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Common Cause Failure Analysis for Nuclear Power Plant Instrumentation and Control Systems

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IAEA Virtual Consultancy Meeting on I&C CCF Research Project, 5–8 February 2024

IAEA International Atomic Energy Agency

Idaho National Laboratory

Acronyms

- BNL Brookhaven National Laboratory
- CCF common cause failure
- DI&C digital instrumentation and control
- DOE Department of Energy
- EPRI Electric Power Research Institute
- FTA fault tree analysis
- HAZCADS hazards and consequences analysis for digital systems
- HRA human reliability analysis
- I&C instrumentation and control
- IAEA International Atomic Energy Agency
- IDCCS integrated data collection and coding system
- IEC International Electrotechnical Commission
- IEEE Institute of Electrical and Electronics Engineers
- INL Idaho National Laboratory
- INPO Institute of Nuclear Power Operations
- IRIS Industry Reporting and Information System
- LER licensee event report
- LWRS light water reactor sustainability
- NRC Nuclear Regulatory Commission
- OpE operating experience
- ORNL Oak Ridge National Laboratory
- PRA probabilistic risk assessment
- RISA risk-informed systems analysis
- SPAR standardized plant analysis risk
- STPA systems-theoretic process analysis

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  - Digital I&C OpE Study
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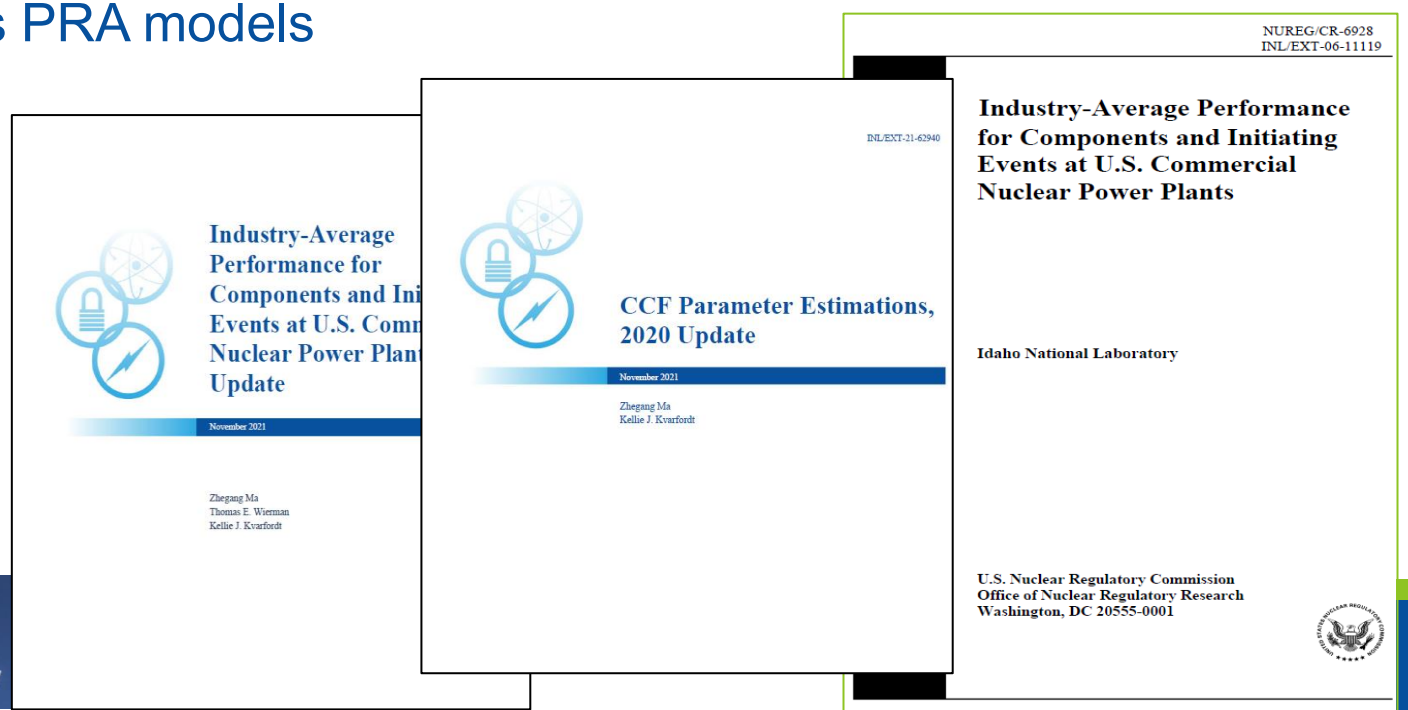
Introduction

- INL has provided technical assistance to the U.S. NRC in reliability and risk analysis including the OpE program since the 1980s
- The U.S. nuclear OpE data sources include
  - INPO IRIS Database
  - Licensee Event Reports
  - Event Notification Reports
  - Monthly Operating Reports
- In early 2000s, INL developed the Integrated Data Collection and Coding System to capture and characterize nuclear industry OpE data

Introduction (cont.)

- OpE data are characterized for different studies
  - **Component Failure**: system, component type, failure mode, p-value, failure cause…
  - **Initiating Event**: loss-of-offsite power, general transients, LOCAs…
  - **CCF**: failure cause, coupling factor, shared cause factor, time delay factor…
- These studies provide input parameters to the NRC's SPAR models as well as the industry's PRA models



INL Activities – U.S. NRC: Classical CCF Analysis

- NUREG/CR-4780 and NUREG/CR-5485 provide guidelines and procedures on modeling CCFs in PRA
  - **Alpha Factor Model**
  - Impact vector and mapping methods
- NUREG/CR-6268 provides the guidance for collecting, classifying, and coding CCF events and describes the **CCF database and software system** that is used to estimate CCF parameters
- NUREG/CR-5497 estimates CCF parameters for the majority of the **risk important safety systems and components** in commercial NPPs based on the CCF data collection effort from 1980–1995
- INL/EXT-21-62940 was published in 2022 updating CCF parameter estimates with data from 2006–2020

INL Activities – U.S. NRC: Classical CCF Analysis (cont.)

- Classical CCF analysis is focused on the PRA components
  - Motor-driven pumps
  - Diesel generators
  - Motor-operated valves
  - Breakers
- The failure modes are related to the PRA components
  - Fail to start
  - Fail to run
  - Fail to operate
  - Fail to open
  - Spurious operation

INL Activities – U.S. NRC: Digital I&C OpE Study

- To support the NRC's DI&C Study, INL conducted a limited DI&C literature review focusing on OpE and reliability analysis
  - NRC studies in NUREG and contractor (ORNL, BNL, etc.) reports
  - Industry studies including EPRI reports
  - IAEA reports
  - IEEE and IEC standards
- INL is currently reviewing about 2,000 INPO IRIS events that are coded with the cause category of *Digital/Cyber/Instrumentation Condition*
- The objective is to incorporate DI&C failure events into the IDCCS database and conduct DI&C reliability and CCF analysis

INL Activities – U.S. NRC: Digital I&C OpE Study (cont.)

- The new DI&C coding system would include fields for both DI&C component and the PRA component it impacted

For DI&C Equipment

- Device ID
- System
- Component Type
- Failure Mode
- P Value
- Failure Cause
- Detection
- Recovery
- Number of Failures

- **For Impacted PRA Component**
  - Device ID
  - System
  - Component Type
  - Failure Mode
  - P Value
  - Failure Cause

INL Activities – U.S. NRC: Digital I&C OpE Study (cont.)

- Two Different Kinds of DI&C CCF
  - DI&C "Internal" CCF: CCF among redundant DI&C equipment in different trains of the DI&C system
    - Can be treated with current CCF analysis process
  - DI&C "External" CCF: DI&C failures that impact and trigger multiple outside-of-DI&C-system key component failures
    - New area for CCF study
    - The impacted "external" key components could be
      - Redundant within the same system → same function
      - In the same system but not redundant → multiple functions
      - In different systems → multiple functions
- DI&C "Internal" CCF analysis would be needed for DI&C system reliability analysis
- DI&C "External" CCFs would need more focus as they are new and can lead to unanalyzed risks that are not included in the existing models

INL Activities – U.S. NRC: Digital I&C OpE Study (cont.)

For DI&C "Internal" CCF

- CCCG
- Event Type => CCF Type = Internal?
- Event Level
- Cause Code
- Coupling Factor
- Coupling Strength
- Defense Mechanism
- Shock Type
- Time Delay Factor
- Failure Mode App

For DI&C "External" CCF

- No CCCG?
- CCF Type = External
- DCCG – Digital Cause Component Group?
- Coupling Factor
- Coupling Strength
- Defense Mechanism
- Shock Type
- Time Delay Factor

Thoughts, Issues, and Challenges

- In general, I&C (including DI&C) is within the PRA key component boundary →
  - The key component's failure probability estimates have included the contributions from I&C
- However, intersystem component failures due to the common cause of DI&C are not included in the current SPAR or industry PRA models
  - Existing CCF database and parameter estimates are limited to the redundant components in the same system
- This is likely the biggest CCF concern and the largest risk contributor that we should work on

Thoughts, Issues, and Challenges (cont.)

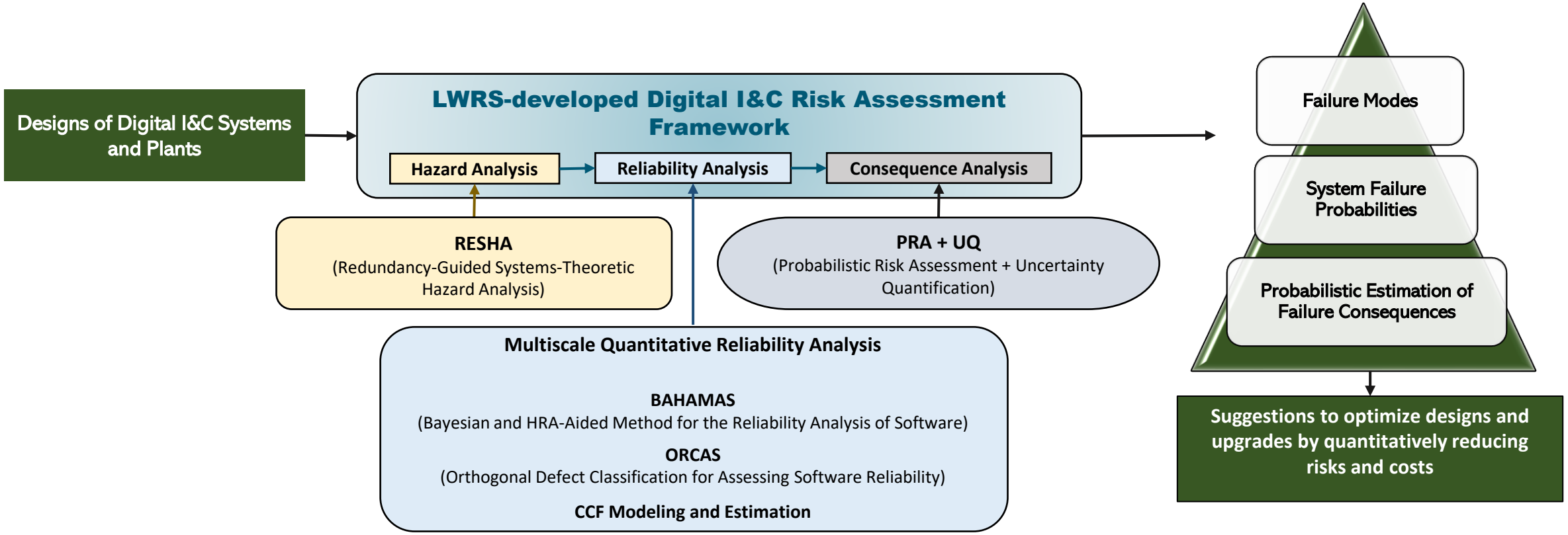
- Do we have sufficient OpE data to support the data-driven DI&C analysis?
  - Of the 2,000 IRIS failures events with the digital cause category, how many were actual DI&C failures?
  - What about LERs?
  - If we can obtain the number of DI&C failures, can we get their demands or run hours?
- Can we find a good DI&C coding system that meets most of needs?
- How to assess the impacted multiple components and functions that are outside of the scope of classical CCF analysis?
  - New methodology for DI&C "External" CCF?
- Representative DI&C systems and their descriptions will be needed for specific digital I&C study

INL Activities – U.S. DOE LWRS

- The U.S. DOE LWRS Program RISA Pathway supports plant owner-operator decisions with the aim to improve the economics, reliability, and maintain the high levels of safety of current nuclear power plants over periods of extended plant operations
- The goals of the LWRS DI&C Risk Assessment project:
  - Evaluate the design architecture of various DI&C systems to support system design decisions on diversity and redundancy applications
  - Develop approaches to address CCFs and estimate corresponding risk for DI&C technologies
  - Support existing risk-informed DI&C design guides by providing quantitative risk-informed evidence

INL Activities – U.S. DOE LWRS (cont.)

The LWRS DI&C Risk Assessment Framework



INL Activities – U.S. DOE LWRS (cont.)

- **Hazard Analysis**
  - Incorporates the concept of combining FTA and STPA from HAZCADS
  - Reframes STPA in a redundancy-guided way to identify various CCFs in highly redundant DI&C systems
  - Identifies and traces failures in both the actuation and information feedback pathway of DI&C systems due to unintended latent design or implementation defects or intended cyberattacks

INL Activities – U.S. DOE LWRS (cont.)

- **Reliability Analysis**
  - Bayesian and HRA-Aided Method for the Reliability Analysis of Software
    - Developed for the conditions with limited testing/operational data or for reliability estimations of software in early development stage
    - Provide an estimation of failure probabilities to support the design of software and target DI&C systems
  - Orthogonal Defect Classification for Assessing Software Reliability
    - Developed for the conditions with sufficient testing/operational data
    - A more refined estimation of software failure probabilities can be provided

INL Activities – U.S. DOE LWRS (cont.)

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Questions?

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