General Insights from Analysis of Common-Cause Failure Data at U.S. Nuclear Power Plants

1980–2001

The common-cause failure (CCF) study uses operating experience to characterize the frequency and nature of component failure data from operating U.S. commercial nuclear power plants. The evaluation is based on the operating experience from 1980 through 2001. The data sources for this report include:

- License Event Reports (LERs), 1980 to 2001
- Nuclear Plant Reliability Data System (NPRDS), 1980 to 1996
- Equipment Performance and Information Exchange (EPIX), 1997 to 2001

The CCF database is a rich source of information on various aspects of CCF. Exploring the full potential of the database merits a dedicated activity and is outside the scope of the current effort, which has focused on building the infrastructure for such analyses. Nevertheless, some general observations have been made on the character of CCF events, including their causes and shared cause factors, and frequency of occurrence. Some of these insights are summarized in this section.

Table 1 lists the systems, component types, and failure modes for which CCF events have been collected and entered into the database. It also contains the number of CCF events for each system and component combination and the number of independent failure events. Table 1 shows the event counts for failure modes that are relevant to PRA studies. Other failure modes, such as failure to close for reactor trip breakers, were found in the source data; these events were coded and entered into the CCF database, although they are not likely to be used in PRA studies.

Basic information about the nature of CCF events is displayed in Figure 1 and Figure 2. These figures illustrate the distribution of CCF event proximate causes and coupling factors, respectively. This information provides a general picture of the types of events that may be expected to occur, and what design features might be most susceptible to CCF events. These figures also illustrate the different characteristics of partial CCF events and complete CCF events (events with timing factor, shared cause factor, and component degradation values for each component in the CCCG =1.0). Figure 3 and Figure 4 display the number of CCF events by year of occurrence.

A general review of the actual events and the distributions provided in Figure 1 and Figure 2, reveals the following insights regarding CCF events:

- Human errors related to procedures caused a small percentage of the total events, but the impact of the individual events is usually greater, since human errors have overridden the programmatic controls. This is illustrated by comparing Figure 1, the All case with the Complete case, which shows that human error causes a larger portion of complete CCF events than partial CCF events. Examples of events caused by human error are all EDG day tanks simultaneously drained for chemistry surveillance, two pump breakers racked out as the plant changed modes from shutdown to power.

- A vast majority of All CCF events are not due to multiple failures in response to an operational demand, but result from a "condition of equipment." The most common is inspection or surveillance test of one component revealing a deficiency that prompts the licensee to inspect/test the redundant component, resulting in the discovery that the same defective condition exists on both components. This demonstrates that detection of failures during the testing and surveillance program prevents CCF events from occurring during demand situations.

- A major contributor to CCF events is programmatic maintenance practices. The frequency of scheduling has been a factor in the numerous wear-caused and aging-caused events. Additionally, the quality of the maintenance, both in the procedures and in performance of the maintenance activities, is an essential factor. Similar events have occurred at different plants—lubrication of circuit breakers (too much, too little, or too long between lubrications), improperly set torque and limit switches on MOVs that are reported as mis-adjustments and not setpoint drift. This indicates that there are maintenance practices that need to be reviewed to reduce CCF potential. However, the maintenance issue generally does not cause complete CCF events.

- Among complete CCF events, design problems are the major contributor. Many of the design-related events resulted from a design modification, indicating that perhaps the modification review processes were not rigorous and resulted in CCF susceptibilities.

- The CCF database contains several examples where both CCF and independent events recur at some, but not all, plants, perhaps indicating ineffective root cause analysis and corrective action. Examples of repeated events are water in compressed air systems, pump seal wear-out, and turbine governor mis-adjustments. Additionally, not all plants experience the same type of recurring event. This indicates that plant-to-plant variability exists in the CCF parameters that might cause the CCF parameter estimates for some plants to be higher than the industry average, for some component and system combinations. Thus, it is very important to perform plant-specific CCF parameter estimations for plant-specific PRAs and reliability studies.

With respect to quantification of CCFs, the overall conclusion is that, based on the evaluation of over 20 years of operating experience data, CCF parameters for similar components vary among systems and failure modes.

Table 1. Component types and systems analyzed for CCF events (1980–2001).

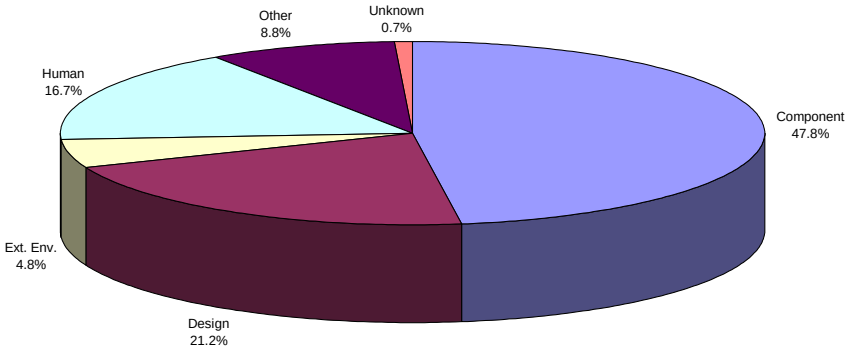
Component Type	Systems Analyzed for Component Type s	PRA-relevant Failure Mode	No. of Events for System and Component Type		Total No. of Events for Component Type	
			CCF	Independent	CCF	Independent
Air-Operated Valves	Auxiliary Feedwater (PWR)	Fail to Open	12	121	52	296
		Fail to Remain Closed	8	34		
		Spurious Operation	7	8		
		Fail to Close	17	91		
	Emergency/Essential Service Water	Fail to Open	2	13		
	High Pressure Safety Injection (PWR)	Fail to Close	1	4		
	Isolation Condenser	Spurious Operation	2	2		
	Main Steam	Fail to Open	1	3		
	Residual Heat Removal	Fail to Close	1	11		
		Fail to Open	1	9		
Batteries/Chargers	DC Power Distribution	High Output	7	20	66	1130
		No Output	59	1110		
Check Valves	Auxiliary Feedwater (PWR)	Fail to Close	16	71	170	687
		Fail to Open	5	23		
		Fail to Remain Closed	42	131		
	Containment Spray	Fail to Remain Closed	3	6		
	Containment Vacuum Relief	Fail to Open	2	8		
	Emergency/Essential Service Water	Fail to Close	5	17		
		Fail to Open	2	10		
Check Valves	Emergency/Essential Service Water	Fail to Remain Closed	1	7	170	687
	High Pressure Coolant Injection (BWR)	Fail to Close	2	44		
		Fail to Open	7	21		
		Fail to Remain Closed	14	30		

Component Type	Systems Analyzed for Component Type s	PRA-relevant Failure Mode	No. of Events for System and Component Type		Total No. of Events for Component Type	
			CCF	Independent	CCF	Independent
	High Pressure Safety Injection (PWR)	Fail to Remain Closed	15	82		
		Fail to Close	2	55		
		Fail to Open	5	24		
	Main Steam	Fail to Close	3	6		
	Reactor Core Isolation Cooling	Fail to Remain Closed	1	4		
	Residual Heat Removal	Fail to Close	9	76		
		Fail to Open	4	17		
		Fail to Remain Closed	32	55		
Circuit Breakers	AC Power Distribution	Fail to Close	47	471	170	1668
		Fail to Open	29	195		
		Spurious Operation	27	384		
	DC Power Distribution	Fail to Close	4	39		
		Fail to Open	4	67		
		Spurious Operation	3	65		
	Reactor Protection	Fail to Open	26	129		
		Spurious Operation	5	75		
		Fail to Close	25	243		
Emergency Diesel Generators	Emergency Power	Fail to Start	61	964	152	1739
		Fail to Stop	3	30		
		Fail to Run	88	745		
Heat Exchangers	Containment Spray	No Flow/Plugged	13	15	22	43
	Isolation Condenser	No Flow/Plugged	1	3		
	Residual Heat Removal	No Flow/Plugged	8	25		
Main Steam Isolation Valves	Main Steam	Fail to Close	81	232	204	587

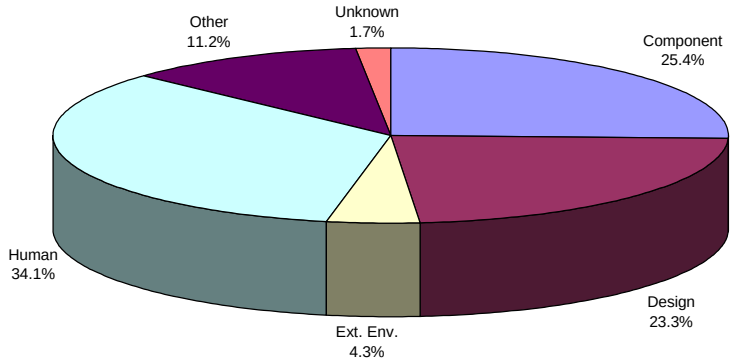
Component Type	Systems Analyzed for Component Type s	PRA-relevant Failure Mode	No. of Events for System and Component Type		Total No. of Events for Component Type	
			CCF	Independent	CCF	Independent
		Fail to Open	13	106		
		Fail to Remain Closed	72	98		
		Spurious Operation	38	151		
Motor-Operated Valves	Auxiliary Feedwater (PWR)	Fail to Remain Closed	4	53	206	2720
		Fail to Close	10	119		
		Spurious Operation	2	6		
		Fail to Open	14	284		
	Containment Spray	Fail to Close	2	17		
		Fail to Open	12	19		
		Fail to Remain Closed	1	7		
	Emergency/Essential Service Water	Fail to Close	2	17		
		Fail to Open	2	18		
		Fail to Remain Closed	1	5		
	High Pressure Coolant Injection (BWR)	Fail to Close	2	104		
Motor-Operated Valves	High Pressure Coolant Injection (BWR)	Fail to Open	4	174	206	2720
		Fail to Remain Closed	3	45		
	High Pressure Safety Injection (PWR)	Fail to Remain Closed	6	33		
		Fail to Close	11	110		
		Fail to Open	23	257		
	Isolation Condenser	Fail to Close	1	13		
		Fail to Open	1	29		
	Main Steam	Fail to Close	1	10		
	Reactor Coolant	Fail to Close	5	95		
		Fail to Open	1	56		

Component Type	Systems Analyzed for Component Type s	PRA-relevant Failure Mode	No. of Events for System and Component Type		Total No. of Events for Component Type	
			CCF	Independent	CCF	Independent
		Fail to Remain Closed	2	15		
	Reactor Core Isolation Cooling	Fail to Close	4	27		
		Fail to Open	2	47		
	Residual Heat Removal	Fail to Close	27	343		
		Fail to Open	40	737		
		Fail to Remain Closed	22	58		
		Spurious Operation	1	22		
Pumps	Auxiliary Feedwater (PWR)	Fail to Run	26	521	311	3969
		Fail to Start	29	511		
	Containment Spray	Fail to Start	2	28		
	Emergency/Essential Service Water	Fail to Run	81	971		
Pumps	Emergency/Essential Service Water	Fail to Start	68	413	311	3969
		Fail to Stop	1	38		
	High Pressure Coolant Injection (BWR)	Fail to Run	1	116		
		Fail to Start	2	129		
		Fail to Stop	1	22		
	High Pressure Safety Injection (PWR)	Fail to Run	27	315		
		Fail to Start	19	224		
	Low Pressure Core Spray	Fail to Start	1	13		
	Residual Heat Removal	Fail to Start	17	189		
		Fail to Stop	2	33		
		Fail to Run	22	358		
	Standby Liquid Control	Fail to Start	3	19		
		Fail to Stop	1	7		

Component Type	Systems Analyzed for Component Type s	PRA-relevant Failure Mode	No. of Events for System and Component Type		Total No. of Events for Component Type	
			CCF	Independent	CCF	Independent
		Fail to Run	8	62		
Safety and Relief Valves	Main Steam	Fail to Close	12	111	219	1831
		Fail to Open	130	493		
		Fail to Remain Closed	20	334		
		Spurious Operation	18	97		
	Reactor Coolant	Fail to Close	2	101		
		Fail to Open	22	270		
		Fail to Remain Closed	12	346		
Safety and Relief Valves	Reactor Coolant	Spurious Operation	3	79	219	1831
Strainers	Emergency/Essential Service Water	No Flow/Plugged	52	241	54	243
	Residual Heat Removal	No Flow/Plugged	2	2		
Total					1626	14913

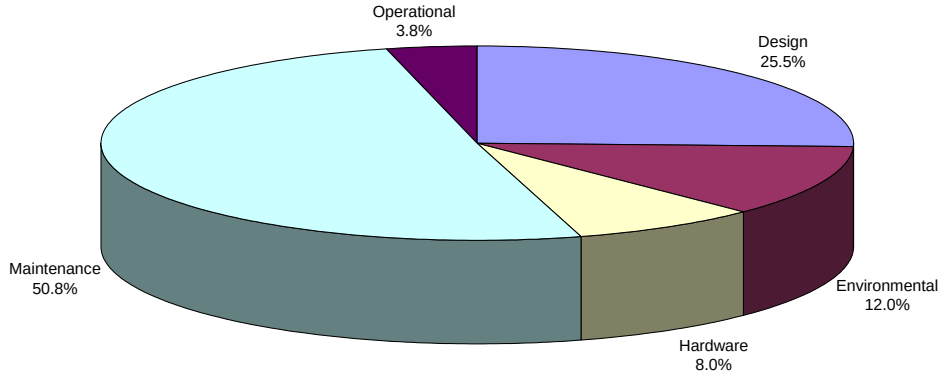


Distribution of causes of complete and partial CCF events

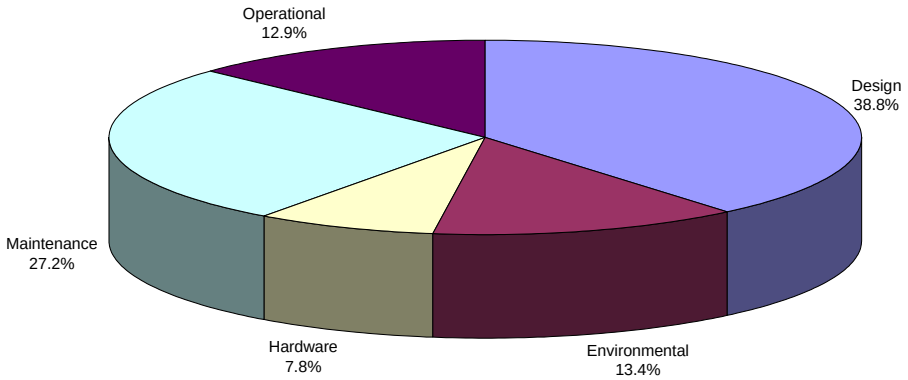


Distribution of causes of only the complete CCF events.

Figure 1. Distribution of CCF events by proximate cause.



Distribution of coupling factors for both complete and partial events.



Distribution of coupling factors for only the complete CCF events.

Figure 2. Distribution of CCF events by coupling factor.

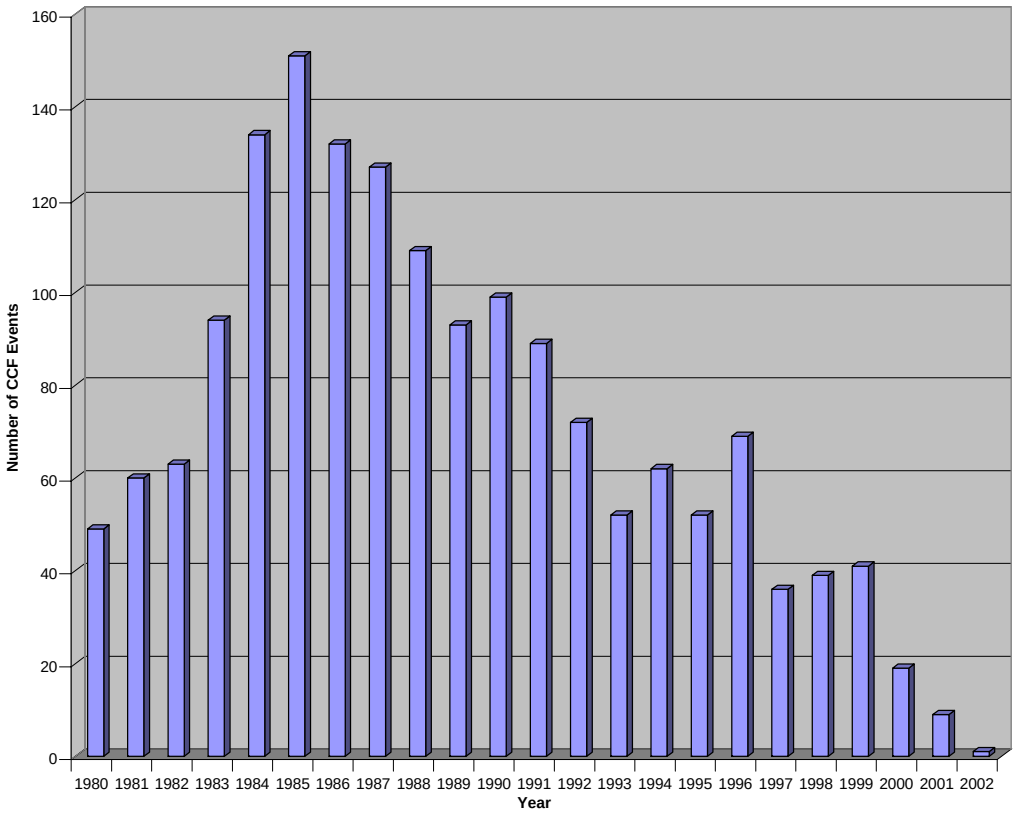


Figure 3. Distribution of all CCF events by year.

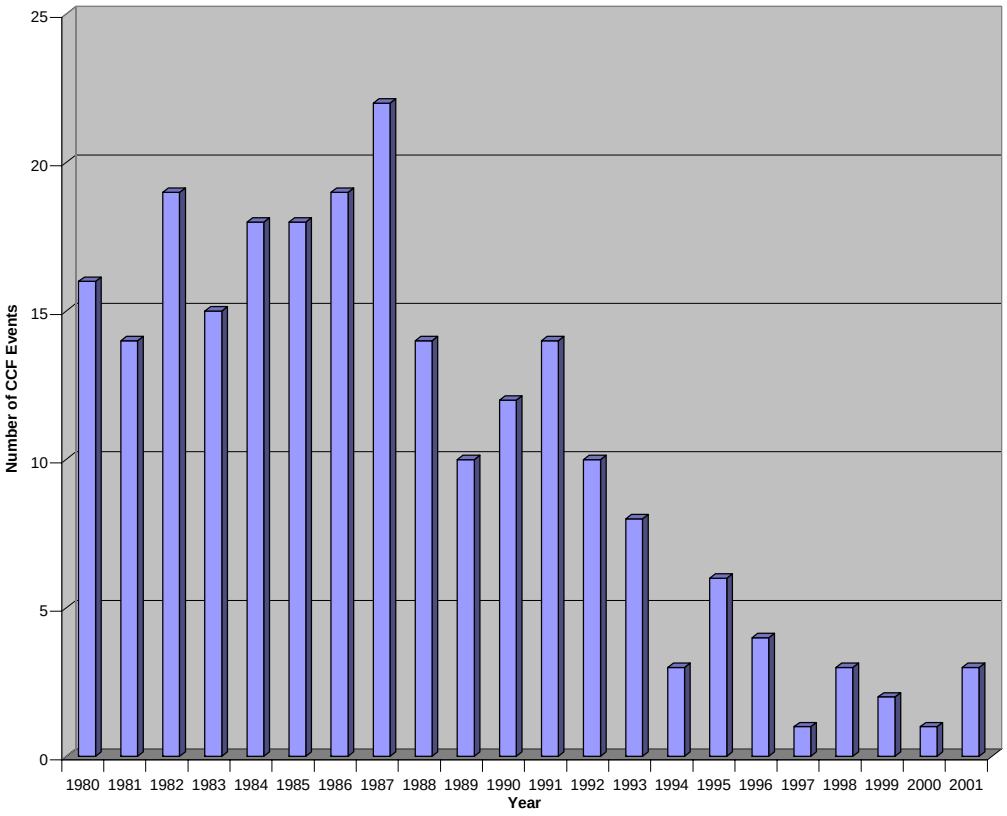


Figure 4. Distribution of complete CCF events by year.