



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
Rick Vilim (ANL)
Ken Thomas and Ron Boring (INL)**

September 17, 2014



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.



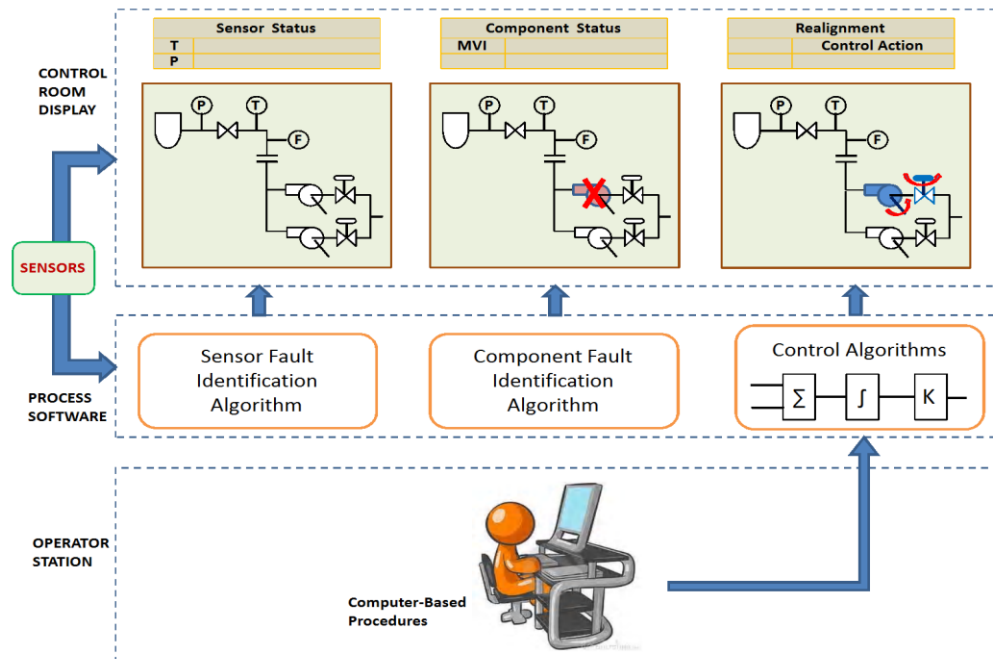
Project Overview (2/3)

■ 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)





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 using 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

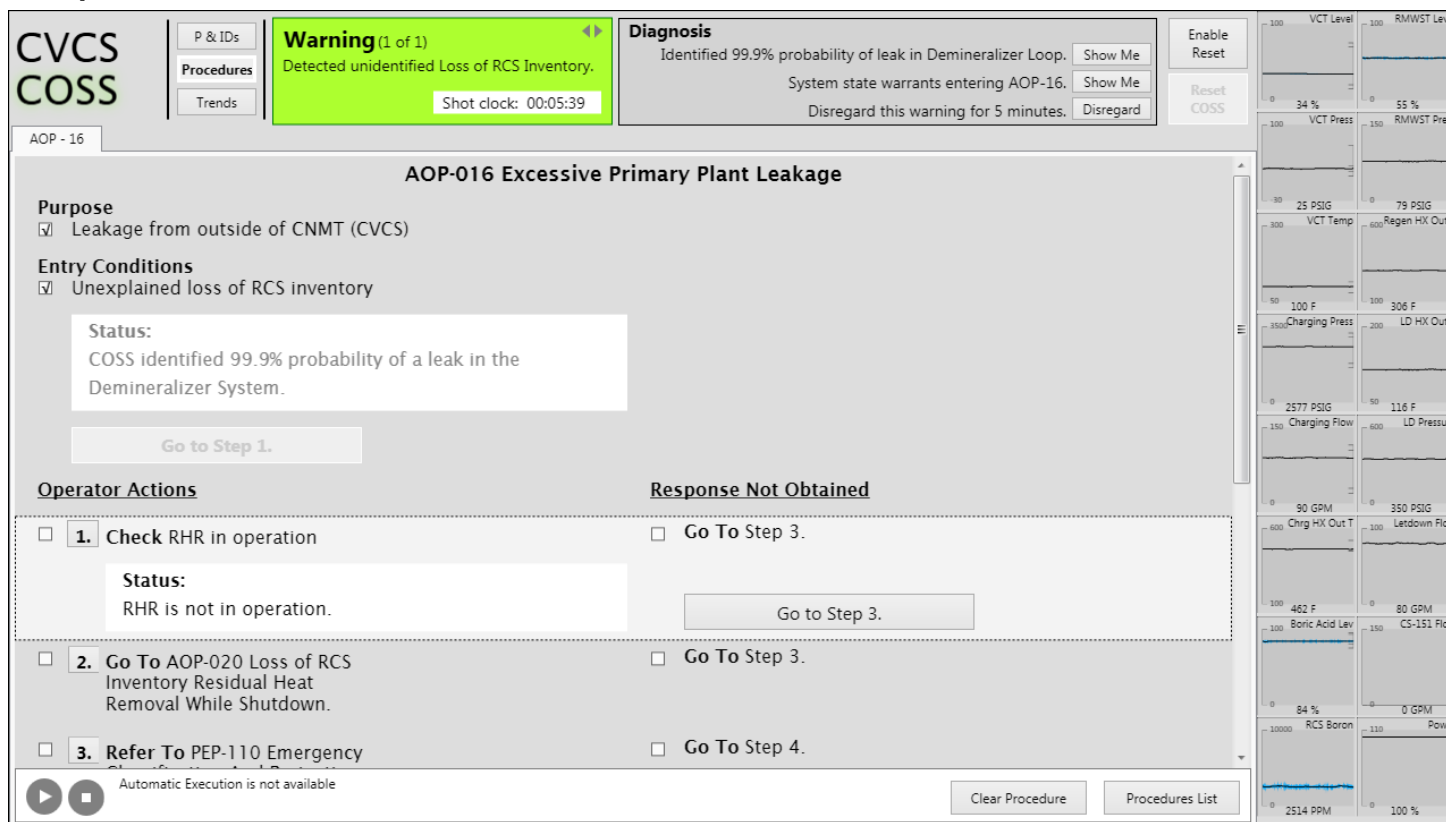




Accomplishments (5/8)

■ Developed Computer Operator Support System Prototype (cont'd)

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

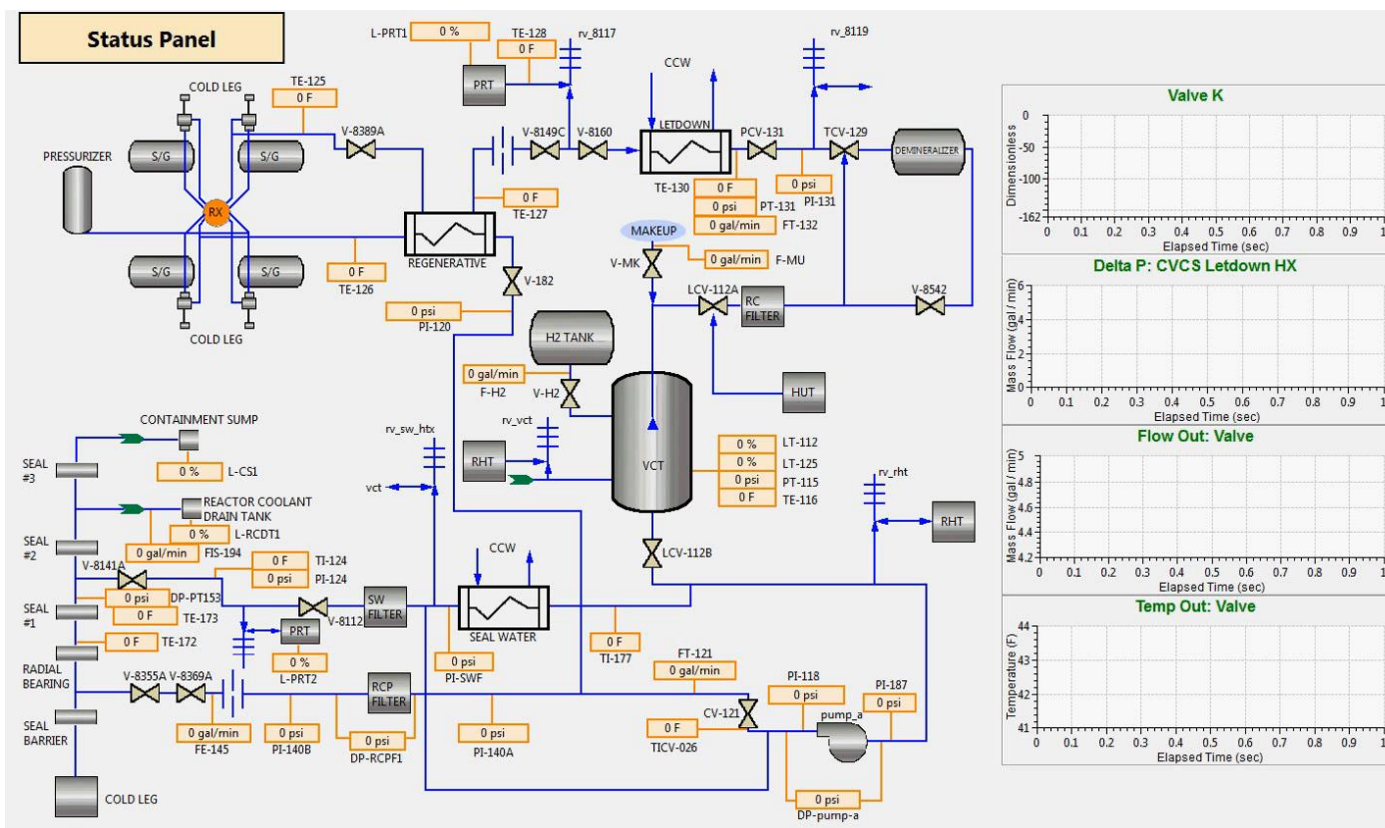




Accomplishments (6/8)

■ Created Test-Bed for Fault Diagnosis Algorithms

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

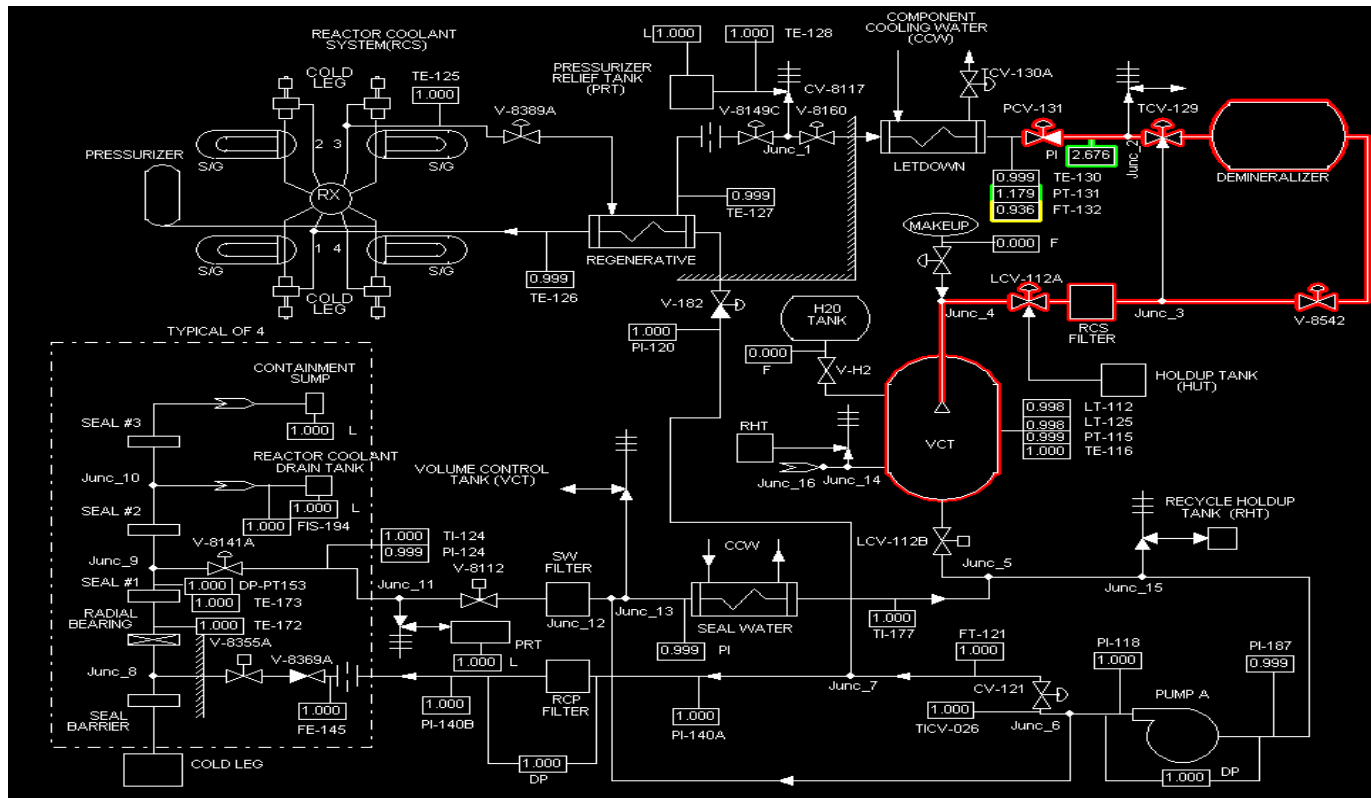




Accomplishments (7/8)

■ Performed Equipment Fault Diagnosis Studies on Test-Bed

- Fault detected before operator sees it

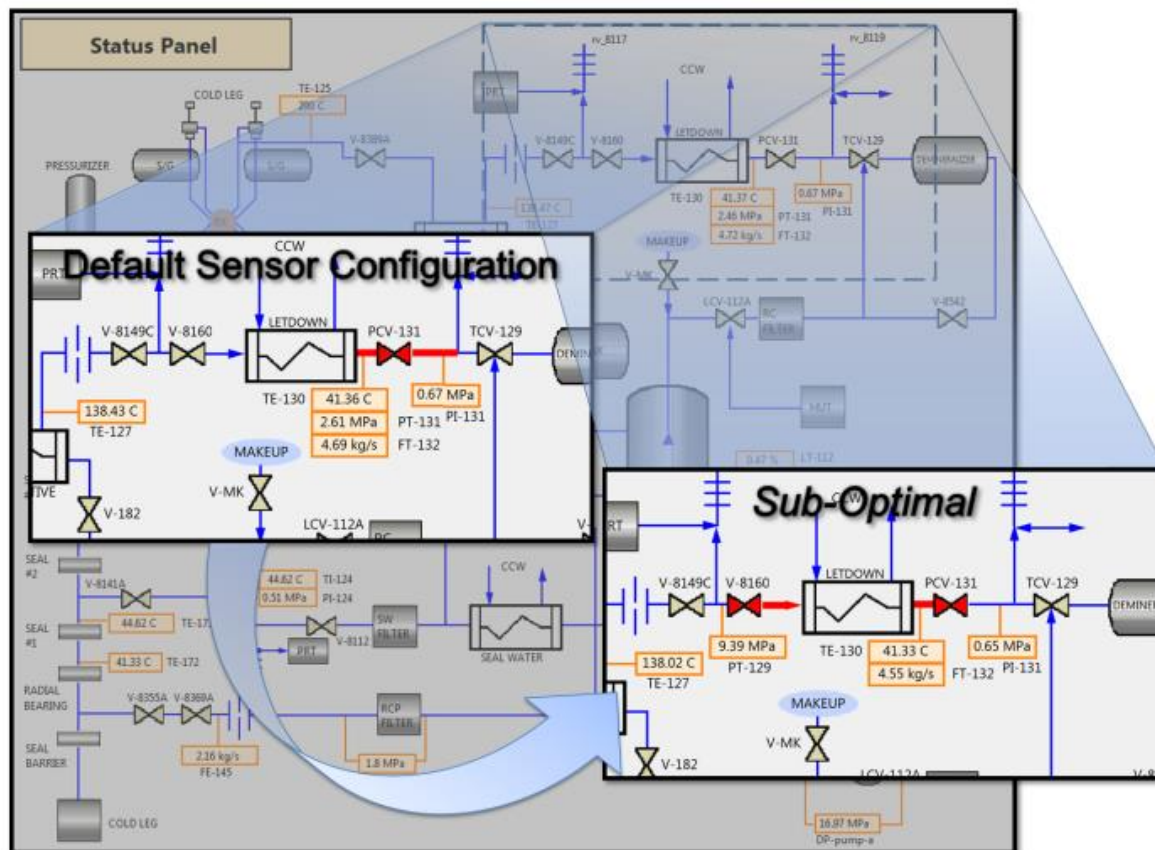


GUI Highlighting Location of Fault in CVCS



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

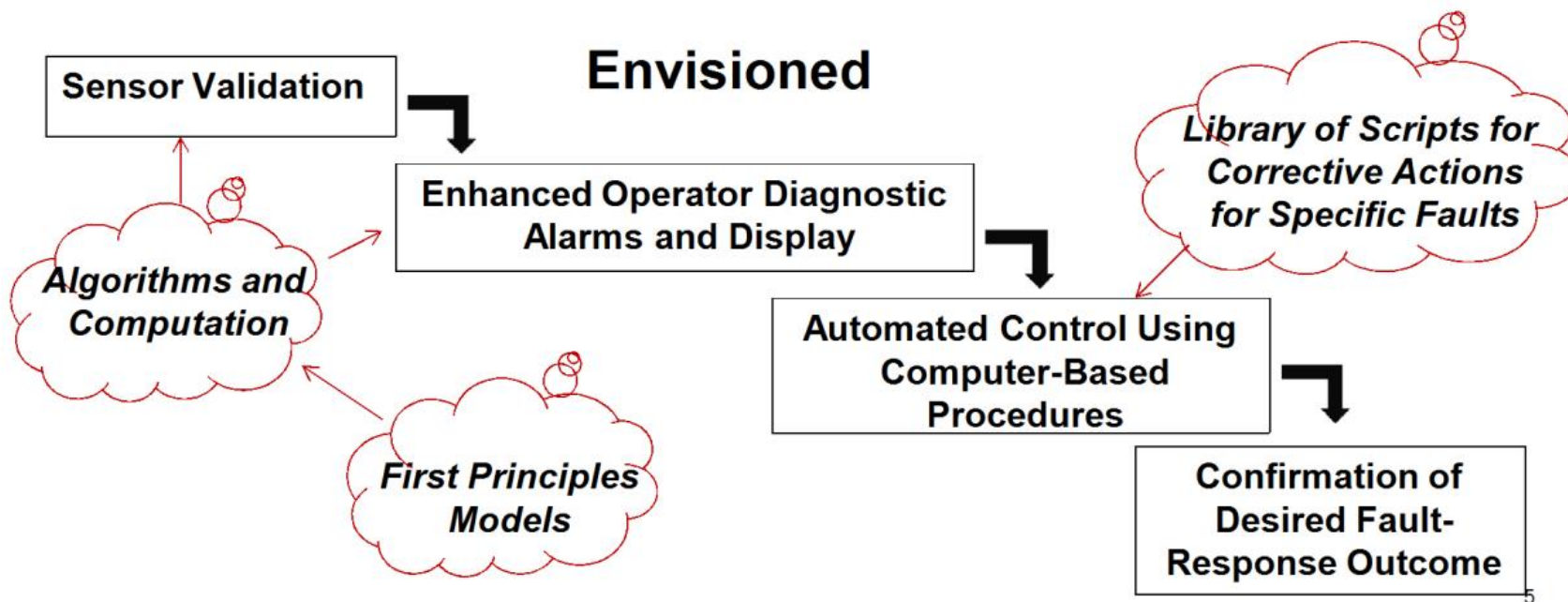


Technology Impact (2/2)

Today



Envisioned





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