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Component Reliability Data Issues for Continued Discussion with NRC

Based on Report PWROG-18029-NP and Project PA-RMSC-1494

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June 2020

Introduction

Purpose of project PA-RMSC-1494 and report PWROG-18029

- Provide a strong basis for engaging with the NRC to improve the generic component reliability data sources.
- Support the long-term needs of the nuclear power industry for high quality generic component reliability estimates for utility PRAs.

Objective of the interaction with NRC

- Ensure that the data issues in PWROG-18029 are understood by the NRC and INL staff.
- Support efforts to address these data issues in the next NRC reliability data sets (2020).

Objective of this meeting

- Continue discussion of key technical issues
- Identify potential options to address these issues

Discussion Topics

DQ.5: Long-Term Failure Rates

DC.5 to DC.9: Spurious Operation Failure Modes

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DQ.5:
Long-Term Failure Rates

DQ.5: Long-Term Failure Rates

This issue includes four related technical issues:

- DQ.5a: Pooled components included in the MDP-SBY group
  - Should this component-group be subdivided into MDP-SBY (components that are operated only in standby) and MDP-SBY-NO (standby components that also have a normally operating mode)?
- DQ.5b: Short Term (first hour) vs. Long Term (beyond first hour) failure rate data for Standby components
  - Does the data support separate RUN failure modes for First Hour and Beyond First Hour for standby components?
- DQ.5c: Definition of **Demand vs. Run** failure modes for event classification
  - Should the failure events currently included in First Hour Run be classified as demand failures or run failures?
- DQ.5d: Definition of **Load** failure mode for event classification
  - Should the failure events included in Load-Run be classified as demand failures or run failures?

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DQ.5a: Pooled Components Included in the MDP-SBY Group

- Issues:
  - MDP-SBY-FTR>1H run-hours data are much too long (2.01E7 hrs.) for pumps that are truly "standby." With 4.82E5 starts, this implies 40 hrs. per start.
  - MDP-SBY group includes pumps that are always standby (e.g., containment spray pumps, HPI pumps) and ones that are normally standby but have a normal operational mode (e.g., RHR pumps, AFW pumps).
  - Should this component-group be subdivided into MDP-SBY (components that are operated only in standby) and MDP-SBY-NO (standby components that also have a normally operating mode)?
- Potential Options:
  - Create two groups, MDP-SBY and MDP-SBY-NO, to model these pumps in more homogeneous groups.
    - Use the *average number of run-hours per start* as a metric to determine the pumps that should be included in each groups.
    - Does this leave the new MDP-SBY group with a dataset that is too limited?
  - Are there other engineering bases for which pump-types should be grouped (e.g., high pressure vs low pressure)?
  - Are the data sufficient to support separate groups for some component-types: MD-AFW pumps, RHR pumps?

DQ.5b: Short-Term-Run vs. Long-Term-Run Failure Rate Data for Standby Components

- Issues:
  - Does the data support separate RUN failure modes for Short-Term (first hour) and Long-Term (beyond first hour for standby components?
  - For many standby components, Long-Term-Run failure rates are not lower than Short-Term, inconsistent with what one might expect.
  - Limited long-term run data for truly "standby" components (e.g., PDP-SBY, positive displacement pumps). Test runs are typically no longer than 1 hour.
  - For other components classified as Standby, the Long-Term-Run success data is much greater than the Short-Term-Run data (e.g., ACX-FTS, Air Cooling Heat Exchanger, Normally Standby).
  - For some components, the data (failures, run-hours) appear to have been split evenly between Short-Term-Run and Long-Term-Run (e.g., CHL, Chiller Unit, Normally Standby).
  - Difficult to determine whether failure events are actually Short Term or Long Term
- Potential Options:
  - Combine Short-Term-Run and Long-Term-Run data for standby components
  - Address the DQ.5c and DQ.5d issues for failures currently classified as Short-Term-Run

DQ.5b: Short-Term-Run vs. Long-Term-Run Failure Rate Data for Standby Components

Difficult to determine whether failure events are actually Short Term or Long Term.

- Example, an EDG failure event labeled as a FTLR:

  EDG2-2 was running unloaded during the performance of the monthly surveillance test when a lube oil leak from a four inch piping coupling was identified by local operators. The lube oil leak was observed approximately 10 minutes into the run of the engine. The lube oil leakage was initially documented as 224 drops per minute and increased to a steady 'pencil stream' along with a second intermittent stream outside the downstream follower. These streams were observed for approximately 2 minutes before EDG2-2 was shut down and declared inoperable.

- This is determined to be a failure due to the large rate of lube oil leakage. However, is it appropriate to consider this a “one-hour-run-failure” just because it occurred in the first few minutes of this test run?
  - While the event description does not provide details regarding why the leak occurred, it is likely that it was the result of high cycle fatigue failure where the wear-cycles occurred over a number of run-hours.
  - It is likely that the leak was due to the aggregate number of EDG run-hours which accumulated over a number of one-hour test runs but could have occurred during an extended EDG run given a real demand.

DQ.5c: Definition of **Demand vs Run** Failure Modes for Event Classification

- Issues:
  - Should the failure events currently included in Short-Term-Run failure mode be classified as demand failures or run failures?
  - This is related to DQ.5b, the difficulty in determining whether run failure events are actually Short Term or Long Term
  - This addresses the question of which failure events are demand-related (i.e., fail to start) or run-time-related (i.e., fail to run)
- Potential Options:
  - Define (refine) failure modes for event classification:
    - Fail to Start: *failure to reach a stable running state within a few minutes of start demand.*
    - Fail to Run: *failure to continue to run after reaching a stable running state.*
  - Review events classified as “Fail to run < 1H” in light of these definitions and reclassify as appropriate.

DQ.5d: Definition of **Load-Run** Failure Mode for Event Classification

- Issues:
  - Should the failure events currently included in Load-Run failure mode be classified as demand failures or run failures?
  - This applies only to component-types where LOAD is included as a failure mode: EDG & CHL (Gas Turbine Generator).
  - This addresses the question of which failure events are demand-related (i.e., fail to start, fail to load) or run-time-related (i.e., fail to run).
- Potential Options:
  - Revise failure definitions to clarify demand-failures from run-failures:
    - FTS: *failure to reach a stable start-run state.*
      A stable start-run state includes adequate starting air to roll the EDG; automatic start from an undervoltage signal or test start from the main control room; and reaching normal and stable speed.
    - FTL: *failure to reach a stable load-run state.*
      A stable load-run state includes EDG output breaker closed, stable engine speed, generator field successfully flashes, stable output voltage & frequency, carrying full capacity load, and cooling flow established.
    - FTR: *failure to continue to run after reaching a stable running (or load-run) state.*

DQ.5: Long-Term Failure Rates

Specific Suggestion for EDG Failure Rate Calculations

- Use revised failure definitions to clarify demand-failures from run-failures:
- Define FTLR (FTL) as demand-failure.
- Review FTLR failure events using new definition of FTL.
  Move any run-failure events to calculation of FTR.
- Calculate FTR using all Run-Failure events and all Run-Hours

EDG Failure Mode	Description	# Failures	Demands or Run-Hours	d or h	PointEst	Comments
EDG-FTS	Diesel Generator Fails To Start	214	75,452	d	2.84E-03	Revised calculation for FTL and FTR assumes half of FTLR are load-failures and half run-failures.
EDG-FTLR	Diesel Generator Fails To Load & Run, Early	239	65,993	h	3.62E-03	
EDG-FTR	Diesel Generator Fails To Run, Late Term	184	133,976	h	1.37E-03	
EDG-FTL	Diesel Generator Fails to Load	120	65,993	d	1.82E-03	
EDG-FTR	Diesel Generator Fails To Run	303	199,969	h	1.52E-03	

DQ.5: Long-Term Failure Rates

Component Failure Mode	Description	# Failures	Demands or Run-Hours	d or h	# Compnts	PointEst	Mean	Pt.Est. Ratio (E+L)/L	Comments
MDP-SBY-FTS	Motor Driven Pump Fails To Start, Normally Standby	351	482,206	d	1311	7.28E-04	7.94E-04		Combine early & late, small increase in FTR compared to FTR>1HR due to the overwhelming evidence is in the late-term. However, Late term run hours (2.0E7 hrs) seems extremely large for standby pumps. That implies 41 hrs per start.
MDP-SBY-FTR<1H	Motor Driven Pump Fails To Run, Early Term	48	437,647	h	1311	1.10E-04	1.22E-04		
MDP-SBY-FTR>1H	Motor Driven Pump Fails To Run, Late Term	143	20,062,180	h	1311	7.13E-06	1.15E-05		
FTR	Early + Late Fail to Run	191	20,499,827			9.32E-06		1.31	
TDP-SBY-FTS	Turbine Driven Pump Fails To Start (Pooled Systems), Normally Standby	146	26,558	d	133	5.50E-03	6.01E-03		Combine early & late due to limited evidence in the late-term, small increase in FTR compared to FTR>1HR.
TDP-SBY-FTR<1H	Turbine Driven Pump Fails To Run (Pooled Systems), Early Term	61	18,025	h	133	3.38E-03	3.70E-03		
TDP-SBY-FTR>1H	Turbine Driven Pump Fails To Run (Pooled Systems), Late Term	23	11,205	h	133	2.05E-03	2.10E-03		
FTR	Early + Late Fail to Run	84	29,230			2.87E-03		1.40	
TDP-FS-NS-AFW	AFW Turbine Driven Pump Fails To Start, Normally Standby	72	18,054	d	74	3.99E-03	4.33E-03		Combine early & late due to limited evidence in the late-term.
TDP-FR-E-AFW	AFW Turbine Driven Pump Fails To Run, Early Term	40	12,076	h	74	3.31E-03	3.67E-03		
TDP-FR-L-AFW	AFW Turbine Driven Pump Fails To Run, Late Term	13	9,283	h	74	1.40E-03	1.45E-03		
FTR	Early + Late Fail to Run	53	21,358			2.48E-03		1.77	

DQ.5: Long-Term Failure Rates

Component Failure Mode	Description	# Failures	Demands or Run-Hours	d or h	# Compnts	PointEst	Mean	Pt.Est. Ratio (E+L)/L	Comments
TDP-FS-NS-HCI-RCI	HCI-RCI Turbine Driven Pump Fails To Start, Normally Standby	41	4,929	d	31	8.32E-03	8.78E-03		Combine early & late due to limited evidence in the late-term
TDP-FR-E-HCI-RCI	HCI Turbine Driven Pump Fails To Run, Early Term	21	5,949	h	59	3.53E-03	3.75E-03		
TDP-FR-L-HCI-RCI	HCI-RCI Turbine Driven Pump Fails To Run, Late Term	10	1,922	h	59	5.20E-03	5.52E-03		
FTR	Early + Late Fail to Run	31	7,871			3.94E-03		0.76	
EDP-FTS	Engine Driven Pump Fails To Start, Normally Standby	26	17,988	d	37	1.45E-03	2.17E-03		Combine early & late due to limited evidence in the late-term
EDP-FTR<1H	Engine Driven Pump Fails To Run, Early Term, Normally Standby	10	10,717	h	37	9.33E-04	9.80E-04		
EDP-FTR>1H	Engine Driven Pump Fails To Run, Late Term, Normally Standby	11	5,820	h	37	1.89E-03	1.98E-03		
FTR	Early + Late Fail to Run	21	16,537			1.27E-03		0.67	
AFW-EDP-FTS	AFW Engine-driven pump Fails to Start	3	1,275	d	5	2.35E-03	2.74E-03		Combine early & late due to limited evidence in the late-term
AFW-EDP-FTR<1H	AFW Engine-driven pump Fails to Run <1H	4	739	h	5	5.41E-03	6.09E-03		
AFW-EDP-FTR>1H	AFW Engine-driven pump Fails to Run >1H	2	262	h	5	7.62E-03	9.53E-03		
FTR	Early + Late Fail to Run	6	1,002			5.99E-03		0.79	
PDP-SBY-FTS	Positive Displacement Pump Fails To Start, Normally Standby	16	10,799	d	72	1.48E-03	1.53E-03		Combine early & late due to limited evidence in the late-term
PDP-SBY-FTR<1H	Positive Displacement Pump Fails To Run, Early Term	2	4,699	h	72	4.26E-04	5.32E-04		
PDP-SBY-FTR>1H	Positive Displacement Pump Fails To Run, Late Term	2	1,710	h	72	1.17E-03	1.46E-03		
FTR	Early + Late Fail to Run	4	6,409			6.24E-04		0.53	

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DQ.5: Long-Term Failure Rates

Component Failure Mode	Description	# Failures	Demands or Run-Hours	d or h	# Compnts	PointEst	Mean	Pt.Est. Ratio (E+L)/L	Comments
ACX-FTS-NS	Air Cooling Heat Exchanger Fails to Start, Normally Standby	55	149,242	d	382	3.69E-04	5.57E-04		Combine early & late due to overwhelming evidence in the late-term
ACX-FTR<1H	Air Cooling Heat Exchanger Fails to Run <1H Normally Standby	0	148,103	h	382	0.00E+00	3.38E-06		
ACX-FTR>1H	Air Cooling Heat Exchanger Fails to Run >1H Normally Standby	45	10,793,680	h	382	4.17E-06	4.22E-06		
FTR	Early + Late Fail to Run	45	10,941,783			4.11E-06		0.99	
CHL-FTS-NS	Chiller Unit Fails To Start, Normally Standby	0	20,433	d	63	0.00E+00	2.45E-05		Results are suspect (early and late entries are exactly the same). If this is correct, combine early and late since evidence is the same.
CHL-FTR<1H	Chiller Unit Fails To Run <1H, Normally Standby	61	279,348	h	63	2.18E-04	2.20E-04		
CHL-FTR>1H	Chiller Unit Fails To Run >1H, Normally Standby	61	279,348	h	63	2.18E-04	2.20E-04		
FTR	Early + Late Fail to Run	122	558,697			2.18E-04		1.00	
FAN-SBY-FTS	HVAC Fan Fails To Start, Normally Standby	37	57,512	d	130	6.43E-04	6.52E-04		Combine early & late due to overwhelming evidence in the late-term
FAN-SBY-FTR<1H	HVAC Fan Fails To Run, Early Term, Normally Standby	16	43,744	h	130	3.66E-04	3.77E-04		
FAN-SBY-FTR>1H	HVAC Fan Fails To Run, Late Term, Normally Standby	27	137,892	h	130	1.96E-04	1.99E-04		
FTR	Early + Late Fail to Run	43	181,636			2.37E-04		1.21	
MDC-FTS-NS	Motor Driven Compressor Fail To Start, Normally Standby	61	23,363	d	58	2.61E-03	4.16E-03		Results are suspect (early and late entries are exactly the same). If this is correct, combine early and late since evidence is the same.
MDC-FTR<1H	Motor Driven Compressor Fail To Run (0 To 1 Hour)	22	1,683,943	h	58	1.31E-05	1.34E-05		
MDC-FTR>1H	Motor Driven Compressor Fail To Run (> 1 Hour)	22	1,683,943	h	58	1.31E-05	1.34E-05		
FTR	Early + Late Fail to Run	44	3,367,886			1.31E-05		1.00	

DQ.5: Long-Term Failure Rates

Component Failure Mode	Description	# Failures	Demands or Run-Hours	d or h	# Compnts	PointEst	Mean	Pt.Est. Ratio (E+L)/L	Comments
EDC-FS-NS	Engine Driven Compressor Fails To Start, Normally Standby	17	2,122	d	5	8.01E-03	8.24E-03		Combine early & late due to limited run-hour evidence
EDC-FR-E	Engine Driven Compressor Fails To Run <1H, Normally Standby	0	2,122	h	5	0.00E+00	2.36E-04		
EDC-FR-L	Engine Driven Compressor Fails To Run >1H, Normally Standby	0	1,735	h	5	0.00E+00	2.88E-04		
FTR	Early + Late Fail to Run	0	3,857			0.00E+00		n/a	
CTF-STBY-FTS	Cooling Tower Fan Fails To Start (Standby)	16	44,600	d	54	3.59E-04	3.70E-04		Combine early & late due to overwhelming evidence in the late-term
CTF-STBY-FTR<1H	Cooling Tower Fan Fails To Run <1H (Standby)	0	44,488	h	54	0.00E+00	1.12E-05		
CTF-STBY-FTR>1H	Cooling Tower Fan Fails To Run >1H (Standby)	2	1,073,115	h	54	1.86E-06	2.33E-06		
FTR	Early + Late Fail to Run	2	1,117,603			1.79E-06		0.96	
HTG-FTS	Hydro Electric Turbine Generator Fails To Start	11	7,270	d	2	1.51E-03	1.58E-03		The evidence may be sufficient to justify a different early vs late failure rate due to unique nature of this component.
HTG-FTLR	Hydro Electric Turbine Generator Fail To Run (< 1 Hour)	7	4,629	h	2	1.51E-03	1.62E-03		
HTG-FTR	Hydro Electric Turbine Generator Fail To Run (> 1 Hour)	1	10,678	h	2	9.36E-05	1.40E-04		
FTR	Early + Late Fail to Run	8	15,307			5.23E-04		5.58	
CTG-FTS	Gas Turbine Generator Fails To Start, Normally Standby	18	503	d	3	3.58E-02	5.12E-02		Combine early & late due to limited run-hour evidence
CTG-FTLR	Gas Turbine Generator Fails To Load And Run, Early Term	2	432	d	2	4.63E-03	5.79E-03		
CTG-FTR	Gas Turbine Generator Fails To Run, Late Term	5	648	h	2	7.72E-03	8.49E-03		
FTR	Early + Late Fail to Run	7	1,080			6.48E-03		0.84	

DC.5 to DC.9:
Component Spurious Operation

DC.5 to 9: Component Spurious Operation[1]

- NRC Dataset (2015) identifies events classified for several component types:
  - PORVs, Safety/Relief valves
  - AOVs, MOVs, SOVs
  - Breakers
- Issues:
  - The term "spurious operation" is used in Fire PRA for a specific fire-induced failure mode. This term should not be used for hardware failures.
  - The failure events included in spurious operation failure modes could (should) be modeled using other existing failure modes.
  - Spurious operation failure mode is defined using a number of IDs and descriptions, without clear distinction.
  - Spurious operation event count is inconsistent between NROD and 2015 Dataset.
- Potential Options:
  - Eliminate spurious operation as a component failure mode.
  - Map events identified as spurious operation (SOP/SO/CS/SC) to an existing component failure mode or to an IE.

DC.5 to 9: Component Spurious Operation^2

- Spurious Operation (SOP): *a component changes state without a real demand*
- Logical classification of SOP failure modes/impacts:
  1. SOP where a component changes state without a real demand, causing a plant transient.
     - These events are precursor to an Initiating Event.
     - They should be treated with the IE dataset, not the component reliability dataset
     - Some of these SOPs could occur only during LPSD, when the plant is transitioning.
  2. SOP where a component changes state without a real demand, without causing a plant transient but causing an alarm or other indication.
     - These events represent standby failures but because of the alarm/indication, the cause would be investigated and the condition corrected.
     - These could be modeled as contributing to component unavailability, but not as component failures.
  3. SOP where a component changes state without a real demand, without causing a plant transient and without alarm or other indication.
     - These events represent standby failures.
     - They could be treated as failure on demand (since the failure state would only be identify by a real or test demand).

DC.5 to 9: Component Spurious Operation[3]

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.
  - 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).
- The naming convention and descriptions are not used consistently.
  - ID Names: the xxx-SC label is used 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).
  - Descriptions: spurious operation, spurious opening, spuriously transfers, transfers open, fails to remain open.

DC.5 to 9: Component Spurious Operation[4]

- 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.
- The count of events in the NROD Database was significantly lower than in the NRC Dataset:
  - MOV_SOP events: 63 in NRC Dataset (2015) and 48 in the NROD Database.
  - AOV_SOP events: 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.

DC.5: PORV Spurious Operation

NRC Dataset (2015) identifies 24 events classified as PORV-SOP (PORV spurious opening), including both primary-side and secondary-side PORVs.

NROD Database search over the same time period (1998 to 2015) found 35 PORV-SOP events: 7 RCS, 28 MSS. Over the more recent time period (2006 to 2015), 16 PORV-SOP events:

- 2 RCS Events, PORV-SOP
  - 1 event occurred during troubleshooting and was immediately identified and recovered. This could be considered a precursor of SLOCA.
  - 1 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.
- 14 MSS Events, PORV-SOP:
  - 7 events involved the MSS PORV opening with no maintenance or plant operation in progress.
    5 events occurred during maintenance or while the plant was shutting down or starting up.
    2 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 SLB initiators, although the actions to isolate the open MSS PORV should be highly reliable since the cue is generally clear and actions are straightforward.

Suggestions:

- Classify PORV-SOP as precursor events and include in the Initiating Event dataset (rather than with component reliability dataset).
- Separate this data between primary-side PORVs and secondary-side PORVs.

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.

A review of the NROD database identified 7 SVV-SOP events (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,
- 3 occurred when a unit was returning to normal pressure following a refueling outage,
- 1 led to a manual reactor trip.

For the most part, these are not random events; they occur in response to a change in plant configurations and some may not be actual failures.

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).

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 should be captured in the IE 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.

DC.9: CCF Modeling of Spurious Operation

NRC CCF Dataset (2015) provides extremely sparse evidence of common cause failures for spurious operation failure modes:

- 0 events for check valves and DC circuit breakers,
- 1 event each for MOVs, AOVs, and 480 VAC circuit breakers,
- 3 events for 4160 VAC circuit breakers.

As discussed in #DC.6 and #DC.7, 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.

- For example, check valve spurious operation which has zero CCF events and zero independent events, but still produces a CCF parameter α2 = 4.07E-2 (for CCCG = 2).

Suggestion: 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.

Conclusions

- **PWROG**
  - We are available to support the development and review of the next revision to the NRC reliability and CCF databases.
  - We are open to options for how and when to provide comments.