RECENT INSIGHTS FROM THE INTERNATIONAL COMMON CAUSE FAILURE DATA EXCHANGE (ICDE) PROJECT

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Abstract:

Common-cause failure (CCF) events can significantly impact the availability of safety systems of nuclear power plants. In recognition of this, the international CCF data exchange (ICDE) project was initiated in 1994. The objectives of the ICDE project are: to provide a framework for a multinational co-operation; to collect and analyze CCF events over the long term so as to better understand such events, their causes, and their prevention; to generate qualitative insights into the root causes of CCF events which can then be used to derive approaches or mechanisms for their prevention or for mitigating their consequences; to establish a mechanism for the efficient feedback of experience gained in connection with CCF phenomena, including the development of defenses against their occurrence, such as indicators for risk based inspections; and to record event attributes to facilitate quantification of CCF frequencies when so decided by the member countries of the Project. Until January 2014, 1346 ICDE events had been analyzed and reported in public OECD/NEA reports
This paper presents recent activities and lessons learnt from data collection on Control Rod Drive Assemblies and Heat Exchangers and on cross-component analysis on events which were due to external factors.

Key Words: Common cause failure, CCF, ICDE

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 most countries. 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 and coupling factors, which are important to the assessment of the events, are usually written in the native language of the countries where the events were observed.

To overcome these obstacles, the preparation for the international common cause data exchange (ICDE) project was initiated in August of 1994. Since April 1998, the OECD/NEA has formally operated the project. Phase II had an agreement period that covered years 2000-2002, phase III covered the period 2002-2005, phase IV covered years 2005-2008 , phase V covered 2008-2011, and phase VI covers 2011-2014. Member countries under the Phase VI Agreement of OECD/NEA and the organisations representing them in the project are: Canada (CNSC), Finland (STUK), France (IRSN), Germany (GRS), Japan (JNES), Korea (KAERI), Spain (CSN), Sweden (SSM), Switzerland (ENSI), United Kingdom (HSE), United States (NRC) and Czech Republic (UJV).

The objective of this paper is to give generic information about the ICDE activities and the lessons learnt from recent analysis of CCF events in the ICDE database of Control Rod Drive Assemblies and Heat Exchangers and a cross-component analysis of common-cause-failure events which were due to external factors.

2 ICDE OBJECTIVES AND OPERATING STRUCTURE

The objectives of the ICDE project (denoted later as the Project) are:

- to provide a framework for a multinational co-operation;
- to collect and analyze CCF events over the long term so as to better understand such events, their causes, and their prevention;
- to generate qualitative insights into the root causes of CCF events which can then be used to derive approaches or mechanisms for their prevention or for mitigating their consequences;
- to establish a mechanism for the efficient feedback of experience gained in connection with CCF phenomena, including the development of defenses against their occurrence, such as indicators for risk based inspections; and
- to record event attributes to facilitate quantification of CCF frequencies when so decided by the member countries of the Project.

The ICDE Steering Group (SG) controls the Project with assistance from the NEA project secretary and the Operating Agent. The Operating Agent is responsible for the database and consistency analysis. The NEA Secretariat is responsible for administering the project on behalf of the OECD. The ICDE operating structure and documents related to it are depicted in Figure 1.

Running an international project requires funding and consequently the participating countries make yearly an agreed ICDE contribution to the NEA for reimbursement of the costs of the Operating Agent and the OECD NEA Secretariat. In addition, each participant bears all other costs, like the ones for data collection and national analysis, associated with participation in the Project. These costs are generally much higher that the costs of running the Operating Agent. Moreover, the in-kind principle is followed in the data exchange in that each country gets the dataset corresponding to its own data sent to the Operating Agent. Thus, just participating and paying the fees does not lead to directly receiving any data without a member’s own data collection and submittal effort.

The SG meets twice a year on average. Its responsibilities include the following types of decisions: to secure the financial (by approval of budget and accounts) and technical resources necessary to carry out the project; to nominate the ICDE project chairman; to define the information flow (public information and confidentiality); to approve the accession of new members; to nominate project task leaders (lead countries) and key persons for the Steering Group tasks; to define the priority of the task activities; to monitor the development of the project and task activities; to monitor the work of the Operating Agent & quality assurance and to prepare the three-year legal agreements “Terms and Conditions”, see Figure 1, for project operation. The ICDE experience tells that such a legal agreement completed by internal operating rules and summary presentations are vital prerequisites of mutual understanding and a functioning framework for a long-term internal co-operation with many countries involved.

An agreement and an Operating Agent do not alone guarantee good quality results, but data collection and analysis has to be organized at national level. In most countries, the data exchange is carried out through the regulatory bodies. They often delegate this to other organizations, since arriving at the information required by ICDE requires access to plant maintenance data. That data is normally proprietary. Consequently, the ICDE database is only available for signatory organizations and restricted by proprietary rights. The only possibility to get access to the working material is to actively take part in the data exchange.

OECD/NEA is responsible for administering the project according to OECD rules. This means secretarial and administrative services. Issuing publicly available ICDE reports, calling for member contributions/fees, paying expenses incurred in connection with the Operating Agent activities and keeping the financial accounts of the Project are examples of these activities. NEA appoints the Project Secretary from amongst its administrators.

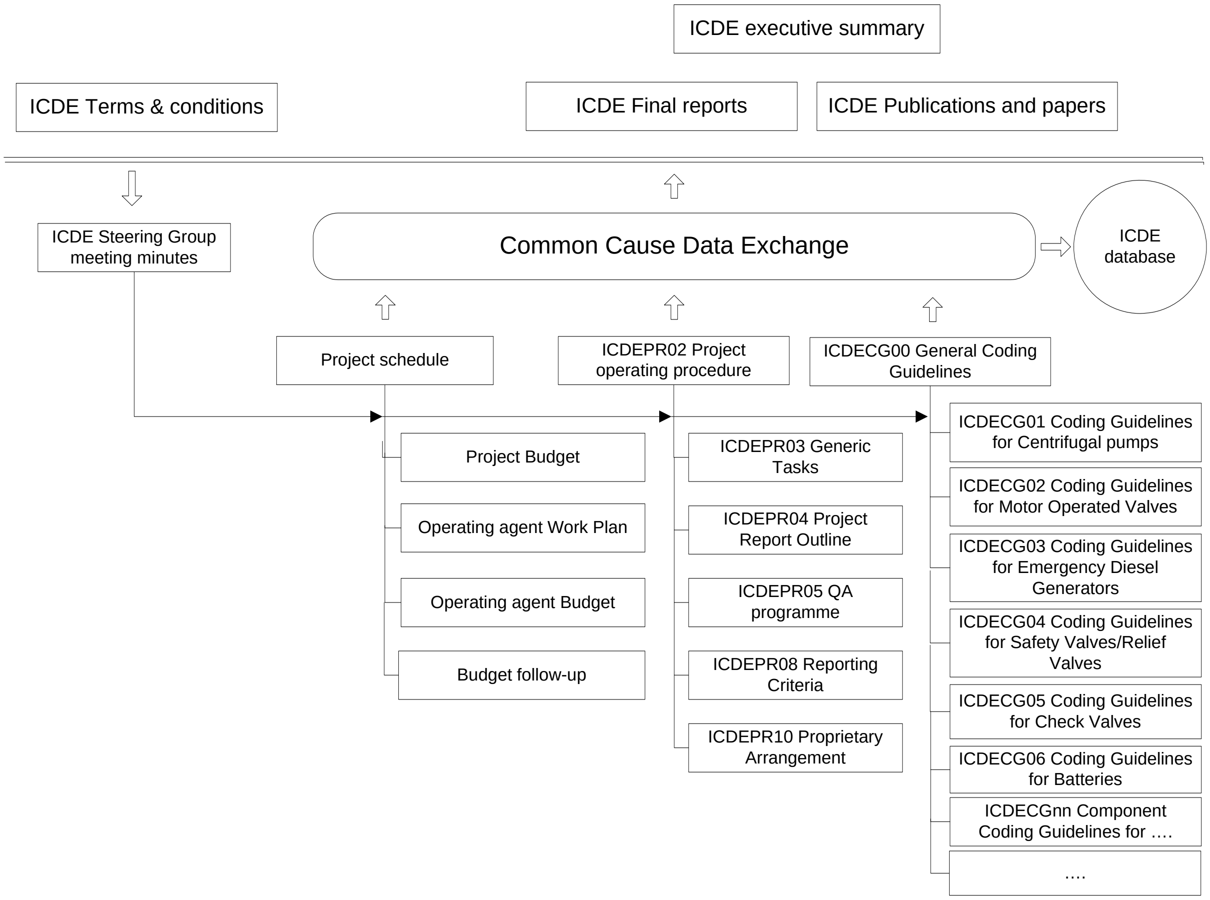

Figure 1. Operating procedure documents overview.

To assure consistency of the data contributed by the national coordinators, the project operates through an Operating Agent. The Operating Agent verifies whether the information provided by members complies with the ICDE Coding Guidelines. It also verifies the correctness of the data included in the database jointly with the national coordinators. In addition the Operating Agent operates, and develops if necessary, the ICDE databank. ES Konsult in Sweden is currently running the Operating Agent.

3 TECHNICAL SCOPE OF THE ICDE ACTIVITIES

The ICDE operates with a clear separation of the collection and analysis activities. In the first stage of the project, emphasis has been on the collection of data. The analysis results mostly in qualitative CCF information. It may be used for the assessment of 1) the effectiveness of defenses against CCF events and 2) the importance of CCF events in the PSA framework. The qualitative insights on CCF events generated are made public as CSNI reports. The member countries are free to use the data in their quantitative and PSA related analyses.

It is intended to include in ICDE the key components of the main safety systems. The data collection and qualitative analysis result in a quality assured database with consistency verification performed within the project. The responsibilities of participants in technical work, document control and quality assurance procedures as well as all other matters dealing with work procedures are described in a special ICDE Quality Assurance Program and the ICDE operating procedures.

The ICDE activity defines the formats for collection of CCF events in order to achieve a consistent database. This task includes the development and revision of a set of coding guidelines describing the classification, methods and documentation requirements necessary for the ICDE database(s). Based on the generic guidelines, component specific guidelines are developed for all analyzed component types as the Project progresses. These guidelines are made publicly available as a CSNI technical note [1].

The ICDE Steering Group prepares publicly available reports containing insights and conclusions from the analysis performed whenever major steps (i.e. analysis of a dataset for a certain component type like check valves) of the Project have been completed. The ICDE Steering Group assists the appointed lead person in reviewing the reports. Following this, an external review is provided by the NEA Committee on Safety of Nuclear Installation (CSNI). ICDE reporting also includes papers to suitable international conferences like PSAM and PSA, and journals. The intention is to make the lessons learnt known to a large nuclear safety audience.

The ICDE time schedules define the milestones of data collection tasks for each analyzed component group. The time schedule is reassessed and revised at each ICDE Steering Group meeting. The work starts with drafting the guidelines, getting comments, making a trial data collection, approving the guidelines, making the data exchange, resolving the remaining problem cases and reporting. Generally, it takes between 1,5 and 2 years from the first guideline draft to commencing the data exchange itself. Furthermore, from that point it takes about 2-3 years to approving the final report. Thereafter, new exchange rounds (database updating) are possible.

The database contains general information about event attributes like root cause, coupling factor, detection method and corrective action taken. As for the current phase V (January 2014), data analysis and exchange have been performed for Centrifugal Pumps, Diesel Generators, Motor-operated Valves, Safety Relief Valves, Check Valves, Batteries, Level Measurement Components, Switching Devices and Circuit Breakers, control rod drive assemblies and heat exchangers. Also, first round data collection has started on fans, main steam isolation valves and digital instrumentation and control equipment. The breakdown of resulted ICDE events in the database, i.e. events involving at least incipient common cause characteristics, of various components is shown in Table 1. Special emphasis is given on CCF events in which each component fails completely due to the same cause and within a short time interval. These events are called “Complete CCF”.

Public **final reports** for Centrifugal Pump, Diesel Generators, Motor-operated valves, Safety & Relief Valves, Check Valves, Batteries, Level Measurement Components, Switching Devices and Circuit Breakers and Control Rod Drive Assemblies have been issued in the NEA CSNI series [2]-[11], a report for Heat Exchangers is in preparation, (see also: http://www.nea.fr/html/nsd/docs/indexcsni.html). Guidelines for fans, main steam isolation valves and digital instrumentation and control equipment have been approved. Also, an updated report on Centrifugal Pumps has been issued.

4 STATUS OF ICDE DATA COLLECTION

Until January 2014, 1346 ICDE events had been analyzed and reported. The total number of event records collected in the database for the analyzed component types is 1712. The breakdown into the various components is shown in Table 1. The third column shows the numbers of events in which each redundant component failed completely due to the same cause and within a short time interval.

Table 1 Number of ICDE events

Component	No. of events in component report	No. of ICDE events with complete CCF in report	No. of events in database (January 2014)	Data amount change since component report
Centrifugal pumps	353[i2] (125[i1])	42[i2] (19[i1])	384	9%
Diesels	106	17	223	110%
MOVs	86	5	167	94%
SRVs	149	14	261	75%
Check valves	94	7	116	23%
Batteries	50	3	77	54%
Breakers	104	6	106	2%
Level measurement	146	6	154	5%
Control Rod Drive Assemblies	169	0	171	1%
Heat Exchanger	46	4	53	15%
Total	1303	104	1712	31%

[i1] Issue 1 presented in year 1999
[i2] Issue 2 published 2013

5 ANALYSIS OF CCF EVENTS OF CONTROL ROD DRIVE ASSEMBLIES

This study was performed on a set of 169 common-cause failure (CCF) events of Control Rod Drive Assemblies (CRDA) derived from the ICDE-database.

These events were examined by tabulating the data and observing trends. Once trends were identified, individual events were reviewed for insights.

The data span a period from 1980 through 2003. The data are not necessarily complete for each country through this period. Besides verbal descriptions, these data includes coded information like failure mode, root cause, coupling factor, detection method, corrective action, observed population (OP) size, degree of failure and affected subsystem.

The most frequently occurring **failure mode** of control rod drive assemblies was ‘Failure to completely insert for gravity insertion systems (FCI-G)’ with 50 percent of the events.

The analysis of the 169 events of the database reveals that there are two complete CCF events for CRDAs. These events did not affect the scram function of the CRDAs, but they affected other CRDA safety functions. For these events the exposed populations associated with these safety functions were only a portion of the total observed populations of CRDAs for the respective plants. However, the entire exposed population associated with the safety function was completely failed. One of these events involved a backup insertion system containing 29 CRDAs. The total observed population at the plant is 57 CRDAs.

The most likely **root cause** is ‘state of other component’ (44 percent). This is consistent with CRDA architecture which implies a high interaction between control rods and fuel assemblies. Fuel assemblies can be deformed by irradiation, thermal, mechanical and hydraulic loading and jam control rods. Another important root cause is 'design, manufacture or construction inadequacy'; it accounts for 25 percent of CCF events.

The dominant **corrective action** is 'design modifications' (58 percent). The major parts of the components which are modified are fuel assemblies, axial seals of drive shaft and anti-rotation screws.

In looking for further qualitative engineering aspects the events were analysed with respect to failure symptoms and failure cause categories which are defined as follows:

Failure Symptom: An observed deviation from the normal condition or state of a component, indicating degradation or loss of the ability to perform its mission.

Failure Symptom Categories: Are component-type-specific groupings of similar failure symptom aspects.

Failure Cause Categories: A list of potential deficiencies in operation and in design, construction and manufacturing which rendered possible a CCF event to occur.

One failure symptom category was identified as dominant in the data: 'Movability problems due to deformation of core internals / fuel assemblies'. Most of the movability problems are caused by 'deficiency in design of hardware', and these design deficiencies involve deformations of the core and fuel assemblies.

Deficiencies in operation contributed to 21 percent of the failure causes. Each of the failure cause categories 'Deficient procedures for maintenance and/or testing' (13 events), 'Insufficient attention to aging of piece parts' (10 events) and 'Operator performance error during maintenance/test activities' (13 events) has a significant contribution to the total deficiencies in operation.

Design, construction and manufacturing deficiencies contributed to 79 percent of the failures causes, mainly due to failure cause category 'Deficiency in design of hardware'. Most of these failures were caused by core or fuel assembly deformations due to irradiation, thermal, mechanical and hydraulic loading, and their mutual interaction.

One additional conclusion is that some CCF events may be qualified as 'generic' for a specific plant series or CRDA design. That is, the same CCF mechanism has been observed in events occurring at plants with similar CRDA designs. Two examples of this are revealed in the database:

1) Many of the events coded with root cause category 'State of other components' involve CRDAs that failed to completely insert due to fuel assemblies that may have deformed due to creep induced by irradiation, thermal, mechanical and hydraulic loading, and their mutual interaction. There are 69 events in the database that match this description. These events occurred at a series of similar plants.

2) A number of events in the database involve degradation of a sub-component found in hydraulic-driven CRDA designs. Degradation of the seating material used in some SCRAM solenoid pilot valves has been found to slow the actuation of the valves and ultimately result in high rod insertion times. This failure mechanism appears in 26 ICDE events. The events occurred at plants with similar CRDA designs during the 1980s and early 1990s.

These problems have been addressed by licensees by communicating operating experience and/or in using a generic modification of the CRDAs or other components. These events highlight the importance of having a reliable design for the CRDA component, its sub-components, and those components that interface or interact with the CRDAs. These events also demonstrate that CCF phenomena can appear across a series of plants with similar CRDA designs. Communication of operating experience with CCF phenomena is important to ensure that plants can implement the appropriate defences and controls to prevent significant impacts on plant safety.

6 ANALYSIS OF CCF EVENTS OF HEAT EXCHANGERS

This study was performed on a set of ICDE events related to heat exchangers. Organisations from Canada, Germany, Japan, Spain, Sweden and the United States contributed to the exchange.

46 ICDE events, exhibiting at least some degree of dependency, and spanning a period from 1987 through 2007, were examined in the study.

The **failure mode** relevant from a PSA point of perspective is the failure mode HT-General (Failure of heat transfer) representing 100% of the events.

Degree of impairment: 4 of the events (8,7%) are complete CCFs (all redundant components had failed in a short time interval and for the same cause) while 1 event is defined as partial CCF (at least two, but not all completely failed components). The majority of the events (78%) have low impairment vectors, i.e. less than two components that have completely failed. Because of the small number of complete CCFs, the statistical significance of any result concerning complete CCFs should be handled carefully.

Dominant **root causes** were “abnormal environmental stress”, “procedure inadequacy” and “design, manufacture or construction inadequacy”, accounting for in total 37 events (83% of the events) with 1/3 in each of these root cause classes.

The **coupling factors** are strongly dominated by “environmental internal” (28%). However, if coupling factors are combined into top-level categories of environmental, hardware and operational, there is no dominant group.

Detection modes: 26 events (57%) were detected during test and maintenance activities, i.e. the equipment failure was discovered during the performance of a scheduled test or during maintenance activities. Only 7 events (15%) were revealed by demand events. Furthermore, 3 of the 4 complete CCFs were revealed by “test during operation”. These results imply that the employed procedures and practices for detecting common-cause failures have been effective.

Concerning **corrective actions**, design related actions make up only 23% of the corrective actions, although “deficiencies in design, hardware and manufacturing” were involved in 65% of the events.

The identification of the relationship of **failure symptom categories** and **failure cause categories** was based on the verbal event descriptions and further engineering analysis for all of the ICDE events.

Heat exchangers are passive components operated in different systems and environmental conditions. In the majority of the events, dependencies occur in systems with an aggressive environment affecting heat exchanger internals as tubes, plates, chambers in multiple trains and components. Observed failures have also lead to leaks and impeded flow due to corrosions (corrosion, erosion) and dirt accumulation (pitting, fouling). There are also direct human/operator related faults causing dependencies of heat exchanger trains, e.g. by faulty alignment of valve configuration and wrong maintenance procedures and/or –practices.

The failure symptom aspect analysis reveals that there are three strong manifestations leading to flow problems: fouling, foreign objects or dirt accumulation impedes flow. If grouping the failure symptom aspects, there are two groups completely dominating:

- Impeding flow problems, 56 % of the events
- Erosion/corrosion problems leading to internal leak, 40 % of the events

Deficiencies in design, construction and manufacturing contribute 65% of the failure causes, the majority due to failure cause category "Deficiency in design of hardware". The other 35% of failure causes are deficiency in operation, mainly due to failure cause category “Deficient procedures for maintenance and/or testing”. Among the four complete CCFs, 3 of 4 were due to deficiencies in design, construction and manufacturing.

The study shows that there are several test interval lengths practiced in the member countries.

A more frequent testing and –maintenance practice would be a powerful approach to reduce failures on less important failures, e.g. as shorter test intervals, more frequent cleaning, faster change of degraded heat exchangers, improved instrumentation of in/out flows and water temperatures, improved maintenance and/or testing instructions.

7 ANALYSIS OF CCF EVENTS DUE TO EXTERNAL FACTORS

In the light of the Fukushima accident, a cross-component study was performed on a set of common-cause failure events due to external factors, "External events", meaning that not only storms and hurricanes are included but also high outdoor temperatures and excessive algae growth. The events were derived from the ICDE database, where a brainstorming exercise performed by the Operating Agent on how to identify interesting events resulted in finding 52 events related to the topic out of 1600 ICDE events in total. The study is based on a workshop performed during an ICDE Steering Group meeting in April 2012, were the scope of "external events" were analysed in work groups. During the workshop additionally nine events were pointed out as not external events and therefore outside the workshop scope, i.e. this study includes the assessment of 43 ICDE events.

The majority of the events include centrifugal pumps (40%), followed by diesels (30%). The most common failure modes for pumps respectively diesels are failure to run (FR) and demand was the main way of detecting external problems (37%).The high number of demand events suggests that these type of "external failures" may be difficult to detect in periodic movement tests.

Additional engineering insights about the events were achieved by identifying the observed failure mechanisms. Table 2 lists representative failure mechanisms sorted by component type

Table 2 Representative Failure Mechanisms sorted by component type

Component type	Occurred failure mechanisms
Battery	- Potential loss of function during earthquake due to cracks in battery casings
Centrifugal Pumps	- Freezing led to blocking by ice of suction lines of service water pumps - Heavy seaweed in combination with low tide caused lack of water - Excessive sand and shellfish in sea water led to wear of pump impeller - Extremely low level of sea water was not considered in design - Algae growth in diesel fuel tank led to failure of operation of diesel driven pumps
Diesels	- Sludge in sea water reduced cooling capacity - Excessive sand and shellfish in sea water led to clogging of heat exchangers
Heat Exchanger	- High temperatures led to fast growth of clams and mussels with subsequent clogging of heat exchangers - Very high water level in combination with highly polluted water (foliage and grass) led to clogging of heat exchangers
Safety and Relief Valves	- Diaphragms installed in the air supply regulators of safety relief valves were dry and cracked due to long term high temperature environment leading to failure to open of the valves

The identified areas of improvements and lessons learnt can be divided into two subcategories - human/operational respectively hardware related improvements. Both "increased monitoring" and "improve cleaning of strainers" was concluded as important improvements for events involving pumps, diesels and heat exchangers. In addition, there were especially three events where the surveillance procedure was identified as a successful defence. All three events involve slow processes where excessive sand or shellfish in the sea water causing wear of the pump´s impeller or clogging in the heat exchanger. Due to the slowly developing failure, it was possible to detect the event with differential pressure monitoring before degradation of the pump or heat exchanger.

Three diesel events at the same site experiencing the same cause failure mechanism are indication that back fitting of operational experience takes long time sometimes. These events involved sludge in the sea water leading to reduced cooling capacity and therefore too high temperatures of the diesel´s cooling water. Here it could be concluded that thorough root cause identification is crucial before continuation of operation to prevent a second failure.

Since many of the events due to external factors involve sea water problems, important hardware improvements involve the construction of the water intake. One diesel event, where sludge in the sea water led to reduced cooling capacity and therefore too high temperatures of the diesel´s cooling water, could have been prevented if the water intake was diversified. An example of a diversified water intake could be one surface intake and one deep water intake. Another interesting event was a pump event where both emergency feed water pumps run by diesel engines where degraded due to algae growth in the shared diesel fuel tank. The shared fuel tank is an indication that the separation of redundant pumps is not consequently done.

Two other interesting aspects were found. The first involves correlated hazards, which should be taken into account for better defence. There is one heat exchanger event where very high water level in combination with high amount of pollution in water such as foliage and grass led to clogging of the tubes in the heat exchangers. The second interesting aspect is related to a pump event where it was concluded “slight impairment by chance” because the detection was not via monitoring but by testing during outage.

The results of this analysis may serve as input for an in depth review of the methods and assumptions used in external hazards PSA.

8 DISCUSSION

What can be said is that the ICDE has changed the views to CCFs a great deal. Many insights would not have been possible to identify without a deep plant data collection and combining information from many sources. This paper discusses such insights about CCF events of the component types control rod drive assemblies and heat exchangers as well as insights about CCF event which were due to external factors.

Maybe the most important generic lesson is that it is worth forming specialized data exchange projects like ICDE. This, however, requires firstly the will of several countries to form a critical mass by combining their operating experience efforts, secondly national efforts to collect lower level data than made publicly available as LER or IRS reports, thirdly forming a legal framework to protect this proprietary data and fourthly a long term commitment to consistently continue and develop the activity.

OECD NEA and ES Konsult as the Operating Agent have provided means to run the international dimension of the ICDE, but national efforts are the key to the success of any project relying on operating experience. The success of ICDE has given a birth to several similar types of projects, among which are the OPDE for pipe failure events and OECD-FIRE for NPP fire events.

More information about ICDE may be obtained by visiting the site CSNI report site: http://home.nea.fr/html/nsd/docs/indexcsni.html, the Operating Agent website: www.eskonsult.se/icde or contacting the responsible OECD administrator.

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