U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Office Of Nuclear Energy
Advanced Sensors and Instrumentation
Annual Review Meeting

Operator Support Technologies for Fault Tolerance and Resilience

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Ken Thomas and Ron Boring (INL)

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Project Overview (1/3)

Background

- Automated systems perform more reliably than humans at rote tasks such as procedures-driven control actions. Humans on the other hand perform much better at system oversight, evaluating complex situations and formulating an appropriate response.
- Advanced equipment fault-detection and identification algorithms can provide the plant operator with tools for a more informed response to equipment faults. Computer-based operator advisory system will permit the operator's response to be more timely compared to one initiated through paper-based procedures

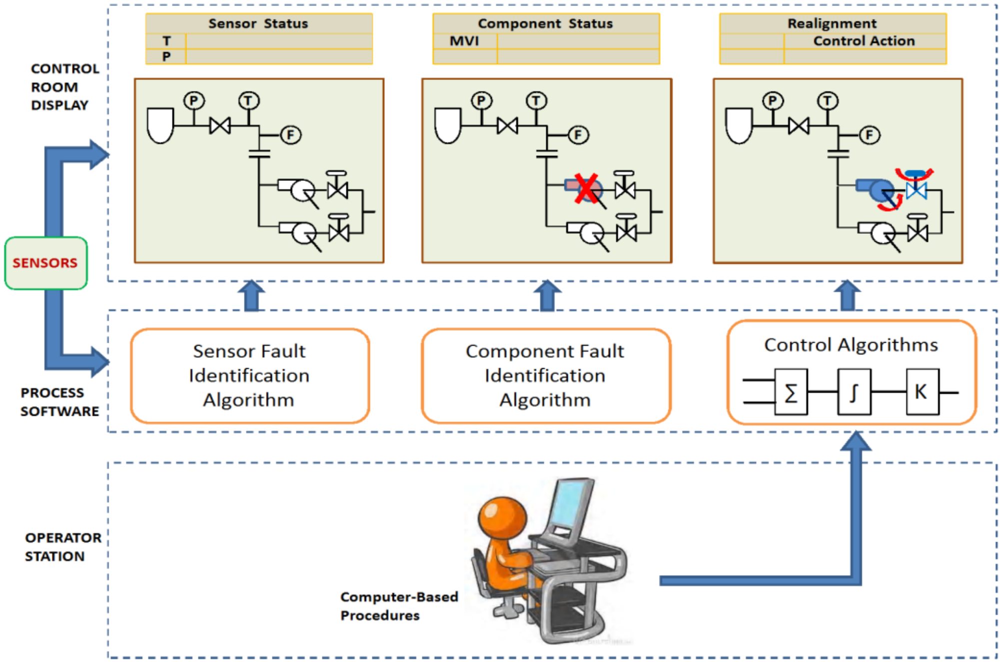
Goal

- To improve operational reliability, improve nuclear safety, and reduce human error through the development of advanced NPP computer-based operator support technologies.

Project Overview (2/3)

Objectives

- Develop technology to assist and support operators with complex fault diagnosis and selection of appropriate mitigation control actions
  - Advises NPP control room operators of the time-critical plant conditions and allows them to enable an automated response to mitigate the fault.
- Develop the underlying fault detection and diagnosis algorithms
- Demonstrate on full-plant simulator



Participants

- Rick Vilim (ANL)
- Ken Thomas, Ron Boring (INL)

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Project Overview (3/3)

Schedule

Year	Task
1	INL - Identification and classification of internal faults/degradation along with prioritization. Analysis of likelihood of continued operation. ANL - Conceptual development and initial coding of detection and identification algorithms.
2	INL - Acquire plant simulator for a representative light water reactor plant. Develop concept of Computer Operator Support System ANL - Begin testing fault detection and identification software in standalone fashion using simulator-based test-bed.

Accomplishments (1/8)

- ***Design to Achieve Fault Tolerance and Resilience*, INL/EXT-12-27205, September 2012.**
  - Describes opportunities for replacing procedure-based manual control with automated control
  - Describes issues and approaches associated with NPP run-back to house loads following loss-of-load transient
- ***Description of Fault Detection and Identification Algorithms for Sensor and Equipment Failures and Preliminary Tests Using Simulations*, ANL/NE-12-57, November 30, 2012.**
  - Presents findings of review of the PRODIAG software developed at ANL for diagnosing component faults in nuclear power and process industry plants
  - Describes plan to modernize the PRODIAG software so that its automated reasoning (AR) capability is more maintainable and extensible. Essentially a rewrite of the software suing current generation AR coding techniques.

Accomplishments (2/8)

- ***A Computer Operator Support System*, INL/EXT-13-29561, August 2013.**
  - Describes the architecture and design of planned COSS and first-phase implementation of computer-prompted procedures on full-scale simulator.
- ***Comprehensive Tests of Fault Detection and Identification Algorithms for Sensor and Equipment Failures Using Simulations*, ANL/NE-12-57, September 30, 2013.**
  - Describes results of simulation-based tests of component fault-diagnosis and sensor validation algorithms and software. Sensitivity of fault diagnosis characterized with respect to sensor types and numbers and to the severity of fault.
- **Invited Article**
  - R.B. Vilim, et al., "Monitoring and Diagnosis of Equipment Faults," Nuclear Engineering International, November 2013.

Accomplishments (3/8)

- **Readied Full-Scale Simulator (DOE Human Systems Simulation Laboratory or HSSL, located at Idaho National Laboratory)**
  - Prepared target platform for implementation of COSS computer-prompted procedures and follow-on human factor studies

Accomplishments (4/8)

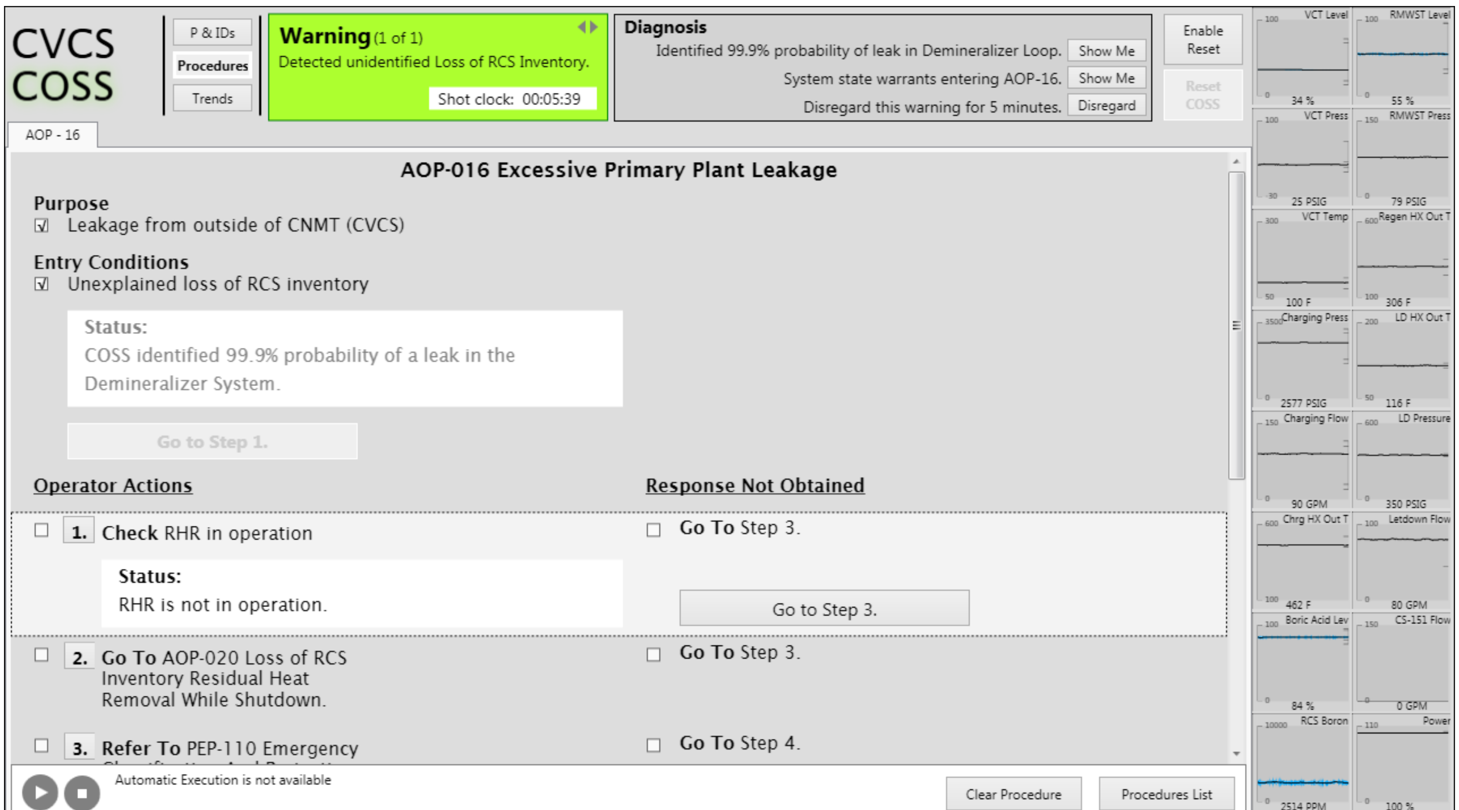
■ Developed Computer Operator Support System Prototype

- Designed protocols for operator interaction with computer-prompted procedures and programmed these on full-scale simulator

Accomplishments (5/8)

Developed Computer Operator Support System Prototype (cont'd)

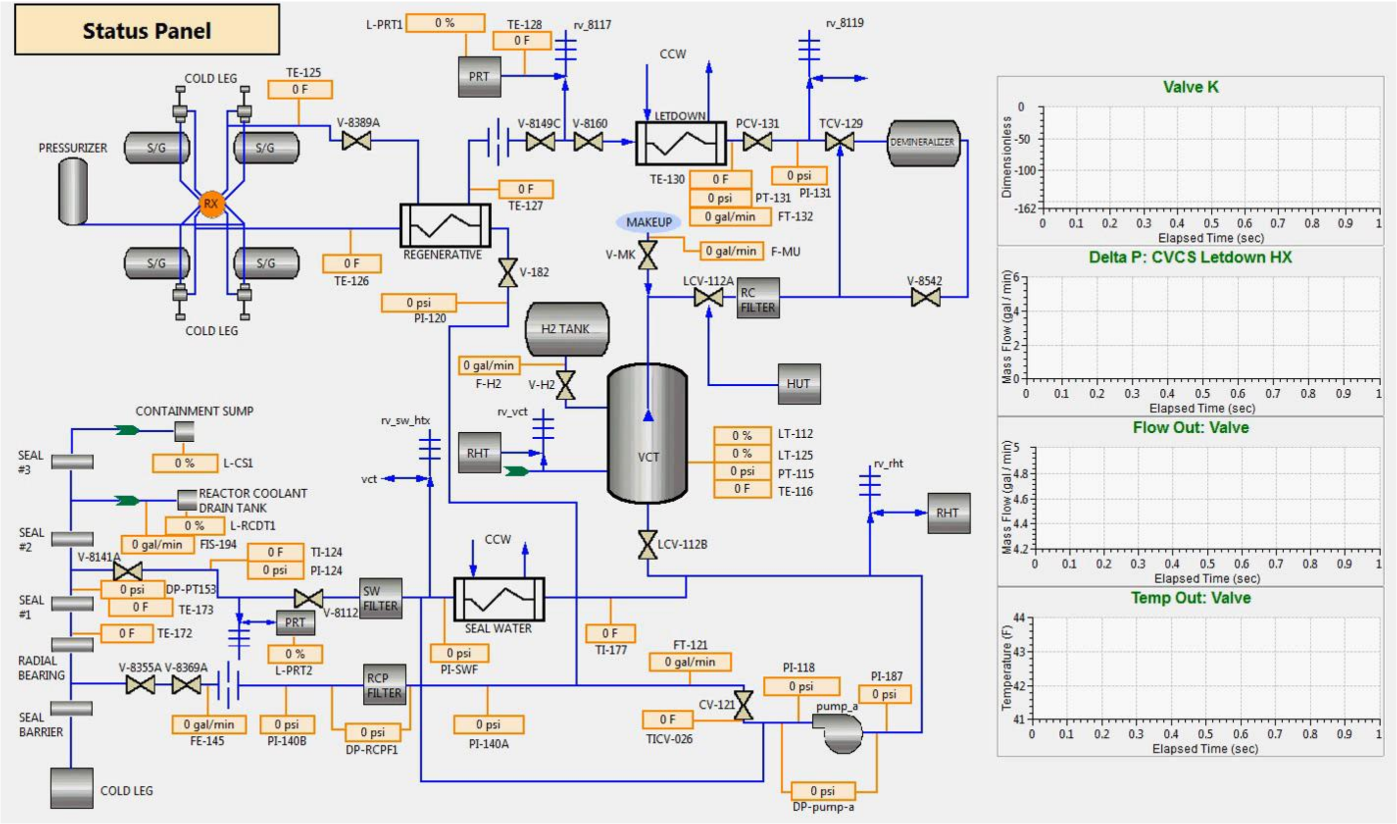
- Defined and developed the operator alarm display
- Developed and demonstrated the fault scenario



Accomplishments (6/8)

■ Created Test-Bed for Fault Diagnosis Algorithms

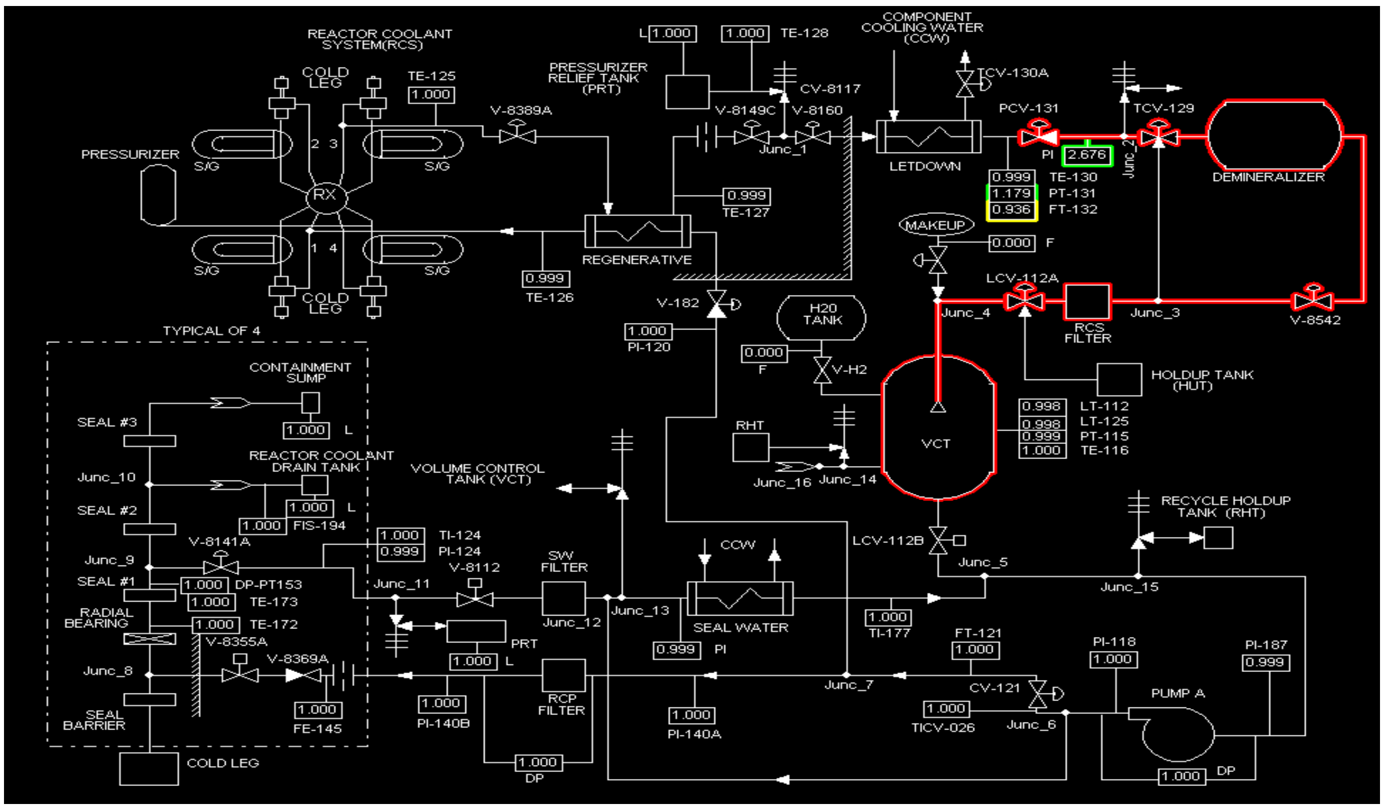
- Generated Chemical and Volume Control System (CVCS) simulation data with capability for injecting faults



Accomplishments (7/8)

Performed Equipment Fault Diagnosis Studies on Test-Bed

- Fault detected before operator sees It



GUI Highlighting Location of Fault in CVCS

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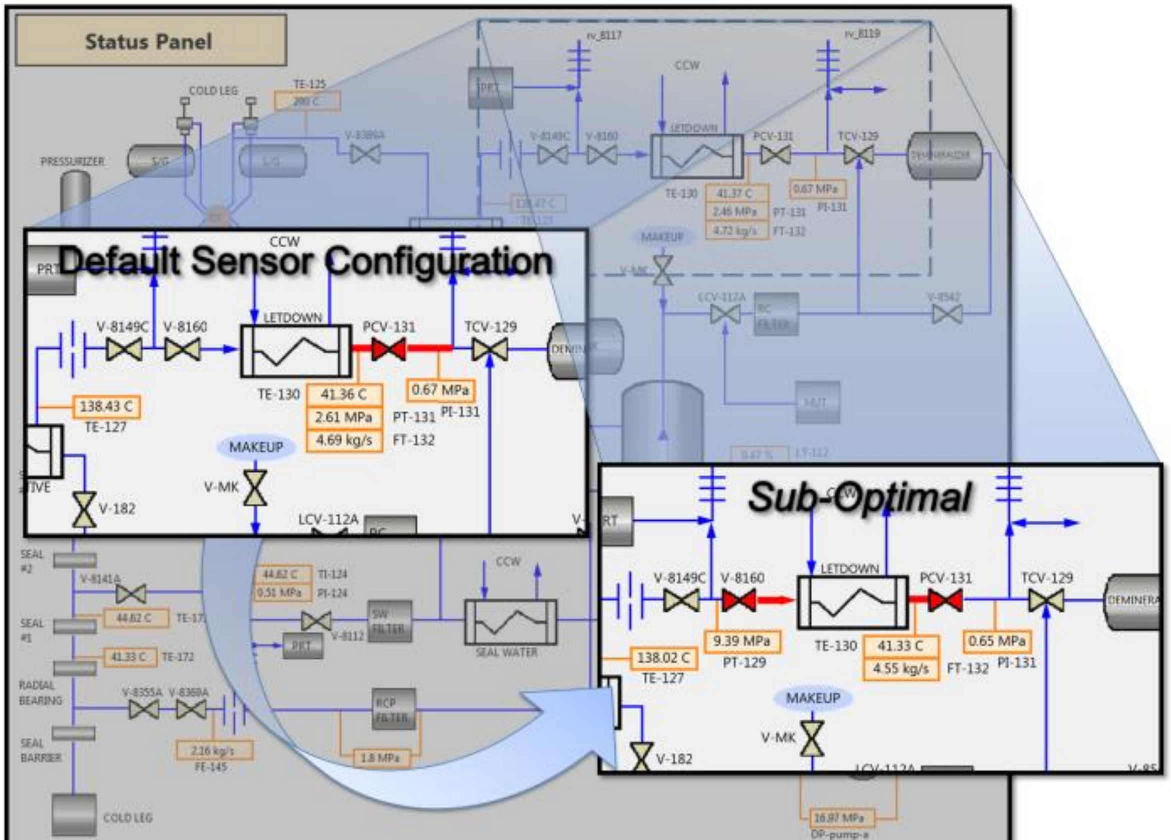
Accomplishments (8/8)

- **Characterized Sensitivity of Fault Diagnosis to Types and Numbers of Sensors and to Severity of the Fault**



Technology Impact (1/2)

- **Diagnosis of Component Faults Presently Limited by the Need for Operator Reasoning at the Sensor Level**
  - This work, through quantitative reasoning, elevates these tasks to the level of the component and its system allowing for more informed operator control actions
  - Method is generic and applicable to industrial processes – nuclear power, oil and gas, etc.
  - Improve plant safety with respect to faults through quantitative reasoning
- **Events Handled Manually by Operators Could Benefit from New Technology that Combines the Best of Both: Fast Automatic Response with Accurate Diagnosis and Nuanced Actions**
  - Would mitigate plant transients much quicker and avoid reactor trips and safety system actuations

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Technology Impact (2/2)

Today

Plant Status Display

Alarm Panel

Paper-Based Procedures

Control Station

Envisioned

Sensor Validation

Enhanced Operator Diagnostic Alarms and Display

Automated Control Using Computer-Based Procedures

Confirmation of Desired Fault-Response Outcome

Algorithms and Computation

First Principles Models

Library of Scripts for Corrective Actions for Specific Faults

5

Conclusion

- **Next-Generation Operator Support Technology**
  - Improves operational reliability
  - Improves nuclear safety
  - Reduces human error
- **Directly Supports Future Projects in the LWRS II&C Pathway**
- **Enables Advanced Concepts of Operation for New Reactor Types**
- **Supports the Advanced Distributed Control Systems Now Being Implemented in Many of the Current Operating Plants**