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Component Reliability Data Issues for Discussion with NRC Research

Risk Management Committee

PA-RMSC-1494

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EDF Energy	Sizewell B (W)	X	
Electrabel	Doel 1, 2 & 4 (W)	X	
	Tihange 1 & 3 (W)	X	
Electricite de France	58 Units	X	
Elektriciteits Produktiemaatschappij Zuid-Nederland	Borssele 1 (Siemens)	X	
Eletronuclear-Eletrobras	Angra 1 (W)	X	
Emirates Nuclear Energy Corporation	Barakah 1 & 2	X	
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	Hanbit 1 & 2 (W)	X	
	Hanbit 3, 4, 5 & 6 (CE)	X	
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EXECUTIVE SUMMARY

The purpose of this data investigation and data analysis is to provide a strong basis for engaging with the Nuclear Regulatory Commission (NRC) to improve the generic component reliability data sources (References 1 through 4). This report supports the long-term needs of the nuclear power industry for high quality generic component reliability estimates for utility probabilistic risk assessments (PRAs).

This report addresses two general topics related to data analysis for utility PRAs:

(a) *Data Investigation: Data Issues.* This topic relates to investigations into a number of issues with component reliability data. The data issues relate primarily to problems and shortcomings with the current NRC datasets. These issues are listed in Table ES-1 below and are documented in Sections 2 and 3, with details provided in Appendix A.

(b) *Data Analysis: EDG and Pump Reliability.* Component failure rates for Emergency Diesel Generators (EDGs) have been developed independent of NRC data sources. In addition, common cause failure (CCF) events for EDGs and pumps have been reviewed regarding their classification as CCF events. These independently developed reliability estimates and CCF classifications were developed to be used in discussions with the NRC regarding the future of the NRC datasets. This data analysis is documented in Sections 4 and 5.

Table ES-1: Data Issues

DQ	**NRC Datasets: Data Quality Issues**
DQ.1	General Issues with NRC Dataset (2015)
DQ.3	Datasets Consistency
DQ.3	Component Boundary
DQ.4	Failure Rate Changes
DQ.5	Long-term Failure Rates
DQ.6	Flow Sensor Failure Rate Based on Judgment
DQ.7	Basis for Error Factors
DQ.8	CCF Weighted Data & Mapping-Up Assumptions
DQ.9	SPAR Models
DA	**NRC Datasets: Data Aging Issues**
DA.1	Time Trends of Component Failure Events
DA.2	Time Trend of CCF Events
DA.3	Failure Rates Based on Old Data
DA.4	Failure Rate for Safety Valve Fail to Reclose Based on Judgment
DA.5	Sensor Failure Rates Based on Old Data
DC	**NRC Datasets: Data Classification Issues**
DC.1	New Failure Modes
DC.2	Leakage Probability
DC.3	Large Internal Leakage Probability Based on Limited & Old Data
DC.4	Large External Leakage Probability Based on Limited & Old Data
DC.5	PORV Spurious Operation
DC.6	Safety/Relief Valve Spurious Operation
DC.7	AOV, MOV, SOV Spurious Operation
DC.8	Breaker Spurious Operation
DC.9	CCF Modeling for Spurious Operation
DC.10	Treatment of Highly Recoverable Failures

TABLE OF CONTENTS

LIST OF TABLES

ACRONYMS

AC	Alternating Current
ACC	Accumulator
AFW	Auxiliary Feedwater
ANS	American Nuclear Society
AOV	Air Operated Valve
ASDV	Atmospheric Steam Dump Valve
ASME	American Society of Mechanical Engineers
BWR	Boiling Water Reactor
CBK	Circuit Breaker
CCCG	Common Cause Component Group
CCF	Common Cause Failure
CCP	Centrifugal Charging Pump
CCW	Component Cooling Water
CKV	Check Valve
CVC, CVCS	Chemical and Volume Control System
DA	Data Aging Issue
DC	Data Classification Issue
DC	Direct Current
DG	Diesel Generator
DQ	Data Quality Issue
EDG	Emergency Diesel Generator
EF	Error Factor
EFW	Emergency Feed Water
ELL	External Leak Large
ELS	External Leak Small
EPIX	Equipment Performance Information Exchange
FTCL	Fail to Reclose Passing Liquid
FTLR	Fail to Load/Run
FTO	Fail to Open, Fail to Operate
FTOP	Fail to Operate
FTR	Fail to Run
FTS	Fail to Start
HEP	Human Error Probability
HOV	Hydraulic Operated Valve
HPI	High Pressure Injection
HR	Human Reliability Analysis (PRA Standard Element)
HTX	Heat Exchanger
I&C	Instrument and Control
IAS	Instrument Air System
ICES	INPO Consolidated Event System
ILL	Internal Leak Large
ILS	Internal Leak Small
IND	Independent

INL	Idaho National Laboratory
INPO	Institute for Nuclear Power Operation
LOOP	Loss of Offsite Power
LPI	Low Pressure Injection
LR	Load-Run
MDP	Motor-Driven Pump
MFW	Main Feed Water
MOV	Motor Operated Valve
MRFF	Maintenance Rule Functional Failure
MSPI	Mitigating Systems Performance Indicator
MSS	Main Steam System
MSV	Main Steam Isolation Valve
NPP	Nuclear Power Plant
NR	Normally Running
NRC	Nuclear Regulatory Commission
NROD	NRC Reactor Operating Experience Data
OG	Owners Group
PA	Project Authorization
PDP	Positive Displacement Pump
PORV	Pilot Operated Relief Valve
PRA	Probabilistic Risk Assessment
PROB	Probability
PWR	Pressurized Water Reactor
PWROG	PWR Owners Group
RADS	Reliability and Availability Database System
RCS	Reactor Coolant System
RMSC	Risk Management Subcommittee
RVL	Relief Valve
SBY	Standby
SC	Spurious Close
SI	Safety Injection
SLBO	Steam Line Break Outside Containment
SLOCA	Small Loss of Coolant Accident
SO	Spurious Open
SOP	Spurious Operation
SOV	Solenoid Operated Valve
SPAR	Standardized Plant Analysis Risk
SR	Supporting Requirement
SRV	Steam Relief Valve
SSC	Structures, Systems, and Components
SSV	Steam Safety Valve
STBY	Standby
STF	Sensor/Transmitter – Flow
STL	Sensor/Transmitter – Level
STR	Strainer
SW	Service Water

SWS	Service Water System
TD	Turbine Driven
TDP	Turbine Driven Pump
TNK	Tank
XVM	Manual Valve

1 INTRODUCTION

1.1 PURPOSE

The purpose of this data investigation and data analysis is to provide a strong basis for engaging with the NRC to improve the generic component reliability data sources (References 1 through 3). This report supports the long-term needs of the nuclear power industry for high quality generic component reliability estimates for utility probabilistic risk assessments (PRAs).

This report addresses two general topics related to data analysis for utility PRAs:

(a) *Data Investigation: Data Issues.* This topic relates to investigations into issues with component reliability data. The data issues summarized in Section 2 relate primarily to problems and shortcomings with the current NRC datasets (see Section 1.2 for a description of these datasets). In addition, Section 3 lists several potential changes to the PRA Standard based on data issues. Detailed discussions of these issues are documented in Appendix A.

(b) *Data Analysis: EDG and Pump Reliability.* Component failure rates for EDGs have been developed independent of NRC data sources. In addition, common cause failure (CCF) events for EDGs and pumps have been reviewed regarding their classification as CCF events. These independently developed reliability estimates and CCF classifications will be used in discussions with NRC regarding the future of the NRC datasets. This data analysis is documented in Sections 4 and 5.

1.2 BACKGROUND

The most recent NRC component reliability datasets are labeled in this report as **NRC Dataset (2015**) and **NRC CCF Dataset (2015)**. These are described as follows:

NRC Dataset (2015), "Summary of SPAR Component Unreliability Data and Results: 2015 Parameter Estimation Update," http://nrcoe.inl.gov/resultsdb/AvgPerf/, 2016 (Reference 1).

This is the most recent report of component failure rates that was preceded by a 2007 report NUREG/CR-6928 (Reference 4) and an updated report issued in 2010. The 2015 report includes failure events from 1998 to 2015. NUREG/CR-6928 is still an important reference for data methods and parameter definitions, such as component boundaries. However, the 2015 report supersedes the earlier data reports. Note, the NRC Dataset (2015) was issued both as an HTML report and as a PDF report, with some minor differences.

NRC CCF Dataset (2015), U.S. Nuclear Regulatory Commission, "CCF Parameter Estimations, 2015 Update," http://nrcoe.inel.gov/resultsdb/ParamEstSpar/, 2016 (Reference 2).

This is the most recent report of component CCF parameters. The initial CCF parameter estimates were documented in the 1998 report NUREG/CR-5497 (Reference 5) with updates issued in 2003, 2005, 2007, 2009, 2010, and 2012. The current report includes CCF events from 1997 to 2015.

In addition, the NRC/INL **NROD Database** (http://nrcoe.inel.gov/results) (Reference 3) provides the raw event data and documents how each event is treated to generate the data distributions presented in the NRC datasets.

2 ISSUES WITH GENERIC NRC DATASETS

The NRC, through analysts at the Idaho National Laboratory (INL), is the author of the major generic datasets for component reliability data used throughout the nuclear power plants (NPPs) domestically as well as internationally. These datasets are comprehensive in their scope and are based on detailed data collection and data analysis methods. As such, they have no equal domestically or internationally as a quality source of generic failure rate estimates.

However, a detailed review of these datasets identified some issues related to potential problems or limitations of these NRC datasets when used in utility PRAs. These issues have been classified into three (3) groups:

- Data Quality issues (DQ),
- Data Aging issues (DA), and
- Data Classification issues (DC).

These issues are summarized in Sections 2.1 through 2.3, below, with details provided in Appendix A. The suggested changes identified for each issue were developed to support a constructive discussion with NRC.

2.1 DATA QUALITY ISSUES

Data quality issues relate to problems with the NRC datasets that appear to be errors. These are relatively minor in light of the large data analysis effort, but represent areas that should be reviewed and corrected in the next data update.

#DQ.1 General Data Issues with NRC Dataset (2015)

A number of issues have been identified with the NRC Dataset (2015), including duplicate entries, documentation errors in the Data Source and Comment fields, questionable number of demands and run-hours, and entries labeled fail-to-start but identified as per-hour rather than per-demand.

For example, TDP-FS-NR-MFW (Turbine Driven Pump Fails to Start, Normally Running, Main Feed Water) is listed as having 5,984,882 demands over the 17-year period from 1998 to 2015. This is an extremely large number that seems inconsistent with expectations. Even if all 100 plants had two such pumps, this would require over 1700 demands per year over the 17-year data period.

These specific issues are listed in Appendix A, Issue #DQ.1.

#DQ.2 Datasets Consistency

NRC Dataset (2015) and NRC CCF Dataset (2015) are not consistent in the total number of failure events. These two datasets do not quite match for event dates included. NRC Dataset (2015) covers 1998 to 2015. NRC CCF Dataset (2015) covers 1997 to 2015. However, it is not clear the one additional year of data for NRC CCF explains the differences. See examples in Table DQ.3-1 in Appendix A.

The total number of failure events should be consistent between these two datasets for the same component failure mode, since these are used to calculate inter-related component failure rates: the total failure rate and the CCF rate. It would help, as a start, to use a consistent set of event dates. In addition, the counts should be consistent between published reports and the NRC Reactor Operating Experience Data (NROD) Database.

#DQ.3 Component Boundary

NUREG/CR-6928 and NRC CCF Dataset (2015) are not consistent in at least one important component boundary: EDGs. In Section 5.1 of NUREG/CR-6928, room cooling is excluded from the EDG component boundary while in NRC CCF Dataset (2015), heating, ventilation and air conditioning are within the EDG boundary. The definitions of component boundaries should be consistent between these datasets, since these are used to calculate inter-related component failure rates: the total failure rate and the CCF rate. The boundary definitions used in NUREG/CR-6928 should be used for both datasets.

#DQ.4 Failure Rate Changes

NRC datasets from 2007, 2010, and 2015 show significant changes in some component failure rate mean values. For example, the mean value for EDG-FTS (EDG fails to start) changed over the course of these three datasets from 4.53E-3 to 2.88E-3 (36% decrease), EDG-FTLR (EDG fails to load/run) from 2.90E-3 to 3.72E-3 (28% increase), and EDG-FTR (EDG fails to run) from 8.48E-4 to 1.52E-3 (79% increase).

It is not clear whether these are based on changes in average component performance, changes in failure data collection or data treatment, or changes in estimates of success data. Other data issues (e.g., #DA.1 and #DA.2) examined some of the reasons for changes in failure rates.

#DQ.5 Long-term Failure Rates

The run-hours for Standby Motor-Driven Pumps appear to be excessive. In the 2015 Dataset, the estimated LATE (> 1 hour) run-hours per start are about 40 hours (# MDP-SBY-FTR>1H / # MDP-SBY-FTS = 2.01E7 hours / 4.82E5 starts). The 2010 Dataset result is about the same; the 2007 Dataset values show about seven hours per start. This amount of run time per start is puzzling for standby pumps, since one would expect these pumps to be run for only a few hours during tests.

The "MD Pump – Standby" data should be reviewed to see why the average run time per start is so high. This data appears to be more representative of normally running pumps rather than standby pumps.

#DQ.6 Flow Sensor Failure Rate Based on Judgment

The FLOW sensor/transmitter failure rates (STF FTOP-D, STF FTOP-R) are based on judgment by using the same data as the LEVEL sensor/transmitter event data (STL FTOP-D, STL FTOP-R) in NUREG/CR-6928 (from NUREG/CR-5500). However, there is no basis for this data treatment.

Failure rates should be developed specifically for FLOW process logic and FLOW sensors/transmitters based on recent failure event data (2006 to 2015). In the interim, a basis should be provided for the use of LEVEL data as an appropriate surrogate for FLOW sensors. Note, requirement DA-D2 in the PRA Standard (Addendum B) allows for such estimation, but includes the phrase “use data or estimates for the most similar equipment available…” A basis should be provided for why level sensors (and not pressure or temperature) are the most appropriate similar equipment.

#DQ.7 Basis for Error Factors

The data distributions in the NRC Dataset (2015) may not fully account for the uncertainties in the failure rate estimates. The Error Factors (EFs)[1] range from 1.2 to 18.8, with about 90 of the 332 component failure modes having an EF less than 2.0.

The largest EFs (18.8) are applied to the “large leakage” failure rates based on judgment. For most of the other components, the EFs result from the Bayesian updating of a non-informative prior distribution with large amounts of generic data. The results of this mathematical treatment, which is based on assuming homogeneous data populations, are distributions with small error factors. In reality, there are a number of uncertainties not reflected in the raw number of failures and successes for a specific component failure mode. For example, the following uncertainties are not accounted for:

- Uncertainty in the number of failure events
- Uncertainty in the type and consequence of the failure event
- Uncertainty in the number of demands or run times
- Uncertainty in the homogeneity of components in the group based on component attributes such as manufacturer, size, process fluid, ambient environment, etc.
- Uncertainty in the homogeneity of components based on plant-to-plant variability

The current error factors underestimate the uncertainty in most component failure rates. A method of accounting for the other sources of uncertainty should be considered. This includes

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[1] The Error Factor is a measure of the range of the data distribution. For a lognormal distribution, the EF is defined as the 95th percentile / 50th percentile or the 50th percentile / 5th percentile, based on the symmetry of this distribution. For gamma and beta distributions, the EF is defined as the 95th Percentile / 50th percentile, based on the lack of symmetry of these distributions.

generic sources of uncertainty and sources of uncertainty that arise based on the specific application of the data.

#DQ.8 CCF Weighted Data & Mapping-Up Assumptions

The values used in characterizing CCF events to calculate CCF parameters (weighting factors and mapping-up factors) are critical to understanding the basis for these CCF parameters. The NROD Database (Reference 3) allows the user to view the weighting factors, but it is not clear how the combination of Timing, Component Degradation, and Shared Cause are used to calculate the overall weighting factors. Further, the mapping-up factors and their bases are totally invisible in the NROD Database. These factors and their bases should be clearly displayed. Once these are available for review, the bases can be reviewed and potentially challenged.

#DQ.9 SPAR Models

The NRC datasets, including NUREG/CR-6928, are developed to support NRC Standardized Plant Analysis Risk (SPAR) models. While it is clear that these datasets meet the requirements for Data in the PRA Standard (DA-C1) by direct reference, it is not clear that they meet all the attributes of a generic data source needed to support a utility PRA. While this data issue did not identify any specific issues, it did generate a potential change in the PRA Standard (see Section 3).

2.2 DATA AGING ISSUES

The most significant data issues identified in the NRC datasets relate to the use of a wide date-range of reliability data that is not reflective of more current component reliability. These issues are addressed in the first two items below related to time trends. The other data aging issues relate to the use of very old data for a few components.

#DA.1 Time Trends of Component Failure Events

The current NRC Dataset (2015) includes data (component failures and success) for a 20-year period, 1996 to 2015. However, the average performance of components industry-wide is significantly better in the most recent 10-year period, 2006 to 2015.

For example, for motor-driven pumps (MDP), the pooled data shows that the number of failure events has decreased significantly from 1996 to 2005 compared to 2006 to 2015 as shown in Table 2.2-1. This includes all MDP failure modes: FTS (fail to start), SBY-FTR (standby pump fails to run), and NR-FTR (normally running pump fails to run).

Table 2.2-1: Change in Number of Failures of Motor-driven Pumps

Component Failure Mode	Number of Failure Events (Average Number per Year)		
	1996-2005	2006-2015	Percent Change
MDP-FTS	464 (46.4)	313 (31.3)	32.5% decrease
MDP-SBY-FTR	179 (17.9)	130 (13.0)	27.4% decrease
MDP-NR-FTR	227 (22.7)	205 (20.5)	9.7% decrease

This comparison assumes an equal number of components and success data for these two time periods, a reasonable assumption for that 20-year period. While all component failure modes do not show the same degree of improvement, the data generally shows a positive trend. Note, this time-trend may not be as apparent on a yearly basis because of the variability in the number of failures, but in 10-year groups, it becomes clear.

Table DA.1-1 (in Appendix A) presents the number of failures for several component failure modes, comparing two 10-year periods (from the NROD Database). As the comparison demonstrates, the number of failures has decreased, in some cases significantly, for almost all component failure modes. Assuming the success data is the same (same number of components, same start and run data), this is reflective of overall improved component reliability.

The most recent set of events (2006 to 2015) should be used to calculate generic failure rates. These datasets should be consistent with CCF parameter calculations (see Issue #DA.2).

#DA.2 Time Trend of CCF Events

The current NRC CCF Dataset (2015) includes CCF data (component failures and success) for a 19-year period, 1997 to 2015. However, the average performance of components industry-wide as measured by common cause failures is significantly better in the most recent 10-year period, 2006 to 2015.

Table 2.2-2 shows the pooled CCF data for "demand" failure modes and "rate" (per hour) failure modes. The CCF data is divided into two time periods, but because the periods are not equal, the percent change is based on the average yearly count (in parentheses).

Table 2.2-2: Change in Number of CCF Events

Component CCF Failure Mode	Number of Failure Events (Average Number per Year)		
	1997-2005	2006-2015	Percent Change(a)
Total "Demand" CCF Events	77 (8.5)	30 (3.0)	64.7% decrease
Total "Rate" CCF Events	70 (7.8)	46 (4.6)	41.0% decrease

Notes:
(a) The percent change is based on the ratio of the average number per year, rather than the total number of failure events.

In addition to these statistics, specific CCF events for the recent period (2006 to 2015) were reviewed. These illustrate that the raw count of CCF events tends to overstate the CCF issue:

- Motor-Driven Pumps (standby) FTS: One of the two CCF events (2006) was due to two AFW trains not aligned for auto actuation, easily recovered. The second CCF event in 2007 involved events with Time Delay Factor of 0.50.
- Motor-Driven Pumps (running) FTR: Two of the five CCF events occurred at one site (2010), but both were described as "CVCS pumps low flow due to check valve wear." The other three CCF events all occurred at the same site in June, August, and October of the same year (2008), due to debris in the source of cooling water that led to oil cooler fouling.
- Steam Generator PORVs FTO: One of three CCF events (2006) has Time Delay Factor of 0.1 (events were several months apart). A second event (2007) is failure to open ASDVs manually (valves opened 50% of stem movement, took longer than required time).
- EDG FTS: The single CCF event is "both EDGs inoperable due to improper switch position."
- EDG FTL: One of the two CCF events (involving 3 of 4 EDGs) has a P_value of 0.1.
- EDG FTR: One of the three CCF events involved 5 EDGs. One EDG had a P_value of 1.0. The other four had a P_value of 0.1.

- DC Battery FTO: The single CCF event (2011) is two vital batteries that failed to deliver 80% capacity required due to room ambient temperature at 70°F rather than 77°F. The P_value = 0.50.
- DC Battery Charger FTO: One of two CCF events (2006) had a Time Delay Factor of 0.1, based on time between failures of 45 days.
- Air Compressor FTS: The single CCF event (2010) was IA compressors fail to run due to low ambient temperature.

Table DA.2-1 (in Appendix A) presents the number of CCF events for several component failure modes, comparing 9-year period (1997-2005) with the recent 10-year period (2006-2015). This table provides the count for CCF events as well as independent (IND) failure events. As the comparison demonstrates, both CCF and IND counts have decreased for most component failure modes, but the CCF counts have decreased more dramatically. In addition, for a number of component failure modes (check valve fail to close, 480VAC circuit breakers fail to open or close, and air compressors fail to start), there were zero CCF failures over that 10-year period.

The most recent set of events (2006 to 2015) should be used to calculate generic CCF parameters. These datasets should be consistent with component reliability calculations (see Issue #DA.1). Also, detailed analyses of CCF event classification are provided in Section 4.2 for EDGs and Section 5 for pumps.

#DA.3 Failure Rates Based on Old Data

Of the 332 component failure modes included the NRC Dataset (2015), 70 are based on old data, mostly from the 1980s and 1990s. Data more than 20 years old may not be reflective of current component reliability. Appendix A offers suggestions for addressing each of these old data elements. The most important are four (4) special PORV failure modes (PORV-L, PORV-T, PORV-Lquid, and PORV-P1) that come directly from NUREG/CR-7037. Issues #DA.4 and #DA.5 address additional specific cases of old data.

#DA.4 Failure Rate for Safety Valve Fail to Reclose Based on Judgment

NUREG/CR-6928 included failure rates for Safety Valve and Safety Relief Valve failure to reclose passing liquid (SVV FTCL, SVR FTCL, mean = 0.1) based on judgment with very limited basis. The NRC Dataset (2015) eliminates these failure modes. It includes a new failure mode, PORV-Lquid, with a mean value 6.25E-2, given the evidence of zero failures and seven demands. This PORV failure rate comes from NUREG/CR-7037 and is based on data from 1987 to 2007.

The basis for the PORV-Lquid is both old data and very limited data, with zero failures. This data analysis should be updated with recent failure event data (2006 to 2015). However, it is likely that the data will continue to be so limited as to not be helpful in assessing this failure rate. Expert elicitation should be considered for this component failure rate.

#DA.5 Sensor Failure Rates Based on Old Data

The sensor/transmitter failure rates in the NRC Dataset (2015) are from NUREG/CR-6928 (2007), and are based on NUREG/CR-5500 (1999). The sensor/transmitter failure rates are based on data from 1984 to 1995, so 20 to 30 years old.

Failure data should be collected from the recent period (2006 to 2015) for at least one sensor-type (e.g., pressure) and used to calculate new failure rates (demand, time). This could be used to compare with the failure rates in the NRC Dataset (2015). If the failure rates for this test case are significantly different, the data analysis effort should be expanded to address the other sensor-types.

2.3 DATA CLASSIFICATION ISSUES

Data classification has to do with several related issues. Issue #DC.1 addresses the broad issue of the change in component failure rate identifiers and descriptions from one revision of the NRC dataset to another. The next issues address the treatment of component leakage (#DC.2 to #DC.4) and spurious operation (#DC.5 to #DC.8) failure modes.

#DC.1 New Failure Modes

The NRC datasets have increasing numbers of component failure modes, from 171 in 2007 to 227 in 2010 to 331 in 2015. This includes adding new component failure modes, renaming existing component failure modes, and dropping some failure modes.

Of the 331 component failure modes in the 2015 dataset, only 53 (16%) match the 2007 dataset, 118 (36%) were changed, and 160 (48%) were new failure modes. This lack of consistency in naming and definitions of component failure modes creates significant challenges in utilizing the newer datasets. A consistent set of component failure rates and associated IDs should be developed and maintained for future data updates.

#DC.2 Leakage Probability

Small Leakage failure mode (internal or external component leakage) is defined in NUREG/CR-6928 for valves, pumps, etc. as leakage from 1 to 50 gpm. The definition of Small Leakage (1 to 50 gpm) is not helpful because it covers the range from nuisance leakage, which should not impact system performance to the point where leakage may not be insignificant (depending on the system). Also, it is not clear that the events used to calculate the Small and Large leakage probabilities define the actual leak rate. Clearly the data for these leakage probabilities represent old events (15 to 20 years old).

“Component Leakage” would be better defined for leaks in the range 10 to 50 gpm. Leakage any larger than 50 gpm external to the device should be classified as an internal flood event and be excluded from this component reliability database. Leakage any larger than 50 gpm internal to the device could be considered a component failure (e.g., manual valve leakage larger than 50 gpm should be counted as Manual Valve Fails to Remain Closed). Leakage less than 10 gpm should be considered nuisance leakage which should not impact system performance[2]. Leakage in the range from 10 to 50 gpm is still a challenge to model (i.e., what is the true impact of such a leak rate), but would help to focus the concern on more likely leakage events that may challenge system function over a period of time.

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[2] For some low-capacity systems, this definition of nuisance leakage may not be sufficient. However, that is expected to be the exception. Generally, fluid systems in NPPs have large amounts of water.

Also, leakage data should be gathered from the most recent period (e.g., 2006 to 2015). See Issues #DC.3 and #DC.4. It may be appropriate to assign weighting factors to events where the event record is not definitive regarding the leakage rate.

#DC.3 Large Internal Leakage Probability Based on Limited & Old Data

The probability of Large Internal Leak in NUREG/CR-6928 is defined as 0.02 x PROB(small leak). The value 0.02 is used as the ratio of ILL/ILS (large vs. small internal leak failure rate) for valves (SRV, SVV, PORV, RVL), tanks (TNK, ACC, STR), and heat exchangers (HTX). This value is documented in Table A.1.2-1 of NUREG/CR-6928 and is based on 3 large internal leaks vs. 185.5 small internal leaks (with the ratio rounded off). This data is from the 8-year period from 1997 to 2004. This same ratio (0.02) is used in the NRC Dataset (2015) although the data used to calculate the small leakage (ILS) failure rate appears to be updated. Thus, this value 0.02 is based on 3 large leaks from data that are 15 to 20 years old.

Internal Leakage data (using the definition of leakage suggested in Issue #DC.2) should be gathered from the most recent period (e.g., 2006 to 2015). This data better represents the current component performance and maintenance practices. Documentation of more recent data events also may provide more detail regarding the events.

#DC.4 Large External Leakage Probability Based on Limited & Old Data

The probability of Large External Leak in NUREG/CR-6928 is defined as 0.07 x PROB(small leak). The value 0.07 is used as the ratio of ELL/ELS (large vs. small external leak failure rate) for valves (SRV, SVV, PORV, RVL) and tanks (TNK, ACC, STR). This value is documented in Table A.1.2-1 of NUREG/CR-6928 and is based on 2.0 large external leaks vs. 35.0 small external leaks (with the ratio rounded off). This data is from the 8-year period from 1997 to 2004. This same ratio (0.07) is used in the NRC Dataset (2015) although the data used to calculate the small leakage (ELS) failure rate appears to be updated. Thus, this value is based on 2 large leaks from data that are 15 to 20 years old.

Separate ELL/ELS values are calculated for:

- Heat exchangers (HTX): 0.15, based on 1.0 ELL and 10.0 ELS events
- SW pipe: 0.2, based on 0.0 ELL and 3.5 ELS events, and
- Non-SW pipe: 0.1, based on 1.5 ELL and 8.5 ELS events.

External Leakage data (using the definition of leakage suggested in Issue #DC.2) should be gathered from the most recent period (e.g., 2006 to 2015). This data better represents the current component performance and maintenance practices. Documentation of more recent data events also may provide more detail regarding the events.

#DC.5 PORV Spurious Operation

The NRC Dataset (2015) identifies 24 events classified as PORV-SOP (PORV spurious opening), but it is not clear whether these are primary-side or secondary-side PORVs or both.

A search of the NROD Database found 35 events over the same time period that seem to match the definition of PORV-SOP, using the following search criteria:

- System: RCS, MSS
- Component: PORV
- Failure Mode: spurious operation
- Event Date: 1998 to 2015

Of these 35 events from the NROD Database, most (28) were from MSS, with the remainder (7) from RCS. A review was performed of the events in the most recent 10-year period, 2006 to 2015: a total of 16 events. This includes 2 RCS events and 14 MSS events classified as PORV-SOP. The conclusions from this investigation:

Conclusions: PORV-SOP (RCS)

There are only 2 RCS events in the most recent 10-year period. One event occurred during troubleshooting and was immediately identified and recovered. The second event is a spurious closure event, applicable only when the PORV is already open. This would better be modeled as a Failure-to-Open event.

The first event could be considered a precursor of SLOCA, although the actions to isolate the open RCS PORV should be highly reliable since the cue is clear and actions are straightforward. Due to the low frequency of this precursor and the reliability of the recovery action, this event could be screened out:

- SLOCA(PORV-SOP Remains Open) = PORV-SOP-RCS x Operator Fails to Close PORV = (1 event / 60 PWRs * 10 yrs) * 1E-3 = 2E-6 / year,

The human error probability (HEP = 1E-3) is based on the judgment that the cue is clear and actions are straightforward. Note, the conclusion (that this event could be screened out) does not depend on the HEP being so low, but this value does reflect the judgment that this would be a highly reliable action.

With such little significant data events over the last 10 years, this component failure mode should be excluded from the NRC Database.

Conclusions: PORV-SOP (MSS)

Half (7) of these events involved the MSS PORV opening (partially or fully) with no maintenance or plant operation in progress. Five events occurred during maintenance or while the plant was shutting down or starting up. Two events from one plant involved a frozen sensing line. All events were quickly identified because of the impact on plant operation and quickly corrected, typically by taking the controller to manual or closing the manual isolation valve.

These events might be considered precursors to SLBO (steam line break outside containment) initiators, although the actions to isolate the open MSS PORV should be highly reliable since the cue is generally clear and actions are straightforward. Also, the steam relief from one MSS PORV is much less than a steam line break, so grouping this with SLB would be highly conservative.

This component failure mode (PORV-SOP) should be reclassified as a precursor event and included in the Initiating Event dataset (rather than with component reliability).

#DC.6 Safety/Relief Valve Spurious Operation

The NRC Dataset (2015) identifies a spurious-operation failure mode for several safety and relief valve types (SRV-SOP, SVV-SOP, SVV-SOP-PWR-MSS, and SVV-SOP-PWR-RCS) in addition to PORV-SOP (addressed in Issue #DC.5).

These component failure modes have failure rates ranging from 5.4E-8 to 1.4E-7 per hour from the NRC Dataset (2015). Based on a review of the NROD Database, 7 SVV-SOP events were identified (3 MSS, 4 RCS), in contrast with the count of 11 in the NRC Dataset (2015). Of these 7 events, 3 were associated with a plant trip, one led to a manual reactor trip, and the other three occurred when a unit was returning to normal pressure following a refueling outage. For the most part, these are not random events; they occur in response to a change in plant configurations.

These events should be re-classified as: (a) safety/relief valve opening during a transient or (b) precursor events and include these in the Initiating Event dataset (rather than with component reliability).

#DC.7 AOV, MOV, SOV Spurious Operation

The NRC Dataset (2015) identifies a spurious-operation failure mode for a number of valve types, including AOV-OC/SOP, MOV-OC/SOP, and SOV-SOP. It is not clear whether these events represent internal valve failures or inadvertent actuation signals.

The NRC Dataset (2015) includes spurious operation of the following valve types: MOV (motor), AOV (air), HOV (hydraulic), SOV (solenoid), MSV (main steam isolation), CKV (check), and XVM (manual), with failure rates ranging from 3.1E-7 to 2.6E-9 per hour. These component failure modes are labeled xxx-SOP, xxx-SO, xxx-SC, and xxx-OC. The xxx-SC label is used only for check valve spurious closure. The label xxx-SO is used for three (3) valve types. Six (6) valve-types are labeled xxx-OC. The OC label is used strictly for valves identified by specific system (CCW, IAS, SWS). The SOP label is used for other valve-types. The descriptions of these failure modes include: spurious operation, spurious opening, spuriously transfers, transfers open, fails to remain open. So the naming convention and descriptions are not used consistently.

Based on a review of the NROD Database, significant inconsistencies were noted in the count in the NROD Database vs. the NRC Dataset (2015). For example, the count of MOV_SOP (motor operated valve spurious operation) events was 63 in NRC Dataset (2015) and 48 in the NROD Database. Similarly, the count of AOV_SOP (air operated valve spurious operation) events was 132 in NRC Dataset (2015) and 67 in the NROD Database. Spurious operation of SOVs, check valves, and manual valves had counts of 9, 2, and 6 (respectively) in NRC Dataset (2015) but zero events in the NROD Database.

Based on a sample of failure reports from the NROD Database, these events include valves changing position due to inadvertent demand signals, due to setpoint drift, and due to switch failure. Generally these repositioning events were accompanied by an indication (alarm, valve position change).

These events should be reviewed to determine whether the failures are within the component boundary (e.g., inadvertent demand signal should typically be outside the boundary). Some of these events might be more appropriately categorized as fail to open or fail to close. Finally, other spurious valve events should be re-classified as precursor events and included in the Initiating Event dataset (rather than with component reliability).

The inconsistency between the NROD Database and the NRC Dataset (2015) is significant for some of these valve types. These inconsistencies should be resolved.

#DC.8 Breaker Spurious Operation

The NRC Dataset (2015) identifies a spurious-operation failure mode for four types of circuit breakers: high voltage AC (13.8KV & 16KV, CBKHV-SOP); medium voltage AC (4.16KV & 6.9KV, CBKMV-SOP); low voltage AC (480V, CRB-CO-480); and DC (CBKDC-SOP).

The failure rates for breakers spuriously transferring are extremely low, ranging from 3.5E-8/hr for DC breakers to 4.8E-7/hr for high voltage breakers. Spurious operation of a breaker would generally be immediately alarmed in the control room. This would lead to breaker unavailability while the event was investigated and maintenance performed. Any such unavailability would be captured in the system/train unavailability. If this caused a plant upset leading to an initiating event, that would be captured in the initiator frequencies.

A sample review of Breaker Spurious Operation failure events from the NROD Database identified that these events are commonly caused by a maintenance activity. In all cases, the spurious operation is alarmed, although in some events, the condition was discovered only during a test. In some cases, the failures were also identified in the NROD Database as ones that were quickly recovered.

Based on the sample review, Breaker Spurious Operation contains (at least) two types of failure events: (a) maintenance events where the breaker spurious operation occurred as a result of some aspect of that activity and (b) test events where the breaker failed to remain closed. The first set of events should be screened out as not applicable to an accident sequence. They may be related to precursor events. The second set of events should be reclassified as Breaker Failure to Close. If the number of these events is comparable to the total number of "Breaker

Failure to Close" events, then a standby failure mode should be added (Breaker Failure to Close while in standby) where the time between tests could be accounted for.

#DC.9 CCF Modeling for Spurious Operation

The NRC CCF Dataset (2015) provides extremely sparse evidence of common cause failures for spurious operation failure modes: zero events for check valves and DC circuit breakers; one event each for MOVs, AOVs, and 480VAC circuit breakers; and three events for 4160VAC circuit breakers. As discussed in Data Issues #DC.6 and #DC.7 above, the evidence for independent spurious operation events is limited and, in many cases, would be better characterized as precursor events.

Despite this limited data, CCF parameters are calculated and displayed in the NRC CCF Dataset (2015) for spurious operation modes for valves and circuit breakers. This includes check valve spurious operation which has zero CCF events and zero independent events, but still produces a CCF parameter $\alpha 2$ = 4.07E-2 for common cause component group (CCCG) = 2.

The spurious operation failure modes should be removed from the CCF Dataset based on the limited data for both independent and common cause spurious operation.

#DC.10 Treatment of Highly Recoverable Failures

The documentation of failure events in the NROD Database includes an assessment of whether the failure was recoverable and, if recoverable, an estimate of the recovery duration. Yet, these failures are treated the same as other failures that may be highly non-recoverable (i.e., with a much longer recovery time). Failure events that are highly recoverable (e.g., recoverable within 60 min) should be treated as weighted failures to acknowledge that such events have much less risk importance than other failure events.

The P_value could be revised to include a weighting factor based on the recoverability of the failure event. One possible treatment:

- Failure events recoverable from the control room within a few minutes without any significant trouble-shooting (e.g., control switch in pull-to-lock): P_value = 0.1.
- Failure events recoverable within 15 minutes without any significant trouble-shooting (e.g., resetting the turbine-driven AFW pump trip/throttle valve): P_value = 0.2.
- Failure events recoverable within 60 minutes without any significant trouble-shooting (e.g., resetting a pump breaker): P_value = 0.5.

These values may be seen as screening HEPs that are consistent with the current range of P values used in NROD Databases.

3 POTENTIAL CHANGES TO PRA STANDARD

For several potential changes to the PRA Standard were identified related to data issues.

SPAR Models (See DQ.9)

Supporting requirement (SR) DA-C1 in the PRA Standard (Reference 6) states, "USE generic parameter estimates from recognized sources…" and includes NUREG/CR-6928 as an example of "recognized source" for component failure rates. However, there are no requirements that the generic data meet specific attributes, e.g., that the data reflect current operational practices. Thus, the NRC datasets meet the PRA Standard by default, despite the fact that they were developed to support SPAR models, not utility PRAs.

The PRA Standard DA-C1 could explicitly define the attributes of an acceptable generic data source, rather than citing "recognized sources" without any challenge.

Bayesian Update Reasonableness Check

SR DA-D4 in the PRA Standard (Reference 6) states, "ENSURE that the posterior distribution is reasonable …" and provides five (5) example tests for reasonableness. The first two tests apply only to Bayesian updating using discrete probability distributions. The last three tests just restate the requirement. For example, the fifth bullet says, "confirmation of the reasonableness of the posterior distribution mean value." More specific tests should be provided that can be used to justify reasonableness of posterior distributions.

Miscalibration Errors in Sensor Data

SRs HR-A2 and HR-A3 in the PRA Standard (Reference 6) require the identification of calibration activities as part of the process of identifying potential miscalibration errors. However, since miscalibration is built into the generic hardware failure rates and CCF parameters, it may be appropriate to revise the PRA Standard to delete requirement HR-A2 and to revise HR-A3 to remove references to miscalibration.

4 EMERGENCY DIESEL GENERATOR RELIABILITY DATA

Reliability data for EDGs was collected and analyzed independent of the NROD Database (Reference 3) and the NRC Dataset (2015) (Reference 1). This allows for the calculation of a separate and independent set of reliability parameters that can be compared with the parameters from the NROD/RADS and the NRC Dataset.

The EDG success and failure data were collected from the INPO Consolidated Event System (ICES) Database for 236 EDGs at 95 US NPPs for the 10-year period from 2006 to 2015. The data was processed as described below to generate point estimate failure rates. These values are then compared to EDG failure rates from the NROD Database and the NRC Dataset (2015).

EDG common cause failure (CCF) events from NROD (Reference 3) for the same time period, from 2006 to 2015, were selected for a detailed review and assessment. This assessment determined whether the designation of a CCF event was appropriate.

4.1 EDG RELIABILITY CALCULATIONS

Table 4-1 provides a summary of the parameters that were used to calculate a point estimate failure rate for each EDG failure mode. This table includes three (3) sets of results:

- Results calculated for this report (in red text) for the time period 2006 to 2015;
- Results from the NROD Database (Reference 3) for the same time period, 2006 to 2015; and
- Results from the NRC Dataset (2015) (Reference 1) for the period 1998 to 2015.

For all three results, the number of failures and number of successes (demands or run-hours) are provided. The failure rates are provided as point estimates, based on the ratio of failures to successes. These point estimate results are provided to allow a simple comparison among results, without the additional complication of the prior chosen for Bayesian updating.

For the FTS (fail-to-start) failure mode, the three point estimate results are in good agreement, within 8%. This report includes a few additional EDGs (236 vs 232) and additional failures (120 vs 111), compared to NROD/RADS. The count of EDG failures in this report is based on the review and assessment of each EDG failure event which resulted in the reduction in FTS failure events from 144 to120. The number of starts (successes) is almost identical between this report and NROD/RADS despite the additional EDGs in this report.

For the FTLR (fail-to-load-run) failure mode, the three point estimate results are in good agreement, within 15%, with the point estimate from this report as the lowest value. The count of EDG failures in this report is after the review and assessment of each EDG failure event, which resulted in the reduction in FTLR failure events from 125 to 118. Note that the NROD/RADS results and NRC Database results are provided in units of “hours” while the results from this report are in units of “demands.” While this does not directly impact the FTLR failure rates (since in the NRC definition, the run-time is one hour), it does have implications for the next failure mode.

For the FTR (fail-to-run or fail-to-run late term) failure mode, the comparison is more complicated. In this report, because the FTLR calculation was performed on a “demand” basis, all of the run-hours were used in the success term for FTR. The resulting point estimate (8.44E-4 per hour) is significantly lower than either the NROD/RADS or NRC Database point estimates. The count of EDG failures in this report is after the review and assessment of each EDG failure event, which resulted in the reduction in FTR failure events from 97 to 83. The failure count in this report is significantly lower than in the NROD/RADS result for the same time period.

On the other hand, if FTLR results (36,631 demands) were assumed to represent 1 hour of run-time (i.e., the first hour), then the Load-Run success data represents 36,631 run-hours. If this first-hour run time is subtracted from the total run-hours and this reduced run-hour total is used for the calculation of EDG-FTR, then the alternate point estimate (1.35E-3 per hour) is much closer to the NRC value (although somewhat smaller than the NROD/RADS result).

While it is not certain how NRC calculates run-hours in the FTR failure mode, it appears that they are following the alternate calculation above. The basis for the approach followed in this report is the way load-run (LR) success data is reported by utilities to INPO. In all cases, it is reported as “demand” events. Thus, it seems appropriate to consider FTS and FTLR as demand failure rates and to include all run-time success data in the FTR as hourly failure rates.

This difference in approaches for EDG-FTR is responsible for an almost doubling of the failure rates in this report, from 8.44E-4 per hour to 1.35E-3 per hour. This treatment is a significant issue in the estimation of EDG availability over a 24-hour mission time.

Table 4-1: FAILURE RATE CALCULATIONS for Emergency Diesel Generators (EDG)

ID	Description	Data Source	# Failures	Demands or Hours	d, h	# Compo-nents	Point Estimate [(a)]	Date Range	Data Analysis Source	Ratio (OG/NRC)
EDG-FTS	Diesel Generator Fails To Start	INPO ICES	120	41,772	d	236	**2.87E-03**	**2006 - 2015**	PWROG (this Report)	--
DGN-FS	Diesel Generator Fails To Start, Normally Standby	EPIX/ RADS	111	41,675	d	232	**2.66E-03**	**2006 - 2015**	NROD/RADS	1.079
EDG-FTS	Diesel Generator Fails To Start, Normally Standby	EPIX/ RADS	214	75,452	d	232	**2.84E-03**	1998 - 2015	NRC Dataset (2015)	1.013
EDG-FTLR	Diesel Generator Fails To Load and Run	INPO ICES	118	36,631	d [(b)]	236	**3.22E-03**	**2006 - 2015**	PWROG (this Report)	--
DGN-FR-E	Diesel Generator Fails To Load And Run, Early	EPIX/ RADS	137	36,260	h	232	**3.78E-03**	**2006 - 2015**	NROD/RADS	0.853
EDG-FTLR	Diesel Generator Fails To Load And Run, Early	EPIX/ RADS	239	65,993	h	232	**3.62E-03**	1998 - 2015	NRC Dataset (2015)	0.889
EDG-FTR	Diesel Generator Fails To Run	INPO ICES	83	98,306	h	236	**8.44E-04**	**2006 - 2015**	PWROG (this Report)	--
EDG-FTR[(c)]	Diesel Generator Fails To Run, Late Term	INPO ICES	83	61,675	h	236	**1.35E-03**	**2006 - 2015**	PWROG (this Report) [(c)]	--
DGN-FR-L	Diesel Generator Fails To Run, Late Term	EPIX/ RADS	129	64,476	h	232	**2.00E-03**	**2006 - 2015**	NROD/RADS	0.422 (0.673)[(c)]
EDG-FTR	Diesel Generator Fails To Run, Late Term	EPIX/ RADS	184	133,976	h	232	**1.37E-03**	1998 - 2015	NRC Dataset (2015)	0.615 (0.980)[(c)]

Notes:

(a) The point estimates are calculated as the ratio of the number of failures over the number of demands or run-hours. The NRC Dataset (2015) provides the following mean values:
- The mean value for EDG-FTS = 2.88E-3
- The mean value for EDG-FTLR = 3.72E-3
- The mean value for EDG-FTR = 1.52E-3

(b) EDG-FTLR is listed as an hourly failure in the NRC Dataset (2015) and in NROD/RADS, but the success data from INPO is "per demand" for this failure mode.

(c) This calculation of EDG-FTR is more consistent with the NRC approach. The Load-Run demands (36,631) are assumed to represent 1 hour of run-time (the first hour). This first-hour run time is subtracted from the total run-hours and these reduced run-hours are used for the calculation of EDG-FTR. Thus, EDG-FTR = 83 failures / (98305.7 - 36631.0) run-hours = 1.35E-3/hr. This point estimate is much closer to the NRC value.

4.2 EDG COMMON CAUSE FAILURE DATA

A total of six (6) sets of EDG events are classified as common cause failure (CCF) events[1] in the NROD Database (Reference 3) for the 10-year period, 2006 to 2015. These events were assessed by reviewing event descriptions in the NROD and INPO ICES Databases to determine whether the determination of these events as CCF events is appropriate. The summary of CCF events by EDG failure mode is provided in Table 4-2.

Table 4-2: Summary of EDG CCF Events by Failure Mode, 2006 to 2015

EDG Failure Mode	Count of CCF Events Based on NROD	Count of CCF Events Based on Assessment in Table 4-3
EDG-FTS (fail to start)	1	0
EDG-FTLR (fail to load-run)	2	1
EDG-FTR (fail to run)	3	0
TOTAL	**6**	**1**

The count of CCF events is a limited view of these events since they are assessed with a number of parameters. Table 4-3 provides a more complete definition of each set of CCF events including a summary description of the events. The last two columns of Table 4-3 provide an assessment (and basis) for whether these should be considered CCF events.

The conclusion of this assessment is that only one CCF event occurred in the 321 EDG failures during the period 2006 to 2015 (the EDG failure count is based on the assessment from this report). This single CCF event includes failures with a P_value of 0.1 (i.e., likely not actual failures) and should be modeled with limited coupling strength.

[1] Each CCF event includes multiple individual EDG failure events. In some cases, these individual failure events are reported separately; in other cases, they are reported together. A CCF event is used to mean the collection of individual failure events that make up the CCF.

Table 4-3: Assessment of EDG CCF Events, 2006 to 2015

INPO Data		NROD Data						PWROG Assessment of CCF Events	
Event Date	Event Record	Failure Mode	Record ID	Summary Description	Failures, CCCG	Coupling Strength, Time Delay	P_value	Assessment	Basis
10/7/2009	N/A	FTS	6681	Both EDGs unavailable due to improper switch position.	2 | 2	1.0, 1.0	1.0, 1.0	Not EDG failure events	This condition occurred during Modes 4 & 5 when typically much longer time is available to locally start the EDGs. These should not be counted as EDG failures and certainly not as a CCF event.
3/21/2015	316055	FTLR	11525, 11526	Relays potentially susceptible to noise from adjacent relays, could have prevented loading two EDGs.	2 | 4	1.0, 1.0	0.1, 0.1	CCF event, with limited coupling strength	This condition only occurred if the EDGs were already running and received a breaker closure (LOOP). Also, while the output breaker on EDG3 failed to close due to this condition, the EDG4 output breaker cycled unexpectedly but closed. Thus, the coupling strength should not be 1.0. Also, even the minimum P_value of 0.1 over-weights these events.
1/15/2013	305146	FTLR	10273	Two of four EDGs failed because breaker closing circuit was disabled due to surveillance test.	2 | 4	1.0, 1.0	1.0, 1.0	Not an EDG failure event	This event occurred during a surveillance test on the Remote Shutdown Panel. It resulted in a loss of power to one safety bus, but this is not an EDG failure. Also, this event was immediately recognized and the EDGs were returned to their normal configuration.
8/13/2014, 8/14/2014	313047, 312656	FTR	11365, 11367	Two of three EDGs failed due to cylinder cap screws (manufacturing defect).	2 | 3	1.0, 1.0	1.0, 1.0	Not EDG failure events	The INPO record includes the following, "Based on the extensive analysis performed by MPR, there is a strong justification that EDG 2-2 and 2-3 would have been capable of performing its specified safety function during its 24 hour mission time with the failure of 2 special cap screws on one cylinder on each EDG." Thus, with one bolt broken on one EDG and a second bolt cracked on another EDG, there appears to be no EDG failure events.
8/14/2012	301768, 301870	FTR	9995, 9996	Two EDGs inoperable due to flames coming from turbochargers.	2 | 2	1.0, 1.0	1.0, 1.0	Not EDG failure events	Based on the INPO record, these events were determined to not be MRFF or MSPI failures. While the EDGs were declared inoperable to identify and remedy the minor oil leak, this did not impact the ability of the EDGs to function.
7/12/2008	233170	FTR	6510, 8701	Five EDGs with cracked rubber gland in generator coupling due to poor maintenance.	5 | 5	1.0, 1.0	1.0, 0.1, 0.1, 0.1, 0.1	Not an EDG CCF event	While one EDG can be considered failed due to high vibration, the other EDGs had not shown high vibrations and the inspections showed "varying indications of degradation (cracking)." The other EDGs were not declared inoperable and the plant continued to operate with the EDG couplings replaced over the next few weeks.

5 PUMP COMMON CAUSE FAILURE DATA

A total of 13 common cause failure events are included for all Motor-Driven Pumps in the NROD Database (Reference 3) for the 10-year period, 2006 to 2015. These included a number of MDPs that are outside the scope of the pump reliability analysis (e.g., BWR Core Spray pumps).

These events have been assessed by reviewing event descriptions in the NROD and INPO ICES Databases to determine whether the determination of these events as CCF events is appropriate. The summary of CCF events by pump-type and failure mode is provided in Table 5-1.

Table 5-1: Summary of CCF Events by Pump Type and Failure Mode, 2006 to 2015

Pump Failure Mode	Pump-Type	Count of CCF Events Based on NROD	Count of CCF Events Based on Assessment (see Table 5-2)
FTS (fail to start)	MDP-NR-SWS	1	1
	MDP-SBY-AFW & TDP-SBY-AFW	1	0
	MDP-LP Core Spray (BWR)	1	1
FTR (fail to run)	MDP-NR-SWS	3	3 [(a)]
	MDP-NR-CVC (PDP)	2	2 [(b)]
FTR > 1HR (fail to run long term)	MDP-SBY-SWS	4	3
	MDP-SBY-HPI (CCP)	1	1
TOTAL		**13**	**11**

Notes:
(a) These 3 separate CCF events occurred at the same site and are applicable only to a limited plant configuration where SWS pumps are cooled by service water and potentially subject to debris clogging.
(b) These 2 separate CCF events are applicable only to positive displacement pumps, not to centrifugal charging pumps.

The count of CCF events is a limited view of these events since they are assessed with a number of parameters. Table 5-2 provides a more complete definition of each set of CCF events including a summary description of the events. The last two columns of Table 5-2 provide an assessment (and basis) for whether these should be considered CCF events.

The conclusion of this assessment is that two CCF events should not be classified as CCFs. However, several events are applicable only to specific pump configurations or pump types (e.g., PDPs).

Table 5-2: Assessment of Pump CCF Events, 2006 to 2015

INPO Data		NROD Data							PWROG Assessment of CCF Events	
Date	Event Record	Record ID	Component	Failure Mode	Summary Description	Failures, CCCG	Coupling Strength, Time Delay	P_value	Assessment	Basis
11/3/2006	223703, 223704, 223705	452, 453, 454	MDP-SBY-AFW and TDP-SBY-AFW	FTS	Both trains not aligned for automatic actuation. Third event included only shows up when TDP is selected, though it also says MDP. Group size is three. So it appears the TDP is included in this group (note that this is the only TDP CCF event in NROD).	3 | 3	1.0, 1.0	1.0, 1.0, 1.0	Not a CCF event.	These events involved AFW system controls not aligned for auto actuation while in Mode 2 & 3. In those modes, the time available for actuation of AFW is much longer. To characterize these events as CCF events is to over-emphasize the importance of common cause failures for AFW. There is no means to provide limited weighting that doesn't overstate the real impact of these events.
/25/2007, 2/8/2007	224763, 225014	1434, 1435	MDP-NR-SWS	FTS	Mechanical linkage rod failure (breaker related). Two of four pumps failed.	2 | 4	1.0, 0.5	1.0, 1.0	CCF determination is OK.	-----
2/18/2015	(not found)	11507	MDP-SBY-LPI (BWR Core Spray)	FTS	Two Core Spray pumps automatic initiation inoperable.	2 | 4	1.0, 1.0	0.5, 0.5	CCF determination is OK.	-----
6/21/2008, 6/28/2008	232923, 233001	6534, 6535	MDP-NR-SWS	FTR	Debris obstructed flow to oil cooler. Related to recent flooding.	2 | 3	1.0, 0.5	1.0, 1.0	CCF event with limited applicability.	This event is applicable only to a limited plant configuration where SWS pumps are cooled by service water and potentially subject to debris clogging.
8/25/2008, 8/29/2008	233596, 233726, 233797	6537, 6538	MDP-NR-SWS	FTR	Debris obstructed flow to oil cooler. Related to recent flooding.	2 | 3	1.0, 0.5	1.0, 1.0	CCF event with limited applicability.	Same comment as event in June 2008.

Table 5-2: Assessment of Pump CCF Events, 2006 to 2015

INPO Data		NROD Data							PWROG Assessment of CCF Events	
Date	**Event Record**	**Record ID**	**Component**	**Failure Mode**	**Summary Description**	**Failures, CCCG**	**Coupling Strength, Time Delay**	**P_value**	**Assessment**	**Basis**
10/6/2008	234302, 234303, 234304, 234319	6541, 6542, 6543	MDP-NR-SWS	FTR	Pumps were in standby and lost cooling water to motor bearing oil coolers. Would have failed to run if needed. Related to recent flooding.	3 | 3	1.0, 1.0	1.0, 1.0, 1.0	CCF event with limited applicability.	Same comment as event in June 2008.
1/9/2010, 1/15/2010	241078, 241179	7403, 7404	MDP-NR-HPI (CVCS PDP)	FTR	Two PDP check valves' wear leads to low flow; manufacturing defect.	2 | 3	1.0, 1.0	1.0, 1.0	Potential CCF event for check valves or for PDPs (not Centrifugal Charging pumps). P_values should be 0.5, consistent with the May 2010 events.	This event appears to be a marginal failure (reduced flow), and appears to apply to the discharge check valves associated with the PDP only ("Degradation of P-55C flow capacity was due to wear of the plate disc, a component of the discharge check valve assembly.") IF the check valves are within the PDP component boundary, then this is a CCF applicable only to PDPs.
5/2/2010, 5/4/2010	243049, 243082	8631, 8632	MDP-NR-HPI (CVCS PDP)	FTR	Two PDP discharge check valves fail due to manufacturing defect.	2 | 3	1.0, 1.0	0.5, 1.0	Potential CCF event for check valves or for PDPs (not Centrifugal Charging pumps)	Same comment as January 2010 events.
6/30/2006	221954	3031, 3032	MDP-SBY-SWS	FTR>1H	Erosion of cooling coils led to water in the motor oil reservoir, affecting three pumps.	3 | 4	1.0, 1.0	1.0,1.0, 1.0	CCF determination is OK, but P_values should be 1.0, 0.5, 0.5.	This event involved one failure (pump A) and potential (but not actual) failures on pumps B and C.

Table 5-2: Assessment of Pump CCF Events, 2006 to 2015

INPO Data		NROD Data							PWROG Assessment of CCF Events	
Date	Event Record	Record ID	Component	Failure Mode	Summary Description	Failures, CCCG	Coupling Strength, Time Delay	P_value	Assessment	Basis
5/6/2008	232246	699, 700	MDP-SBY-SWS	FTR>1H	Cooling lost to two of four pumps due to clogging apparently introduced by the test procedure. Since trains are not tested together, this could likely only affect one train at a time, but the CCCG is defined as four.	2 | 4	1.0, 1.0	1.0,1.0	CCF determination is OK.	-----
11/4/2008	234790	4822, 6851	MDP-SBY-SWS	FTR>1H	Hose in suction caused pump trips. “Multiple” pumps affected.	2 | 6	0.1, 1.0	1.0,1.0	CCF determination is OK.	The events on Nov 4 and Nov 7 & 8 should be counted as ONE CCF event.
11/7/2008, 11/8/2008	234865	4823, 4824	MDP-SBY-SWS	FTR>1H	Hose material in suction had significant impact on flow rate. Two pumps affected.	2 | 6	0.5, 1.0	1.0,1.0	Not a (new) CCF event.	The events on Nov 7 & 8 are a continuation of the condition caused on Nov 4th.
1/30/2013	302614	10475, 10476	MDP-SBY-HPI	FTR>1H	HPI pump operation in runout could damage pumps.	2 | 2	1.0, 1.0	0.5, 0.5	CCF determination is OK (although this seems to be highly uncertain).	-----

6 CONCLUSIONS

This report documents investigations into NRC component reliability databases that should support detailed engagement with the regulator to improve the quality and applicability of these databases.

6.1 DATA ISSUES

The NRC, through analysts at the Idaho National Laboratory (INL), is the author of the major generic datasets for component reliability data (References 1 to 4) that are used throughout the US NPPs as well as internationally. These datasets are comprehensive in their scope and are based on detailed data collection and data analysis methods. As such, they have no equal domestically or internationally as a quality source of generic failure rate estimates.

However, a detailed review of these datasets identified some issues related to potential problems or limitations of these NRC datasets when used in utility PRAs. These issues have been classified into three groups:

1. **Data Quality Issues (DQ).** Data quality issues relate to problems with the NRC datasets that appear to be errors. These are relatively minor in light of the large data analysis effort, but represent areas that should be reviewed and corrected in the next data update. These nine issues are described in Section 2.1, with details in Appendix A.1.
2. **Data Aging Issues (DA).** The most significant data issues identified in the NRC datasets relate to the use of a wide date-range of reliability data that is not reflective of more current component reliability. These issues are addressed in the first two items related to time trends. The other data aging issues relate to the use of very old data for a few components. These five issues are described in Section 2.2, with details in Appendix A.2.
3. **Data Classification Issues (DC).** Data classification has to do with several related issues including the change in component failure rate identifiers and descriptions from one revision of the NRC dataset to another. This group of issues also addresses the treatment of component leakage, spurious operation failure modes, and highly recoverable failures. These ten issues are described in Section 2.3, with details in Appendix A.3.

The suggested changes identified for each issue were developed to support a constructive discussion with NRC.

Finally, Section 3 lists three potential changes to the PRA Standard related to data issues.

6.2 COMPONENT RELIABILITY ANALYSIS

Reliability data was collected and analyzed for EDGs (Section 4) for the period 2006 to 2015. The purpose of this effort was to provide independent estimates of component failure rates that could be compared to the NRC datasets. Because the NRC Dataset (2015) represents data from the period 1998 to 2015, a second estimate was generated from NROD/RADS data for the same time period, 2006 to 2015, as this report uses. This allowed a more direct comparison of the inputs to the failure rate calculations. The comparisons were performed using point estimate calculations of the failure rates from different sources. This allowed a simple comparison which suited the purpose of this analysis, to compare the different sources and determine the basis for any differences.

CCF events were reviewed from the NROD Database for EDGs and pumps for the period 2006 to 2015. An assessment was made for each CCF event regarding whether the event was correctly categorized.

7 REFERENCES

1. NRC Dataset (2015), "Summary of SPAR Component Unreliability Data and Results: 2015 Parameter Estimation Update," http://nrcoe.inl.gov/resultsdb/AvgPerf/, 2016.
2. NRC CCF Dataset (2015), U.S. Nuclear Regulatory Commission, "CCF Parameter Estimations, 2015 Update," http://nrcoe.inel.gov/resultsdb/ParamEstSpar/, 2016.
3. NROD Database, http://nrcoe.inl.gov/results.
4. NUREG/CR-6928, "Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants," Idaho National Laboratory, February 2007.
5. NUREG/CR-5497, "Common Cause Failure Parameter Estimations," Idaho National Laboratory, 1998.
6. ASME/ANS PRA Standard RA-Sb-2013, "Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications," 2013.
7. NUREG/CR-6823, "Handbook of Parameter Estimation for Probabilistic Risk Assessment," Sandia National Laboratories, September 2003.

APPENDIX A DATA ISSUES

This appendix provides the details of the investigations into a number of issues related to the NRC generic component failure rate and common cause failure parameter datasets used in US utility PRAs. The issues that initiated each investigation are identified in a text box. In some cases, the issue was produced based on initial review of the generic data sources. In other cases, the issue was proposed and investigated based on previous experience with data analysis.

The data issues were organized into the following three groups (and labeled with a corresponding ID):

- Data Quality Issues with NRC Datasets (DQ)
- Data Aging Issues with NRC Datasets (DA)
- Data Classification Issues with NRC Datasets (DC).

A.1 NRC DATASETS: DATA QUALITY ISSUES (DQ)

DQ.1 General Issues with NRC Dataset (2015)

ISSUE: Some specific quality issues were identified based on an initial review of the NRC Dataset (2015). Further reviews are warranted to identify any additional quality issues.

A number of issues have been identified with the NRC Dataset (2015), including duplicate entries, documentation errors in the Data Source and Comment fields, questionable number of demands and run-hours, and entries labeled fail-to-start but identified as per-hour rather than per-demand.

The tables below identify a number of minor quality issues. Table DQ.1-1 identifies 20 pairs of duplicate entries, with different IDs but identical data entries. Table DQ.1-2 identifies a number of additional entries with different data issues, as described in the last column.

Suggestion for NRC/INL: Review the data issues and revise the NRC Dataset (2015) accordingly. Some of the issues are clearly errors that, hopefully, can be addressed easily. Other issues may involve some level of judgment regarding what this data is intended to represent and how it will be used. The PWROG would like to be involved in helping to make those decisions.

Table DQ.1-1: Pairs of Duplicate Entries with Different IDs

ID	Failures	Demands or Hours	Components
TBV-FTO	8	2,725	73
TBV-FTOC	8	2,725	73
SVV-FTC-PWR-RCS	1	2,907	155
SVV-FTO-PWR-RCS	1	2,907	155
PLF FTOP	3	6,075	*
PLL FTOP	3	6,075	*
PORV-FTO-PPR	16	6,130	114
PRV-CC-PZR	16	6,130	114
STF FTOP-D	5	6,750	*
STL FTOP-D	5	6,750	*
ARV-OO-MSS	19	10,401	111
PORV-FTC-MSS	19	10,401	111
ARV-CC-MSS	42	10,401	111
PORV-FTO-MSS	42	10,401	111
ACX-FTS	45	17,336	139
AHU-NR-FTS	45	17,336	139
IAS-FLT-FC	0	122,688	2
IAS-FLT-PG	0	122,688	2
CHL-FTR<1H	61	279,348	63
CHL-FTR>1H	61	279,348	63
MDC-FTR<1H	22	1,683,943	58
MDC-FTR>1H	22	1,683,943	58
SWS-TSA-PG	0	2,331,600	15
TSA-PG-NE-SWS	0	2,331,600	15
TDP-FR-NR-MFW	62	5,984,882	43
TDP-FS-NR-MFW	62	5,984,882	43
TDP-NR-FTR	62	5,984,882	43
STF FTOP-R	0	9,831,970	*
STL FTOP-R	0	9,831,970	*
TSA-FR	97	30,417,290	212
TSA-FS	97	30,417,290	212
TSA-FTOP	97	30,417,290	212
HTX-CCW-LOHT	17	34,265,020	227
HTX-PG-CCW	17	34,265,020	227
PORV-FC	13	49,398,360	317
PORV-FC-MSS	13	49,398,360	317
SRV-ELS	0	72,220,220	558
SRV-FC	0	72,220,220	558
ROD-FTOP	20	132,832,800	846
ROD-SOP	20	132,832,800	846

Notes:

* These entries are blank in the NRC Dataset (2015).

Table DQ.1-2: Miscellaneous Issues with the NRC Dataset (2015) [(a)]

Component Failure Mode	Description	Data Source	Failures	Demands or Hours	d or h	Compo-nents	Mean	EF	Date Range	Effective Date	Data Issue
AFW-EDP-FTR<1H	AFW Engine-driven pump Fails to Run <1H	EPIX/ RADS	4	739	h	5	6.09E-03	2.0	1998 - 2015	Dec-2016	Limited Data (< 1000 hrs)
AFW-EDP-FTR>1H	AFW Engine-driven pump Fails to Run >1H	EPIX/ RADS	2	262	h	5	9.53E-03	2.5	1998 - 2015	Dec-2016	Limited run-hours do not justify separate data parameters for Early Term and Late Term.
AOV-FTC	Air Operated Valve Fails To Close	EPIX/ RADS	53	201,147	d	1767	3.63E-04	7.6	1998 - 2015	Dec-2016	Questionable # of demands (same as AOV-FTOC)
AOV-FTO	Air Operated Valve Fails To Open	EPIX/ RADS	78	201,147	d	1767	3.91E-04	5.2	1998 - 2015	Dec-2016	Questionable # of demands (same as AOV-FTOC)
CRB-CO-480	Low Voltage (480 v) Circuit Breaker Spurious Operation	EPIX/ RADS	39	396,295,000	h	2629	9.97E-08	1.3	1998 - 2015	Dec-2016	ID should be CBK-xxx to be consistent with other circuit breakers
CRB-FTOC-480	Low Voltage (480 v) Circuit Breaker Fails To Open/Close	EPIX/ RADS	56	55,060	d	1776	1.03E-03	1.2	1998 - 2015	Dec-2016	ID should be CBK-xxx to be consistent with other circuit breakers
CSW-MDP-FR	CSW Motor Driven Pump Fails to Run	EPIX/RADS	25	3,654,539	h	32	6.98E-06	1.4	1998 - 2015	Dec-2016	Data variable and description should be CWS (circ water system) rather than CSW per Table 2-2 of Datasheets.
CTG-FTR	Gas Turbine Generator Fails To Run, Late Term	EPIX/RADS	5	648	h	2	8.49E-03	1.9	1998 - 2015	Dec-2016	Limited run-hours do not justify separate data parameters for Early Term and Late Term.
HCU-FTI	Hydraulic Control Unit Fails to Insert	EPIX/ RADS	0	---	d	0	--		1998 - 2015	Dec-2016	No Failure Rate
MCC-FTOP	Motor Control Center Fail to Operate	EPIX/RADS	6	34,080,880	h	217	1.91E-07	1.8	1998 - 2018	Dec-2016	The end of the Date Range (2018) is inconsistent with the rest of the data (2015) and appears to be in error.
MDC-FTR>1H	Motor Driven Compressor Fail To Run (> 1 Hour)	EPIX/RADS	22	1,683,943	h	58	1.34E-05	1.4	1998 - 2015	Dec-2016	It appears that the data (successes, failures) for MDC-FTR<1H were used here.
MDP-CCW-FTS	CCW Motor-driven pump Fail to Start	EPIX/ RADS	69	88,693	h	291	8.78E-04	4.0	1998 - 2015	Dec-2016	Labeled FTS, but "h" (per hour)
MDP-SBY-FTR>1H	Motor-Driven Pump Fails To Run, Late Term	EPIX/ RADS	143	20,062,180	h	1311	1.15E-05	6.5	1998 - 2015	Dec-2016	# of run-hours seems to be too high for standby pump (based on RunHrs per pump per yr)
MOD-ILS	Motor Operated Damper Internal Leakage (Small)	EPIX/ RADS	1	17,147,900	d	111	8.75E-08	3.3	1998 - 2015	Dec-2016	Questionable # of demands

Table DQ.1-2: Miscellaneous Issues with the NRC Dataset (2015) [(a)]

Component Failure Mode	Description	Data Source	Failures	Demands or Hours	d or h	Compo-nents	Mean	EF	Date Range	Effective Date	Data Issue
MOV-FTC	Motor Operated Valve Fail To Close	EPIX/ RADS	234	740,890	d	6902	3.35E-04	3.0	1998 - 2015	Dec-2016	Questionable # of demands (same as MOV-FTOC)
MOV-FTC-BFV	Butterfly Valve Fail To Close	EPIX/ RADS	34	109,522	d	961	3.38E-04	4.0	1998 - 2015	Dec-2016	Questionable # of demands (same as MOV-FTOC)
MOV-FTO	Motor Operated Valve Fail To Open	EPIX/ RADS	293	740,890	d	6902	4.21E-04	2.3	1998 - 2015	Dec-2016	Questionable # of demands (same as MOV-FTOC)
MOV-FTO-BFV	Butterfly Valve Fail To Open	EPIX/ RADS	27	109,522	d	961	2.51E-04	1.3	1998 - 2015	Dec-2016	Questionable # of demands (same as MOV-FTOC)
NSW-MDP-FR	Nuclear Service Water MDP Fails to Run	EPIX/RADS	64	10,256,170	h	104	6.72E-06	4.0	1998 - 2015	Dec-2016	This variable is named SWN (normally operating SW) in the data sheets (Table 2-2). Also, this data set has 104 components compared to MDP-SWS-FTR which has 106. It is not clear what the difference is between these two groups.
PDP-SBY-FTR>1H	Positive Displacement Pump Fails To Run, Late Term	EPIX/ RADS	2	1,710	h	72	1.46E-03	2.5	1998 - 2015	Dec-2016	Limited run-hours do not justify separate data parameters for Early Term and Late Term.
PLDT FTOP	Process Logic (Delta Temperature) Fail to Operate	RPS SSs	24	4,887	d	---	5.07E-03	8.4		Feb-2007	Documentation error. The Comment says, “The PLL data was used to estimate the flow process logic reliability.” It should not refer to flow devices.
PMP-Volute	Pump Volute Fails To Run (Driver Independent Centrifugal Pumps)	EPIX/ RADS	25	158,885	h	207	1.60E-04	1.4	1998 - 2015	Dec-2016	# of run-hours seems to be too high compared to other MDP-SBY based on RunHrs per pump per yr)
PORV-FC	Main Steam Power Operated Relief Fails To Control (Cooldown)	EPIX/ RADS	13	49,398,360	d	317	2.57E-07	10.0	1998 - 2015	Dec-2016	Questionable # of demands
PORV-FC-MSS	Main Steam Power Operated Relief Fails To Control (Cooldown)	EPIX/ RADS	13	49,398,360	d	317	2.57E-07	10.0	1998 - 2015	Dec-2016	Questionable # of demands
PORV-L	PORVs/SRVs Open During LOOP	Special Calc			d	0	1.48E-01			Nov-2011	Data Source should use reference: NUREG/CR-7037 Table 13
PORV-Lquid	PORVs Fail To Close After Passing Liquid	Special Calc	0	7	d	0	6.25E-02	10.3		Nov-2011	Data Source should use reference: NUREG/CR-7037 Table 30
PORV-P1	PWR One PORV/SRV Sticks Open	Special Calc	18	13,897	d	0	1.46E-03	2.8		Nov-2011	Data Source should use reference: NUREG/CR-7037 Table 30

Table DQ.1-2: Miscellaneous Issues with the NRC Dataset (2015) [(a)]

Component Failure Mode	Description	Data Source	Failures	Demands or Hours	d or h	Compo-nents	Mean	EF	Date Range	Effective Date	Data Issue
PORV-T	PORVs/SRVs Open During Transient	Special Calc			d	0	3.55E-02			Nov-2011	Data Source should use reference: NUREG/CR-7037 Table 13
ROD-FTOP	Control Rod Fails to Operate/Insert Rod	EPIX/ RADS	20	132,832,800	d	846	1.54E-07	1.4	1998 - 2015	Dec-2016	Questionable EF [(b)]
STT FTOP-D	Sensor/Transmitter (Temperature) Fail to Operate on Demand	RPS SSs	17	40,759	d	---	4.32E-04	8.4		Feb-2007	Documentation error. The Comment says, "The STL data was used to estimate the flow sensor/transmitter reliability." It should not refer to flow devices.
SWS-MDP-FS-NE	SWS Pump Non-Enviro-FTS	EPIX/ RADS	149	249,957	h	446	7.55E-04	3.8	1998 - 2015	Dec-2016	Labeled FTS, but "h" (per hour)
TBV-FTC	Turbine Bypass Valve Fails to Close	EPIX/ RADS	0	2,725	d	73	1.83E-04	8.4	1998 - 2015	Dec-2016	Questionable # of demands (same as TBV-FTOC)
TBV-FTO	Turbine Bypass Valve Fail to Open	EPIX/ RADS	8	2,725	d	73	3.12E-03	1.7	1998 - 2015	Dec-2016	Questionable # of demands (same as TBV-FTOC)
TDP-FR-L-HCI-RCI	HCI-RCI Turbine Driven Pump Fails To Run, Late Term	EPIX/ RADS	10	1,922	h	59	5.52E-03	2.8	1998 - 2015	Dec-2016	Limited run-hours do not justify separate data parameters for Early Term and Late Term.
TDP-FS-NR-MFW	MFW Turbine Driven Pump Fails To Start, Normally Running	EPIX/ RADS	62	5,984,882	d	43	1.09E-05	3.2	1998 - 2015	Dec-2016	# of demands seems to be too high (based on demands per pump per yr)
TNK-FC	Tank Rupture	EPIX/RADS	15	59,350,270	h	379	2.61E-07	1.5	1998--2018	Dec-2016	The end of the Date Range (2018) is inconsistent with the rest of the data (2015) and appears to be in error.
TSA-FS	Traveling Screen Fails To Start	EPIX/ RADS	97	30,417,290	d	212	3.67E-06	6.9	1998 - 2015	Dec-2016	Questionable # of demands
VBV-FTC	Vacuum breaker fails to close	EPIX/ RADS	6	27,842	d	167	2.15E-04	5.7	1998 - 2015	Dec-2016	Questionable # of demands (same as VBV-FTOC)
VBV-FTO	Vacuum Breaker Valve Fail to Open	EPIX/ RADS	2	27,842	d	167	8.98E-05	2.5	1998 - 2015	Dec-2016	Questionable # of demands (same as VBV-FTOC)

Notes:
(a) The cells with red text are the ones that contain the error described in the last column.
(b) This entry (ROD-FTOP) has an error factor (1.4) that seems to be too small based on general observation. In the component failure modes listed in this table, the EFs range from 1.2 to 10.0. The range of EFs doesn't make sense since most of these entries have large amounts of data. It particular, the small EFs seem too small in general.

DQ.2 Datasets Consistency

ISSUE: The NRC Dataset (2015) and NRC CCF Dataset (2015) are not consistent in the total number of failure events. These two datasets do not quite match for event dates included. NRC dataset covers 1998 to 2015. NRC CCF Dataset (2015) covers 1997 to 2015. However, it is not clear the one additional year of data for NRC CCF explains the differences. In addition, inconsistencies were noted among the NRC CCF Dataset (2015), the NROD Database, and the NROD/RADS PRA Calculator.

Table DQ.2-1 provides examples of the discrepancy in counts of failure events between the NRC Dataset (2015) and the NRC CCF Dataset (2015).

Table DQ.2-1: Comparison of Count of Failure Events

Component Failure Mode	# Failure Events in NRC Dataset (1998 – 2015)	# Failure Events in NRC CCF Dataset (1997 – 2015)	Delta
EDG FTS	214	$258.4^{IND} + 4^{CCF} = 262.4$	48.4
EDG FTLR	239	$271.3^{IND} + 5^{CCF} = 276.3$	37.3
EDG FTR	184	$222.0^{IND} + 6^{CCF} = 228.0$	44.0
TD AFW FS	72	$89.0^{IND} + 0.0^{CCF} = 89.0$	17.0
TD AFW FR	40 + 13 = 53	$59.3^{IND} + 0.0^{CCF} = 59.3$	6.3

More significant inconsistencies were noted between the published 2015 NRC datasets and the results from the NROD Database. For example, for MOV-SOP (motor-operated valve spurious operation), the NRC Dataset (2015) shows 63 failure events while the NROD Database shows 48 events for the same time frame (1998 to 2015). See the response to Issue #DC.7 for additional comparisons of the count of spurious operation valve failure modes in the NRC Dataset (2015) with the count from the NROD Database.

Inconsistencies were noted between the NRC CCF Dataset (2015) and the NROD Database and the NROD/RADS PRA Calculator. It is not clear why there should be such a significant difference between the NROD Database and the NROD/RADS PRA Calculator. For the total pooled data for "generic demand CCF" events, the CCF count agreed (107), but the independent count was 3598.6 vs 3630.9. Similarly for the total pooled data for "generic rate CCF" events, the CCF count agreed (116), but the independent count was 3224.0 vs 3246.4. While the differences are small, it does point to a minor consistency issue.

Additional issues were identified for CCF events from the NROD Database:

- The search criteria for different categories sometimes overlap.

- In some cases, the number of events returned by the NROD Database was different than the number quoted in the report for NRC CCF Dataset (2015). It appears that there may be some binning to account for overlap, but it is not consistent.
- Occasionally, events are returned that do not match the search criteria.

In spite of these issues, the numbers of events from the database were generally similar to the numbers quoted in the report and the events themselves are judged to be appropriately characterized as CCF events.

Suggestion for NRC/INL: The total number of failure events should be consistent between the published NRC Datasets (2015) and the results from the NROD Database and the NROD/RADS PRA Calculator for the same component failure mode, since these are used to calculate component failure rates, the total failure rate and the CCF rate. It would help, as a start, to use a consistent set of event dates between the NRC CCF Dataset (2015) and NRC Dataset (2015). In addition, the counts should be consistent between published reports and the NROD Database and the NROD/RADS PRA Calculator.

DQ.3 Component Boundary

ISSUE: The component boundaries between NRC Dataset (2015) (as defined in NUREG/CR-6928) and NRC CCF Dataset (2015) should be consistent.

NUREG/CR-6928 and NRC CCF Dataset (2015) are not consistent in at least one important component boundary: EDGs. In Section 5.1 of NUREG/CR-6928, room cooling is excluded from the EDG component boundary while in NRC CCF Dataset (2015), heating, ventilation and AC are within the EDG boundary.

Suggestion for NRC/INL: The definitions of component boundaries should be consistent between these datasets, since these are used to calculate inter-related component failure rates, the total failure rate and the CCF rate. The boundary definitions used in NUREG/CR-6928 could be used for both datasets.

DQ.4 Failure Rate Changes

ISSUE: NRC datasets from 2007, 2010, and 2015 show significant changes in some component failure rate mean values. What are the reasons for these changes? Could these be based on changes in average component performance, changes in failure data collection or data treatment, changes in estimates of success data, etc.?

Table DQ.4-1 compares the mean values for 123 component-failure-mode IDs that are common between datasets. Because a number of component-failure-mode IDs were changed or added in the newer datasets (see Issue #DC.1), only 123 of 333 entries in 2015 can be compared.

The changes from 2010 to 2015 result in some increases (29) and some decreases (88), with 18 having increased failure rates by more than 30%. Similarly, changes from 2007 to 2015 result in some increases (27) and some decreases (25), with 22 having increased failure rates by more than 30%.

Table DQ.4-1: Comparison of Failure Rates in NRC Datasets 2015, 2010, & 2007

ID	2015 Mean	2010 Mean(b)	2007 Mean(b)	2015/2010	2015/2007
ACC-ELL	8.40E-09	7.77E-09	3.46E-09	1.08	2.43
ACC-ELS	1.20E-07	1.11E-07	4.94E-08	1.08	2.43
ADU-FTOP	5.00E-06	5.00E-06	5.00E-06	1.00	1.00
AOD-SOP	1.12E-07	7.27E-08	---	1.54	---
AOV-ELL	3.14E-09	3.86E-09	9.01E-10	0.81	3.48
AOV-ELS	4.49E-08	5.51E-08	1.29E-08	0.81	3.49
AOV-FC	2.28E-07	2.49E-07	3.00E-06	0.92	0.08
AOV-ILL	1.55E-09	1.94E-09	4.84E-09	0.80	0.32
AOV-ILS	7.76E-08	9.69E-08	2.42E-07	0.80	0.32
AOV-SOP	1.05E-07	1.31E-07	---	0.80	---
BAT-FTOP	3.72E-07	5.86E-07	1.86E-06	0.63	0.20
BCH-FTOP	2.59E-06	2.71E-06	5.08E-06	0.96	0.51
CHL-FTR	6.93E-05	3.05E-05	---	2.27	---
CHL-FTS	9.21E-03	1.30E-02	---	0.71	---
CKV-ELL	5.37E-10	7.35E-10	2.06E-09	0.73	0.26
CKV-ELS	7.67E-09	1.05E-08	2.94E-08	0.73	0.26
CKV-FTC	1.57E-04	2.38E-04	1.04E-04	0.66	1.51
CKV-FTO	9.24E-06	1.07E-05	1.30E-05	0.86	0.71
CKV-ILL	4.16E-09	6.15E-09	2.96E-08	0.68	0.14
CKV-ILS	2.08E-07	3.08E-07	1.48E-06	0.68	0.14
CKV-SC	5.63E-09	5.47E-09	---	1.03	---
CKV-SO	2.56E-09	3.48E-09	---	0.74	---
CRD-FTOP	1.15E-07	9.91E-08	1.32E-05	1.16	0.01
CRD-SOP	1.88E-07	1.94E-07	---	0.97	---

Table DQ.4-1: Comparison of Failure Rates in NRC Datasets 2015, 2010, & 2007

ID	2015 Mean	2010 Mean(b)	2007 Mean(b)	2015/2010	2015/2007
CTG-FTLR	5.79E-03	1.60E-05	---	361.88	---
CTG-FTR	8.49E-03	7.40E-03	---	1.15	---
CTG-FTS	5.12E-02	1.56E-02	---	3.28	---
EDG-FTLR(a)	3.72E-03	3.78E-03	2.90E-03	0.98	1.28
EDG-FTR(a)	1.52E-03	1.10E-03	8.48E-04	1.39	1.79
EDG-FTS(a)	2.88E-03	2.89E-03	4.53E-03	1.00	0.64
EDG-SBO-FTR	1.50E-03	1.30E-03	---	1.15	---
EDG-SBO-FTS	2.98E-02	4.32E-02	---	0.69	---
EDP-ELL	6.38E-08	8.40E-08	---	0.76	---
EDP-ELS	9.12E-07	1.20E-06	---	0.76	---
EDP-FTR>1H	1.98E-03	2.27E-03	---	0.87	---
EDP-FTS	2.17E-03	5.09E-03	---	0.43	---
FAN-SBY-FTR>1H	1.99E-04	4.54E-05	---	4.38	---
FAN-SBY-FTS	6.52E-04	8.42E-04	---	0.77	---
HCU-FTI	--	9.27E-06	---		---
HCU-FTOP	1.81E-08	3.28E-08	---	0.55	---
HCU-SOP	2.16E-08	1.94E-08	---	1.11	---
HOD-ILS	2.58E-08	3.60E-08	---	0.72	---
HOD-SOP	4.38E-07	6.11E-07	---	0.72	---
HOV-ELL	9.38E-09	1.56E-08	1.03E-09	0.60	9.07
HOV-ELS	1.34E-07	2.23E-07	1.48E-08	0.60	9.07
HOV-FC	4.57E-07	4.86E-07	3.00E-06	0.94	0.15
HOV-ILL	9.66E-10	5.72E-10	7.63E-10	1.69	1.27
HOV-ILS	4.83E-08	2.86E-08	3.82E-08	1.69	1.27
HOV-SOP	1.88E-07	2.00E-07	---	0.94	---
HTG-FTLR	1.62E-03	2.10E-03	---	0.77	---
HTG-FTS	1.58E-03	1.46E-03	---	1.08	---
INV-FTOP	4.97E-06	5.60E-06	5.28E-06	0.89	0.94
MCC-FTOP	1.91E-07	2.61E-07	---	0.73	---
MDC-FTR	6.51E-05	8.50E-05	---	0.77	---
MDC-FTS	3.41E-02	1.71E-02	---	2.00	---
MDP-ELL	2.04E-08	2.40E-08	8.05E-09	0.85	2.53
MDP-ELS	2.91E-07	3.42E-07	1.15E-07	0.85	2.53
MDP-SBY-FTR>1H	1.15E-05	1.04E-05	---	1.10	---
MDP-SBY-FTS	7.94E-04	9.47E-04	---	0.84	---
MOD-ILS	8.75E-08	1.39E-07	---	0.63	---
MOD-SOP	2.92E-08	4.62E-08	---	0.63	---

Table DQ.4-1: Comparison of Failure Rates in NRC Datasets 2015, 2010, & 2007

ID	2015 Mean	2010 Mean(b)	2007 Mean(b)	2015/2010	2015/2007
MOV-ELL	1.90E-09	2.29E-09	9.84E-10	0.83	1.93
MOV-ELS	2.71E-08	3.28E-08	1.41E-08	0.83	1.93
MOV-FC	5.90E-08	6.62E-08	3.00E-06	0.89	0.02
MOV-ILL	1.52E-09	2.02E-09	3.34E-09	0.75	0.46
MOV-ILS	7.58E-08	1.01E-07	1.67E-07	0.75	0.45
MOV-SOP	3.24E-08	3.39E-08	---	0.96	---
MSV-ELS	3.15E-08	1.34E-07	---	0.24	---
MSV-FTOC	8.93E-04	7.79E-04	---	1.15	---
MSV-ILS	8.01E-07	1.51E-06	---	0.53	---
MSV-SOP	3.10E-07	3.85E-07	---	0.81	---
ORF-PG	1.00E-06	1.00E-06	---	1.00	---
PDP-ELL	7.56E-08	5.18E-08	9.03E-09	1.46	8.38
PDP-ELS	1.08E-06	7.40E-07	1.29E-07	1.46	8.38
PDP-SBY-FTR>1H	1.46E-03	2.13E-03	---	0.69	---
PDP-SBY-FTS	1.53E-03	1.79E-03	---	0.85	---
PORV-ELS	7.20E-09	1.19E-07	---	0.06	---
PORV-FC	2.57E-07	2.70E-07	---	0.95	---
PORV-ILS	2.66E-07	5.08E-07	---	0.52	---
PORV-SOP	3.53E-07	4.65E-07	---	0.76	---
ROD-FTOP	1.54E-07	2.98E-07	---	0.52	---
ROD-SOP	1.54E-07	1.94E-07	---	0.79	---
RVL-ELS	2.60E-07	6.65E-08	---	3.91	---
RVL-FTC	6.34E-03	2.69E-03	---	2.36	---
RVL-FTO	1.07E-01	2.69E-03	---	39.80	---
RVL-ILS	1.19E-06	6.65E-08	---	17.90	---
RVL-SO	5.19E-08	6.65E-08	---	0.78	---
SMP-PG	1.02E-07	5.08E-07	---	0.20	---
SOV-ELL	1.71E-09	2.40E-09	6.53E-10	0.71	2.62
SOV-ELS	2.44E-08	3.43E-08	9.33E-09	0.71	2.61
SOV-FC	4.07E-07	3.00E-06	3.00E-06	0.14	0.14
SOV-ILL	2.86E-09	3.58E-09	5.56E-09	0.80	0.51
SOV-ILS	1.43E-07	1.79E-07	2.78E-07	0.80	0.51
SOV-SOP	6.62E-08	3.43E-08	---	1.93	---
SRV-ELS	6.92E-09	2.40E-08	---	0.29	---
SRV-FTC	8.86E-04	8.56E-04	7.95E-04	1.04	1.11
SRV-FTO	2.42E-03	2.77E-03	7.71E-03	0.87	0.31
SRV-SOP	1.40E-07	2.43E-07	---	0.58	---
SVV-ELS	1.18E-08	2.79E-08	---	0.42	---

Table DQ.4-1: Comparison of Failure Rates in NRC Datasets 2015, 2010, & 2007

ID	2015 Mean	2010 Mean(b)	2007 Mean(b)	2015/2010	2015/2007
SVV-FTC	1.47E-04	2.02E-04	6.76E-05	0.73	2.17
SVV-FTO	2.18E-04	4.23E-04	2.47E-03	0.51	0.09
SVV-ILS	6.86E-08	8.99E-08	---	0.76	---
TBV-FC	6.05E-07	1.05E-06	---	0.58	---
TBV-FTC	1.83E-04	2.47E-04	---	0.74	---
TBV-FTO	3.12E-03	4.20E-03	*	0.74	---
TDP-ELL	3.77E-08	5.07E-08	8.56E-09	0.74	4.40
TDP-ELS	5.38E-07	7.24E-07	1.22E-07	0.74	4.40
TDP-SBY-FTR>1H	2.10E-03	1.56E-03	---	1.35	---
TDP-SBY-FTS	6.01E-03	6.49E-03	---	0.93	---
TFM-FTOP	2.89E-06	9.44E-07	9.04E-07	3.06	3.20
TRK-PG	2.23E-06	3.95E-06	---	0.56	---
TSA-PG	2.53E-06	3.07E-06	---	0.82	---
VBV-FTC	2.15E-04	2.97E-04	3.42E-04	0.72	0.63
VBV-FTO	8.98E-05	2.24E-04	4.79E-04	0.40	0.19
VBV-ILS	2.94E-07	4.16E-07	---	0.71	---
XVM-ELL	7.91E-09	1.83E-08	3.12E-09	0.43	2.54
XVM-ELS	1.13E-07	2.62E-07	4.46E-08	0.43	2.54
XVM-ILL	1.38E-09	2.68E-09	1.33E-09	0.51	1.03
XVM-ILS	6.88E-08	1.34E-07	6.67E-08	0.51	1.03
XVM-SOP	5.07E-08	8.42E-08	---	0.60	---
CTF-STBY-FTR>1H	2.33E-06	---	4.49E-05	---	0.05
CTF-STBY-FTS	3.70E-04	---	2.31E-03	---	0.16
EOV-FTO	4.90E-03	---	1.07E-03	---	4.60

Notes:

(a) The EDG component failure mode IDs in 2007 had an additional “STBY”, e.g., EDG STBY FTS.

(b) Blank cells indicate component failure modes from the 2015 dataset that were not defined for the 2010 or 2007 datasets.

DQ.5 Failure Rates for Long-Term Run Failure Modes

ISSUE: Do the pump and DG failure event reports provide adequate support to separate Failures the 1st Hour from Longer-term (> 1 hour) Failures? Do the differences in failure rates and model impacts for the 1st hour vs longer-term (> 1 hour) runs justify the model complexity?

Several example component groups have been investigated, including emergency diesel generators, turbine-driven pumps, and motor-driven pumps. The investigations are summarized below.

(a) Emergency Diesel Generator

For the 2015 dataset, the FTR (> 1 hour) failure rate is about 2.5 times smaller than the FTLR (first hour). For the 2010 and 2007 datasets, the ratio FTLR/FTR is about 3.4. Thus, the long-term fail-to-run rate is smaller than the first hour rate, as one would suspect. The FTR failure rate increased by 30% from 2007 to 2010, and by 80% from 2007 to 2015. This appears to be due primarily to fewer estimated LATE (> 1 hour) run-hours per start: 2.5 hr per start (2007), 1.9 hr per start (2010), 1.8 hr per start (2015).

It is not clear why the average long-term run-hours per start have decreased over the three datasets, but the values (1.8 to 2.5 hours) look reasonable.

(b) Turbine-Driven AFW Pump

In the 2015 dataset, a separate entry was provided for AFW TD pumps. Previously the TD pump-standby data was pooled. Since we are interested in the TD AFW pump, that failure rate is used for 2015 in the following comparison.

For the 2015 dataset, the FTR>1HR failure rate is about 2.5 times smaller than the FTR<1HR. For the 2010 dataset, the ratio FTR<1HR / FTR>1HR is about 2.8. However, this included all TD pumps. The 2015 dataset identifies a total of 133 TD pumps, of which 74 are TD AFW pumps. For 2007, the long-term failure rate is much lower by a factor 20, compared to the 2015 failure rate. However, this failure rate was based on just 6 components.

Thus, the long-term fail-to-run rate is smaller than the first hour rate, as one would suspect. The FTR>1HR failure rates are about the same in 2010 and 2015. The estimated LATE (> 1 hour) run-hours per start: 0.4 hr per start (2010), 0.5 hr per start (2015).

The average long-term run-hours per start (0.4 to 0.5 hours) look reasonable, but indicate limited long-term data on which to base the long-term failure rate.

(c) Motor-Driven Pump, Standby

For the 2015 and 2010 datasets, the FTR>1HR failure rate is about 10 times smaller than the FTR<1HR.

Thus, the long-term fail-to-run rate is smaller than the first hour rate, as one would suspect. The FTR>1HR failure rates are about the same in 2010 and 2015, about 2 times the 2007 failure rate. For both 2015 and 2010 datasets, estimated LATE (> 1 hour) run-hours per start are about 40 hrs, compared to 7 hours for 2007.

This amount of run time per start seems extreme for standby pumps, since one would expect these pumps to be run for a few hours during tests.

(d) Motor-Driven Pump, Operating

The NRC datasets have only a single fail-to-run failure mode for normally operating pumps. The FTR failure rates have been relatively consistent: 4.5E-6/hr (2007), 3.5E-6/hr (2010), 3.8E-6 (2015).

Thus, the most significant issue for most of these component-groups is the total long-term run data. For EDGs, the average run-time per start has decreased over the 3 NRC datasets. For TD AFW pumps, the average run time is just over 1 hour, so very little long-term run data.

Suggestion for NRC/INL: Review the “MD Pump – Standby“ data to see why the average run time per start is so high. This data appears to be representing normally running pumps rather than standby pumps.

DQ.6 Flow Sensor Failure Rate Based on Judgment

ISSUE: The FLOW sensor/transmitter failure rates (STF FTOP-D, STF FTOP-R) are based on the LEVEL sensor/transmitter event data (STL FTOP-D, STL FTOP-R) in NUREG/CR-6928 (from NUREG/CR-5500). Is there adequate basis for this treatment?

No basis could be identified to justify use of level sensor data to calculate flow sensor failure rates. The requirement DA-D2 in the PRA Standard (Addendum B) allows for such estimation, but includes the phrase “use data or estimates for the most similar equipment available…”. A basis should be provided for why level (and not pressure or temperature) is the most appropriate similar equipment.

Suggestion for NRC/INL: Develop failure rates specifically for FLOW process logic and FLOW sensors/transmitters based on recent failure event data (2006 to 2015). If that change is not possible in the near term, at least provide a basis for the use of LEVEL data as an appropriate surrogate for FLOW sensors.

DQ.7 Basis for Error Factors

ISSUE: The data distributions in the NRC Dataset (2015) may not fully account for the uncertainties in the failure rate estimates. The Error Factors range from 1.2 to 18.8, with about 90 component failure modes have an EF less than 2.0.

The largest EFs (18.8) are applied to the "large leakage" failure rates based on judgment. For most of the other components, the EFs result from the Bayesian updating of a non-informative prior distribution with large amounts of generic data. The results of this mathematical treatment assuming homogeneous data populations are distributions with small error factors. In reality, there are a number of uncertainties not reflected in the raw number of failures and successes for a specific component failure mode. For example, the following uncertainties are not explicitly accounted for:

- Uncertainty in the number of failure events
- Uncertainty in the type and consequence of the failure event
- Uncertainty in the number of demands or run times
- Uncertainty in the homogeneity of components in the group based on component attributes such as manufacturer, size, process fluid, ambient environment, etc.
- Uncertainty in the homogeneity of components based on plant-to-plant variability

The use of Beta and Gamma distributions in the NRC datasets also impacts how the data distribution is represented. It is not clear that these distributions best represent the uncertainty (see Issue #UD.12).

Additional uncertainties may arise based on how a generic failure rate is applied to a specific component, especially when the component is not directly represented in the generic data.

The current EFs underestimate the uncertainty in most component failure rates. A method of accounting for the other sources of uncertainty should be considered. This includes generic sources of uncertainty and sources of uncertainty that arise based on the specific application of the data. Note, this issue of underestimated EFs has a direct impact on the calculation of the SOKC, resulting in an underestimate of the SOKC.

DQ.8 CCF Weighted Data

ISSUE: To what extent are CCF values in NRC datasets based on fractional events (e.g., weighting factors less than 1.0)? For CCF parameters based on sparse data, is it possible that such low weighted events (i.e., not likely to be a CCF) are controlling the calculation?

NUREG/CR-6268 documents the CCF database and analysis system set up by INL for NRC. This NUREG describes "a database" that matches the NROD Database, though that name is never used in the NUREG. The NUREG suggests various weighting factors that are incorporated via the database for events based on uncertainty in Timing, Component Degradation, and Shared Cause. Three (3) additional factors are used in assessing CCF failure events: Shock Type, Failure Mode Applicability, and Defense Mechanism.

These six (6) factors are described below with regard to their impact on the CCF calculations:

1. Timing
    - A weighting factor used to assess whether a set of failures constitute CCF based on the time between the failures.
    - Range is from 0.1 to 1.0.
    - For more than two components, the maximum time between two events is used.
    - For announced failures (time-based):
        - If time < PRA mission, weight = 1.0.
        - If PRA mission < time < 2x PRA mission, weight = 0.5.
        - If 2x PRA mission < time < 3x PRA mission, weight = 0.1.
        - If time > 3x PRA mission or time < 3x PRA mission with equipment overhaul as a result of the failures, considered not a CCF.
        - One success between failures, weight = 0.5.
        - Two successes between failures, weight = 0.1.
    - For unannounced failures (demand-based):
        - Zero successes of subsequent components between failures, weight = 1.0.
        - One success of subsequent component between failures, weight = 0.5.
        - Two successes of subsequent components between failures, weight = 0.1.
        - More than two successes of subsequent components between failures, considered not a CCF.
2. Component Degradation (P_value)
    - A weighting factor used to assess whether a component was failed (or could fail in the same class of event) during the PRA mission.
    - Range is from 0.0 to 1.0.
    - If the component is failed, p = 1.0.
    - If the component is partially failed (i.e., it could still fail during the PRA mission), p = 0.5.

- The component had only slight degradation but the safety function was impacted, p = 0.1.
- Considered inoperable but the component could still perform its PRA function, p = 0.01.
- No failure, p = 0.0.

3. Shared Cause Factor (Coupling Strength)
    - A weighting factor used to assess the degree to which the causes for failure are sufficiently common.
    - Range is from 0.1 to 1.0.
    - If it is clear that the cause is the same, coupling strength = 1.0.
    - There is evidence that the cause is the same, though it is not specified in the event description, coupling strength = 0.5.
    - The cause is different, but there is still some evidence that a root cause is the same, coupling strength = 0.1.
4. Shock Type
    - Lethal is defined as all components failed regardless of group size.
    - Lethal means the shared cause factor (coupling strength) = 1.0 and the P_value = 1.0.
5. Failure Mode Applicability
    - A weighting factor used to assess the potential that one CCF event may express as multiple different failure modes.
    - Range is from 0.0 to 1.0.
    - If multiple applicable failure modes, they are entered with weighting factors simply based on the number of failure modes; e.g., two failure modes → 0.5 each.
6. Defense Mechanism (Applicability Factor)
    - This is a multiplicative factor (less than 1.0) intended to capture the benefits of existing defenses against the CCF event. For example, indications that would lead to immediate identification and correction of a failure.

The method is to develop impact vectors for CCF events and then translate those into CCF parameters (alpha or MGL). This is all done in the database while simultaneously accounting for the various weights as well as applicability factors and mapping factors. Given the description in NUREG/CR-6268 and the outputs of the NROD/RADS PRA Calculator, it is difficult to reproduce even the simplest of cases independently. For example:

- It is not clear how each weighting factor is applied. For example, P_values are applicable to individual failures within a CCF event but timing depends on all of the failures in the CCF event.
- It is not clear how the applicability factor is used (defense mechanisms). Both this and the mapping factors are black boxes.
- The NROD/RADS PRA Calculator shows independent number of events and then an effective number of independent events, but no details about how it arrived at the effective number, though it is presumably based on similar weighting factors as

described above, but for independent events. A similar effective number of CCF events should be getting generated as well, but it is not shown, which contributes to the difficulty in reproducing the results.

- It is not clear how CCF parameters are generated when there are zero events.

Also it was observed that only three (3) LETHAL events were identified in the NROD/RADS PRA Calculator for all CCF demand- and rate-based events. This seems to imply that there are only three lethal events in the CCF database, which makes one wonder why so few and why use the Lethal/Non-Lethal designators if so few are indeed Lethal. Also, it is not clear if the mapping up of lethal events is only applicable to those the three identified or if the database use some other criteria (e.g., coupling strength = P_value = 1.0).

Suggestion for NRC/INL: Create a database guideline that provides the details regarding how the NUREG method gets implemented in the NROD/RADS PRA Calculator – specifically how weighting values and mapping-up values are created.

In addition, review whether the mapping-up process was consistently applied considering the lack of clarity in treating lethal shock cases.

DQ.9 SPAR Models

ISSUE: The NRC datasets, including NUREG/CR-6928, are developed to support NRC SPAR models. Are these datasets adequate to meet the requirements for Data in the PRA Standard?

No Significant Issue: From PRA Standard (Addendum B), SR DA-C1 states, "USE generic parameter estimates from recognized sources…" and includes NUREG/CR-6928 as an example of "recognized source" for component failure rates. There are no requirements that the generic data reflect current operational practices, for example. Thus, the NRC datasets meet the PRA Standard by default – there is nothing better.

Potential Change to PRA Standard: The PRA Standard DA-C1 should define the attributes of an acceptable generic data source, rather than citing examples without any challenge.

A.2 NRC DATASETS: DATA AGING ISSUES (DA)

DA.1 Time Trends of Component Failure Events

ISSUE: For component failure rates in the NRC Dataset (2015) that include data more than 10 years old, is that data representative of current component performance?

The Table DA.1-1 below presents the number of failures for several component failure modes, comparing two 10-year periods (from the NROD Database). As the comparison demonstrated, the number of failures has decreased, in some cases significantly, for all but two component failure modes. Assuming the success data is the same (same number of components, same start/run data), this is reflective of overall improved component reliability. Also see Item #DA.2 which addressed the trend for CCF events over the same time periods.

Table DA.1-1: Number of Failure Events by Time Period

Component Failure Mode	Number of Failure Events		
	1996-2005	**2006-2015**	**Percent Change**
DG FTS	161	134	16.8% decrease
DG FTLR	150	142	5.3% decrease
DG FTR	87	166	90.8% *increase*
TD AFW FTS	49	56 *	14.3% *increase*
TD AFW FTR	36	32 *	11.1% decrease
MOV-FTO/C	404	312	22.8% decrease
CKV FTO/C	41	26	36.6% decrease
MDP-FTS	464	313	32.5% decrease
MDP-SBY-FTR	179	130	27.4% decrease
MDP-NR-FTR	227	205	9.7% decrease

Notes:

* The data analysis in PA-1389 included the TD-AFW pumps in the time period 2006 to 2015. A total of 39 FTS (vs 56) and 29 FTR (vs 32) events were identified as failures. This illustrates the conservative nature of the reporting of failure events to INPO; that the actual number of failures may be somewhat less than the count from the NROD Database.

Suggestion for NRC/INL: For component failure modes with sufficient data, use the most recent set of events (2006 to 2015) to calculate generic failure rates. These should be consistent with CCF parameter calculations (see Issue #DA.2).

DA.2 Time Trends of CCF Events

ISSUE: For the events counted in the NRC CCF Dataset (2015) is it possible to identify how many events occurred by year? Are CCF events more prevalent previously due to poor component performance or lack of event detail (and assumptions made with the lack of information)?

Table DA.2-1 provides a comparison of CCF data and independent failure data (IND) from NROD/RADS PRA Calculator) for the 9-year period (1997 to 2005) with the most recent 10-year period (2006 to 2015). This is provided for a select set of component-types and failure modes as representative of the entire dataset. This table illustrates the decrease in counts, both # CCF and # IND, for the most recent period (2006 to 2015) in comparison to the older period (1997 to 2005). These periods represent a total of 19 years, during which time the number of operating NPPs in the US stayed relatively constant.

For the first entry (Generic Demand CCF), there were 77 CCF events the first 9 years (8.5 per yr) compared to 30 the next 10 years (3.0 per yr). In the same time periods, the independent events decreased from 1938 (215.3 per yr) to 1692.9 (169.3 per yr). Thus, both the rate of independent failure events and CCFs decreased, but the CCF rate decreased more dramatically.

In addition to these statistics, specific CCF events for the recent period (2006 to 2015) were reviewed. These illustrate that the raw count of CCF events tends to overstate the CCF issue:

- MD Pumps (standby) FTS: One CCF event (2006) was due to 2 AFW trains not aligned for auto actuation. The 2nd CCF event in 2007 involved events with Time Delay Factor of 0.50.
- MD Pumps (standby) FTR: Of the 5 CCF events, 2 events (2008) appear to be the same set of events (suction hose drawn into SW pump). One set (Nov. 4) has Coupling Strength 0.1; the others on Nov. 7 & 8 have a Coupling Strength of 0.50. Another CCF event (2013) was based on a design issue where HPSI pumps could operate in runout during injection phase of LOCA for longer than the one hour limit in runout. This had a P_value = 0.50.
- MD Pumps (running) FTR: Two of the 5 CCF events occurred at one site (2010), but both were described as “CVCS pumps low flow due to check valve wear.” The other 3 CCF events all occurred at the same site in June, August, and Oct of the same year (2008), due to debris in the source of cooling water that led to oil cooler fouling.
- MOV SO: One CCF report was for all 4 Core Spray inside isolation valves unexpectedly opening. At the time of the unexpected opening, I&C performance of surveillance test, Low-Low Reactor Water Level Instrument Trip Channel Calibration, was in progress. It was discovered that fuse 16D in ATS cabinet D was blown. This blown fuse de-energized the 2K83 relay, causing an undetected Channel 12 initiation logic trip for opening the Core Spray inside isolation valves. When I&C performed the surveillance test, which brings in the Channel 11 side of the initiation logic, the Core Spray inside isolation valves opened.

- AOV FTO/C: Two of the 3 CCF events were MS turbine bypass valves.
- SG PORVs FTO: One of 3 CCF events (2006) has Time Delay Factor of 0.1 (events were ~2 months apart). A second event (2007) is failure to open ASDVs manually (valves opened 50% of stem movement, took longer than required time).
- EDG FTS: The single CCF event is “both EDGs inoperable due to improper switch position.”
- EDG FTL: One of the 2 CCF events (involving 3 of 4 EDGs) has a P_value of 0.1.
- EDG FTR: One of the 3 CCF events involved 5 EDGs. One EDG had a P_value of 1.0. The other four had a P_value of 0.1.
- DC Battery FTO: The single CCF event (2011) is 2 vital batteries that failed to deliver 80% capacity required due to room ambient temperature at 70F rather than 77F. The P_value = 0.50.
- DC Battery Charger FTO: One of 2 CCF events (2006) had a Time Delay Factor of 0.1, based on time between failures of 45 days.
- Air Compressor FTS: The single CCF event (2010) was IA compressors fail to run due to low ambient temperature.

Suggestion for NRC/INL: Consider revising the NRC CCF Dataset (2015) and the NRC Dataset (2015) (see Issue #DA.1) to use data from the most recent period (2006 to 2015) exclusively as more representative of expected component reliability. The implications of using only the most recent data may need to be evaluated for component failure modes with limited data.

Table DA.2-1: Time Trend for CCF Events, based on NROD/RADS PRA Calculator Results

Component Type	Failure Mode	1997-2005		2006-2015	
		#CCF	# IND	#CCF	# IND
Generic Demand CCF	Failure on demand	77	1938	30	1692.9
Generic Rate CCF	Failure to operate	70	1578.6	46	1667.8
Motor-driven pumps (standby)	Fail to start	19	243.1	2	186.6
Motor-driven pumps (standby)	Fail to run	10	113.5	5	103.8
Motor-driven pumps (normally running)	Fail to run	4	198.9	5	173.3
AFW Turbine driven pump	Fail to start	0	39.9	0	50.1
Motor operated valves	Fail to open / close	7	335.3	2	293.4
Air operated valves	Fail to open / close	11	153.7	3	113.5
Check valves	Fail to close	2	26	0	23.1
Heat exchangers	Plug, Fail to transfer heat	2	14.7	0	11.5
SG PORVs	Fail to open	3	50.1	3	37.6
PZR PORVs	Fail to open	2	10.1	0	10.5
	Fail to close	0	3	0	2.5
EDGs	Fail to start	3	135.8	1	126.1
	Fail to load-run	3	133.5	2	141.8
	Fail to run	3	71.1	3	146
480VAC Circuit Breaker	Fail to open	3	18.7	0	13.6
	Fail to close	1	41.7	0	17.5
DC Batteries	Fail to operate	0	11	1	21.1
DC Battery Chargers	Fail to operate	7	183	2	136
Air Compressors	Fail to start	2	156.1	0	142.1
	Fail to run	3	403	1	328.7

DA.3 Failure Rates Based on Old Data

ISSUE: What component failure rates in the NRC Dataset (2015) are based primarily on OLD data (more than ~20 years old)? Are these representative of current component performance?

Of the 332 component failure rates in the NRC Dataset (2015), 70 are based on old data:

- *Large internal/external leaks (38) – from EPIX, 1997 to 2004.* While the small leakage events have been updated to 2015, the large leakage rates are still based on the factors developed from the 1997 to 2004 EPIX data (as described in Issues DC.3 and DC.4.
- *Pipe leaks (4) – from EPIX, 1997 to 2004.* PIPE SWS-ELS and PIPE OTHER-ELS are based on data. The ELL failure rates are based on the ELS failure rates times a factor (0.2 for SWS, 0.1 for Other) based on NUREG/CR-6928 (see Issue #DC.2)
- *Control circuit failures (3) – from WSRV, 1980s to 1990.* The NRC Dataset (2015) labels the source of these component failure modes (ICC-FA, ICC-FC, ACT-FC) as NUCLARR but the Component Reliability Data Sheets identify the source as WSRC. Note, these three component failure rates are described differently but use exactly the same Mean and EF.
- *Air dryer unit (1) – from WSRV, 1980s to 1990.* The NRC Dataset (2015) labels the source of this component failure mode, ADU-FTOP, as NUREG/CR-6928 but the Component Reliability Data Sheets identify the source as WSRC.
- *Orifice plugging (1) – from WSRV, 1980s to 1990.* The failure rate for this component failure mode, ORF-PG, comes from the Westinghouse Savannah River Company (WSRC) database.
- *Sensors, bistable, manual switch, process logic, RPS breaker (19) – from NUREG/CR-5500, 1984-1995.* The failure rates for these components that are part of the reactor protection system come from Volume 2 (Westinghouse), Volume 10 (CE), and Volume 11 (B&W) of NUREG/CR-5500.
- *PORV (4) – special calc, from NUREG/CR-7037, 1987 to 2007.* The sources for the failure rates for these four (4) special PORV failure modes (PORV-L, PORV-T, PORV-Lquid, PORV-P1) are described as "special calc" but they come directly from NUREG/CR-7037.

Suggestions for NRC/INL: Suggestions are provided below by groups of components.

- PORVs – Of the component failure modes above, the most important to risk appear to be the PORV failure modes. Those should be highest priority for updating with more current data events.
- Large internal/external leaks – these failure modes are addressed in suggestions for Issue #DC.2.
- Pipe leaks – these should be deleted from this NRC Dataset (2015) since they are addressed in internal flood datasets.
- WSRV-based data – for the five (5) component failure modes that use the WSRV data, this data should be eliminated based on its age and lack of availability of the source

data. If failure rates for these component failure modes are required, consider failure rates from “similar equipment” (per requirement DA-D2 in the PRA Standard).

- RPS components – these failure rates are well developed and documented. They should be on a list for update in the future. It might be appropriate to do a sample of more recent data to see how representative this old data is of current system performance. Also, see #DA.5.

DA.4 Failure Rate for Safety Valve Fail to Reclose Based on Judgment

ISSUE: The failure rates for Safety Valve and Safety Relief Valve failure to reclose passing liquid (SVV FTCL, SVR FTCL, mean =0.1) in NUREG/CR-6928 are based on judgment (the average of the 95th percentiles of fail-to-close data entries from the 1980s). Are there better data sources for the component failure mode? What happened to this component failure mode in the 2015 dataset?

The 2007 and 2010 NRC datasets have this component failure mode (safety valve failure to reclose given liquid release) but the NRC Dataset (2015) does not have these failure modes. It does have a new failure mode, PORV-Lquid, with a mean value 6.25E-2, given the evidence of zero failures and 7 demands. This PORV failure rate comes from NUREG/CR-7037 and is based on data from 1987 to 2007.

Suggestion for NRC/INL: The basis for the PORV-Lquid is both old data and very limited data, with zero failures. This data analysis should be updated with recent failure event data (2006 to 2015). However, it is likely that the data will continue to be so limited as to not be helpful in assessing this failure rate. Expert elicitation should be considered for this component failure rate.

It is not clear from the 2015 dataset if safety valve fail-to-reseat following liquid relief was removed because it was not considered a credible failure mode. A 2004 EPRI report (TR-1011047) documents an expert elicitation for Safety Valve fail-to-reseat following steam and liquid relief. While this report may be considered dated, it may provide a good outline for an updated expert elicitation that might cover both Safety Valves and PORVs.

DA.5 Sensor Failure Rates Based on Old Data

ISSUE: The sensor/transmitter failure rates in the NRC Dataset (2015) are from NUREG/CR-6928 (2007), and are based on NUREG/CR-5500 (1999). Does this data adequately represent current component performance?

The sensor/transmitter failure rates are based on data from 1984 to 1995, so 20 to 30 years old. A total of 5.5 Level sensor failures, 37.5 pressure sensor failures, and 46.1 temperature sensor failures were used in the failure rate calculations. The failures were divided into Demand failures and Time-related failures.

The Level sensor data comes from the GE study only (NUREG/CR-5500 Volume 3). Of the 5.5 failures counted for Level sensor, there were NO “certain” failures; i.e., the failure count came from events where it was unclear that the event represented a true failure and, as a result, a weighting factor was applied. Note, the Level sensor failure rates were used to represent Flow sensors as well (see NUREG/CR-6928 Section A.2.43).

The Pressure sensor data comes from all four (4) RPS reliability studies (NUREG/CR-5500 Volumes 2, 3, 10, 11). Of the 37.5 counted failures, 24 were “certain” failures, the rest from weighted events of “uncertain” failures.

The Temperature sensor data comes from the PWR studies (Volumes 2, 10, 11). Of the 46.1 counted failures, 34 were “certain” failures, the rest from weighted events of “uncertain” failures.

The “uncertain” failures come from limited data reports. The data reports to the INPO ICES Database have improved in level of detail since this data was collected.

Suggestion for NRC/INL: For one sensor-type (e.g., pressure), collect failure data and calculate new failure rates (demand, time) from the recent period (2006 to 2015). Compare this to the failure rates from the 1984 to 1995 time frame currently in the NRC Dataset (2015). If the failure rates are significantly different, expend the data analysis effort to address the other sensor-types.

A.3 NRC DATASETS: DATA CLASSIFICATION ISSUES (DC)

DC.1 New Failure Modes

ISSUE: NRC introduces new component failure modes in NRC datasets from 2007, 2010, 2012, and 2015. Does the PRA Standard or state-of-practice require inclusion of these failure modes in utility PRAs? Are there justifications for excluding specific failure modes on a generic basis? Should some similar failure modes (e.g., where limited component reliability data has been divided by system) be grouped based on lack of significant amounts of data?

The NRC datasets have increasing numbers of component failure modes: 171 (2007), 227 (2010), and 331 (2015). Table DC.1-1 shows the number of changes from 2007 and 2010 to 2015.

Table DC.1-1: Changes in Component Failure Mode Definitions

NRC Datasets to Compare	Match	Change	New
2015 to 2010	120	107	104
2015 to 2007	53	118	160

Thus, of the 331 component failure modes in the 2015 dataset, only 120 (36%) are the same as in the 2010 dataset, and only 53 (16%) match the 2007 dataset. This lack of consistency in naming and definitions of component failure modes creates significant challenges in utilizing the newer datasets.

Suggestions for NRC/INL: A consistent set of component failure rates and associated IDs should be developed. Other issues (e.g., #DC.2, DC.5, DC.3, DC.4) provide suggestions for the treatment of specific sets of component failure modes.

DC.2 Leakage Probability

ISSUE: Probability of a Small Leak (internal or external) is defined in NUREG/CR-6928 for valves, pumps, etc. as leakage from 1 to 50 gpm. Do the events provide enough information to allow an estimate of the leakage rate?

At the low end (say 1 to 10 gpm), this could easily be screened out from most (maybe all) systems as not impacting system function (based on time available to identify and stop the leak or makeup to the system).

Section A.1.2 of NUREG/CR-6928 discusses the criteria for leakage events from EPIX (1997 to 2004):

- External leakage events were reviewed to identify small leaks (1 to 50 gpm), large leaks (> 50 gpm), and leaks too small to be of interest in this study (< 1 gpm).
- Internal leakage events were reviewed to identify small leaks (leaks exceeding the local leak rate test allowable limits or 1 to 50 gpm), large leaks (typically resulting from component internal degradations greater than just pitting or wearing or > 50 gpm), and negligible leaks (less than the local leak rate test limits or < 1 gpm).

From this description, it would appear that external leaks may have specified a leakage rate while internal leaks may have only identified “leak exceeds local leak rate test” or “internal degradation” rather than a specific leak rate.

Suggestions for NRC/INL: The definition of Small Leakage (1 to 50 gpm) is not helpful because it covers the range from nuisance leakage which should not impact system performance to the point where leakage may not be insignificant (depending on the system). Also, it is not clear that the events used to calculate the Small and Large leakage probabilities define the actual leak rate. Clearly the data for these leakage probabilities represent OLD data (15 to 20 years old).

Consider a definition of Leakage in the range 10 to 50 gpm. Leakage any larger than 50 gpm *external* to the device should be classified as an internal flood event and be excluded from this Database. Leakage any larger than 50 gpm *internal* to the device could be considered a component failure (e.g., manual valve leakage larger than 50 gpm should be counted as Manual Valve Fails to Remain Closed. Leakage less than 10 gpm should be considered nuisance leakage which should not impact system performance. Leakage in the range from 10 to 50 gpm is still a challenge to model, but should help to focus the concern on leakage events that are more likely to challenge system function over a period of time.

Second, consider gathering leakage data from the most recent period (e.g., 2006 to 2015). This data better represents the current component performance and maintenance practices. More recent data events typically provide more detail regarding the event.

Also see related Issues #DC.3 and #DC.4.

DC.3 Large Internal Leakage Probability based on Limited & Old Data

ISSUE: Probability of Large Internal Leak in NUREG/CR-6928 is defined as 0.02 x PROB(small leak), but no basis is provided for this factor. Is it possible to determine a more defensible conditional failure probability?

The value 0.02 is used as the ratio of ILL/ILS (large internal leak failure rate / small) for valves (SRV, SVV, PORV, RVL), tanks (TNK, ACC, STR), and heat exchangers (HTX). This value is documented in Table A.1.2-1 of NUREG/CR-6928 and is based on 3 large internal leaks vs 185.5 small internal leaks (with the ratio rounded off). This data is from the 8-year period from 1997 to 2004. This same ratio (0.02) is used in the 2015 dataset although the data used to calculate ILL failure rate appears to be updated. Thus, this value is based on 3 large leaks from data that is 15 to 20 years old.

Suggestions for NRC/INL: Issue #DC.2 (leakage probability) provides several recommendations regarding the source of data (more recent events) and the classification of leakage data. Those recommendations apply here as well.

DC.4 Large External Leakage Probability based on Limited & Old Data

ISSUE: Probability of Large External Leak in NUREG/CR-6928 is defined as 0.07 x PROB(small leak), but no basis is provided for this factor. Is it possible to determine a more defensible conditional failure probability?

The value 0.07 is used as the ratio of ELL/ELS (large external leak failure rate/small) for valves (SRV, SVV, PORV, RVL) and tanks (TNK, ACC, STR). This value is documented in Table A.1.2-1 of NUREG/CR-6928 and is based on 2.0 large external leaks vs 35.0 small external leaks (with the ratio rounded off). This data is from the 8-year period from 1997 to 2004. This same ratio (0.07) is used in the 2015 dataset although the data used to calculate ILL failure rate appears to be updated. Thus, this value is based on 2 large leaks from data that is 15 to 20 years old.

Separate ELL/ELS values are calculated for:

- Heat exchangers (HTX), 0.15 based on 1.0 ELL and 10.0 ELS events
- SW pipe, 0.2, based on 0.0 ELL and 3.5 ELS events, and
- Non-SW pipe, 0.1 based on 1.5 ELL and 8.5 ELS events.

Suggestions for NRC/INL: Issue #DC.2 (leakage probability) provides several recommendations regarding the source of data (more recent events) and the classification of leakage data. Those recommendations apply here as well. Specifically, for external leakage events greater than 50 gpm, it suggests excluding those since they should be captured by internal flood event data.

DC.5 PORV Spurious Operation

ISSUE: The NRC Dataset (2015) identifies 24 events classified as PORV-SOP (PORV spurious opening). Do these represent SLOCA or SLB events or is this leakage? How should these events be treated in a PRA?

NRC Dataset (2015) has 24 events over the time period 1998 to 2015, with a mean of 3.53E-7/hr for PORV-SOP.

A search of the NROD Database found 35 events over the same time period that seem to match the definition of PORV-SOP:

- System: RCS, MSS
- Component: PORV
- Failure Mode: Spurious Operation
- Event Date: 1998 to 2015

Of these 35 events from the NROD Database, most (28) were from MSS, with the remainder (7) from RCS. A review was performed of the events in the most recent 10-year period, 2006 to 2015, a total of 16 events. This includes 2 RCS events and 14 MSS events classified as PORV-SOP. The conclusions from this investigation:

Conclusions: PORV-SOP (RCS)

- There are only 2 events in the most recent 10-year period. One event occurred during troubleshooting and was immediately identified and recovered. The second event is a spurious closure event, applicable only when the PORV is already open. This would better be modeled as a Failure-to-Open event.
- The first event could be considered a precursor of SLOCA, although the actions to isolate the open RCS PORV should be highly reliable since the cue is clear and actions are straightforward. Due to the low frequency of this precursor and the reliability of the recovery action, this event might be screened out using an approach such as:
  - SLOCA(PORV-SOP Remains Open) = PORV-SOP-RCS x Operator Fails to Close PORV = (1 event / 60 PWRs * 10 yrs) * 1E-3 = 2E-6 / year
- With such little significant data events over the last 10 years, this component failure mode should be excluded from PRA models.

Conclusions: PORV-SOP (MSS)

- Half (7) of these events involved the MSS PORV opening (partially or fully) with no maintenance or plant operation in progress.
- Five (5) events occurred during maintenance or while the plant was shutting down or starting up.
- Two events from one plant involved frozen sensing line.

- All events were quickly identified because of the impact on plant operation and quickly corrected, typically by taking the controller to manual or closing the manual isolation valve.
- These events might be considered precursors to steam line break outside containment (SLBO) initiators, although the actions to isolation the open MSS PORV should be highly reliable since the cue is generally clear and actions are straightforward. Also the steam relief from one MS PORV is much less than a steam line break, so grouping this with SLB would be highly conservative.

Suggestion for NRC/INL: Consider re-classifying this component failure mode (PORV-SOP) as a Precursor event and include this in the Initiating Event dataset (rather than with component reliability). Examine the impact of PORV spurious operation events for their potential to be precursors to an Initiating Event. To be a significant precursor, they would need to represent a new IE with impacts greater than existing IEs or to contribute to the frequency of similar IEs currently modeled (where the frequency included the additional failures that would need to occur for the precursor event to be an IE).

DC.6 Safety/Relief Valve Spurious Operation

ISSUE: The NRC Dataset (2015) identifies a spurious-operation failure mode for several safety and relief valve types (SRV-SOP, SVV-SOP, SVV-SOP-PWR-MSS, SVV-SOP-PWR-RCS) in addition to PORV-SOP (addressed in Issue DC.5). Do these represent SLOCA or SLB events or is this leakage? How should these events be treated in a PRA?

These component failure modes have failure rates ranging from 5.4E-8 to 1.4E-7/hr based on NRC Dataset (2015). Based on a review of the NROD Database, 7 SVV-SOP events were identified (3 MSS, 4 RCS), in contrast with the count of 11 in the NRC Dataset (2015). Of these 7 events, 3 were associated with a plant trip, one led to a manual reactor trip, and the other 3 occurred when a unit was returning to normal pressure following a refueling outage. For the most part, these are not random events; they occur in response to a change in plant configurations.

Suggestion for NRC/INL: Consider re-classifying these events as: (a) safety/relief valve opening during a transient or (b) Precursor events and include these in the Initiating Event dataset (rather than with component reliability). Examine the impact of safety/relief spurious operation events for their potential to be precursors to an Initiating Event. To be a significant precursor, they would need to represent a new IE with impacts greater than existing IEs or to contribute to the frequency of similar IEs currently modeled (where the frequency includes the additional failures that would need to occur for the precursor event to be an IE).

DC.7 AOV, MOV, SOV Spurious Operation

ISSUE: The NRC Dataset (2015) identifies a spurious-operation failure mode for a number of valve types (AOV-OC/SOP, MOV-OC/SOP, SOV-SOP, etc.).

Do these events represent internal valve failure or inadvertent actuation signals? Are these spurious events identified as spurious OPEN or CLOSE events? Is there a difference between OC and SOP failure modes?

Can we develop a generic basis for screening out some (most) valve spurious operation failure modes from IE-PRA models?

The NRC Dataset (2015) includes spurious operation of the following valve types: MOV (motor), AOV (air), HOV (hydraulic), SOV (solenoid), MSV (main steam isolation), CKV (check), and XVM (manual), with failure rates ranging from 3.1E-7 to 2.6E-9 per hour. These component failure modes are labeled xxx-SOP, xxx-SO, xxx-SC, and xxx-OC. The xxx-SC label is used only for check valve spurious closure. The label xxx-SO is used for 3 valve types. Six valve-types are labeled xxx-OC. The OC label is used strictly for valves identified by specific system (CCW, IAS, SWS). The SOP label is used for other valve-types. The descriptions of these failure modes include: spurious operation, spurious opening, spuriously transfers, transfers open, fails to remain open. So the naming convention and descriptions are not used consistently.

The maximum valve SOP failure rate is 3.1E-7/hr. Assuming such a failure would be immediately identified, the exposure time for such a failure is the 24 hour mission time. Thus, the maximum "unavailability" due to the Valve SOP = 3.1E-7 x 24 = 7.4E-6. This is much lower than typical demand failure rates (fail to start, fail to open/close). However, it is not clear that the consequence of such a SOP would be consistent with the modeling of most components, which are modeled as failures.

Based on a review of the NROD Database, the following inconsistencies in Table DC.7-1 were noted in the count in NROD vs the NRC Dataset (2015).

Table DC.7-1: Comparison of Spurious Valve Operation Event Counts

Spurious Operation Valve Failure Mode	# Failures per NRC Dataset (2015)	# Failures per NROD Database (1998 to 2015)
MOV_SOP (motor-operated)	63	48
AOV_SOP (air operated)	132	67
HOV_SOP (hydraulic operated)	17	1
SOV_SOP (solenoid operated)	9	0
MSV_SOP (MS isolation valve)	25	27
CKV_SO (check valve)	2	0

Table DC.7-1: Comparison of Spurious Valve Operation Event Counts

Spurious Operation Valve Failure Mode	# Failures per NRC Dataset (2015)	# Failures per NROD Database (1998 to 2015)
XVM_SOP (manual valve)	6	0
TOTAL	**254**	**143**

Based on a sample of failure reports from the NROD Database, these events include valves changing position due to inadvertent demand signals, due to setpoint drift, and due to switch failure. Generally these repositioning events were accompanied by an indication (alarm, valve position change).

Suggestion for NRC/INL: Consider reviewing these events to determine whether the failures are within the component boundary (e.g., inadvertent demand signal should typically be outside the boundary). Other events might be more appropriately categorized as fail to open or fail to close. Generally, the SOP failure mode should not be considered a credible failure mode contributing to component unavailability.

Also, for other spurious valve events, consider re-classifying these as Precursor events and include these in the Initiating Event dataset (rather than with component reliability, if appropriate. To be a significant precursor, they would need to represent a new IE with impacts greater than existing IEs or to contribute to the frequency of similar IEs currently modeled (where the frequency include the additional failures that would need to occur for the precursor event to be an IE).

The inconsistency between the NROD Database and the NRC Dataset (2015) is significant for some of these valve types. This inconsistency should be resolved.

DC.8 Breaker Spurious Operation

ISSUE: The NRC Dataset (2015) identifies a spurious-operation failure mode for four types of circuit breakers: high voltage (13.8KV & 16KV, CBKHV-SOP); medium (4.16KV & 6.9KV, CBKMV-SOP); low voltage (480V, CRB-CO-480); and DC (CBKDC-SOP). Can we develop a generic basis for screening out breaker spurious operation failure modes from IE-PRA models?

The failure rates for breakers spuriously transferring are extremely low, range from 3.5E-8/hr for DC breakers to 4.8E-7/hr for high voltage breakers. Spurious operation of a breaker would be immediately alarmed in the control room. This would lead to breaker unavailability while the event was investigated and maintenance performed. Any such unavailability would be captured in the system/train unavailability. If this caused a plant upset leading to an initiating event, that would be captured in the IE frequency.

A sample review of Breaker Spurious Operation failure events from the NROD Database identified that these events are commonly caused by a maintenance activity. In all cases, the spurious operation is alarmed, although in some events, the condition was discovered only during a test. In some cases, the failures were identified as ones that were quickly recovered.

Suggestion for NRC/INL: Based on the sample review, Breaker Spurious Operation contains (at least) two types of failure events: (a) maintenance events where the breaker spurious operation occurred as a result of some aspect of that activity and (b) test events where the breaker failed to remain closed.

The first set of events should be screened out as not applicable to an accident sequence. They may be related to precursor events. Examine the impact of breaker spurious operation events for their potential to be precursors to an Initiating Event. To be a significant precursor, they would need to represent a new IE with impacts greater than existing IEs or to contribute to the frequency of similar IEs currently modeled (where the frequency includes the additional failures that would need to occur for the precursor event to be an IE).

The second set of events should be reclassified as Breaker Failure to Close. If the number of these events is comparable to the number of the total number of “Breaker Failure to Close” events, then a standby failure mode should be added (Breaker Failure to Close while in standby) where the time between tests could be accounted for. .

DC.9 CCF Modeling for Spurious Operation

ISSUE: The NRC CCF Dataset (2015) includes common cause failure parameters for valves and circuit breakers. Does this require CCF modeling of spurious operation for these components in utility PRAs?

The NRC CCF Dataset (2015) provides extremely sparse evidence of common cause failures for spurious operation failure modes: zero events for check valves and DC circuit breakers; one event each for MOVs, AOVs, and 480VAC circuit breakers; and three events for 4160VAC circuit breakers. As discussed in Data Issues #DC.6 and #DC.7 above, the evidence for independent spurious operation events is limited and, in many cases, would be better characterized as precursor events.

Despite this limited data, CCF parameters are calculated and displayed in the NRC CCF Dataset (2015) for spurious operation modes for valves and circuit breakers. This includes check valve spurious operation which has zero CCF events and zero independent events, but still produces a CCF parameter $\alpha 2$ = 4.07E-2 (for CCCG = 2).

Suggestion for NRC/INL: Consider removing the spurious operation failure modes from the CCF Dataset based on the limited data for both independent and common cause spurious operation..

DC.10 Treatment of Highly Recoverable Failures

ISSUE: The failure events recorded in the NROD Database include an assessment of whether the failure was recoverable and an estimate of the recovery duration. Yet, these failures are treated the same as other failures that may be highly non-recoverable (i.e., with a much longer recovery time). Is there a way to account for failures that are highly recoverable in the estimate of failure rates?

Failure events that are highly recoverable (e.g., recoverable within 60 minutes) should be treated as weighted failures to acknowledge that such events have much less risk importance than other failure events.

Suggestion for NRC/INL: Consider revising the P Value to include a weighting factor based on the recoverability of the failure event. One possible treatment:

- Failure events recoverable from the control room within a few minutes without any significant trouble-shooting (e.g., control switch in pull-to-lock): P_value = 0.1
- Failure events recoverable within 15 minutes without any significant trouble-shooting (e.g., resetting the turbine-driven AFW pump trip/throttle valve): P_value = 0.2
- Failure events recoverable within 60 minutes without any significant trouble-shooting (e.g., resetting a pump breaker): P_value = 0.5

These values may be seen as screening HEPs that are consistent with the current range of P values used in NROD Database.

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