VVER SPECIFIC COMMON CAUSE FAILURE DATA

G.V.Tokmachev[1]

[1]Atomenergoproekt, Moscow, Russia

Advances in Safety and Reliability. C. Guedes Soares (Ed.), Proceedings of the ESREL'97 International Conference on Safety and Reliability, 17-20 June, 1997, Lisbon Portugal, Volume 3, pages 2189-2194, Elsevier Science, 1997.

ABSTRACT

This paper presents some results of the development of VVER specific common cause failure (CCF) data base. Twelve units with VVER-440 & 1000 reactors were under consideration. The data base covers about 73 reactor years and more than 25,000 component years of 3930 components. Section 2 points out that approximately 850 CCF groups of components were identified. Section 3 addresses the issue of importance of raw data interpretation. The event data base includes 2003 events classified. Section 4 provides an overview of three types of screening which were applied to CCF candidate analysis. Section 5 discusses the subject of CCF model parameters' estimation taking into account a staggered testing scheme. Numerical values of the parameters of Multiple Greek Letter model and Alpha Factor model were developed.

KEYWORDS

VVER reactors, data base, common cause failure, component groups, parameter estimation.

STUDY OBJECTIVES

The derivation of CCF rates from data is normally extremely difficult due to the limited amount of relevant data that is available. Thus, the results of PSA are still subject to a great deal of uncertainty due to CCF data treatment. So data collection activities aimed to PSA purposes have been implemented on four NPP's sites to look for evidence of dependencies. Twelve units with VVER-440 and 1000 reactors were under consideration.

With respect to CCF, the analysis of the experience data had two main objectives (Tokmachev, 1991):

- to estimate VVER specific CCF parameters in a manner that makes the maximum possible use of event data, and
- to learn which were the important factors that affect CCF origin.

This required review, classification and interpretation of the available information to obtain specialised failure data.

CCF COMPONENT GROUP DEFINITION

The data base covers about 73 reactor years and more than 25,000 component years of 3930 components which are as follows:

- pumps,
- fans,
- diesel generators,

- motor-operated and air-operated valves,
- control valves,
- check valves,
- safety and relief valves,
- inverters and rectifiers,
- circuit breakers.

They belong to either front-line or support safety systems. The same component boundary definitions were used for data extracted from different sources of field data.

Approximately 850 CCF groups of components were identified from system diagrams and other plant documents. This required a substantial amount of plant-specific information. As a rule, the component groups of interest were groups of similar components belonging to the same system within the Unit. Some dissimilar components that were all affected by the same operating procedures or not separated from a source of a specific harsh environment by barriers were also identified as susceptible to CCF. However, it was found that the emergency and normal procedure-related root cause of CCF were also more likely to affect similar components. On the other hand, components belonging to different trains of the safety system seem to be mostly not susceptible to CCFs caused by harsh environments because of complete physical separation of the trains.

For some configurations, where components are shared between units, it was necessary to make some assumptions about CCF group definition. For example, nine pumps provide a twin plant with water. Each unit has three pumps of these. The other three pumps are redundant to pumps belonging to specific units. Assumption was made to assign redundant pumps to both CCF groups. It means that nine pumps were split into two CCF pseudo groups each consisting of six pumps.

PRIMARY INTERPRETATION OF FIELD DATA

The estimation of CCF parameters is based on review of plant records covering the period from early 1987 through 1995. Most of the information was derived from field data sources such as work requests, accident reports, test reports and equipment tag-out logs. This provides quite complete data source for the events. Detailed operating history data were collected for this study, including failure descriptions, number of actuations, test intervals, operation times, maintenance and repair outage times. So good quality single failure data were available. Besides, relevant background material including data on type of equipment, physical location, testing strategy was mainly available.

It should be noted, however, that none of field data sources is specifically geared to make the collection of failure data a simple process. The event records are very brief and difficult to classify. It is appropriate the guidelines of the European Common Cause Failure Reliability Benchmark Exercise (Poucet *et al.*, 1987) pointed out that the most important source of uncertainty and variation in the numerical results lay in the area of data interpretation. So, careful attention was given to this task.

Due to the limited event description contained in the records, our classification method could be highly subjective. Therefore additional information was obtained through direct contacts with plant personnel. After that, additional engineering analysis of raw data was performed. To understand a more thorough review of the CCF potential, plant maintenance & reliability personnel were consulted during the data review to ensure that an accurate interpretation of events was achieved. Thus, the required data not directly retrievable from the field documents were the result of analysis.

The event data base includes 2003 events, each having failed or unavailable component. Functionally unavailable states of components are not included in the event data base. It was necessary to check each case to distinguish catastrophic failures and potential (incipient or degraded) ones. The classification of events also makes important distinctions between independent failure events and events involving common cause failure candidates.

According to Technical Specification implemented in VVER NPPs a functional test of safety system trains is to be staggered among the three trains. A procedure calls for testing all redundant components in case of any failure discovered. Based on the impact of such testing strategy on CCF detection, a narrow time span between failure discovery times was used as a primary factor for identification of CCF candidates. This enabled to extract only those portions of the statistics that were applicable to the specific problem.

SCREENING

Three types of screening were applied to CCF candidate analysis (Hirschberg *et al*., 1990):

- exclusion of “non-CCF” events;
- design-oriented screening;
- application-oriented screening.

To eliminate independent events IAEA Guidelines (Hirschberg et al., 1992) for historic event interpretation were used. Some sets of failures were not considered important from a CCF standpoint based on consideration of failure mode and mechanism in spite of those multiple failures had occurred close in time. After that, a review of data identified about 80 potential or actual common cause events summarised in Table 1.

TABLE 1
DISTRIBUTION OF DIFFERENT TYPES OF CCF OBSERVED

Component	The number of components failed in CCF event			
	Two	Three	Four	Five
Pump	29	8	-	-
Fan	2	-	-	-
Diesel generator	10	1	-	-
Motor-operated valve	10	1	1	1
Control valve	6	-	-	-
Check valve	1	-	2	-
Safety valve	1	1	-	-
Circuit breaker	4	1	-	-
Motor generator	1	-	-	-

Some of the reasons for the common cause events were clogging of pump suction lines, incomplete combustion of diesel fuel resulting in surging problem, degradation of cable insulation, corrosion products clogging safety valve spindle, low bus transient voltage during sequencer operation resulting in trip of pumps, leaks in oil breakers chambers due to rubber gasket ageing, incorrect torque-switch settings of motor-operated valves, procedure inadequacy. There were situations where several causes acting together were identified as being involved in creating a given CCF state. CCF event of the largest size was a motor failure of five valves. Among CCFs of the whole group, an event of the largest size was a sticking of four check valves in open position.

Design-oriented screening was done with great caution and a few events occurred at NPPs with VVER-440 reactors have been only screened out as being inapplicable to VVER-1000 design based on consideration of defences against CCF. For those cases both the number of independent failure events and the exposure were reduced in order to compensate for the deletion of CCF events.

Application-oriented screening of the events in the data base has mainly been done by using the impact vector mapping method as proposed at NRC CCF Guide (Mosleh *et al*., 1988). Essence of the method is the translation of CCF event description into a binary form to establish relationships between data bases of systems having different level of redundancy. The method introduces event representation called the impact vector. The binary impact vector of an event that has occurred in a component group of size **m** has **m+1** elements. Each element represents the number of components that can fail in an event.

It was identified that the size of CCF component groups in which the data originated varies from two to twelve. Since the identified CCFs originate from CCF groups of different size, adjustment were made to account for a difference in size among the CCF groups in the plants, in which the events occurred, and the plant being analyzed. This adjustment was made on a case by case basis. The event reinterpretation was summarised in terms of binary impact vectors. The summation over each of the components of the impact vectors provides the pseudo VVER specific data base in terms of the number $\mathbf{n_k}$ of the events in which **k** components failed.

In a situation in which the component state was classified as potentially failed, potential CCF including combinations of incipient or degraded conditions of components were handled by weighting factors. As an example, a weight of 0.1 was given to a hypothesis reflecting a degree of confidence that pumps were actually failed in case of external leaks.

To perform upward mapping of impact vectors, the binomial failure rate model was used (Mosleh *et al*., 1988).

In some cases mapping down data from CCF groups having more than four components was developed because it was not considered in Mosleh *et al* (1988). A formula for mapping down data is (Eqn.1):

$$P_l^{(m)} = \sum_{k=l}^{l+n-m} \left(\frac{\binom{m}{l}\binom{n-m}{k-l}}{\binom{n}{k}} \cdot P_k^{(n)} \right) \qquad l \in (0, m), \quad n > m \tag{1}$$

where
$\mathbf{P_l^{(m)}}$ - the $\mathbf{P_l}$ element of the impact vector in system with size **m** mapping to;
$\mathbf{P_k^{(n)}}$ - the $\mathbf{P_k}$ element of the impact vector in system with size **n** mapping from.

PARAMETER ESTIMATION

The choice of parametric models was dependent on capabilities of the Risk Spectrum code (Berg *et al*., 1994) used for PSA analyses by Atomenergoproekt institute. The following parametric models were selected:

- Multiple Greek Letter (MGL) model;
- Alpha factor model.

For the above models, numerical values of the various parameters were developed. The maximum likelihood estimators were based on assuming a staggered testing scheme. The staggered based estimators for MGL model are given as (Eqn.2 and 3):

$$\hat{\beta} = \frac{\sum_{k=2}^{m} n_k}{\sum_{k=1}^{m} n_k} \qquad (2)$$

$$\hat{\gamma} = \frac{\sum_{k=3}^{m} n_k}{\sum_{k=2}^{m} n_k} \qquad (3)$$

where
$\mathbf{n_k}$ - number of events involving **k** components in a failed state.

CCF parameters were derived for pumps, diesel generators and motor-operated valves. For other components for which little or no data on CCFs is available, their CCF parameters are not possible to estimate yet. It should be noted that the numerical differences of CCF parameters derived for pumps and especially for motor-operated valves are very significant depending on mapping scheme used. It is of great importance for VVER-440 because redundancy of safety related systems belonging to VVER-440 units varies from 2 to 6. Data originated from VVER-1000 are more uniform because all active safety systems of VVER-1000 are completely separated into three trains. Nevertheless there are identical valves within the same train. Therefore, CCF component group definition may involve a considerable amount of judgement. Thus, it was found that the definition of size of CCF component group in which the data on motor-operated valves originated has a decisive impact on CCF parameter values.

Diesel generators are the main contributor to core damage frequency for VVER-1000 according to PSA performed for Balakovo NPP (Hohn *et al*, 1996). Therefore, CCF parameters for diesel generators presented in Table 2 are of major interest. It is important that adjustments for system size had no impact on values obtained because all plants from which data came had three diesel generators per unit.

TABLE 2
CCF PARAMETERS FOR THREE COMPONENT GROUP OF DIESEL GENERATORS
FAILURE MODE: FAILURE TO START

CCF model	MGL		α-factor		
Parameter	β	γ	α_1	α_2	α_3
Value	0.1	0.17	0.95	4.4E-2	6.1E-3

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