INL/RPT-22-66950

NRC Reactor Operating Experience Analysis and Trend Summary: 2020 Update

March 2022

Zhegang Ma

Idaho National Laboratory

INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance, LLC

INL/RPT-22-66950

NRC Reactor Operating Experience Analysis and Trend Summary: 2020 Update

Zhegang Ma

March 2022

Idaho National Laboratory
Regulatory Support Department
Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
Division of Risk Assessment
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
NRC Agreement Number 31310019N0006
Task Order Number 31310019F0022

Page intentionally left blank

ABSTRACT

This report presents a summary of the Nuclear Regulatory Commission (NRC) reactor operating experience analyses with data through 2020 as well as the reliability and frequency trends identified in the 2020 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/).

Page intentionally left blank

CONTENTS

TABLES

Page intentionally left blank

ACRONYMS

AFW	auxiliary feedwater
AOV	air-operated valve
EDG	emergency diesel generator
EPS	emergency power system
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
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
TDP	turbine-driven pump

Page intentionally left blank

NRC Reactor Operating Experience Analysis and Trend Summary: 2020 Update

1. INTRODUCTION

The report presents a summary of the Nuclear Regulatory Commission (NRC) reactor operating experience (OpE) analyses with data through 2020 as well as the reliability and frequency trends identified in the 2020 update reports provided on the NRC Reactor Operating Experience Results and Databases website (https://nrcoe.inl.gov/). The 2020 update included the following OpE analyses and reports:

- **Loss-of-Offsite-Power (LOOP) Analysis**, which is updated annually
    - *Analysis of LOOP Events 2020 Update* [1]
- **Initiating Event (IE) Analysis**, which is updated annually
    - *Initiating Event Rates at U.S. Nuclear Power Plants, 2020 Update* [2]
- **Component Performance Studies**, which are updated every other year starting with the 2016 update
    - *Enhanced Component Performance Study: Air Operated Valves (AOVs) 1998–2020* [3]
    - *Enhanced Component Performance Study: Emergency Diesel Generators (EDGs) 1998–2020* [4]
    - *Enhanced Component Performance Study: Motor Driven Pumps (MDPs) 1998–2020* [5]
    - *Enhanced Component Performance Study: Motor Operated Valves (MOVs) 1998–2020* [6]
    - *Enhanced Component Performance Study: Turbine Driven Pumps (TDPs) 1998–2020* [7]
- **System Performance Studies**, which are updated every other year starting with the 2016 update
    - *System Study: Auxiliary Feedwater (AFW) 1998–2020* [8]
    - *System Study: Emergency Power System (EPS) 1998–2020* [9]
    - *System Study: High-Pressure Coolant Injection (HPCI) 1998–2020* [10]
    - *System Study: High-Pressure Core Spray (HPCS) 1998–2020* [11]
    - *System Study: High-Pressure Safety Injection (HPSI) 1998–2020* [12]
    - *System Study: Isolation Condenser (ISO) 1998–2020* [13]
    - *System Study: Reactor Core Isolation Cooling (RCIC) 1998–2020* [14]
    - *System Study: Residual Heat Removal (RHR) 1998–2020* [15]
- **Industry-Average Parameter Estimates**, which is updated approximately every five years and includes estimations of component unreliability, component or train unavailability, and initiating event frequency.
    - *Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants: 2020 Update* [16]
- **Common-Cause Failure (CCF) Parameter Estimates**, which is updated approximately every five years

- *CCF Parameter Estimations, 2020 Update* [17]

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 includes component unreliability and initiating event frequency estimates; and the CCF parameter estimates includes estimations of CCF alpha factor, causal alpha factors, and CCF prior distributions. Different periods of data have been selected and used in the specific studies with various 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 2020 update of NRC OpE analyses.

In the remaining sections, the important statistically significant trends (on reliability and unavailability), either increasing or decreasing, identified in the 2020 update are presented.

Table 1. Data periods used in the 2020 update of NRC OpE analyses.

Analysis	Specific Analysis	2020 Update	
		Data Period	Comment
LOOP Analysis	LOOP Initiating Event Frequency	2006–2020	The most recent 15-year period
	LOOP Frequency Trending	2011–2020	Trending analyses use the most recent 10-year period
	LOOP Duration Analysis	1997–2020	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 fits to the model and was used. 1997 has been historically used as the starting year for various LOOP associated analyses.
	LOOP Frequency Seasonal Effects	2006–2020	The most recent 15-year period
	Multi-Unit LOOP Conditional Probability	2006–2020	The most recent 15-year period
	Consequential LOOP - Transient	2006–2020	The most recent 15-year period
	Consequential LOOP - LOCA	1986-2006	The special analysis is not updated.
	Engineering Analysis	2006–2020	The most recent 15-year period
IE Analysis	IE Baseline Analysis	Various	Detailed statistical analyses were conducted to determine the IE baselines
	IE Frequency Trending	2011–2020	Trending analyses use the most recent 10-year period
Component Studies	Trending Analysis	2011–2020	Trending analyses use the most recent 10-year period
System Studies	Trending Analysis	2011–2020	Trending analyses use the most recent 10-year period
Industry-Average Parameter Estimates	Component Unreliability (UR)	2006–2020	The most recent 15-year period
	Component or Train Unavailability (UA)	2006–2020	The most recent 15-year period
	Initiating Event (IE) Frequency	Various	Detailed statistical analyses were conducted to determine the IE baselines
Common-Cause Failure (CCF) Parameter Estimates	CCF Alpha Factors	2006–2020	The most recent 15-year period
	CCF Generic Priors	1997–2015	The CCF priors were developed in 2017
	CCF Causal Alpha Factors	2006–2020	The most recent 15-year period
	CCF Causal Priors	1997–2015	The CCF priors were developed in 2017

2. LOSS OF OFFSITE POWER EVENTS

The following trends were identified in critical operation LOOP frequencies in the most recent 10-year period from 2011 to 2020 [1]:

- Decreasing trend in critical operation all-categories LOOP frequencies
- Decreasing trend in critical operation switchyard-centered LOOP frequencies.

The following trends were identified for LOOP durations over the 1997–2020 post-deregulation period:

- Increasing trend in all-operations 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 trend here is the trend for all LOOP categories combined, including only initiating events, whereas the events considered in the LOOP study above are all events during critical operation.

The following trends were identified for initiating event frequencies in the most recent 10-year period from 2011 to 2020:

- Decreasing trend in LOOP 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 2020. The summary provided in this section is therefore the latest available information until the next update, which is scheduled for completion when the 2022 data are available.

The trending analysis in the study used data over the last 10 years, from 2011 to 2020. Important trends (on reliability and unavailability) and observations from the analysis are presented below.

<u>Same Trends as in the 2018 Update</u>

- The unavailability trend for standby MDPs is extremely statistically significant and decreasing. This trend was observed in the *2018 MDP Update Report* [18] as highly statistically significant.
- The failure rate estimate trend for normally running MDPs to run is statistically significant and decreasing.
- The failure probability estimate trend for MOVs to open or close for low-demand valves is extremely statistically significant and decreasing. This trend shows no sign of changing, as it existed in previous component performance analyses including the *2018 EDG Update Report* [19].

- The unavailability trend for standby TDPs is extremely statistically significant and decreasing. The same trend was observed in the *2018 TDP Update Report* [20] as highly statistically significant.

<u>New Trends Not in the 2018 Update</u>

- 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 highly statistically significant and decreasing.

- The failure rate estimate trend for AOVs to operate spuriously for low-demand valves is statistically significant and decreasing.

- The failure probability estimate trend for EPS EDGs to start is statistically significant and decreasing.

- The failure probability estimate trend for EPS EDGs to load and run is highly statistically significant and decreasing.
- The unavailability trend for EPS EDGs is highly statistically significant and decreasing.

- The failure probability estimate trend for HPCS EDGs to start is statistically significant and increasing.
- The failure probability estimate trend for standby MDPs to run in the first hour is statistically significant and decreasing.
- The unreliability (8-hour mission) trend for normally running MDPs is decreasing.

- The failure rate estimate trend for standby TDPs to run after the first hour is statistically significant and decreasing.
- The unreliability (8-hour mission) trend for standby TDPs is highly 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 AOVs to open or close for low-demand valves (those with less than or equal to twenty demands per reactor year) 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 Highly Statistically Significant

- The failure rate for low-demand AOVs to operate or control 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.

4.1.2.2 Statistically Significant

- The failure rate for low-demand AOVs to spuriously operate was found to be decreasing.
- The frequency of spurious operation 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 Highly Statistically Significant

- The frequency of demands per reactor year for EPS and HPCS EDGs to start was found to be increasing.

4.2.1.2 Statistically Significant

- The failure probability for HPCS EDGs to start was found to be increasing.
- The frequency of 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 probability for EPS EDGs to load and run was found to be decreasing.
- The EPS EDG unavailability 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.

4.2.2.2 Statistically Significant

- The failure probability for EPS EDGs to start 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 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.

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.
- The frequency of fail to run in the first hour events (events per reactor year) for standby MDPs was found to be decreasing.
- The frequency of fail to run events (events per reactor year) for normally running MDPs 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 MOVs to open or close for low-demand valves (those with less than or equal to twenty demands per reactor year) was found to be increasing.

4.4.2 Decreasing Trends

4.4.2.1 Extremely Statistically Significant

- The failure probability for MOVs to open or close for low-demand valves 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 normally running TDP run hours per reactor year were found to be decreasing.

4.5.2.2 Highly Statistically Significant

- 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 frequency of demands per reactor year for normally running TDPs to start was found to be decreasing.

4.5.2.3 Statistically Significant

- The failure rate for standby TDPs to run after the first hour was found to be decreasing.

5. SYSTEM PERFORMANCE STUDIES

The system performance studies were last updated using data through 2020. The summary provided in this section is therefore the latest available information until the next update, which is scheduled for completion when the 2022 data are available.

The trending analysis in the study used data over the most recent 10 years, from 2011 to 2020, identifying the following trends:

- Decreasing trend in the industry-wide estimates of AFW system start-only mission
- Decreasing trend in the industry-wide estimates of AFW system unreliability (8-hour mission)
- Decreasing trend in the industry-wide estimates of EPS system start-only mission
- Decreasing trend in the industry-wide estimates of EPS system unreliability (8-hour mission).

5.1 Auxiliary Feedwater System

Statistically significant decreasing trends were identified in the industry-wide estimates of the AFW system start-only mission and AFW system unreliability (8-hour mission) for the most recent 10-year period.

5.2 Emergency Power System

Statistically significant decreasing trends were identified in the industry-wide estimates of the EPS system start-only mission and EPS system unreliability (8-hour mission) 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.

5.4 High-Pressure Core Spray System

No statistically significant trends were identified in the HPCS system unreliability trend results.

5.5 High-Pressure Safety Injection System

No statistically significant trends were identified in the HPSI system unreliability trend results.

5.6 Isolation Condenser System

No statistically significant trends were identified in the ISO system unreliability trend results.

5.7 Reactor Core Isolation Cooling System

No statistically significant trends were identified in the RCIC system unreliability trend results.

5.8 Residual Heat Removal System

No statistically significant trends were identified in the RHR system unreliability trend results.

6. REFERENCES

[1] N. Johnson and Z. Ma. 2021. "*Analysis of Loss-of-Offsite-Power Events 2020 Update*." INL/EXT-21-64151, Idaho National Laboratory.

[2] N. Johnson and Z. Ma. 2021. "*Initiating Event Rates at U.S. Nuclear Power Plants, 2020 Update*." INL/EXT-21-63577, Idaho National Laboratory.

[3] Z. Ma. 2022. "*Enhanced Component Performance Study: Air Operated Valves 1998–2020*." INL/RPT-22-66461, Idaho National Laboratory.

[4] Z. Ma. 2022. "*Enhanced Component Performance Study: Emergency Diesel Generators 1998–2020*." INL/RPT-22-66601, Idaho National Laboratory.

[5] Z. Ma. 2022. "*Enhanced Component Performance Study: Motor-Driven Pumps 1998–2020*." INL/RPT-22-66599, Idaho National Laboratory.

[6] Z. Ma. 2022. "*Enhanced Component Performance Study: Motor-Operated Valves 1998–2020*." INL/RPT-22-66600, Idaho National Laboratory.

[7] Z. Ma. 2022. "*Enhanced Component Performance Study: Turbine-Driven Pumps 1998–2020*." INL/RPT-22-66598, Idaho National Laboratory.

[8] Z. Ma. 2022. "*System Study: Auxiliary Feedwater 1998–2020*." INL/RPT-22-66582, Idaho National Laboratory.

[9] Z. Ma. 2022. "*System Study: Emergency Power System 1998–2020*." INL/RPT-22-66583, Idaho National Laboratory.

[10] Z. Ma. 2022. "*System Study: High-Pressure Coolant Injection 1998–2020*." INL/RPT-22-66584, Idaho National Laboratory.

[11] Z. Ma. 2022. "*System Study: High-Pressure Core Spray 1998–2020*." INL/RPT-22-66586, Idaho National Laboratory.

[12] Z. Ma. 2022. "*System Study: High-Pressure Safety Injection 1998–2020*." INL/RPT-22-66587, Idaho National Laboratory.

[13] Z. Ma. 2022. "*System Study: Isolation Condenser 1998–2020*." INL/RPT-22-66588, Idaho National Laboratory.

[14] Z. Ma. 2022. "*System Study: Reactor Core Isolation Cooling 1998–2020*." INL/RPT-22-66589, Idaho National Laboratory.

[15] Z. Ma. 2022. "*System Study: Residual Heat Removal 1998–2020*." INL/RPT-22-66592, Idaho National Laboratory.

[16] Z. Ma, T. E. Wierman, and K. J. Kvarfordt. 2022. "*Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants: 2020 Update*." INL/EXT-21-65055, Idaho National Laboratory.

[17] Z. Ma and K. J. Kvarfordt. 2022. "*CCF Parameter Estimations, 2020 Update*." INL/EXT-21-62940, Idaho National Laboratory.

[18] Z. Ma. 2019. "*Enhanced Component Performance Study: Motor-Driven Pumps 1998–2018*." INL/EXT-19-54610, Idaho National Laboratory.

[19] Z. Ma. 2019. "*Enhanced Component Performance Study: Emergency Diesel Generators 1998–2018*." INL/EXT-19-54609, Idaho National Laboratory.

[20] Z. Ma. 2019. "*Enhanced Component Performance Study: Turbine-Driven Pumps 1998–2018*." INL/EXT-19-54613, Idaho National Laboratory.