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NRC Reactor Operating Experience Analysis and Trend Summary: 2022 Update

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ABSTRACT

This report presents a summary of the Nuclear Regulatory Commission (NRC) reactor operating experience analyses with data through 2022 as well as the reliability and frequency trends identified in the 2022 update reports for component performance study, loss of offsite power analysis, initiating events analysis, and system study provided on the NRC Reactor Operating Experience Results and Databases website (https://nrcoe.inl.gov/).

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ACRONYMS

AFW	auxiliary feedwater
AOV	air-operated valve
EDG	emergency diesel generator
EPS	emergency power system
FTLR	fail to load/run
HPCI	high-pressure coolant injection
HPCS	high-pressure core spray
HPSI	high-pressure safety injection
IE	initiating event
INL	Idaho National Laboratory
ISO	isolation condenser
LOOP	loss of offsite power
LPI	low-pressure injection
MDP	motor-driven pump
MOV	motor-operated valve
NRC	Nuclear Regulatory Commission
OpE	operating experience
PWR	pressurized water reactor
RCIC	reactor core isolation cooling
RHR	residual heat removal
SDC	shutdown cooling
TDP	turbine-driven pump

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NRC Reactor Operating Experience Analysis and Trend Summary: 2022 Update

1. INTRODUCTION

The report presents a summary of the Nuclear Regulatory Commission (NRC) reactor operating experience (OpE) analyses with data through 2022 as well as the reliability and frequency trends identified in the 2022 update reports provided on the NRC Reactor Operating Experience Results and Databases website (https://nrcoe.inl.gov/). The 2022 update included the following OpE analyses and reports:

- Loss-of-Offsite-Power (LOOP) Analysis, which is also updated annually
  - Analysis of LOOP Events 2022 Update [1]
- Initiating Event (IE) Analysis, which is updated annually
  - Initiating Event Rates at U.S. Nuclear Power Plants, 2022 Update [2]
- **Component Performance Studies**, which are updated every other year starting with the 2016 update
  - Enhanced Component Performance Study: Air Operated Valves (AOVs) 1998–2022 [3]
  - Enhanced Component Performance Study: Emergency Diesel Generators (EDGs) 1998–2022 [4]
  - Enhanced Component Performance Study: Motor Driven Pumps (MDPs) 1998–2022 [5]
  - Enhanced Component Performance Study: Motor Operated Valves (MOVs) 1998–2022 [6]
  - Enhanced Component Performance Study: Turbine Driven Pumps (TDPs) 1998–2022 [7]
- **System Performance Studies**, which are updated every other year starting with the 2016 update
  - System Study: Auxiliary Feedwater (AFW) 1998–2022 [8]
  - System Study: Emergency Power System (EPS) 1998–2022 [9]
  - System Study: High-Pressure Coolant Injection (HPCI) 1998–2022 [10]
  - System Study: High-Pressure Core Spray (HPCS) 1998–2022 [11]
  - System Study: High-Pressure Safety Injection (HPSI) 1998–2022 [12]
  - System Study: Isolation Condenser (ISO) 1998–2022 [13]
  - System Study: Reactor Core Isolation Cooling (RCIC) 1998–2022 [14]
  - System Study: Residual Heat Removal (RHR) 1998–2022 [15].

There were no updates on the industry-average parameter estimates, common-cause failure (CCF) parameter estimates, or causal CCF parameter estimates with data through 2022, as they are updated approximately every 5 years. The latest associated reports remain to be those using data through 2020 as follows:

- Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants: 2020 Update [16]
- CCF Parameter Estimations, 2020 Update, Revision 1 [17]
- Causal CCF Parameter Estimations, 2020 Update [18].

The above analyses may include more specific studies (e.g., the LOOP analysis includes the LOOP IE frequency analysis, LOOP frequency trending analysis, and LOOP duration analysis; the IE analysis includes the IE baseline analysis and IE frequency trending analysis; the industry-average parameter estimates include component unreliability and initiating event frequency estimates; and the CCF parameter estimates include estimations of CCF alpha factor, causal alpha factors, and CCF prior distributions). Different periods of data were used in the specific studies for a variety of reasons, (e.g., the most recent 15-year period was generally used in industry-average parameter estimates as well as in the CCF parameter estimates [previously, 1997 or 1998 was mostly used as the starting year for the data period in various analyses including LOOP and parameter estimates]; the most recent 10-year period was usually used in a trending analysis). Table 1 provides a list of data periods used in the latest NRC OpE analysis updates (i.e., 2022 updates for the LOOP and IE analyses and component and system studies, 2020 updates for the industry-average parameter estimates, CCF parameter estimates, and causal CCF parameter estimates).

In the remaining sections, the important statistically significant[a] trends (on reliability and unavailability), either increasing or decreasing, as identified in the 2022 update are presented.

[a] Statistically significant is defined in terms of the “p-value.” A p-value is a probability indicating whether to accept or reject the null hypothesis that there is no trend in the data. P-values less than or equal to 0.05 indicate that we are 95% confident that there is a trend in the data (reject the null hypothesis of no trend). By convention, we use the “Michelin Guide” scale: p-value < 0.05 (statistically significant); p-value < 0.01 (highly statistically significant); p-value < 0.001 (extremely statistically significant).

Table 1. Data periods used in the latest NRC OpE analysis updates.

Analysis	Specific Analysis	2022 (or 2020) Update	
		Data Period	Comment
LOOP Analysis	LOOP Initiating Event Frequency	2008–2022	15-year period for parameter estimation
	LOOP Frequency Trending	2013–2022	10-year period for trending analysis
	LOOP Duration Analysis	1997–2022	The data from 2006–2020 did not have a lognormal distribution that has been used in the LOOP recovery time analysis. Instead, the data from 1997–2020 fit the model and were used. The year 1997 has been historically used as the starting year for various LOOP associated analyses.
	LOOP Frequency Seasonal Effects	2008–2022	15-year period following the practice in parameter estimation
	Multi-Unit LOOP Conditional Probability	2008–2022	15-year period following the practice in parameter estimation
	Consequential LOOP - Transient	2008–2022	15-year period following the practice in parameter estimation
	Consequential LOOP - LOCA	1986-2006	The special analysis is not updated.
	Engineering Analysis	2008–2022	15-year period following the practice in parameter estimation
IE Analysis	IE Baseline Analysis	Various	Detailed statistical analyses were conducted to determine the IE baselines.
	IE Frequency Trending	2013–2022	10-year period for trending analysis
Component Studies	Trending Analysis	2013–2022	10-year period for trending analysis
System Studies	Trending Analysis	2013–2022	10-year period for trending analysis
Industry-Average Parameter Estimates	Component Unreliability (UR)	2006–2020	15-year period for parameter estimation
	Component or Train Unavailability (UA)	2006–2020	15-year period for parameter estimation
	IE Frequency	Various	Detailed statistical analyses were conducted to determine the IE baselines.
CCF Parameter Estimates	CCF Alpha Factors	2006–2020	15-year period for parameter estimation
	CCF Generic Priors	1997–2015	Developed in 2017 and used 1997 as the starting year
Causal CCF Parameter Estimates	CCF Causal Alpha Factors	2006–2020	15-year period for parameter estimation
	CCF Causal Priors	1997–2015	Developed in 2017 and used 1997 as the starting year

2. LOSS OF OFFSITE POWER EVENTS

The following trends were identified in critical operation LOOP frequencies in the most recent 10-year period from 2013 to 2022 [1]:

- Decreasing trend in critical operation all-categories (grid-related, plant-centered, switchyard-centered, and weather-related) LOOP frequencies
- Decreasing trend in critical operation switchyard-centered LOOP frequencies.

The following trends were identified for LOOP durations over the 1997–2022 post-deregulation period:

- Increasing trend in all-operations (critical and shutdown) all-categories LOOP durations
- Increasing trend in all-operations switchyard-centered LOOP durations
- Increasing trend in shutdown operation all-categories LOOP durations.

3. RATES OF INITIATING EVENTS

The occurrence rates trend for IEs are summarized in this section. Sixteen IE categories are trended and displayed in [2]. Note that the LOOP IEs analyzed in the IE analysis are also analyzed in the LOOP analysis as the critical operation, all-categories LOOPs (the LOOP analysis also analyze shutdown operation and individual category LOOPs). The decreasing LOOP trend identified in the 2022 IE Update [2] and presented below is the same trend identified in the 2022 LOOP Update [1] and presented in the previous section for critical operation all-categories LOOP frequencies.

The following trends were identified for initiating event frequencies in the most recent 10-year period from 2013 to 2022:

- Decreasing trend in LOOP (critical operation, all-categories) occurrence rates
- Decreasing trend in the pressurized water reactor (PWR) transient occurrence rates.

4. COMPONENT PERFORMANCE STUDIES

The component performance studies were last updated using data through 2022. The summary provided in this section is therefore the latest available information until the next update, which is scheduled for completion when the 2024 data are available.

The trending analysis in the study used data over the last 10 years, from 2013 to 2022. Important trends (on reliability and unavailability) and observations from the analysis are presented below.

Component Trends Consistent with the 2020 Updates:

- The failure rate estimate trend for AOVs to operate or control for low-demand valves (those with less than or equal to twenty demands per reactor year) is extremely statistically significant and decreasing. This trend was observed in the *2020 AOV Update Report* [19] as highly statistically significant.
- The failure probability estimate trend for EPS EDGs to load and run is statistically significant and decreasing. The same trend was observed in the *2020 EDG Update Report* [20] as highly statistically significant.
- The failure probability estimate trend for standby MDPs to run in the first hour is statistically significant and decreasing. The same trend was observed in the *2020 MDP Update Report* [21].
- The failure rate estimate trend for normally running MDPs to run is statistically significant and decreasing. The same trend was observed in the *2020 MDP Update Report* [21].
- The unavailability trend for standby MDPs is extremely statistically significant and decreasing. The same trend was observed in the *2020 MDP Update Report* [21].
- The unreliability (8-hour mission) trend for normally running MDPs is statistically significant and decreasing. The same trend was observed in the *2020 MDP Update Report* [21].
- The failure probability estimate trend for low-demand MOVs to open or close is extremely statistically significant and decreasing. The same trend was observed in the *2020 MOV Update Report* [22].
- The failure rate estimate trend for standby TDPs to run after the first hour is highly statistically significant and decreasing. The same trend was observed in the *2020 TDP Update Report* [23] as statistically significant.
- The unavailability trend for standby TDPs is extremely statistically significant and decreasing. The same trend was observed in the *2020 TDP Update Report* [23].
- The unreliability (8-hour mission) trend for standby TDPs is extremely statistically significant and decreasing. The same trend was observed in the *2020 TDP Update Report* [23] as highly statistically significant.

New Component Trends Not Identified in the 2020 Updates:

- The failure probability estimate trend for low-demand AOVs to open or close is extremely statistically significant and decreasing.
- The failure rate estimate trend for EPS EDGs to run is statistically significant and decreasing
- The unreliability (8-hour mission) trend for EPS EDGs is highly statistically significant and decreasing.
- The unreliability (8-hour mission) trend for standby MDPs is extremely statistically significant and decreasing.

4.1 Air-Operated Valves

4.1.1 Increasing Trends

4.1.1.1 Extremely Statistically Significant

- The frequency of demands per reactor year for low-demand AOVs to open or close was found to be increasing.
- The frequency of demands per reactor year for AOVs to open or close for high-demand valves (those with greater than twenty demands per reactor year) was found to be increasing.

4.1.2 Decreasing Trends

4.1.2.1 Extremely Statistically Significant

- The failure probability for low-demand AOVs to open or close was found to be decreasing.
- The failure rate for low-demand AOVs to operate or control was found to be decreasing.
- The frequency of fail to open or close events (events per reactor year) for low-demand AOVs was found to be decreasing.
- The frequency of fail to operate or control events (events per reactor year) for low-demand AOVs was found to be decreasing.

4.2 Emergency Diesel Generators

4.2.1 Increasing Trends

4.2.1.1 Extremely Statistically Significant

- The frequency of demands per reactor year for EPS and HPCS EDGs to start was found to be increasing.
- The frequency of fail to load/run (FTLR) demands per reactor year for EPS and HPCS EDGs to load and run was found to be increasing.

4.2.2 Decreasing Trends

4.2.2.1 Highly Statistically Significant

- The failure rate for EPS EDG to run was found to be decreasing.
- The unreliability (8-hour mission) of EPS EDGs was found to be decreasing.
- The frequency of fail to run events for EPS and HPCS EDGs was found to be decreasing.

4.2.2.2 Statistically Significant

- The failure probability for EPS EDGs to load and run was found to be decreasing.
- The frequency of fail to load and run events (events per reactor year) for EPS and HPCS EDGs was found to be decreasing.

4.3 Motor-Driven Pumps

4.3.1 Increasing Trends

4.3.1.1 Extremely Statistically Significant

- The standby MDP run > 1H hours per reactor year were found to be increasing.
- The normally running MDP run hours per reactor year were found to be increasing.

4.3.1.2 Highly Statistically Significant

- The frequency of demands per reactor year for standby MDPs to start was found to be increasing.
- The standby MDP run < 1H hours per reactor year were found to be increasing.

4.3.2 Decreasing Trends

4.3.2.1 Extremely Statistically Significant

- The standby MDP unavailability was found to be decreasing.
- The unreliability (8-hour mission) of standby MDPs was found to be decreasing.

4.3.2.2 Statistically Significant

- The failure probability for standby MDPs to run in the first hour was found to be decreasing.
- The failure rate for normally running MDPs to run was found to be decreasing.
- The normally running MDP unreliability (8-hour mission) was found to be decreasing.

4.4 Motor-Operated Valves

4.4.1 Increasing Trends

4.4.1.1 Extremely Statistically Significant

- The frequency of demands per reactor year for low-demand MOVs to open or close was found to be increasing.

4.4.2 Decreasing Trends

4.4.2.1 Extremely Statistically Significant

- The failure probability for low-demand MOVs to open or close was found to be decreasing.
- The frequency of failure to open or close events (events per reactor year) for low-demand MOVs was found to be decreasing.

4.5 Turbine-Driven Pumps

4.5.1 Increasing Trends

- None

4.5.2 Decreasing Trends

4.5.2.1 Extremely Statistically Significant

- The standby TDP unavailability was found to be decreasing.
- The standby TDP unreliability (8-hour mission) was found to be decreasing.
- The frequency of fail to run after the first hour events (events per reactor year) for standby TDPs was found to be decreasing.
- The normally running TDP run hours per reactor year were found to be decreasing.

4.5.2.2 Highly Statistically Significant

- The failure rate for standby TDPs to run after the first hour was found to be decreasing.
- The failure rate for normally running TDPs to run was found to be decreasing.
- The frequency of demands per reactor year for normally running TDPs to start was found to be decreasing.

4.5.2.3 Statistically Significant

- The frequency of demands per reactor year for standby TDPs to start was found to be decreasing.
- The frequency of hours per reactor year for standby TDPs to run in the first hour was found to be decreasing.

5. SYSTEM PERFORMANCE STUDIES

The system performance studies were last updated using data through 2022. The summary provided in this section is therefore the latest available information until the next update, which is scheduled for completion when the 2024 data are available.

The trending analysis in the study used data over the most recent 10 years, from 2013 to 2022, and identified the following trends:

- Decreasing trend in the industry-wide estimates of AFW system 8-hour mission unreliability
- Decreasing trend in the industry-wide estimates of EPS system 8-hour mission unreliability
- Increasing trend in the industry-wide estimates of HPCS system start-only unreliability
- Increasing trend in the industry-wide estimates of HPCS system 8-hour mission unreliability
- Decreasing trend in the industry-wide estimates of HPSI system start-only unreliability
- Decreasing trend in the industry-wide estimates of HPSI system 8-hour mission unreliability
- Decreasing trend in the industry-wide estimates of RCIC system start-only unreliability
- Decreasing trend in the industry-wide estimates of RCIC system 8-hour mission unreliability
- Decreasing trend in the industry-wide estimates of RHR system low-pressure injection (LPI) start-only unreliability(
- Decreasing trend in the industry-wide estimates of RHR system shutdown cooling (SDC) start-only unreliability
- Decreasing trend in the industry-wide estimates of RHR system LPI 8-hour mission unreliability.

5.1 Auxiliary Feedwater System

A highly statistically significant decreasing trend was identified in the industry-wide estimates of the AFW system 8-hour mission unreliability for the most recent 10-year period.

5.2 Emergency Power System

A highly statistically significant decreasing trend was identified in the industry-wide estimates of the EPS system 8-hour mission unreliability for the most recent 10-year period.

5.3 High-Pressure Coolant Injection System

No statistically significant trends were identified in the HPCI system unreliability trend results for the most recent 10-year period.

5.4 High-Pressure Core Spray System

Statistically significant increasing trends were identified in both the HPCS system start-only unreliability and 8-hour mission unreliability for the most recent 10-year period.

5.5 High-Pressure Safety Injection System

Highly statistically significant increasing trends were identified in both the HPSI system start-only unreliability and 8-hour mission unreliability for the most recent 10-year period.

5.6 Isolation Condenser System

No statistically significant trends were identified in the ISO system unreliability trend results for the most recent 10-year period.

5.7 Reactor Core Isolation Cooling System

Statistically significant decreasing trends were identified in both the RCIC system start-only unreliability and 8-hour mission unreliability for the most recent 10-year period.

5.8 Residual Heat Removal System

Statistically significant decreasing trends were identified in both the RHR system LPI and SDC start-only unreliability. A highly statistically significant decreasing trend was identified in the industry-wide estimate of RHR LPI 8-hour mission unreliability.

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