Issues Related to Development of VVER Specific Data Base on CCFs

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Abstract

The paper discusses issues related to development of VVER specific data base on common cause failures (CCF) based on 75 reactor years of operation of different types of VVER reactors. Twelve units were under consideration including VVER-440 both model 230 and model 213 as well as VVER-1000 model 320. Rare data include more than 2,000 events extracted from different sources of information. Variability in plants with regard to the coupling mechanisms and the difference that exists between the quality of the defences against CCFs in NPPs with different types of VVERs are analysed. Applicability of CCF data collected before modification eliminating some root causes is discussed. The uncertainties associated with incompleteness of data bases are investigated with respect to time delay of failure discovery and ambiguities in the event reports. CCF parameter estimation for alpha-factor model was performed based on optimistic and pessimistic interpretation of the data.

1 Introduction

Level 1 PSAs sponsored by DOE are performed for Kola and Novovoronezh NPPs in Russia. These studies are carried out by NPPs and Russian institutions supported by SAIC from US. Discussions among experts have raised questions about correct modelling of common cause failures (CCF). It is acknowleged that PSAs performed for VVER type reactors using generic data on CCFs have found that CCFs are significant contributor to core damage frequency [1,2]. On the other hand, actual CCF data on VVERs are practically unknown. There is some concern that generic data are applicable to VVERs. The sceptics even believe that there exists hardly any evidence of CCFs experienced recently at VVERs. To answer these questions, data extracted from operation of four NPPs were used to look for evidence of CCFs [3].

2 Summary of Data Collected

Twelve units with VVER reactors were under consideration including VVER-440 both model 230 and model 213 as well as VVER-1000 model 320. Actually, study covers the first decade of VVER-1000 lifetime, the middle of lifetime of VVER-440/213, and the last years of operation of VVER-440/230. This offers a good opportunity to look at CCF behaviour during different phases in plant life cycle.

The estimation of CCF parameters is based on review of plant records as well as accident event reports. Most of the information was retrieved from field data sources such as work requests, accident reports, test reports and equipment tag-out logs. The data base covers about 75 reactor years compiling events from early 1985 through 1995. Approximately 850 CCF groups of 4,000 components, e.g., pumps, diesel generators, and different types of valves, for which the data were collected were identified from system diagrams and other plant documents.

The rare data contain more than two thousand events, each having failed or unavailable component. It should be noted that functionally unavailable states of components are not included in the event data base. Of these, about 90 potential or actual common cause events were identified, some with detailed descriptions and other with very few details.

3 Variability in Plants of Interest

Due to rarity of common cause events and the limited experience of particular plants, it is necessary to combine the data that came from different plants to make statistical inferences about the frequencies of CCFs. However, there is a significant variability in VVER plants, especially with regard to the coupling mechanisms and defences against CCFs. The difference that exists between the quality of the defences against CCFs in NPPs with different types of VVERs is analysed.

The first VVER-440s have the standard plant design referred to as model 230. The design of VVER 440 model 230 was developed in the early sixties. Compared to the current practice, redundancy, independence and segregation is low in some front-line systems, therefore making them susceptible to CCFs [4]. Two trains of safety systems are typical, although there is extra pump redundancy within some functional groups that creates a problem of data treatment related to CCF component groups of large size. Additional weaknesses exist in environmental qualification of equipment belonging to instrumentation and control and electric power supply as well as in the separation between control and safety functions. The system arrangement is such that a single component common to different trains is used in some cases. The overall system layout gives poor protection against environmental impact. For example, all the service water pumps shared between two units are installed close together in the same building. In testing redundant trains consecutive rather than staggered testing is performed.

It should be noted that a lot of defensive measures against CCFs is implemented in a plant Programme for safety upgrading. Some of them have already been applied to system design, including construction of barriers and removal of cross-ties between components susceptible to CCFs. This means that the same plant differs within the period of data collection with respect to defences against CCFs.

The VVER 440/213 nuclear power plants are the second generation pressurized water reactors of Soviet design. The model 213 plants were in operation from the early 1980s. In comparison with older VVERs, VVER 440/213 plant design is much advanced [5]. For example, this includes a fully redundant, independent emergency core cooling system consisting of three trains. Each train is located in separate room and associated with independent train of support systems such as service water, ventilation, DC and AC electric power supply, I&C system. An additional redundancy is incorporated in design of trains of some systems. In order to minimaze both the exposure time for CCFs and the possibility of introduction of human-related CCFs during testing, the redundant trains of all safety systems are tested in staggered manner. Thereby diversity in staff involving in tests of redundant trains is usually realized. However, some deficiencies still remain in such areas as component qualification, physical separation of redundant systems. As an example, all the systems feeding the SGs are located in the turbine hall and are not segregated. There are also cross-ties between redundant trains.

The 1000 MW VVER nuclear power plants are more modern third generation of pressurized water reactors of soviet design. The design of the VVER 1000/320 is consistent with standard international practice for safety systems and safety related systems [6]. Components of safety systems are arranged in three trains which are electrically independent and physically separated. There are no cross-ties between redundant trains of front-line or corresponding support systems. The control and protection channels are also independent. Besides, safety equipment are not shared with any other systems. Different trains are segregated from each other so that there is a law probability of an external impact causing failure of more than one train. Spatial separation is applied to both plant equipment and cables including control and power ones. As a rule, redundant equipment is tested by different staff according to staggered testing scheme.

Based on consideration of the defences against CCFs, it becomes transparent that any event occurred at NPPs with VVER-1000 reactors is supposed to be applicable to VVER-400s. On the other hand, the potential for overestimating CCF parameters exists for VVER-1000 plants. However, design-oriented screening could generate less comprehensive event data, which potentially could increase the standard statistical uncertainties in the estimated CCF parameters.

4 Impact of Modifications

Applicability of CCF data collected before modification eliminating some root causes is questionable. In practice, following an actual common cause event occurred at particular plant, investigation of root cause is performed by expert team according to national rules. In case of clear identification of root cause associated with design errors, modifications are usually applied to the system design at all similar plants of utility to eliminate recurrence of CCFs arising from such design deficiency. Any CCF resulting in change of design or other actions to delete the root cause is found to be of a nonrecurring type. However, some common cause events had recurred a few times within a period before root causes were eliminated through modification needed. Those were the cases of high cost modifications. This introduces additional uncertainty through the interpretation of such recurring events. As an example, there were eight CCFs of atmospheric steam dump valves at VVER-1000s from 1985 to 1987, followed by modification applied to all plants. After that, no common cause event has occurred on any VVER-1000 up to now.

As a rule, to prevent recurrence of CCF caused by significant deficiencies in maintenance, operation or test procedures, modifications to the operational procedures are also implemented. For example, test procedure used at some plants required too frequent tests of diesel generators in idle running mode. Such tests were associated with incomplete combustion of diesel fuel. Following several sequential tests in idle running mode, fuel accumulated in exhaust could result in surging problem and fire in the engine exhaust when diesel generators were loaded. Following identification of root cause, changes to test procedures were applied to all plants of interest. After that, no such CCFs have been registered.

As a matter of fact, CCFs resulting from systematic human errors during maintenance and tests or from harsh environment are of a recurring type. Therefore, contribution of these root causes to CCF frequency seems to be constant whereas contribution of design, manufactoring and installation errors tends to decrease.

VVER operational experience shows that corrective measures that were applied to the system design and operation in order to resolve CCF issues have led to a significant reduction of the common cause event occurrences. In fact, common cause events resulted from conceptual design, manufacturing and installation errors as well as from break-in problems were discovered during the first four-year operation after commissioning. On the other hand, events associated with ageing failures mainly realized as independent failures rather than common cause ones. Perhaps, it can be explained by the fact that multiple failures caused by aging may mainly occur if degraded equipment would be subject to more severe conditions during accident than during periodical tests. However, frequency of such disturbances at the oldest VVER-440/230s is dramatically less than at more modern plants.

Generally, reduction of CCFs observed at VVERs means that area of our ignorance is reduced. However, numerical results that seem to be conservative should be used with care because of uncertainties associated with extrapolation of the event data.

5 Uncertainties associated with event interpretation

In light of the quality of many of the event reports, there were ambiguities in the event descriptions that required to establish different hypotheses regarding the interpretation of the event. This depended on such a factor as how well the root causes of various potential CCFs had been identified in plant records. Because of that, an important source of uncertainty and variation in the numerical results lays in the area of data interpretation.

The uncertainties associated with incompleteness of data bases are investigated following recommendation of NUREG/CR-5801 [7]. Some potential CCF events were supposed to involve failures distributed in time and/or degraded component states. With respect to time delay of failure discovery, twenty-days interval between failure reporting times was used as a primary factor for identification of CCF candidates, based on the impact of staggered testing strategy on CCF detection. However, a majority of potential CCFs has been discovered by extra ordinary tests as well as other demands and inspections within a more narrow time span. Therefore, CCF parameters obtained are slightly sensitive to different hypotheses regarding multiple component failures closely related in time.

Assessment of the degree of component degradation in the CCF event was performed taking into account various degraded states including incipient ones. It is found that CCF parameter values for motor-operated valves are very sensitive to such assessment because many potential CCFs involve the degraded valve states. For example, in case of optimistic interpretation of the data, values of the alpha factors for multiple failures of motor-operated valves tend to zero.

Another finding is that identification of size of CCF component group in which the data on motor-operated valves originated is of great importance because an additional redundancy of motor-operated valves within a train is implemented in design of some systems, e.g., as series-parallel configurations. Therefore, CCF component group definition that influences mapping scheme to be used may involve a considerable amount of judgement. It should be noted that identification of CCF component group in the order of 9 or 12 is also a significant contributor to uncertainty of CCF parameter values for some other components. The concern about treatment of high multiplicity groups composed of the components of the same design is associated with such factors as changeable operation modes of pumps, different start-up modes of pumps depending on appearance of loss of off-site power, CCF component group shared between units, location of air-operated valves inside and outside confinement, and different pressure settings of safety valves.

To assess the total impact that various assumptions in data classification have on CCF parameter values, estimation for alpha-factor model was performed based on optimistic and pessimistic interpretation of the data. In addition to mentioned above, uncertainties associated with interpretation of repeated CCFs and splitting failures into different failure modes, i.e. failures to run and failures to start, are also taken into account. The parameters presented in Table 1 seem to be directly applicable to VVER-440 plants and to be conservative for VVER-1000s because no CCF event observed was screened out based on consideration of plant-to-plant variability.

Table 1

Estimates of alpha-factors for three component groups
Failure mode: failure to start

Component	Estimate	Alpha 1	Alpha 2	Alpha 3
Pump	Point	0.975	0.017	0.008
	Optimistic	0.985	0.01	0.005
	Pessimistic	0.957	0.033	0.01
Diesel generator (including breaker)	Point	0.95	0.039	0.011
	Optimistic	0.969	0.025	0.006
	Pessimistic	0.925	0.056	0.019

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