Office Of Nuclear Energy Sensors and Instrumentation Annual Review Meeting

Operator Support Technologies for Fault Tolerance and Resilience

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NEET ASI

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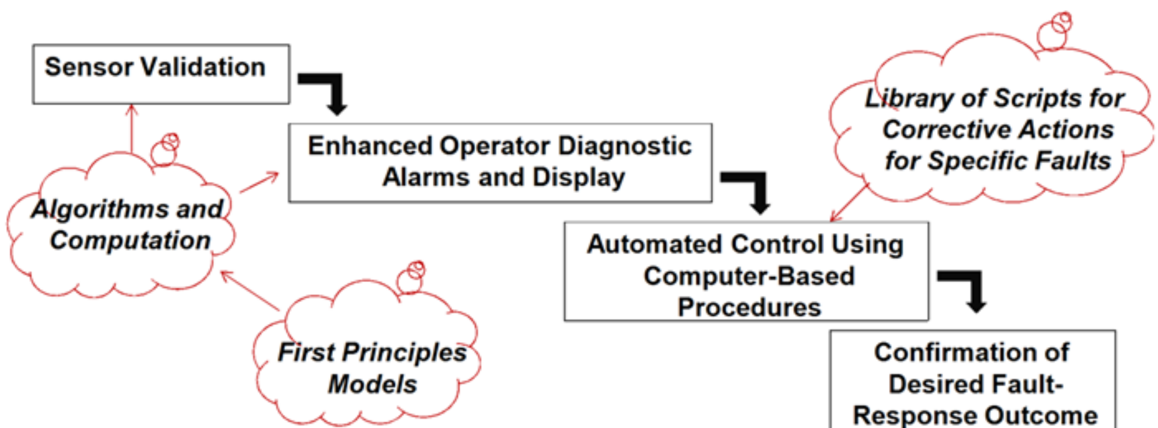
Project Overview

- **Goal - Increase situational awareness for nuclear plant operations using first principles-based diagnostic aids in an environment that takes into account human factors**
  - Support for control room operations by improving operator response to time-critical component faults

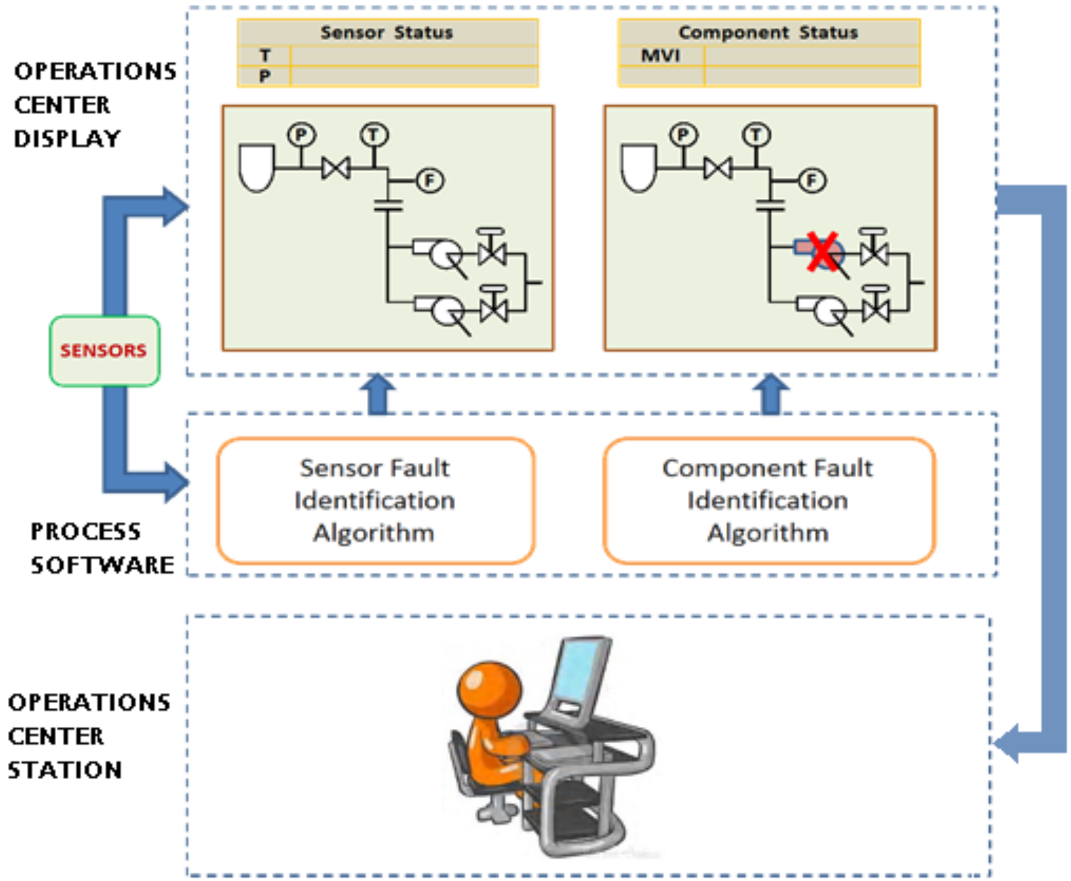
Today

Envisioned



Project Overview (cont'd)

- Support for Utility Operations Center by automating surveillance



Project Overview (cont'd)

Objectives

- FY15 (Year 1)
  - ANL verification and validation of diagnostic methods and algorithms
  - INL development of operator interface in Human Systems Simulation Laboratory (HSSL)
- FY16 (Year 2)
  - Link ANL algorithms to INL operator interface in preparation for operator performance tests at HSSL
- FY17 (Year 3)
  - Assess human performance improvement through tests with Palo Verde NPP operators in HSSL

Participants

- Richard Vilim, Argonne National Laboratory
- Ken Thomas and Ron Boring, Idaho National Laboratory

Background

- **PRO-AID: Parameter-Free Reasoning Operator for Automated Identification and Diagnosis**
  - Fault diagnosis by humans is time consuming and prone to error
  - Why not compare sensor readings against predictions of a first-principle model that incorporates hypothesized fault?
    - Difficult to generalize because of the need for plant-specific models
  - Data-driven model in conjunction with the conservation laws (written as confluence equations) does not suffer from these limitations
    - Not a black-box approach

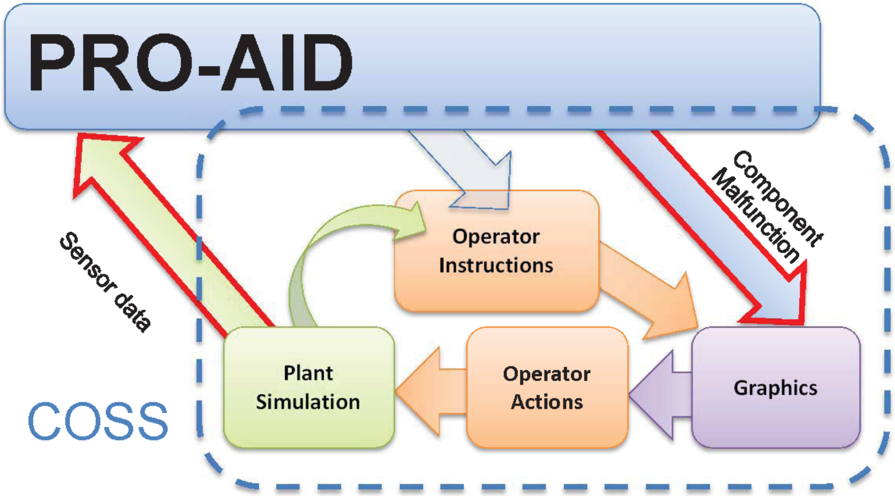
Sensor Trend	Status Indicators	Fault Diagnosis
$[\Delta P] = /-$ and $[dw] = -$	n/a	Sensor Error
$[\Delta P] = -$ and $[dw] = /-$	n/a	Sensor Error
$[dw_{in}] = \downarrow$ and $[dw_{out}] = \uparrow$ and $[P] = \uparrow$	$\Rightarrow d[Q_{mass}] = \uparrow$ and $d[Q_{mass}] = \downarrow$	Leak
$[dw_{in}] = \uparrow$ and $[dw_{out}] = \downarrow$ and $[P] = \downarrow$	$\Rightarrow d[Q_{mass}] = \downarrow$ and $d[Q_{mass}] = \uparrow$	Leak
$[\Delta P] = \uparrow$ and $[dw] = \downarrow$	$\Rightarrow d[Q_{mom}] = \downarrow$ and $d[Q_{mass}] = -$	Blockage
$[\Delta P] = \downarrow$ and $[dw] = \uparrow$	$\Rightarrow d[Q_{mom}] = \uparrow$ and $d[Q_{mass}] = -$	Opposite of Blockage

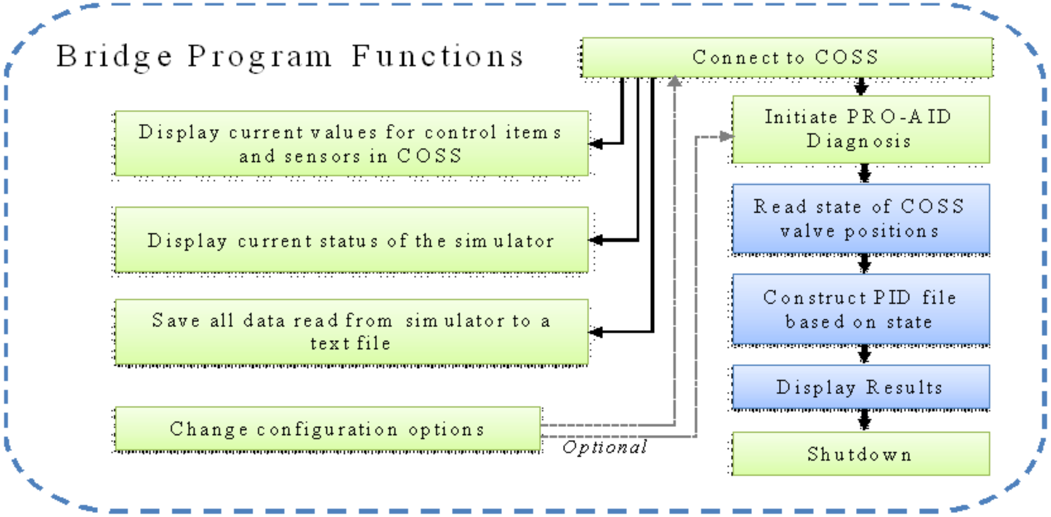
Background (cont'd)

- HSSL: Human Systems Simulation Laboratory at INL
- Full-scale test facility for performing human factors experiments with control room operators

Accomplishments

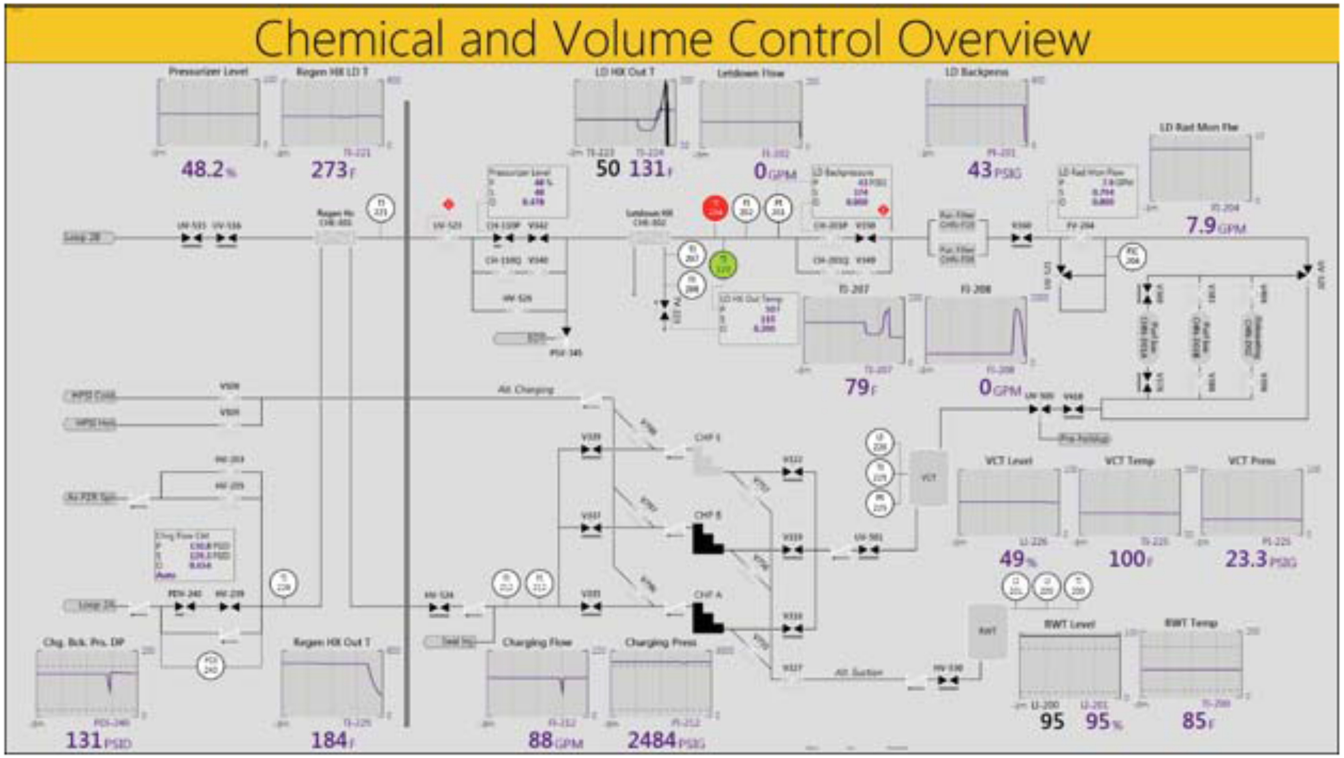
- **Developed bridge program that couples PRO-AID to HSSL simulator**





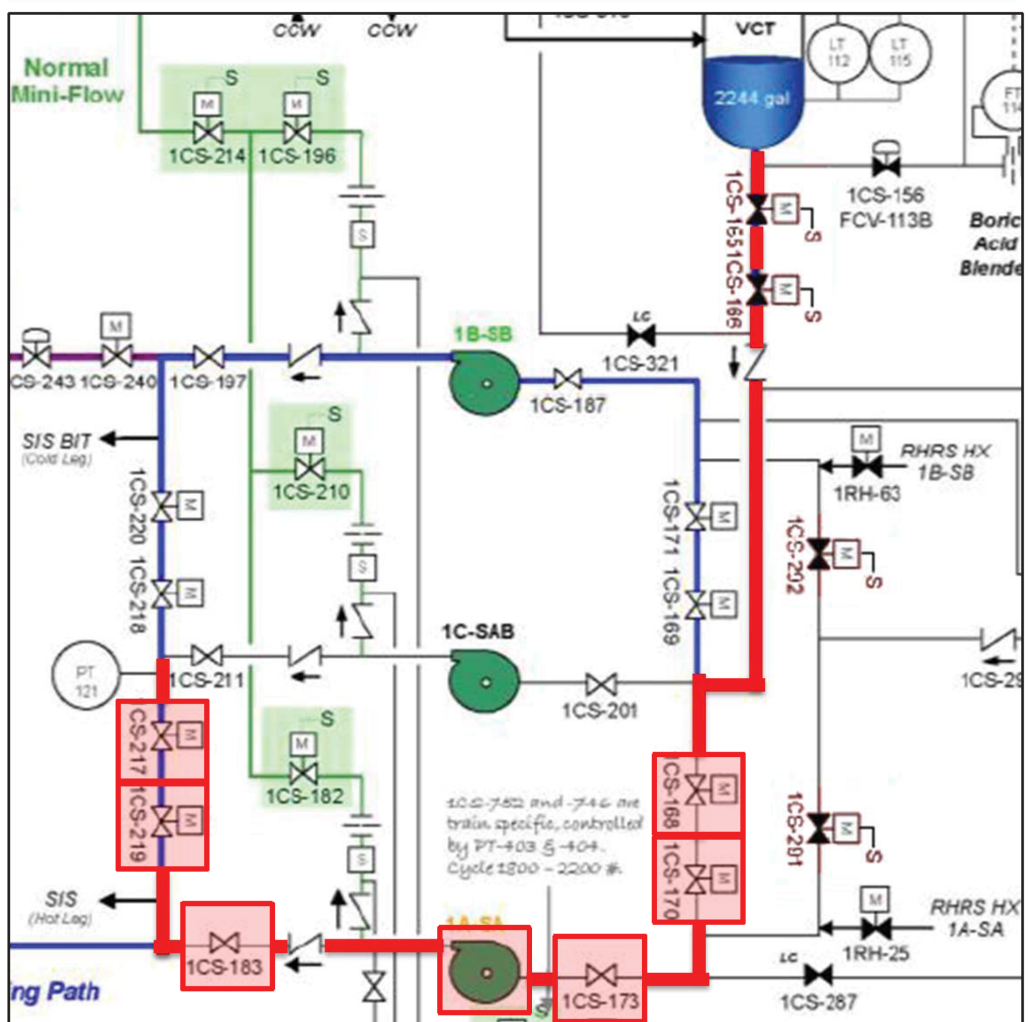
Accomplishments

- Assembled PRO-AID input files for performing fault diagnosis in Palo Verde NPP chemical and volume control system



Accomplishments

- **Performed several fault diagnosis shakedown test cases with bridge program coupling COSS to HSSL simulator**



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Accomplishments

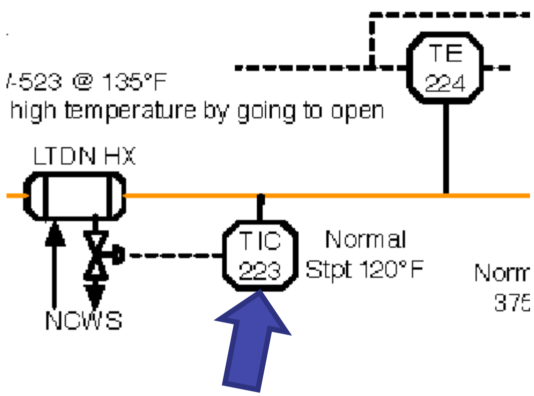
- Conducted a human performance assessment with Palo Verde operators in August 2016 – Prelude to FY17 studies
- Performed a simulated fault injection to gauge operator performance for PRO-AID assisted/not-assisted scenarios

Accomplishments

Injected-Fault Test Scenario

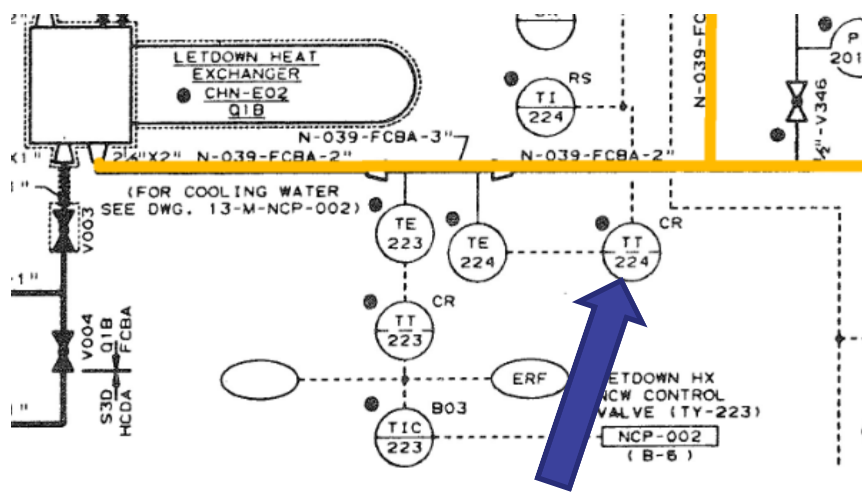
- Controller temperature sensor on letdown line fails low
- Component cooling water (CCW) flow rate adjusts to its minimum value of 20% in response to the perceived overcooling of letdown flow.

Component Cooling Water Circuit



Controller temperature sensor on letdown line fails low

Letdown Flow Circuit



Surveillance temperature sensor detects actual undercooling of letdown line; automatic programmed isolation of letdown line begins

Accomplishments

- **Fault evolution with no operator intervention**
  - Approximately 60 s into fault, automatic control system isolates letdown line from rest of plant
  - Plant operates with reduced CVCS volume-control function
  - Plant in an operating mode that cannot be sustained long-term. i.e. letdown line isolated
  - Maintenance must troubleshoot problem
- **Fault evolution with PRO-AID diagnosis**
  - Operator alerted to HX cooling problem by PRO-AID three sec after fault injection
  - Failed temperature sensor identified by PRO-AID
  - Operator places letdown control valve in manual mode to maintain CVCS volume-control function
  - Plant in an operating mode that can be sustained long-term, i.e. letdown isolation avoided
  - Maintenance proceeds to repair letdown temperature controller

Accomplishments

- **Deliverables**
  - A. Grelle and R. Vilim, "Description of Linked Algorithms and Simulator for Fault Diagnosis in the CVCS," ANL-NE-24, September 30, 2016.
  - T. Ulrich, R. Lew, R. Boring, "A Computerized Operator Support System – Test Plan Implementation and Evaluation Study," INL/LTD-16-40101, September 2016
- **Papers**
  - R.B. Vilim, Y.S. Park, and A. Grelle, "Parameter-Free Conservation-Based Equipment Fault Diagnosis," 9th International Conference on NPIC & HMIT, Charlotte, NC, February 23-26, 2015.
  - A. L. Grelle, Y. S. Park, and R. B. Vilim, "Development and Testing of Fault-Diagnosis Algorithms for Reactor Plant Systems," Proceedings of the 2016 24th International Conference on Nuclear Engineering, ICONE 24, June 26-30, 2016, Charlotte, North Carolina.

Technology Impact

- **Advancing state of the art, supporting mission of NE**
  - Economics - Manpower reduction through automation of surveillance and through fewer forced outages
  - Maintenance and Operations – Check/confirmation on equipment status and plant configuration
  - Safety – Potentially fewer PPS challenges through improved situational awareness
- **Impacting the nuclear industry**
  - Control room operations – We are working with Arizona Public Service to demonstrate and conduct human performance tests with Palo Verde NPP operators
  - Operations Support Center – Our capability is cited in the five-year EPRI commercialization roadmap in preparation and due out December 2016

Conclusion

- Developing innovative technology for improving safety, economics, and maintenance and operations for nuclear energy option
- Based on sound application of engineering first-principles and on human-performance principles
- Cross cuts commercial and advanced reactors
- Working to bring to the nuclear industry technology that rivals that of peer industries such as aviation and oil and gas
- Laying foundation and creating industry awareness of advanced technology with commercial potential developed under Office of Nuclear Energy sponsorship