pes}(m \mid n) = P\{$Some m out of n component fail, while the other n - m survive the demand$\}$

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Avaplan Oy – Impact Vector Method – ICDE Seminar, Stockhom 2001

## Connection to the Estimation of CCF Parameters

***Sum impact vector is the general way for estimating the parameters of many CCF models, e.g. Alpha Factors:***

$$\langle \alpha(m \mid n) \rangle = \frac{v(m \mid n)}{\sum_{k=1}^{n} v(k \mid n)}$$

CCF Projects\ICDE\Stockholm2001\ImpVe-Slides.ppt, Slide 12, 04.06.2001

Avaplan Oy – Impact Vector Method – ICDE Seminar, Stockhom 2001

## Concluding Remarks

*Impact vector method is a general tool for quantitative analysis of dependencies*

*It facilitates the full use of observed multiple failure information, including potential CCFs*

*Nordic Workgroup of CCF Analysis has started the development of instructions for impact vector construction, preparing also a spectrum of practical example cases*

CCF Projects\ICDE\Stockholm2001\ImpVe-Slides.ppt, Slide 13, 04.06.2001

Avaplan Oy – Impact Vector Method – ICDE Seminar, Stockhom 2001

# From failure data to CCF –rates and basic event probabilities

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**07901 Loviisa, Finland**

SUMMARY

The common cause Failure (CCF) quantification procedure under development at Fortum is presented in Fig.1. It starts from identification of generic (global) CCF-event data sources such as EPRI and ICDE, in addition to plant-specific events that occurred at the plant under study (PUS).

After selecting a type and a group (of size n) of components for quantification, the second step is the evaluation of each event i at each plant ν and determine the impact vector weights

$w_{k/n}(i,\nu)$ = probability that in event i at plant ν exactly k components failed out of n identical parallel components (CCF –group size n).

Guidelines for assessing and quantification of these weights are based on component degradations, shared causes and timing (simultaneity), provided by ICDE and NRC.

There are two alternatives for the next step. Part of it is the selection of plants to be used as the sampling population for which the prior distributions of k/n- event rates will be determined. Option 1 is to use data only from plants that have the same degree of redundancy (n) as PUS. This subset of plants may be mutually more homogeneous with respect to CCF's than all plants together, and no "mapping" of weights $w_{k'/n'}$ from one system size n' to another size n are needed. Option 2 is to accept data from all plants and use "mapping up" (when n'<n) and "mapping down" (when n'>n) rules to obtain weights supposed to be valid for plants with the same system size n as PUS. -This option is based on rather strong assumptions about the similarity and frequencies of CCF –causes and consequences.

The fourth step is to determine individual plant –specific CCF-rates $\Lambda_{k/n}(\nu)$ of events in which exactly k components out of n fail, for each plant ν. The mean value and the variance of $\Lambda_{k/n}(\nu)$ are determined by the weights $w_{k/n}(i,\nu)$ as derived in [1].

The same two plant –specific moments can be obtained for a classical estimator (or by using Bayesian estimation with a non-informative prior) if a specific number $N_{k/n}(\nu)$ of k/n –events have been observed in time $T_n(\nu)$. Equating the moments yields these equivalent data pairs

$$\hat{N}_{k/n}(\nu) = \frac{(\sum_{i=1}^{N_n} w_i)^2 + \alpha \sum_{i=1}^{N_n} w_i^2}{\sum_{i=1}^{N_n} w_i(2-w_i) + \alpha}, \qquad \hat{T}_n(\nu) = \frac{\sum_{i=1}^{N_n} w_i + \alpha}{\sum_{i=1}^{N_n} w_i(2-w_i) + \alpha} T_n,$$

where $N_n$ is the true total number of events at plant ν in time $T_n$ and $w_i = w_{k/n}(i,\nu)$, and α is a user-specified parameter between 0 and 1, normally $\alpha = ½$.

The equivalent data pairs for selected plants ν are then input to an Empirical Bayes Estimation (EBE) process that yields the population distribution of the rate $\Lambda_{k/n}$ of k/n –events for the whole

plant population. This is the empirical prior distribution used in EBE to obtain the posterior distribution of $\Lambda_{k/n}(\nu)$ for PUS. A robust parametric moment matching method is used as the EBE [2]. The computerised procedure calculates the posterior distributions for all plants included in the prior-calculation, not only for PUS. The distribution of the rate of *specific* k failures out of n, $\lambda_{k/n}(\nu) = \Lambda_{k/n}(\nu)/\binom{n}{k}$ is obtained easily by dividing the mean value and the standard deviation by the Binomial factor.

Finally, the rates are transformed to the probabilities of the basic events $Z_{ij..}$ needed in the system (or PSA) fault tree, failing exactly specific k components i,j,.. . For standby safety components tested with test interval T these values are

$$Pr(Z_{ij..}) = c_{k/n}\lambda_{k/n}T,$$

where $0 < c_{k/n} < 1$, and the coefficients $c_{k/n}$ depend on k, n, test staggering, repair policy and the system success criterion [3].

The computerised EBE method has been developed also for probabilities per demand, $Q_{k/n}$, in which case $T_n(\nu)$ is the total number of system –demands (opportunities)[4]. Then the parameters $q_{k/n} = Q_{k/n}/\binom{n}{k}$ are directly the basic event probabilities, but this approach ignores the dependencies on test interval and staggering, which may be important for optimisation.

The methods described have been applied as a part of Loviisa 1 PSA to calculate CCF –rates for diesel generators, for pumps in systems TJ, TH, TQ, VF, TF, RL, RR, some check valves, primary safety valves and steam relief valves. Data[5] from an EPRI –report (1992) and ICDE reports (1999-2000) were used in support of prior distributions and combined with Loviisa –specific data available at different times. This will be a refinement and extension of earlier related work [6], although all numerical calculations have not been performed yet. Some examples of plant-specific posterior rates are given in Table I, for CCF-groups of sizes n = 4. Similar tables are available for prior mean values and prior and posterior standard deviations and for group –rates (obtained under the assumption of complete identity of all plants). Different component groups seem to be rather individual, and there seems to be only a minor trend between older (EPRI) and new (ICDE) data.

Table I. Loviisa 1 posterior mean values of CCF –rates (k/n-event rates) with two prior data sources [$hr^{-1}$]

| CCF – rate: | $\Lambda_{2/4}$ | | $\Lambda_{3/4}$ | | $\Lambda_{4/4}$ | |
|---|---|---|---|---|---|---|
| System & Component / Prior source: | EPRI | ICDE | EPRI | ICDE | EPRI | ICDE |
| HP safety injection pumps | 5.48E-07 | 4.62E-07 | 3.04E-07 | 2.73E-07 | 0.91E-07 | 0.56E-07 |
| LP safety system pumps | 2.96E-07 | 0.33E-07 | 0.91E-07 | 0.42E-07 | 0.91E-07 | 0.56E-07 |
| Service water pumps | 2.28E-07 | 1.35E-07 | 0.91E-07 | 0.76E-07 | 0.91E-07 | 0.63E-07 |
| Component cooling pumps | 0.77E-07 | 0.40E-07 | 0.91E-07 | 0.44E-07 | 0.91E-07 | 0.44E-07 |
| Diesel generators | 8.92E-07 | 10.8E-07 | 0.95E-07 | 0.42E-07 | 29.1E-07 | 35.0E-07 |

## ACKNOWLEDGEMENT

The author is indebted to the PSA- group at Fortum Nuclear Services and especially Mr. Kalle Jänkälä for carrying out extensive data analysis, computer programming and numerical calculations associated with this work.

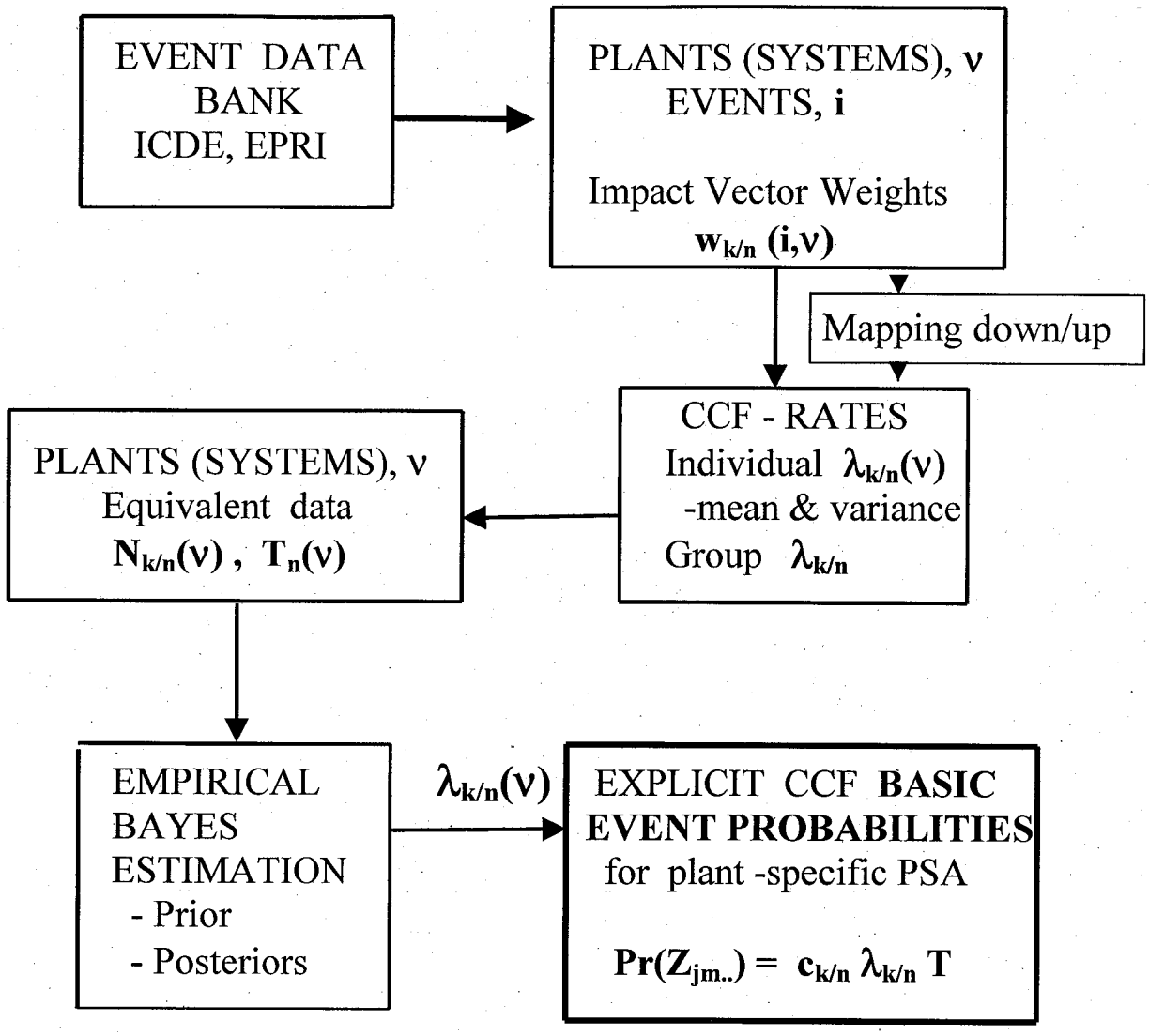


Fig. 1 – Common cause failure quantification procedure

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# FROM FAILURE DATA TO CCF -RATES AND BASIC EVENT PROBABILITIES

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## ICDE Seminar and Workshop on Qualitative and Quantitative use of ICDE data

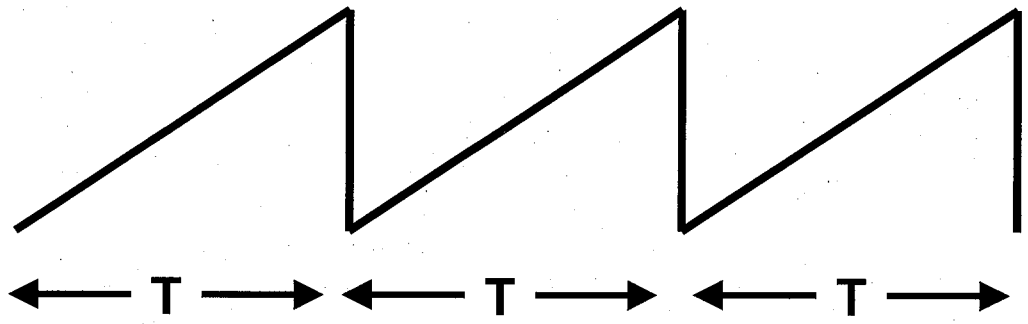
## At Scandic Hotel, Slussen, Stockholm 12. - 13. June 2001

# SINGLE FAILURE BASIC EVENTS

- Failures in standby (safety) components are mostly due to **time – related** causes (wear, corrosion, vibration / loosening sticking, temperature, moisture, …), **not demand – related** causes.

- Must be modelled by **failure rates** $\lambda_j$ , probability per unit time, not by "probability per demand"

- Basic event probabilities $\bar{u} = \frac{1}{2} \lambda_j T$



# SINGLE FAILURE (cont.)

- Components at Loviisa power plant: mixture of Eastern and Western technologies, under Finnish operation and maintenance practice.

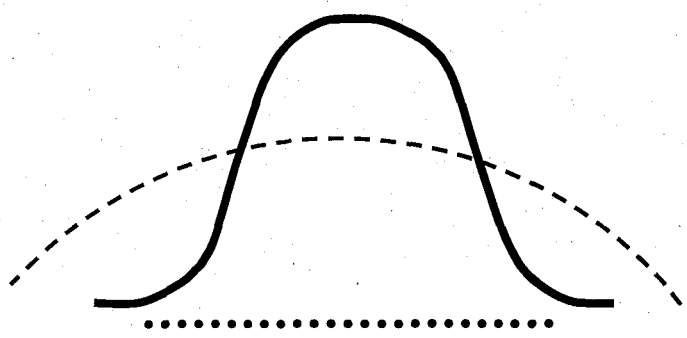
- Computerised failure history available

  ⇒ **Plant-specific component failure rates**

- Population density = Prior-density of Empirical Bayes Method, is based on similar components ON SITE (2 units, typically 8 or more components)

  - More relevant and homogeneous than word-wide data

  ⇒ **Individual failure rates for all components are used in Loviisa PSA**



$$\lambda_j \sim \Gamma(n_j + \alpha, t_j + \beta)$$

# CCF

- **CCF data is word-wide** (plant specific numbers: many 0's, few 1's)

- **Single failure data is plant-specific**

  ⇒ No basis to rely on global ratios (beta, alpha-factors, MGL)

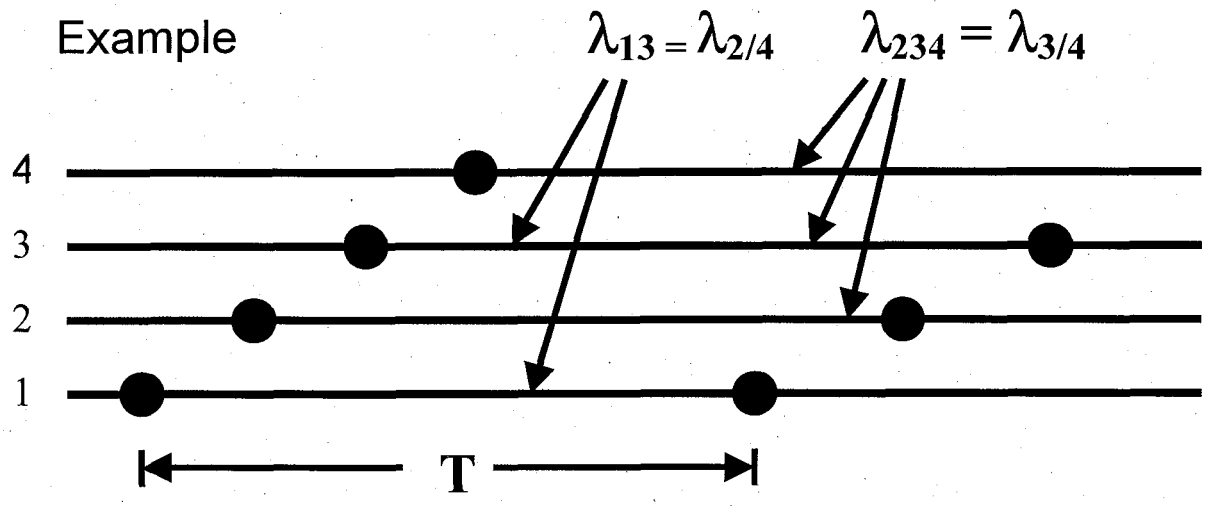
  ⇒ Go directly to parameters that are needed in PSA basic event probabilities

  ⇒ Use word-wide data for CCF-prior distribution in Empirical Bayes method (CCF causes are more generic/universal)

  - But: **use mainly data from plants that have the same degree of redundancy (n) as the plant under study**

  - "mapping" up and down are based on assumptions not proved correct by empirical evidence

- CCF:s are caused by time-related stresses, "shocks" per unit time




- There are no system demand stresses or multiple-failure probabilities per demand

  $\Rightarrow$ Estimate directly CCF rates

$$\Lambda_{k/n} \cup \Gamma(N_{k/n} + \alpha, T_n + \beta)$$

$$\lambda_{k/n} = \Lambda_{k/n} / \binom{n}{k}$$

  - No need to know "number of demands" , but need to know the exposure (observation) times $T_n$
  - $\alpha$ and $\beta$ determined by $\{N_{k/n}, T_n\}$ from all plants (systems) included in the study.

# SINGLE PLANT (SYSTEM) WITH IDEAL DATA

$N_{k/n}$ observed total number of **k**-fold failures in a system of size **n** in observation time $T_n$

$T_n$ exposure time

Estimator of rate $\Lambda_{k/n}$ causing the failure has

**mean value** $$E(\Lambda_{k/n}) = \frac{N_{k/n} + \alpha}{T_n} \qquad (1)$$

**variance** $$\sigma^2(\Lambda_{k/n}) = \frac{N_{k/n} + \alpha}{T_n^{\,2}} \qquad (2)$$

$$0 < \alpha < \tfrac{1}{2}$$

Rate of failure of <u>specific</u> k components

$$\lambda_{k/n} \sim \Lambda_{k/n} / \binom{n}{k}$$

## Single plant (system) with uncertain data:

How many actually failed in each event?

$N_n$ observed total number of events in a system of size **n** in observation time $T_n$

$T_n$ exposure time

$w_i(k/n)$ = probability that the observed event i is a k-fold failure (k/n –event)

$w_i(o/n) + w_i(1/n) + \ldots + w_i(n/n) = 1$ for all events (i).

It has been shown [ Risk Analysis 14 (1994) 383 - 387]

$$E(\Lambda_{k/n}) = \frac{\sum_{i=1}^{N_n} w_i(k/n) + \alpha}{T_n} \qquad (1')$$

$$\sigma^2(\Lambda_{k/n}) = \frac{\sum_{i=1}^{N_n} w_i(2- w_i) + \alpha}{T_n^2} \qquad (2')$$

The same moments can be obtained with ideal data Eqs. 1 & 2 if we use the virtual or effective observations $\{ \hat{N}_{k/n}, \hat{T}_n \}$, i.e.

$$\hat{N}_{k/n} = \frac{\left(\sum_{i=1}^{N_n} w_i\right)^2 + \alpha \sum_{i=1}^{N_n} w_i^2}{\sum_{i=1}^{N_n} w_i(2 - w_i) + \alpha}$$

$$T_n = \frac{\sum_{i=I}^{N_n} w_i + \alpha}{\sum_{i=I}^{N_n} w_i(2 - w_i) + \alpha} \; T_n$$

- The same Empirical Bayes method can be used with uncertain data as with ideal data, by using the effective / virtual observations

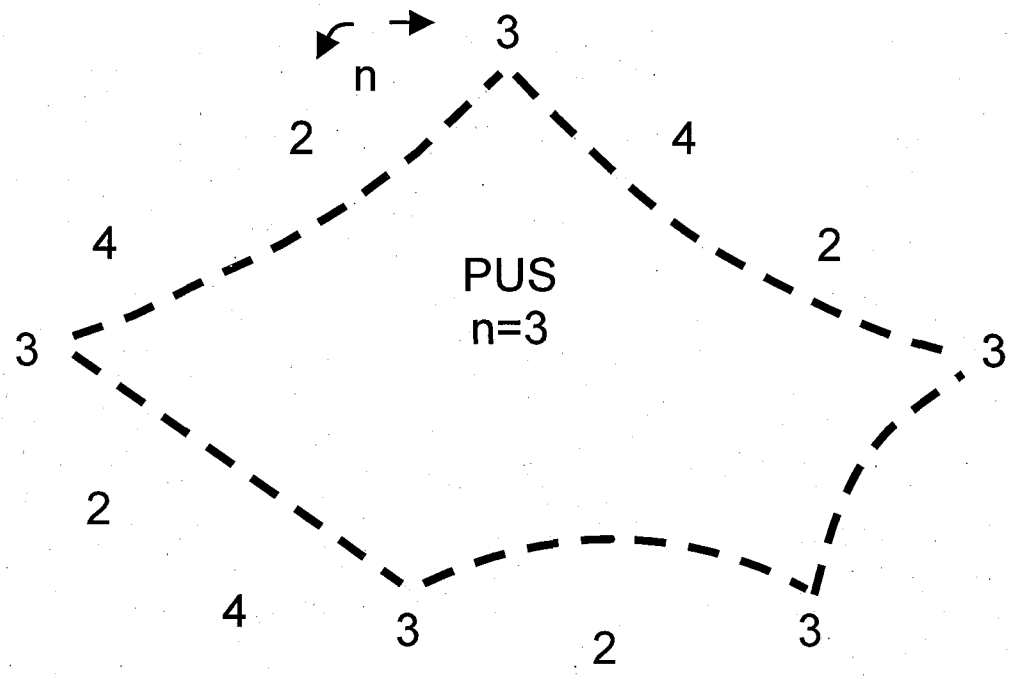
  $\{ \hat{N}_{k/n}(\nu), \hat{T}_n(\nu) \}$

  for all plants $\nu$.

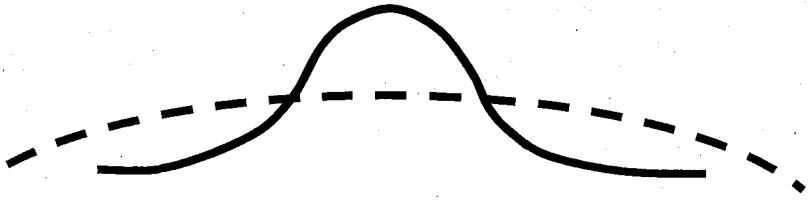
- Used for $\lambda_{2/n}$, $\lambda_{3/n}$, $\lambda_{4/n}$, ...

  – The multi-failures have more universal causes
  – Single failures $\lambda_{1/n}$ have more plant-specific causes

- For prior density of $\Lambda_{k/n}$ use data from plants with the same n (redundancy) as the plant under study ( PUS )

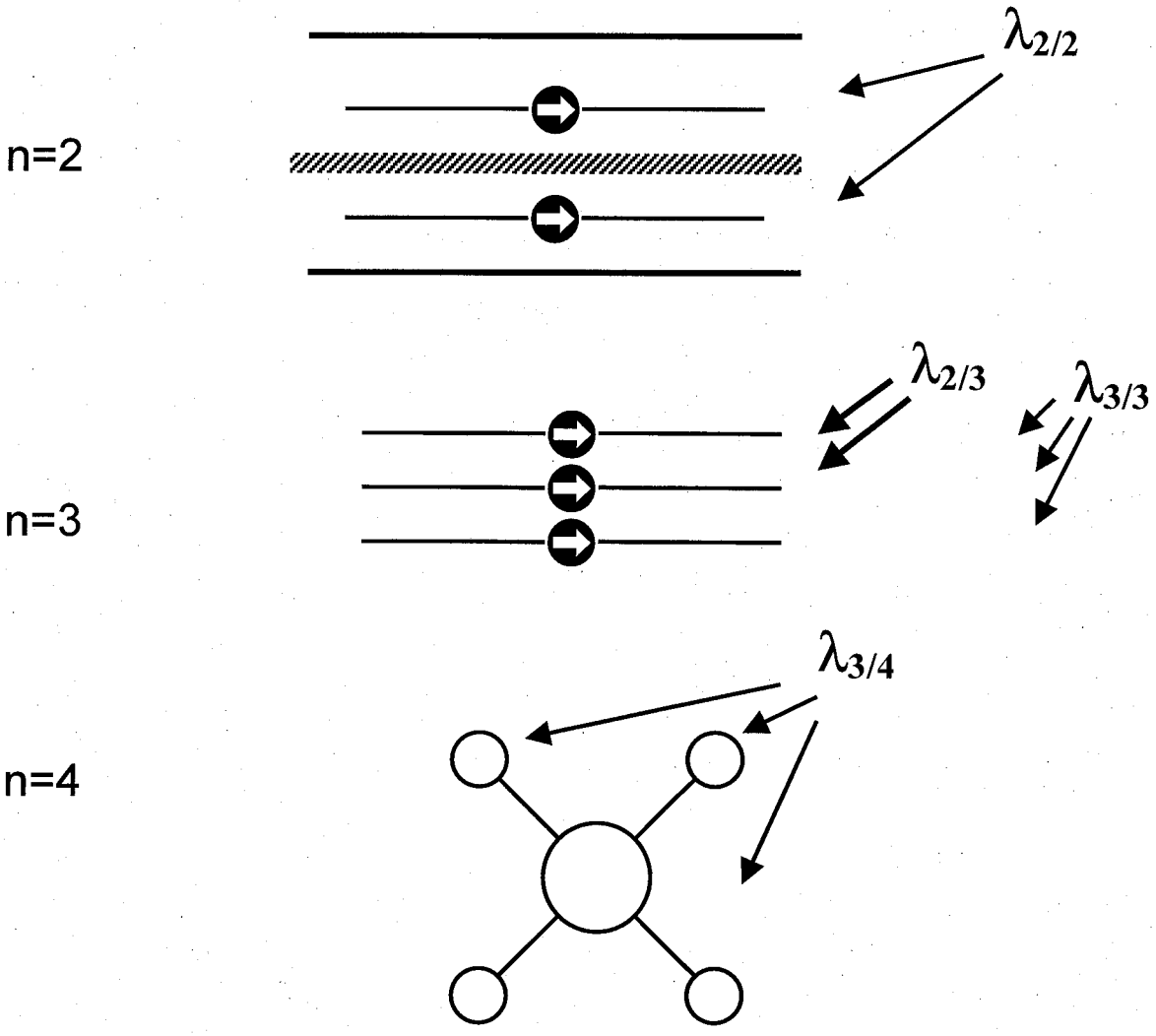



- No mapping – assumptions needed
- More informative ( narrow ) prior



- To be compared with "standard" mapping assumptions ( NUREG/CR – 4780 App.D ) and other rules

Plants with different redundancy ( n ) have been designed with different degrees of separation ( CCF defences ) between trains




⇒ **"standard" mapping – rules questionable**

- assume that all causes are external, not component – initiated
- assume the same external cause rates
- assume the same physical consequences for each cause event

Research: Use also data from plants with different redundancy ( $n' \neq n$ )

- Need to assume mapping rules for impact vector weights to get $\mathbf{w_i(k/n)}$ in terms of $\mathbf{w_i(k'/n')}$

- Mapping down NUREG / CR – 4780 p. D - 9 e.g.

  $w_i(2/2) = 1/3\ w_i(2/3) + w_i(3/3)$

- Mapping up
  - Lethal shocks, $w_i(n/n) = w_i(n'/n')$
  - Non-lethal shocks (p. D - 16)
    - Even more assumptions ($\rho$)

- **To be confirmed or rejected by statistical testing**
- The weights yield effective $\{ \mathbf{N_{k/n}}( \nu ), \mathbf{T_n}( \nu ) \}$ that can be used to estimate $\hat{\Lambda}_{\mathbf{k/n}}$ (Empirical Bayes)

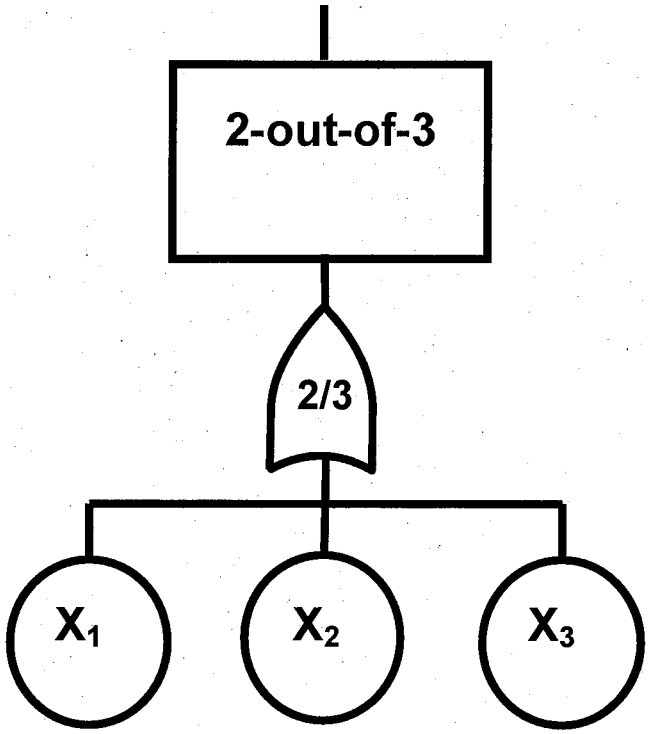



Fig.1. Component-level fault tree (example).

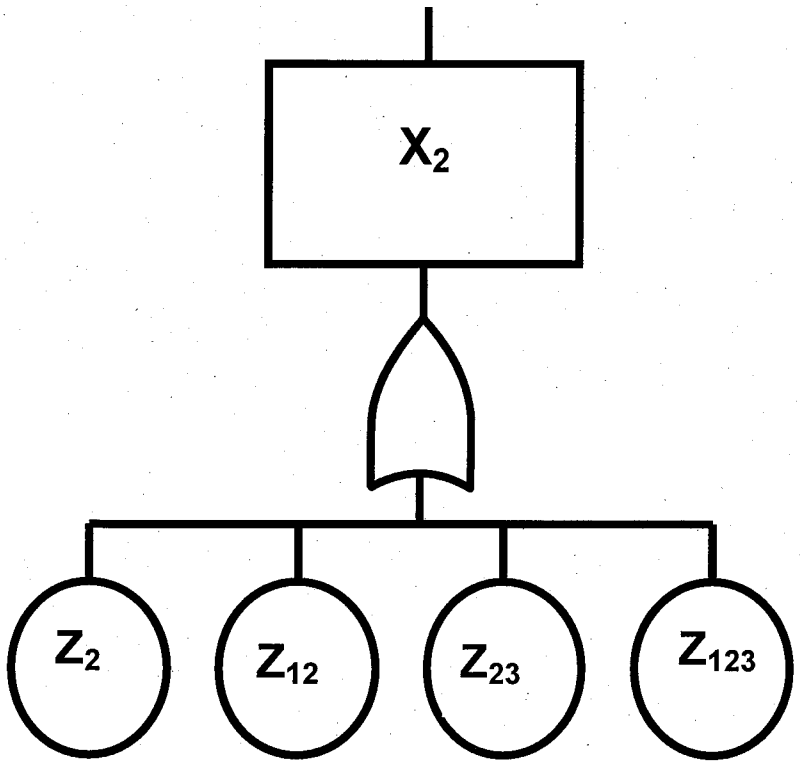
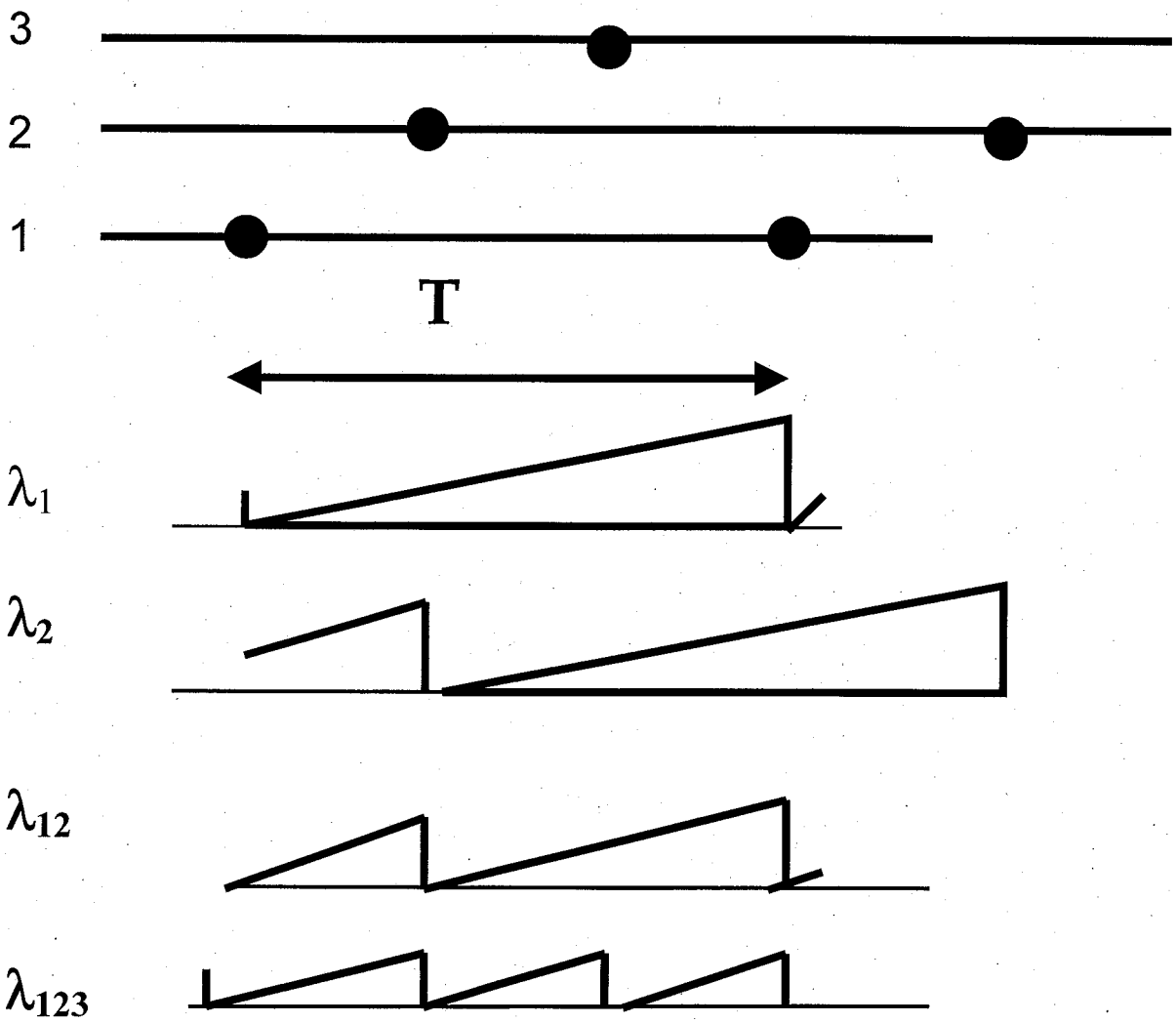



Fig.2. Component event $X_2$ modelled explicitly by cause-events $Z_{ij}$..

## Basic event probabilities Pr (Zij...)

= numbers that yield correct **time-average probabilities** for minimal cut sets




$$\Pr ( Z_{ij...}) = c_{k/n}\ \lambda_{k/n}\ T$$

- staggered testing with extra testing (all repaired at first discovery)
- staggered testing without extra repairs
- simultaneous ( consecutive ) testing
- RESS 43 ( 1994 ) 289 – 305

- Staggered testing **with ETRR**

$$c_{1/n} = \frac{1}{2}$$

$$c_{2/2} = \frac{1}{4}$$

$$c_{2/3} = \frac{5}{18} \qquad c_{3/3} = \frac{1}{6}$$

$$c_{2/4} = \frac{7}{24} \qquad c_{3/4} = \frac{3}{16} \qquad c_{4/4} = \frac{1}{8}$$

- Staggered testing **without ETRR**
  - $c_{k/n}$ depends on system success criterion

2/3 –system: $c_{3/3} = \frac{1}{2}$

2/4 –system: $c_{4/4} = \frac{3}{8}$

3/4 -system: $c_{3/4} = \frac{1}{2}$ $c_{4/4} = \frac{5}{8}$

- DATA SOURSES USED for LOVIISA

1. EPRI report TR – 100382
2. ICDE Diesel DB, DG 991015.1
3. ICDE Pump DB, CP 990910
4. ICDE SV / RV DB, SVRV 990531
5. Loviisa failure history ( 1992, 1997)

- PROBLEMS / APPLICATIONS

1. Many plants in ICDE fail to report observation periods ($T_n$)
2. Shared Cause Factor and Time Factor are missing on many ICDE data events –judgement difficult
3. Plant-specific observation times –combining ICDE and EPRI information sometimes possible
4. Visual Basic programs and Excel macros have been developed for mapping up and down
5. PREB –method / code developed for Empirical Bayes $\lambda_{k/n}$ [ Risk Analysis 7 ( 1987 ) 329 – 338, PSA '87, PSA'93, PSAM5(2000)]
6. Used for Loviisa 1 systems TF, VF, TH, TJ, RR, RL 92/93, RL 94/97, TQ
   - For $\lambda_{2/n}$, $\lambda_{3/n}$, ..., $\lambda_{n/n}$
   - yields posterior rates for all plants / systems, not only for "plant under study"
   - earlier used simpler System Failure Rate Model

# PSA Task Guide: Analysis of Dependencies

Kola NPP Unit 2


| | | |
|---|---|---|
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## Dependencies

1- Phenomena, which lead into an initiating event (IE) and at the same time disable or affect safety related system(s)

2- Various types of system, component or operator failures, where redundant functions or operations are affected simultaneously; the sequence of events after an IE are influenced by the dependence

## PSA Task Guide on Dependencies

Yes - Definition of dependence categories and analysis approach

No - Dependence categories and Data support

## 1- Phenomena

- Common Cause Initiator (CCI) arises from the system or component failures, or from the disturbances in the plant processes (intrinsic events)
- Internal and external hazards are initiators, which occur extrinsic to plant systems and process. Internal hazards originate within the plant rooms or other on-site spaces or areas, e.g. turbine fire. External hazards originate from outside the plant, e.g. snow storm

## 2- Various types of failures

- Functional dependencies cover system and component interconnections, e.g. process connection, control signal, power supply, cooling and lubrication
- System interactions cover dependencies, which are not ordinary functional dependencies but are specific to actual demand conditions and typically not detected in normal operation or by surveillance tests. The system interactions are often called as "subtle dependencies" or "subtle interactions"
- Dynamic effects cover causal failures in connection to pipe breaks
- Dependent component failures, i.e. CCFs
- Operator action dependencies concern the failures of consecutive actions to mitigate a transient or accident sequence; also systematic test or maintenance errors are considered within this dependence category

Table 1 Definition of dependence categories and analysis approach.

The last column refers to the task guides and sections describing the analysis procedure and method.

| # | Dependence category | Analysis procedure or method | Work context | Procedure description |
|---|---|---|---|---|
| 1. | Common Cause Initiators | Analysis of operating experience, insights from other PSA studies, link from functional dependencies, use of fault tree models | Initiating Event analysis, System Analysis | Section 4, Appendix A K2PG-3, -5 |
| 2. | Common Cause Initiators | Loss of room cooling/heating: scooping analysis | Initiating Event analysis | Section 4.3, Appendix F K2PG-3 |
| 3. | Internal and external hazards | Identification of room dependencies as a basic support task | Dependency database construction | Section 5, Appendix D |
| 4. | Internal and external hazards | Evaluation of room importance | Initial quantification | Section 5 |
| 5. | Internal and external hazards | Screening of hazards | Self-standing task | Section 5 |
| 6. | Internal and external hazards | Area Event analysis: index method | Self-standing task | Section 5, Appendix E |
| 7. | Functional dependencies | Component models, FMEA Dependence matrices | System analysis, Fault Tree modeling | Section 6, Appendix D, K2PG-5 |
| 8. | System interactions | Analysis of operating experience, insights from other PSA studies | System analysis, Fault Tree modeling, Event Tree modeling | Section 7 |
| 9. | Dynamic effects | Physical analyses | Initiating Event analysis, pipe breaks | Section 8, K2PG-3 |
| 10. | Dependent component failures, CCFs | Definition of CCCGs, Alpha Factor method for CCFs | System analysis, Fault Tree modeling, Data analysis | Section 9, Appendix C, K2PG-6 |
| 11. | Operator action dependencies | HRA | System analysis, HRA, Fault Tree modeling, Event Tree modeling | Section 10, K2PG-7 |



Table 2 Dependence categories and Data support.

| # | Dependence category | Analysis procedure or method | Data Support | Comment |
|---|---|---|---|---|
| 1. | Common Cause Initiators | Analysis of operating experience, insights from other PSA studies, link from functional dependencies, use of fault tree models | ICDE? | Examples |
| 2. | Common Cause Initiators | Loss of room cooling/heating: scooping analysis | ICDE? | Examples? |
| 3. | Internal and external hazards | Identification of room dependencies as a basic support task | | |
| 4. | Internal and external hazards | Evaluation of room importance | | |
| 5. | Internal and external hazards | Screening of hazards | | |
| 6. | Internal and external hazards | Area Event analysis: index method | FDE | Fire data exchange |
| 7. | Functional dependencies | Component models, FMEA Dependence matrices | | |
| 8. | System interactions | Analysis of operating experience, insights from other PSA studies | ICDE? | Examples in ICDE |
| 9. | Dynamic effects | Physical analyses | | |
| 10. | Dependent component failures, CCFs | Definition of CCCGs, Alpha Factor method for CCFs | ICDE | As we all know! |
| 11. | Operator action dependencies | HRA | ICDE? | Maybe dominant in ICDE |

## Data support

Data covering several dependence categories may be available

Data analysis?

Additional data sources?

# Assessment of Common Cause Failures in IPSN Probabilistic Safety Analyses

**Stockholm, 12th-13th June 2001**

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## SUMMARY

This report presents a synthesis of the methods used by the IPSN to assess common cause failures in probabilistic safety analyses (PSA), the lessons drawn from this study and the prospects of the methods proposed to assess common cause failures.

In France, the common cause failures in the 1990 version of the probabilistic safety analyses [ref. 1] were modelled using the generalized β factor. This method is a generalization of the Fleming β factor method based on the ATWOOD method.

Certain of the common cause failures highlighted by recent operating feedback had not been taken into account in the first version of the probabilistic safety analyses. Some important examples are given below.

An example is also given of common cause failures that affect several units. The example shows evaluation of the generalized β parameters required to assess the failure probability induced by the presence of air in the sump suction lines of 900 MWe reactor safety injection pumps and recirculation pumps at the start of the recirculation phase.

In France, several actions are currently in progress to develop a method to study common cause failures on a more widespread basis. In particular, the ICDE (International Common Cause Data Exchange) method could be used.

## 1. METHODS USED

### 1.1 TAKING ACCOUNT OF COMMON CAUSE FAILURES (CCF)

The 1990 version of the probabilistic safety analyses modeled common cause failures likely to affect identical components within a single system. The types of failure mode modeled were startup or operating failures.

### 1.2 EVALUATION OF PARAMETERS USING THE GENERALIZED β FACTOR

In the 1990 issue of the probabilistic safety analyses, the common cause failures were modeled using the generalized β factor. This method is a generalization of the Fleming β factor calculation method based on the ATWOOD method [refs. 2 to 4].

For any given component, the $\beta^i_n$ factor expresses the ratio between the common cause failure probability of i elements from a common cause failure group consisting of n identical elements, and the total failure probability from all causes, single and common inclusive. The $\beta^2_2$ parameter is known as the Fleming β factor [refs. 2 and 4]. To completely evaluate all common cause failures, it is necessary to characterize the $\beta^i_n$ parameters. This can be done using the ATWOOD method, otherwise known as the BFR method (Binomial Failure Rate method, [ref. 4]) to estimate all $\beta^i_n$ factors (i and $n \leq 4$) from the three parameters: $\beta^2_2$, $\beta^3_3$ and $\beta^4_4$.

Moreover, in some cases operating feedback can be used to estimate the $\beta^i_n$ parameters, by recording the number of single and common cause failures.

## 2. OPERATING FEEDBACK

Operating feedback shows that the main direct causes of common cause failures are design flaws, manufacturing defects, incorrect maintenance, environmental aggressions and human error during operation. Certain of these common cause failures shown up by recent operating feedback had not been taken into account in the first version of the probabilistic safety analyses. Below are a few examples.

### 2.1 Switchboard common cause failures

Since the first issue of the 900 MWe reactor probabilistic safety analysis (that only took into account independent failures for backed-up switchboards), operating feedback (the loss of the LHB switchboard at Cruas on 30/10/90) has shown that there is a common cause failure potentiality with the LHA and LHB switchboards. On October 30th 1990, in the Cruas plant, an electric arc struck one of the poles of the LHB 019 switch supplying auxiliary service water pump SEC 004PO, causing the cubicle to explode and setting fire to the LHB backed-up switchboard, which was completely destroyed. The cause of the arc was overheating and ageing of the shock-mount washers inside the switch. This fault is a common mode failure which could have resulted in failure of both backed-up switchboards and the impossibility of supplying them by the 2 diesel generators of the unit. As a result of this, common cause failures between switchboards have been taken into account in the update of the probabilistic safety analyses.

### 2.2 Common cause failures caused by human error

On November 20th 1991, the operator of unit 1 of the Gravelines power plant noticed that a combination of non-mixable greases was being used on the RRA (residual heat removal system) pumps. This could have induced a common mode failure resulting in the loss of RRA pumps 001 and 002 PO.

On 18th February 1993, the operator of units 1 and 2 of Saint-Alban noticed that this combination of greases presumed to be incompatible was being used on the bearings of the low pressure safety injection pumps and the containment spray pumps. This mixture could at last have degraded the lubrication function and consequently damaged the bearing and thus the pump.

A fault of this type could have resulted in failure of the low pressure safety injection function and part of the containment spray function, both in unit 1 and in unit 2. If a break had occurred that required the use of both of these functions, the risk of core damage and accidental release from the containment would have been increased.

Common cause failures induced by human error have been included case by case in the probabilistic safety analyses. A more in-depth study of the potential inter-dependence between human errors leading to accidents is required.

### 2.3 Inter-system common cause failures

The problem that occurred on January 24th 1999 in unit 1 of the Nogent power plant during a load rejection test was due to a current overload that caused tripping of the 2 essential service water system pumps used to cool the nuclear island (SEC 001 and 003 PO) and of the train A chemical and volume control system charging pump (RCV 171 PO). Tripping of these motor pump assemblies was caused by incorrect setting of the motor current overload relay thresholds. These thresholds had been set during shutdown for reloading while maintenance was being carried out on the train A switchboards. The current thresholds were set to between 6% and 30% less than the value required for all the 6.6 kV cubicles supplied through the train A switchboard (11 actuators including the essential service water pump actuators) and on the equipment supplied by 5 other switchboards (23 actuators). These settings had been made by technicians who were qualified, but who had never carried out this operation. Among the causes of this problem was the fact that the threshold setting and check operations had not been carried out separately, plus inadequate requalification operations. In general, common cause failures between systems are not taken into account in the probabilistic safety analyses. This point must be reconsidered.

### 2.4 Example of common cause failures affecting several units

Operating feedback has also highlighted failure of the RIS-BP (low pressure safety injection) pumps and the EAS (recirculation) pumps in several units of 900 MWe reactors at the start of the recirculation phase, caused by air in the sump suction lines. The risk of loss of the RIS-BP and EAS pumps is caused by the presence of a critical volume of air of 50 l upstream the pump.
The analysis covers twenty eight 900 MWe units, i.e. 56 RIS pumps and 56 EAS pumps. Recorded inoperability affected 14 RIS pumps and 25 EAS pumps. In this example, it is possible to estimate the common cause failure parameters by recording multiple failures separately for the RIS and EAS systems, then for both systems together. The results obtained can be used as a basis for discussion during the operating feedback analyses with Electricité de France.

# 3. LESSONS DRAWN FROM OPERATING FEEDBACK

## 3.1 POSSIBLE IMPROVEMENTS

Operating feedback has shown the possibility of common cause failures with the switchboards, failures caused by human error and inter-system failures. This type of failure was not directly integrated into the first issue of the probabilistic safety analyses. Some of these problems were examined during operating feedback analysis in order to determine their impact on safety functions and were included in the probabilistic safety analysis update. But a thought has to be initiated in particular to inter-system common mode failures. Several actions are currently in progress to analyse common mode failures on a more widespread basis. In particular, the ICDE method could be used.

## 3.2 PROSPECTS AND ESTIMATION OF COMMON MODE FAILURE PARAMETERS BASED ON WORK BY THE ICDE

The ICDE method consists in using a well defined coding system to assign a characteristic impact vector to each event. These impact vectors can be used to evaluate the significant common mode failure parameters. The degradation factors of a component can thus be encoded by assigning a failure rating to the analyzed component. The actual degradation of a system is often difficult to characterize, because it is necessary to determine the degree of simultaneity of the observed failures and the basic causes common to their occurrence. With this method, several degradation factors are encoded and can be used to obtain a more accurate estimation of the actual condition of the component (the coupling factor, the failure simultaneity factor and the factor denoting the existence of one or more causes of failure).

These recorded factors are used together to define the "specific" impact vector that characterizes the failure of a group of components. First, the impact vector must be defined by taking account of the degree of degradation of the equipment. Then the combined effect of the other factors must be assessed and from this the characteristic impact vector is deduced for the system being analysed. The data recorded in this impact vector help to estimate the common mode failure parameters. In particular, the "specific" impact vector must be associated to the generalized β factor or "Multiple Greek letter" method parameters. Several evaluation methods are being studied using the ICDE work to try to obtain the most suitable conversion equations and to characterize the common mode failure parameters. The working method that takes account of the data collected in the ICDE database can either be limited to events occurring in France only, or applied to the entire database. However, with the latter hypothesis, it is necessary to be able to assess the possibility of transposing international data to a specific French unit.

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# Proposal for EDF presentation on CCFs at the ICDE meeting Stockholm, 12th-15th June 2001

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## 1. EDF objectives in the field of CCFs

The probabilistic safety assessments carried out by EDF clearly show the importance of common-cause failures in the estimation of the core-melt frequency. However, the CCF parameters used in the PSA models are derived in part from old and limited feedback, and in part from assessment of international generic CCF data [1]: are they always representative of EDF's nuclear power plants today?

Ever since the first nuclear power plants were brought on line, we have been gathering data on the events that have occurred on units and on the corrective and preventive maintenance carried out on equipment.

EDF is now wondering if it is necessary to update the CCF database that is currently used in PSAs and to make better use of the operational experience data that has been gathered about its nuclear plants. To help answer this question, three aspects of the problem have been — and are still being — examined:

- the definition of CCF groups
- qualitative analysis of operational experience data
- modelling and assessment of parameters.

## 2. Current methodological orientations

### 2.1 *Definition of CCF groups modelled in PSAs*

A recent state-of-the-art review observed that EDF practice regarding the definition of CCF groups is much the same as that adopted by other operators. There are therefore no plans to make any major changes for the moment. Nevertheless, the feedback capitalised on by the works of the ICDE is closely followed since it is felt that it could reveal needs to redefine or define additional groups, particularly constituting of identical functionally redundant components which are located in different systems.

### 2.2 *Qualitative analysis of data*

The methodology currently envisaged is largely based on work carried out by the ICDE working group [2], to which EDF contributes by providing France's official representative, safety authority IPSN, with operational experience data and help in data analysis. The procedure proposed would associate the following parameters to each event affecting a CCF group and forming part of operating feedback:

- a degradation factor for each component in the group; this factor is in fact a conditional probability of failure which reflects the state of the component with respect to the safety mission to be fulfilled;
- a timing factor for the event; this factor is a probability enabling analysts to make a decision regarding the simultaneous occurrence of the failures analysed;
- a shared-cause factor for the event; this factor too is a probability; it enables analysts to make a decision on the existence of a common cause at the origin of the failures analysed.

This type of analysis was carried out experimentally on diesel generators, Auxiliary Feedwater pumps, Low pressure Safety Injection and Containment Spray pumps, and the motor-driven valves and circuit-breakers for 900 and 1300 MW units.

### *2.3 Assessment of CCF parameters*

#### 2.3.1 Background

In 1990, when the first PSA for 1300 MW units was developed, CCFs were modelled by means of $\beta_{ij}$ factors. Somme of them were estimated on the basis of the data gathered on French 900 MW PWR units using a method derived from the Atwood's Binomial Failure Rate (BFR) method. Porting the PSA model to Risk Spectrum required a change of CCF model to the Multiple Greek Letter (MGL) model. The parameters actually used in the current PSA models were therefore obtained by simple conversion of $\beta_{ij}$ factors to MGL parameters.

#### 2.3.2 Prospects

For future updates, it is envisaged to use the method for assessing $\alpha$ factors on the basis of the impact vectors built for each event analysed, as proposed in NUREG/CR 5485 [3], at least for groups of no more than 4 components. The reasons for choosing this method are particularly associated with its ease of use, which has been demonstrated by a test of the method on the quantification of parameters associated with ASG Auxiliary Feedwater pumps.

For CCF groups with more than four components (of which there are in fact few), it is difficult to model CCFs directly in the "CCF basic event" section of PSA models, because the reduction in cutsets means very long computer times; and it is impossible to do so under Risk Spectrum because of its coding constraints. It is therefore necessary to directly model the failure probability of specific subgroups defined in accordance with criteria for the failure of the expected missions. The estimation of such probabilities based on the parameters of the $\alpha$ factor or MGL models would appear to be difficult though not impossible. An exploratory study of the Common Load Method and its implementation for the control rods of 1300 MW units was therefore carried out.

## 3. Examples of applications carried out

### *3.1 Assessment of MGL parameters for Auxiliary Feedwater pumps*

#### 3.1.1 Brief description of the method

The first stage of this quantification method involves associating a mean impact vector, $I_{mean}$, to each event concerning the pumps (independent failure or CCF). For a group of m components, the mean impact vector associated with an event will have m+1 elements which will be defined on the basis of the shared cause factor, c, the timing factor, q, and degradation factors, $p_i$ associated with each component of the group. The MGL parameters are then calculated using the relations linking them with the sum impact vector, i.e. $n_k$ values which are obtained by adding up the $k^{th}$ elements of all the impact vectors considered.

#### 3.1.2 Insights

The method is simple but can be troublesome to implement. For this reason an application that automatically loads the results of qualitative analysis of operating feedback, calculates the elements of the impact vector, and assesses the CCF parameters for three models ($\alpha$ factors, MGL, and $\beta_1$ factors) with up to four components has been developed under Excel while awaiting development of an updating programme.
The results obtained are highly sensitive to the input data obtained by qualitative analysis, particularly to the degradation factors attributed to the components of the group. In fact, the real difficulty lies in the qualitative analysis with definition of degradation factors, shared cause factors, and timing factors which require safety and equipment knowledge (design, operation, and maintenance). Consequently, the choice of analysis rules to be applied (which depend on the component in question) must be discussed by experts in the different fields concerned.

### *3.2 Assessment of probabilities of multiple control-rod cluster jamming in EDF 1300 MW units, using the CLM method*

#### 3.2.1 Brief description of the method

The Common Load Model (CLM) is a parametric model for the quantification of common-cause failures , particularly applicable to highly redundant systems [4]. The model is based on a physical stress–resistance analogy. It assumes that N components of a sample are subject to a common stress, S. A multiple failure occurs when then stress exceeds the resistance of several components.

For the model to be used, the stress is broken down into:

- a basic stress which takes account of low-order multiple failures;
- an "extreme" stress which takes account of higher-order multiple failures, and which represents environmental shocks, inherent design defects, systematic maintenance errors, etc.

The CLM is fully defined for a given CCF group when the following four parameters have been assessed:

p_tot = the total probability of single component failure
p_xtr = the contribution of the extreme part of the stress to the probability of single component failure
c_co = the correlation coefficient for the basic stress part
c_cx = the correlation coefficient for the extreme stress part.

The CLM was implemented on control rod clusters in four steps:

1. Qualitative and quantitative analysis of events, which, as in the case of the α factor method, gives an impact vector; construction of the impact vector calls for substantial knowledge of operations since it is based on a variety of assumptions concerning the state of components subsequent to their being called on, or in light of their operational background;
2. point-by-point assessment of the probabilities of multiple failures, for each order of multiplicity, based on the sum impact vector representing all the operating feedback analysed;
3. determination of the CLM parameters, using the maximum likelihood method or a Bayesian approach;
4. calculation of the probabilities of multiple failure, using the HiDep program, based on the four parameters of the model.

### 3.2.2 Insights

This study served to assess the parameters expected on the basis of feedback taking account of the operation follow-up carried out on these components (regular replacement, periodic testing, CCTV inspection, etc.). The values obtained are slightly lower than those obtained with the approach used previously, but are coherent with them.
In this study one of the main contributions of the CLM was to be able, with a single study, and using the same operating feedback, to obtain all the probabilities necessary for the PSA model (probability of at least one, two, three, four, or five control-rod clusters being jammed). Here too, the requirement to combine expert knowledge of safety analysis and equipment design, in order to determine the impact vectors, was clearly demonstrated.
It would be interesting to compare the results that could be obtained for a single set of data using the three different approaches: CLM, α factor method, and BFR method.

## 4. Conclusions and prospects

EDF operates a sufficiently large and uniform range of nuclear power plants making possible to obtain CCF parameters from its own operating feedback. However, to get data of the good quality and statistical significance, the period of observation must be as long as possible even when pooling events from a large number of reactor units. But this means there is a problem of getting parameters that are not representative of the current state of components at the time of the analysis, because of often implemented modifications. Proving a statistically significant trend for CCF rate is not often possible. Moreover, as has been seen previously, qualitative analysis of data is a decisive and critical stage which requires a multidisciplinary team (safety, maintenance, equipment design). The investment necessary for updating CCF parameters is therefore substantial, whence there is great interest in the ICDE work which, by exchanging data, can help to share the investment required.

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# Overview of EDF involvement in CCF analysis

D. Vasseur - A. Voicu



## Overview of EDF involvement in CCF analysis

- EDF objectives
- Current methodological orientations
- An example : Control Rods CCF analysis
- Conclusions and prospects

## Overview of EDF involvement in CCF analysis

### EDF objectives

- **Current CCF parameters :**
  - limited operating experience
  - adapted international data
- **Are these data still well adapted to EDF plants ? How to use our cumulative operating experience data to update these values ?**

**ASSESS the CCF parameters updating issue**

EDF R&D NEA/CSNI/R(2001)8

## Overview of EDF involvement in CCF analysis

### Methodology : CCF groups of size 4

- **MGL model (Risk Spectrum)**
- **Qualitative analysis :**
  - plant event analysis : degradation, timing and shared cause factors
  - Average impact vector : $I_m = (F_{0m}, F_{1m}, F_{2m}, F_{3m}, F_{4m})$

$F_{0m} = cqF_0 + (1-cq)\ (1-p_j)$ ; $F_{1m} = cqF_1 + (1-cq)\ (p_j)$ ; $F_{2m} = cqF_2$ ; $F_{3m} = cqF_3$, $F_{4m} = cqF_4$

- **Parameters estimation (NUREG/CR 5485) :**

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## Overview of EDF involvement in CCF analysis

### Methodology: CCF Groups of size > 4

- Sub-group failure probability modeled
- Pilot study on the use of CLM method



## Overview of EDF involvement in CCF analysis

### Common Load Model

- parametric model developed for the treatment of failure probabilities and dependencies in highly redundant system structures
- based on physical stress-resistance analogy
  - base load part: low multiplicities
  - extreme load part: high multiplicities

## Overview of EDF involvement in CCF analysis

### CLM Application to French PWR 1300 Plants Control Rods

- operating feedback qualitative and quantitative analysis leading to the impact vector construction
- multiple failure probabilities by point estimation
- CLM parameters estimation:
  - p_tot: total single failure probability
  - p_xtr: extreme load part as contribution to the single failure probability
  - c_co: correlation coefficient of the base load part
  - c_cx: correlation coefficient of the extreme load part
- multiple failure probabilities calculated by CLM

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## Overview of EDF involvement in CCF analysis

### Operating feedback treatment

- 20 PWR 1300 units, observation period from January 1, 1989 to December 31, 1999 (201 reactor-years)
- two failure causes:
  - buckled fuel assembly
  - broken head of anti-rotation screw
- failures detected in automatic scram, periodic tests and operational exploitation
- treatment of both critical failures and degradations

**Most widen possible operating feedback**

EDF R&D NEA/CSNI/R(2001)8

## Overview of EDF involvement in CCF analysis

### Quantification hypothesis

- few critical failures and a lot of degradation events
- impact vector based on component degradation values assesment for each failure cause

- assumption of complete dependence between the degraded components ⟹ conservative approach

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## Overview of EDF involvement in CCF analysis

### Impact vector construction

| Category | Case | Impact vector elements | | | | | | | | | | | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10-53 | |
| Multiple events due to hooked fuel actuation failure | PAL 308 | $1-d_1$ | | | | | $d_1$ | | | | | | 1 |
| | PAL 310 | $1-d_1$ | | | | | | | | | $d_1$ | | 1 |
| Multiple events due to some anomaly | REL 108 | $1-d_2$ | | | | | $d_2$ | | | | | | 1 |
| | FLA 209 | $1-d_2$ | | $d_2$ | | | | | | | | | 1 |
| Single failures (hooked fuel assumption) | SEL 109 | $1-d_1$ | $d_1$ | | | | | | | | | | 1 |
| | PAL 111 | $1-d_1$ | $d_1$ | | | | | | | | | | 1 |
| Single failures (screw anomaly) | SEL 207 | | 1 | | | | | | | | | | 1 |
| | SEL 208 | $1-d_2$ | $d_2$ | | | | | | | | | | 1 |
| Cycles without failures | The 20 units | $n_0 - N_e$ | | | | | | | | | | | $n_0 - N_e$ |
| Sum impact vector | | $N_0 - N_e - N_{neg}$ | $1+2d_1+d_2$ | $d_2$ | 0 | 0 | $d_1+d_2$ | 0 | 0 | 0 | $d_1$ | 0 | $N_0$ |

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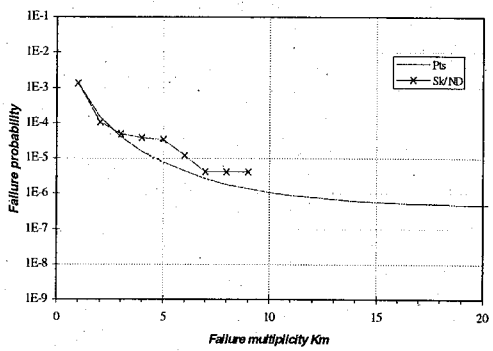
## Overview of EDF involvement in CCF analysis

### Obtained results

- results lower than those nowadays used in PSAs, based on engineering judgement
- obtaining of failure probabilities for various multiplicities necessary for the PSA 1300




EDF R&D NEA/CSNI/R(2001)8

## Overview of EDF involvement in CCF analysis

### Insights

- CLM used at EDF within the periodic safety review framework
- evaluation of all failure probabilities necessary for the PSA 1300 model, with a single study and using the same operating feedback
- interest of a comparison between the results that could be obtained from the same operating feedback treated with CLM, Alpha factor method and BFR method

EDF R&D NEA/CSNI/R(2001)8

## Overview of EDF involvement in CCF analysis

### Conclusions and prospects

- **Estimation methods seem well developed even if there are still some methodological issues of interest (comparison between different methodology for CCF groups of size > 4)**
- **The quality of derived CCF parameters strongly relies on a good qualitative analysis :**
  - enough event data
  - multicompetence team (safety, design, maintenance, ...)

  → a substantial investment
- **ICDE data bank may help to share the burden**

EDF R&D

NEA/CSNI/R(2001)8

Författare
Gunnar Johanson

Datum
2001-06-11
Uppdragsgivare

Projekt
Nordisk Arbetsgrupp för CCF studier
Ärende
Projekt Paper
Till

Kopia till

# NORDIC WORKING GROUP ON CCF STUDIES

## 1 INTRODUCTION

This is a presentaion of a project programme for assessment of CCF events and adoption of international data derived in the ICDE project to conditions in Sweden and Finland.

## 2 OBJECTIVES

The overall objective with the working group is to

- Support safety by studying potential and real CCF events and report conclusions and recommendations that can improve the understanding of these events eventually resulting in increased safety.
- The result is intended for application in NPP operation, maintenance, inspection and risk assessments.

The work is divided into one quantitative and one qualitative part with the following specific objectives:

Qualitative objectives: Compile experiences data and generate insights in terms of relevant failure mechanisms and effective CCF protection measures. The results shall be presented as a guide with checklists and recommendations on how to identify current CCF protection standard and improvement possibilities regarding CCF defences decreasing the CCF vulnerability.

Quantitative objectives: Prepare a Nordic C-book where quantitative insights as Impact Vectors and CCF parameters for different redundancy levels are presented. Uncertainties in CCF data shall be reduced as much as possible. The high redundancy systems sensitivity to CCF events demand a well structured quantitative analysis in support of best possible and realistic CCF parameter estimates, if possible, plant specific.

## 3 PROJECT PROGRAMME OVERVIEW

Survey and review (This activity shall verify the stated objectives with the project or shall provide background for corrections in plans and objectives.)

Quantitative work areas

Qualitative work areas









Topical reports

## 4 MODEL SURVEY AND REVIEW

This survey shall examine available models and their applicability for use on the data.

Several models exist and are used in the Nordic PSAs.

- The Basic Data Format shall be defined to allow for easy adoption to the relevant models.
- The basic estimation procedures for the considered models will be presented
- The model survey will discuss specific regimes of the reviewed models.

## 5 DATA SURVEY AND REVIEW

This survey shall examine available data sources and their applicability. The survey shall review ICDE and other sources and Provide a background for the decision on what data to be used.

Outcome

- Current data coverage in ICDE
- Internationally published CCF data sources
- Generic CCF data
- Risk-importance of main component types
- Perspective of CCF data development

A possible outcome is of course that the ICDE data are shown to cover all other sources, but there are possibilities the ICDE data shall be combined with some other source. The situation also differs depending on component type.

## 6 PLANT AND REGULATOR SURVEY

The survey shall provide a background to this project based on the needs and experience form the plant owners and the regulators. The survey shall try to reach a wide spectrum of personnel from regulation, operation, design engineering, safety committees and risk assessment groups. Important elements of the survey are to carry out a dialog with the organisations to engage them in the issues related to this programme and to marked the outcome and use of the analysis.

Subjects for topical reports shall be discussed.

## 7 QUANTITATIVE WORK AREAS

The quantitative work area cover activities related to the quantitative assessment of the data.

The procedure for common cause failure data analysis is intended to provide guidance on event analysis, the derivation of event statistics, and the estimation of model parameters.

- Impact vector model /methods

- Uncertainties (Qualitative , identify sources for uncertainties in terms of models and completeness)
- Guides /instructions for classification

CCF events do often contribute significantly to the PSA results and it is necessary to have the best estimates possible.

It is important that the data analysis to be

- Reviewable, and thereby achieve a certain level of credibility, the assumptions made through the analysis must be clearly documented.
- Classification rules shall be developed presenting how to deal with some commonly occurring situations and a format for documenting the analysis.
- Quantitative classification shall be applied on the available data, both preliminary and final. Plant specific information shall be recorded and consistency in classification shall be verified.
- Plant specific features shall, thought transparency within the classification, be possible to consider when applying the data and in the choice of CCF -modelling approach.
- The approaches used must be general enough to support a variety of models, direct estimates, Alfa factors, CLM etc..
- The presentation of basic CCF data will most likely be by Impact Vectors or an equivalent approach.
- Any software shall allow for a transparent derivation of plant specific parameters with their corresponding uncertainties.



## 8 QUALITATIVE WORK AREAS

Provide insights into the plant design and operation.

- Applicability aspects
- CCF event defence aspects
- Support of development of a common cause defence handbook to be used in safety work together with the quantitative results of the project:

To allow credit for existing plant defences in PSA work

- The qualitative work area is intended to increase the understanding of the failure mechanisms and the applicability of an event from the plant where it occurred (original plant) to the plant of interest (the target plant).

To support inspection and operation in assessing plant status with regard to CCF defences

- Are important defences applied in an optimum way?
- CCF event evaluation shall be used for defence identification.







- It should be possible to assess the specific CCF defence applied at different plants and identify and prioritise improvements.
- Of special interest is to use the CCF and dependency modelling experience including area and external events dependency modelling in PSAs in developing CCF checklists.

Qualitative classification

- Carry out an application of qualitative classification on the available data.
- Assess the qualitative aspect in relation to CCF and present insight for development of defences.
- It can be noted that the SRD (Safety and Reliability Directorate) branch of UKAEA (United Kingdom Atomic Energy Authority) already 1981 /2/ developed a guide for common mode defence strategies. This guide is used as input to this project.

## 9 TOPICAL REPORTS

This is a proposal for topical reports to be presented by the project.

The survey and discussions with project participant will generate additional proposals to be considered.

1. Model survey and review
2. Data survey and review
3. Quantitative classification: impact vector method
4. Statistical method for uncertainty estimation on CCF data
5. Plan for Plant and Regulator survey
6. Report on Plant and Regulator survey
7. Compilation of qualitative data evaluation
8. Handbook for CCF Management in Inspections And Operations
9. "Handbook" for plant specific estimation of CCF data for Nordic plants based on available data.

# AN ANALYSIS OF PIPING DEGRADATIONS AND FAILURES AS THE ROOT CAUSE OF COMMON CAUSE FAILURE MECHANISMS IN REDUNDANT SAFETY SYSTEMS

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**Abstract**: Since the 1970's, considerable efforts have been expended on the development of methods for the analysis of common cause failure (CCF) events. An important aspect of CCF-analysis involves the data analysis process used to determine the root causes of CCF events, defenses against CCF events and plant-specific CCF data parameters. The root causes of CCF events include active and passive component degradations and failures. Using results and insights from a seven-year R&D project to establish a comprehensive database of piping degradations and failures in commercial nuclear power plants, the objective of this paper is to summarize the role of piping degradations and failures in causing CCF events.

## 1. Background

Recent advances in piping reliability analysis enable detailed consideration of the potential impact of piping degradations and failures on process and safety system availability and plant safety. In part, these advances have been made possible through R&D sponsored by the Electric Power Research Institute [1,2], OECD Nuclear Energy Agency [3] and the Swedish Nuclear Power Inspectorate [4,5]. Established in 2001 by the OECD Nuclear Energy Agency, the OECD Piping Failure Data Exchange (OPDE) Project has established a purpose-designed international database on piping failures. Currently, this database includes on the order of 4,200 reports (or case histories) on degradations and failures in ASME Code Class 1, 2 and 3 piping as well as non-code class piping (e.g., non-essential service water piping and fire protection system piping). The OPDE collection of industry service data includes numerous instances of piping-induced CCF events. The three-fold objective of this paper is to:

(1) Define the different classes of piping-induced CCF events.
(2) Summarize the role of piping-induced CCF events in probabilistic safety assessment (PSA).
(3) Role of event interpretation and root cause analysis to establish an appropriate set of data parameters for piping-induced CCF events.

As an adjunct to the discussion on piping-induced CCF events, the paper includes an overview of some aspects of systematic errors causing piping degradations and failures.

## 2. Classes of Piping-Induced CCF Events

A review of the available 'CCF Insights Reports' that have been generated by the ICDE Project demonstrates the importance of piping induced CCF events [6]. As an example, degradations or failures in the discharge and suction subsystems have caused failure of pumps in redundant safety systems. The following classes of piping-induced CCF events have been defined through systematic evaluations of the OPDE database content:

(1) Structural failure of common recirculation line, suction line or discharge line could lead to pump CCF events. Section 2.1 (CCF Candidate Events Ascribed the Discharge and Suction Subsystems) includes a discussion on the applicable service experience and how a database like OPDE could support the transference of

industry data to plant-specific applications of CCF event data.

(2) Structural failure of any ex-containment piping could result in a major common cause initiating (CCI) event like internal flooding of the reactor building in a BWR or auxiliary building in a PWR. With relevance for internal flooding studies, Section 2.2 (Common Cause Initiating Events) summarizes the service experience in the OPDE database.

(3) Understanding the root causes of piping degradations and failures enhances the quality of the CCF parameter estimation process. An important class of piping degradations and failures includes water hammer events in which degraded piping could fail catastrophically. Water hammer of sufficient magnitude can result in common cause failure of safety injection trains. Additionally, a water hammer event could potentially cause pressure locking in some valves. Section 2.3 (CCF Events Due to Water Hammer) summarizes the water hammer experience that is documented in OPDE.

### 2.1 CCF Candidate Events Ascribed the Pump Discharge & Suction Subsystems

An example of an event classified as a CCF involved a through-wall leak in a common high-pressure safety injection (HPSI) pump recirculation line [6]. Using the OPDE database, the event description in the CCF Insights Report was correlated to an event in the U.S. plant Ginna on August 9, 1994 (LER 50-244/94-009).

While performing a monthly safety injection system test, a small leakage developed at a DN40 socket weld in a common recirculation line for the safety injection pumps. The leak rate was approximately 50 cc/min. All three pumps were declared inoperable, and to comply with the Technical Specifications, the plant was shut down to effect the weld repair. The underlying cause of the leak was determined to be a discontinuity (crack), which initiated from the root of the socket weld. Based on the appearance of the fracture surface, it was believed that the crack had been initiated by a recent tensile overload event. The crack continued to propagate through-wall by a vibratory fatigue mechanism traced to the 'B' HPSI pump. This pump had been been misaligned following an overhaul that was completed about three months prior to the discovery of the weld failure.

As another example of a potential piping-induced CCF event, on April 18, 1999, a small leak was discovered on a section of the Train B essential service water (ESW) system piping (ASME Code Class 3) in Catawba Unit 1 (LER 50-413/99-010). The affected pipe section supplies the Train B Auxiliary Feedwater pump. At Catawba (a twin unit site) the ESW System consists of two independent loops (A and B), each of which is shared between the two units. Each loop therefore supplies two trains (1A and 2A, or 1B and 2B) of essential equipment. Based on Train B radiographic test results, all four AFW pumps were declared inoperable.

Typical of any commercial nuclear power plant, the ESW System is a raw water system, which at Catawba Nuclear Station relies on lakewater as the normal source of water. The cause of the piping degradation was microbiologically induced corrosion (MIC).

While legitimate CCF candidates, there have been numerous similar events. The OPDE database includes many hundreds of piping-induced CCF candidate events. Against the current piping reliability state of knowledge, it seems reasonable to include in the procedures for CCF data analysis special piping reliability considerations to support appropriate (i.e., defensible) plant-specific applications of generic CCF data.

There is significant plant-to-plant variability in piping system design. As an example, some national piping design codes prohibit the use of socket welds in piping over 25 mm in diameter (DN25). Also, the implementation of in-service inspection programs differs from plant-to-plant. Depending on the location of a through-wall crack and leak rate, temporary pipe repairs may be allowed to avoid plant shutdown and to limit the leakage [7]. The significance of a through-wall crack is a function of unique combinations of degradation mechanism, type of piping (e.g., high-energy vs. moderate-energy piping) and pipe wall stress levels. Before classifying a

piping degradation or failure as a contributing factor to CCF candidate events, the data interpretation process must determine how a through-wall leak was identified, what steps were taken to mitigate a leakage, the observed leak rate, and the system configuration at the time of the discovery. Therefore, the plant specific applications of generic CCF data parameters should include data screening rules that reflect piping design and maintenance practices, as well as the component boundary definition that is being used. Such rules should be based on he results of reviews of a sufficiently detailed and validated database on piping failures.

### 2.2 Common Cause Initiating Events

Flooding events have occurred at nuclear power plants and those events have indicated a potential for more serious scenarios involving flood-induced failures of safety equipment. The potential risk significance of internal flooding stems from the susceptibility of multiple spatially dependent components that could be damaged from a single flood occurrence. Hence internal flooding is an important class of common cause initiating events that needs to be considered in the development of a reasonably complete set of accident sequences for a PSA.

An example of a recent internal flooding event is the fire protection header rupture in WNP-2 in June 1998 [8].[1] Due to the remote location of the fire pumps, it took about 12 minutes to stop the pumps. A total of about 620 $m^3$ of firewater was released into the Reactor Building stairwells, flooding two emergency core cooling system (ECCS) equipment rooms. This event occurred during plant startup following the 1998 refueling outage.

In state-of-the-art internal flooding PSA, the consideration of functional and spatial dependencies imposes unique analysis considerations on flood frequency estimation, determination of the plant impact by successful flood isolation and determination of the consequence(s) given unsuccessful flood isolation. A consequence of flooding due to piping failure could be a CCF of pumps as described in Section 2.1 as well as spatial effects that aggravate the conditions for safe plant shutdown.

Wherever there are important flooding vulnerabilities, the flood frequency estimation must be based on detailed assessments of the exposure terms [4]. That is, the frequency should reflect a detailed review of the piping runs in the plant that could be a significant source of flooding. Reviews of isometric drawings together with piping system walkdowns establish accurate counts of welds and/or lengths of piping for input to the plant- and location-specific flood frequency calculations.

The model used to estimate flood frequency data should reflect the overall approach to realistic treatment of flood propagation and equipment damage. That is, to correctly address spatial dependencies the piping runs (including the exposure term assessment) should be mapped onto the plant locations determined to exhibit some flooding vulnerability.

### 2.3 CCF Events Due to Water Hammer

Water hammer of sufficient magnitude can result in common-cause failure of redundant safety system trains. Water hammer induced structural failure safety injection discharge piping could create a containment bypass release path in addition to preventing injection flow. Additionally, a water hammer event could potentially cause pressure locking in some valves.

All plants experience water hammer, but to varying degrees of severity. A plant's susceptibility to water hammer depends on a number of plant-specific factors, including operational practices. There is extensive water hammer experience to support the development of good screening rules to be applied to plant specific evaluations of CCF data on pumps and valves.

## 3. Systematic Errors & Dependent Failures

Data analysis insights point to the significance of systematic piping failures. Classified as 'systematic' are those piping failures that have recurred in one plant or in multiple plants of the same type and design generation and

[1] WNP-2 was renamed Columbia Generating Station in January 2001.

within a short time period (e.g., two inspection intervals). Implementing recommendations of root cause analysis could prevent further systematic failures. Examples of actions to mitigate the recurrence of systematic piping failures could be a design modification (e.g., changed pipe slope, enhanced access for applying non-destructive examination techniques), and an expanded exchange of service experience data between plants. In classifying an event as a systematic failure event it must meet all of the following criteria [3]:

- Degradation mechanism and root cause must be the same.
- Location of the pipe degradation must be the same (e.g., downstream of flow throttling device, between pipe and elbow).
- Metallurgy must be the same.
- Impact on plant operation must be the same.
- Occurs within limited time-period, which could be a test interval or fuel cycle.

In establishing event data collections, systematic piping failures should be identified to capture all dependent events. The data analysis process must recognize the defenses against dependent events and determine whether these defenses have been implemented at plants of similar design.

Consideration of systematic piping failures becomes particularly important when converting generic data to plant-specific data for use in PSA applications. Data collections on piping failures should include appropriate data screening facilities.

## 4. Conclusions

Piping failures are known to be important contributors to CCF of active components. Significant advances have been made in piping reliability analysis including the establishment of comprehensive databases on piping degradations and failures. The results and insights from this work is directly applicable to the analysis of CCF data on pumps and valves.

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# Consideration of Piping Failures in Root Cause Analysis of CCF Candidate Events

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*ERIN Engineering*

***ICDE Seminar & Workshop on Qualitative and Quantitative Use of ICDE Data***
*Stockholm (Sweden), June 12, 2001*

ERIN® Engineering and Research, Inc.

## Outline of Presentation

- Demonstrate synergy of two projects by OECD-NEA
  - ➤ ICDE Project on CCF Data
  - ➤ OPDE Project on Piping Failures (2002 - 2004)
- Objectives of presentation include the following:
  - ➤ Define the different classes of CCF due to piping degradations & failures
  - ➤ Summarize the role in PSA of CCF events attributed to piping failures.
  - ➤ Recommendations for event interpretation & root cause analysis to establish an appropriate set of data parameters for CCF events attributed to piping failure.

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# OPDE Project 2002-2004 (Phase 1)

- Establish a comprehensive & validated database on piping degradations & failures in commercial nuclear power plants worldwide
- OPDE based on an established database (SKI-PIPE; currently ca. 4200 records/case histories)
- Validation of existing database entries for period 1998 - 2000 and addition of new entries
  - ➤ ASME Code Class 1, 2 and 3 piping
  - ➤ Non-Code Class piping; e.g., non-essential SW piping
  - ➤ Rupture - Leak - Through-wall Crack - Wall Thinning

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# Status of OPDE Project

**OPDE Project**

After a presentation of the consensus reached by the OPDE project group at its last meeting in April, a round table showed the following intents of participation:

| | | |
|---|---|---|
| 1 | US | YES, will discuss with EPRI |
| 2 | Spain | YES, considering the new threshold for the 1st part. |
| 3 | Netherlands | YES for Safety Authority, will continue to seek for participation of the utilities |
| 4 | Korea | YES |
| 5 | France | YES |
| 6 | Sweden | YES |
| 7 | Finland | YES |
| 8 | Hungary | YES |
| 9 | Canada | YES |
| 10 | Germany | High confidence in participating |
| 11 | Switzerland | High confidence in participating |
| 12 | Japan | will report and get back later |
| 13 | Czech Republic | Will discuss with Dr ZDAREK |
| 14 | Belgium | maybe, will continue to seek for participation of the utilities |

**With at least 9 participants, the project is viable and will include complete enough data for a broad range of application.**

**Next steps:**

- Presentation of the project to the CSNI in June 2001
- Inform them of the issuance of a formal letter of acceptance in July
- Objective is to start the project by January 2002

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## Classes of CCF Due to Piping Degradation & Failure

- Structural failure of pump common recirculation / suction / discharge line could result in redundant pumps being declared inoperable
- Structural failure of ex-containment piping could result in major common cause initiating event (CCI) event; e.g., internal flooding of reactor building.
- Pipe failure due to water hammer - a special class of events that could result in complicated spatial dependencies ***and*** CCF candidate events involving pumps and valves (e.g., pressure locking). We refer to these events as ***complex dependencies***.

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## CCF Due to Discharge & Suction Subsystems

- Insights from reviews of case histories in SKI-PIPE point to large number of CCF candidate events (many hundred events involving ASME Code Class 2 and 3 piping)
- Important to screen data according to plant and system mode of operation at the time of discovery.
- Significant plant-to-plant variability in piping system design. Differences attributed to national design standards & design vintage.

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## Data Screening Guidelines & Plant-Specific Applications

- Determine how through-wall leak was detected (e.g., routine system walkdown, surveillance testing).
- Determine leak rate and associated Technical Specification Action Statement (if any)
- Determine system configuration at the time of discovery. Make comparison with the as-modeled system configuration (in the PSA)
- Determine the structural margin to a pipe failure that would challenge, say, SI make-up capability.

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## Role in PSA of CCF Events Attributed to Piping Failure

- Programs to mitigate certain degradation mechanisms (e.g., IGSCC, thermal fatigue, vibration-fatigue) typically quite effective.
- The fraction of CCF events ascribed degradation of ASME Code Class 2 piping should be quite small.
- Expect significant plant-to-plant variability due to effects of systematic piping failures (see the technical paper for details), however.

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## Role in PSA of CCI Events Ascribed Piping Failure

- Insights from Internal Flooding Analyses (e.g., Oconee, Surry, Byron & Braidwood) point to important flooding-induced CDF contributions from failure of ASME Code Class 3 and non-Code Class piping failures.
- To correctly address spatial dependencies the piping runs should be mapped onto the plant locations determined to exhibit flooding vulnerability.
- Flood frequency estimation should reflect design issues (e.g., isometrics), inspection issues and service data.

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## Conclusions

- Enhance the screening guidelines for CCF Candidate events ascribed piping degradations & failures by
  - ➤ Documenting the different types of relevant events included in SKI-PIPE/OPDE.
  - ➤ Summarize typical piping system designs of concern and identify realistic component boundaries.
  - ➤ Identify differences in piping system design codes & practices (e.g., use of socket welds). Develop reasonable sets of national versus international screening guidelines.

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# The Use of CCF Data in Safety System Analysis Quantification[1]

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For many years the main reference for common-cause failure analysis (CCFA) was NUREG/CR-4780, *Procedures for Treating Common Cause Failures in Safety and Reliability Studies*. It consists of two volumes–Volume 1, Procedural Framework and Examples, published in January 1988 and Volume 2, Analytical Background published in January 1989. The U.S. Nuclear Regulatory Commission updated that report in 1998 with NUREG/CR-5485, *Guidelines on Modeling Common-Cause Failures in Reliability and Risk Assessment* published November 1998. These references provide guidance on the collection of common-cause failure event data and on the use of these data in reliability and risk studies.

These references also contain a procedural framework for performing a common-cause failure analysis. The major steps are shown in Table 1. All of the steps should be done for a detailed common-cause failure analysis. However, some of the qualitative steps, although probably the most useful in a system evaluation, can be omitted in a quantitative assessment.

For a quantitative assessment, as well as a qualitative assessment, a reliable and complete source of common-cause failure events is required. Of course the best and most relevant CCF data would be plant-specific data. However, plant-specific CCF data are scarce. Therefore, we must rely on CCF experience from other nuclear power plants for our qualitative and quantitative assessments. Since nuclear power plants differ in configuration, operations, and maintenance policies, CCF experience differs among the plants. Thus, we must screen and evaluate the industry CCF data for application to our specific plant of interest. In this way we create a pseudo plant-specific CCF database. We tailor events based on applicability of cause and coupling factor to the specific plant. Because system configurations differ we "map" the events up or down to correspond to plant-specific component configuration or group size.

To aid us in the development of this pseudo plant-specific database, the concept of an event impact vector was introduced. The pseudo plant-specific database is developed through a two-step process to facilitate the estimation of plant-specific CCF parameters from industry CCF experience:

1. Use an "event impact vector" to classify the CCF events according to the level of impact of events and associated uncertainties, and

2. The impact vector is "specialized" or modified to reflect the likelihood of occurrence at the plant of interest.

The impact vectors are specialized for qualitative and quantitative uses. For the qualitative assessment we specialize the event by looking at the applicability of the cause and coupling factor at our specific plant and by assessing the CCF defenses available at the our plant. For the quantitative assessment we account for differences in system size of event and specific plant by mapping up the event or mapping down the

[1]This paper was prepared (in part) by an employee of the United States Nuclear Regulatory Commission. It presents information that does not currently represent an agreed-upon staff position. USNRC has neither approved nor disapproved its technical content.

event as appropriate. The final result is a database in which the events will have characteristics of our plant.

**Table 1. Procedural framework for performing a common-cause failure analysis**

1. Screening Analysis
   - Problem Definition and System Modeling
     - Plant familiarization
     - Identification of system and analysis of boundary conditions
     - Development of component level fault tree
   - Preliminary Analysis of CCF Vulnerabilities
     - Qualitative screening
     - Quantitative screening

2. Detailed Qualitative Screening
   - Review of Plant Design and Operating Practices
   - Review of Operating Experience
   - Development of Cause-Defense Matrices

3. Detailed Quantitative Analysis
   - Common Cause Modeling
     - Identification of Common-Cause Basic Events (CCBEs)
     - Incorporation of CCBEs into Fault Trees
     - Parametric Representation of CCBEs
   - Data Analysis and Parameter Estimation
     - Parameter Estimation
     - Development of Pseudo plant-specific database
     - Estimation of CCF Model Parameters
     - Basic Event Probability Development
   - System Quantification and Results Interpretation
     - System unavailability quantification
     - Results evaluation and sensitivity analysis
     - Reporting

We normally assign words to represent the degree of the timing factor, shared cause factor and the component degradation values. The timing factor and shared cause factor are assigned a value of high medium or low. We code the component degradation values as complete, degraded, incipient, or not failed. To use this information in quantification, we must change these word values into a numerical value. For example, we can code the component degradation values as: Complete = 1.0, Degraded = 0.5, Incipient = 0.1, and Not Failed = 0.0.

Sometimes we want to compare CCF data from different sources. One way of doing this is to compare the estimated CCF parameters from the different sources. We often do not have a count of the independent failures. Thus, we cannot estimate the CCF parameters and make the comparison. Other ways exist for us to make this comparison. First, we can compare them is to calculate the sum of the $n_i$ (i.e., $n_0$, $n_1$, $n_2$, etc.) for the various sources and compare them. Here we can use only events with the same exposed population size (no mapping involved), or we can map all the events to a given size, calculate the $n_i$, and make the comparison.

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Second, we can use the event information and estimate conditional probabilities. What is probability of one or more components being failed given one component is failed. It is important to remember that the probability is conditional on two items--the condition of the component and the fact that the population is restricted to common-cause failure events.

Several ways to estimate the conditional probability depending upon the assumptions made. One way "resembles" the alpha factor estimators. We map all the CCF events to a given size, calculate the $n_i$, and the use them to estimate conditional probabilities. For another way, use the cell counts for the various categories. In this case we assume that the timing and shared cause factors are equal to 1.0. Both methods are illustrated in the presentation using ICDE CCF data.

A final question that we can ask is "What is the affect of numerical value assigned to the component degradation parameter? Normally, we assign a value of 0.5 to a degraded component. We can assign some other value, such as 0.6 or 0.7. The affect of this value on the $n_i$ is illustrated in the presentation using ICDE CCF data.

# The Use of CCF Data in Safety Analysis Quantification

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## Major References for Common-Cause Failure Analysis

- NUREG/CR-4780, "Procedures for Treating Common Cause Failures in Safety and Reliability Studies"
  - Volume 1, Procedural Framework and Examples (January 1988)
  - Volume 2, Analytical Background (January 1989)
- NUREG/CR-5485, "Guidelines on Modeling Common-Cause Failures in Reliability and Risk Assessment" (November 1998)

# Major Steps for CCF Analysis

- Step 1 - Screening Analysis
- Step 2 - Detailed Qualitative Analysis
- Step 3 - Detailed Quantitative Analysis



# Step 1 - Screening Analysis

- Problem Definition and System Modeling
  - Plant familiarization
  - Identification of system and analysis of boundary conditions
  - Development of component level fault tree .
- Preliminary Analysis of CCF Vulnerabilities
  - Qualitative screening
  - Quantitative screening

# Step 2 - Detailed Qualitative Screening

- Review of Plant Design and Operating Practices
- Review of Operating Experience
- Development of Cause-Defense Matrices



# Step 3 - Detailed Quantitative Analysis

- Common-Cause Modeling
- Data Analysis and Parameter Estimation
  - Development of a pseudo plant-specific database
    - Tailor events based on applicability of cause and coupling factor
    - Map the resulting impact vectors up or down to correspond to plant-specific component group size
  - Estimation of CCF model parameters
- System Quantification and Results Interpretation

## General Concepts

- The most relevant data would be plant-specific data.
- However, plant-specific CCF data are scarce.
- Therefore, parameter estimation must rely on CCF experience from other nuclear power plants.



## Use of Industry-Wide CCF Data

- We create pseudo plant-specific data through screening and evaluating industry data for plant-specific characteristics
- This is done through a two-step process to facilitate the estimation of plant-specific CCF parameters from industry CCF experience

## Data Specialization Process

- Step 1 - use an "event impact vector" to classify the CCF events according to the level of impact of events and associated uncertainties
- Step 2 - the impact vector is "specialized" or modified to reflect the likelihood of occurrence at the plant of interest



## Impact Vector Specialization

- Qualitative Assessment
  - Applicability of the cause and coupling factor at the specific plant
  - CCF defenses available at the specific plant
- Quantitative Assessment (account for differences in system size of event and specific plant)
  - Mapping up the event
  - Mapping down the event

# Impact Vector Assessment

- Ways to estimate or assess the impact vector
  - Formulate specific hypotheses
  - Use concepts in NUREG/CR-5485



# Other Quantitative Measures

- Estimation of conditional probabilities
  - What is probability of one or more components being failed given one component is failed
- Comparison of n values ($n_0$, $n_1$, $n_2$, etc.)
  - Use only events with exposed population size, no mapping involved
  - Use all events mapped to a given size

# Component Degradation Values

- Components "failures" are coded as
  - Complete Failure
  - Degraded Failure
  - Incipient Failure
- To use in quantification, we must change the "words" to a numerical value
  - Complete = 1.0
  - Degraded = 0.5
  - Incipient = 0.1



# Comparison of Europe and USA ICDE CCF Pump Data (CCCG = 2)

| Country | $N_0$ | $N_1$ | $N_2$ |
|---|---|---|---|
| Fail to Start | | | |
| Europe | 0.00 | 2.85 | 3.55 |
| USA | 1.56 | 2.58 | 6.86 |
| Fail to Run | | | |
| Europe | 6.85 | 13.29 | 2.89 |
| USA | 0.50 | 2.93 | 3.53 |

# Conditional Probability

- Several ways to estimate this probability depending upon the assumptions made
  - One way "resembles" the alpha factor estimators
    - Uses all CCF available quantitative information (degradation values, shared cause, coupling factor)
    - Calculate the $n_i$ for each event
    - Obtain the sum, $N_i$ , for each $n_i$
  - For another way, use the cell counts for the various categories
    - Assume timing and shared cause factors are 1



# Conditional Probability using $N_i$

- Equation:
  - P[ 2nd Failure | 1st Failure] = $N_2 / ( N_1 + N_2 )$
- ICDE Pump CCF events with CCCG =2
  - Fail to Start
    - Europe - P[ 2nd | 1st ] = 0.55
    - USA - P[ 2nd | 1st ] = 0.73
  - Fail to Run
    - Europe - P[ 2nd | 1st ] = 0.18
    - USA - P[ 2nd | 1st ] = 0.55

# ICDE Pump CCF Event Count
## (CCCG=2 and Combined Failure Modes)

| Event | CC | CD | CI | DD | DI | II |
|---|---|---|---|---|---|---|
| Count | 16 | 6 | 6 | 6 | 0 | 12 |
| Prob. | 0.348 | 0.130 | 0.130 | 0.130 | 0.0 | 0.261 |



# Degradation Probability

- P[C] = P[CC] + P[CD] +P[CI] = 0.609
- P[D] = P[CD] + P[DD] + P[DI] = 0.291
- P[I] = P[CI] + P[DI] + P[II] = 0.391

Note: These events are not mutually exclusive. Must use the the inclusion-exclusion principle to calculate the correct probability.

## Conditional Probabilities

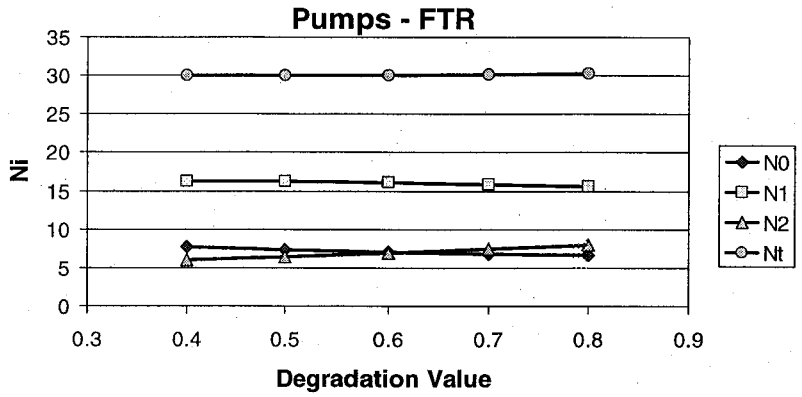
| 'X' | 'X' \| C | 'X' \| D | 'X' \| I |
|---|---|---|---|
| C | **0.571** | **0.500** | **0.333** |
| D | **0.214** | **0.500** | **0.0** |
| I | **0.214** | **0.0** | **0.667** |



## Affect of Degraded Failures

- The value of 0.5 is subjective
- We can assign some other value, such as 0.6 or 0.7
- What affect does another value have on the quantification?

# Affect of Degradation Value

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# Summary

- ICDE CCF events are useful for:
  - Qualitative insights
  - Augment other CCF failure event databases
  - Relative quantitative comparisons
- Important to provide enough information so that a user can make own interpretation
- Information for all fields should be provided
  - If something is unknown, it should be coded as unknown

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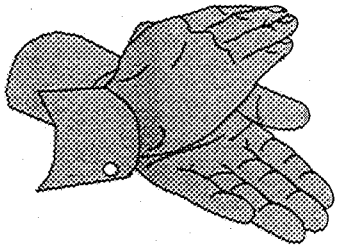
# The End



## Are there any questions?



# Impact Vector Calculation
## (CCCG = 2)

$P_1$ = *Degradation value for component* 1

$P_2$ = *Degradation value for component* 2

$F_0 = (1 - P_1)(1 - P_2)$

$F_1 = P_1(1 - P_2) + (1 - P_1)P_2$ *and*

$F_2 = P_1 P_2$

## Step 3A - Common Cause Modeling

- Identification of Common-Cause Basic Events (CCBEs)
- Incorporation of CCBEs into Fault Trees
- Parametric Representation of CCBEs



## Step 3B - Data Analysis and Parameter Estimation

- Parameter Estimation
  - Development of Pseudo plant-specific database
    - Tailor generic events based on applicability of cause and coupling factors
    - Map up or down the resulting impact vectors to correspond to plant-specific component group size
  - Estimation of CCF Model Parameters
- Basic Event Probability Development

## Step 3C - System Quantification and Results Interpretation

- System unavailability quantification
- Results evaluation and sensitivity analysis
- Reporting