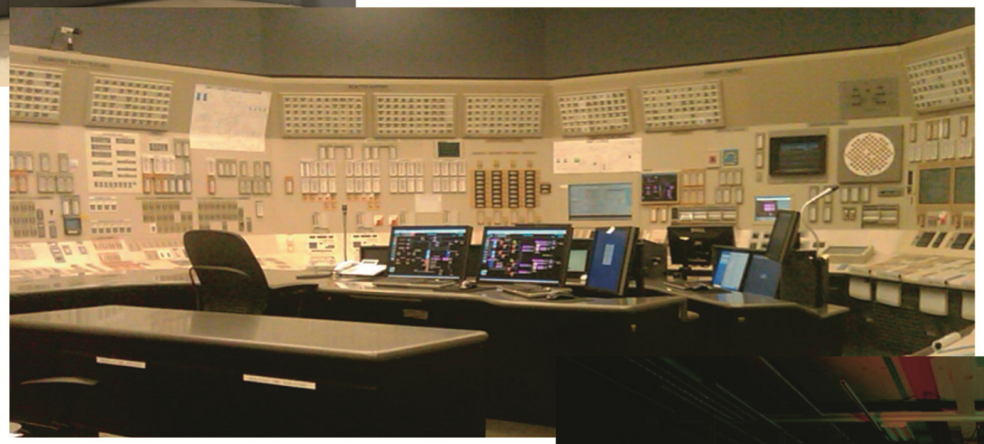
Use of Simulators for Design of Advanced Reactor Control Rooms

Ronald L. Boring, PhD

Idaho National Laboratory

the evolution of
control rooms in
the first 60 years



is less than what
will happen in the
next 10 years

Are we ready?

Do we have the tools?

Do we have the methods?

Are we ready?

Do we have the tools?

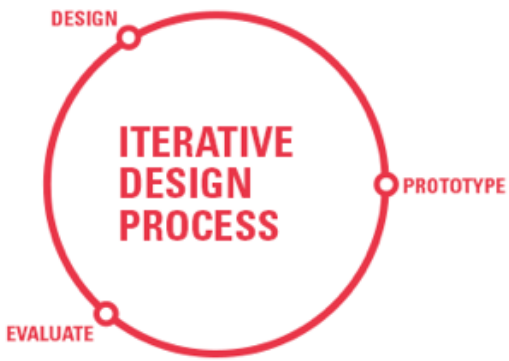
Do we have the methods?

What is the HSSL?

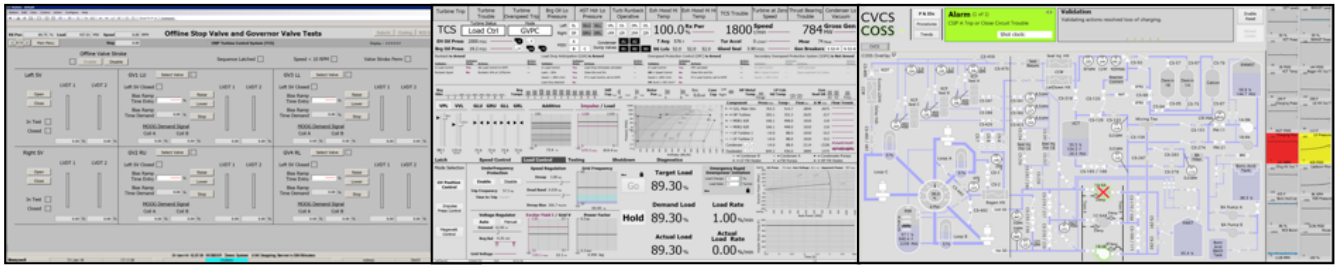
Human Systems Simulation Laboratory

a reconfigurable,
full-scale,
full-scope
research simulator

HSSL: Operator-in-the-Loop Design Studies



our team builds prototypes of control room upgrades that we then evaluate through operator-in-the-loop studies



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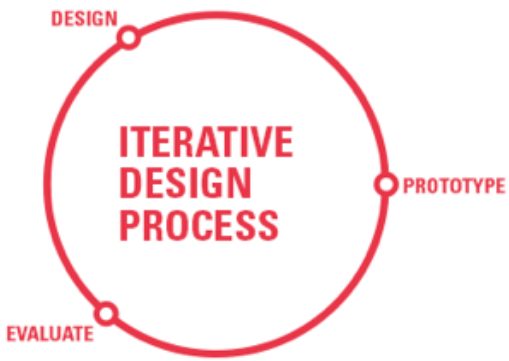

tools

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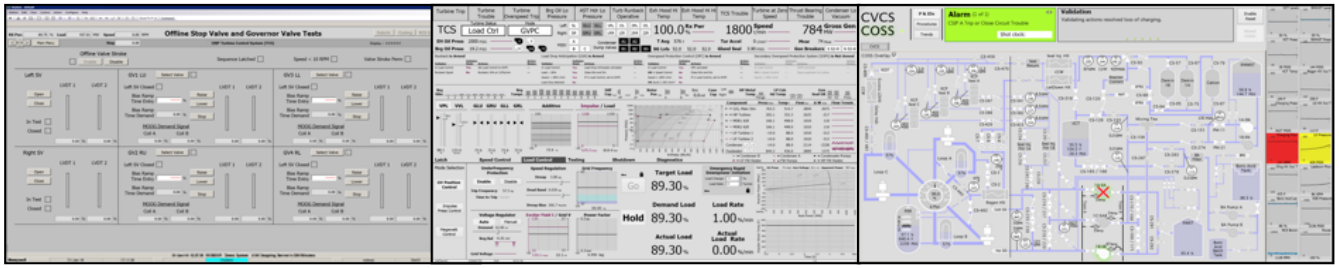


ANIME

a development framework and sample code library for process control

Advanced Nuclear Interface Modeling Environment (ANIME)

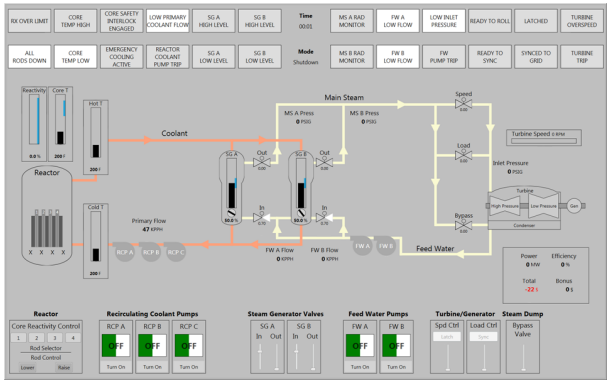
Microsoft Visual Studio

- C# environment for control logic
- Windows Presentation Foundation (WPF)
  - User-defined style sheet for graphical objects that can be linked together by code
    - We've created a library of control system widgets for prototyping
  - Agile development process

Server and Client

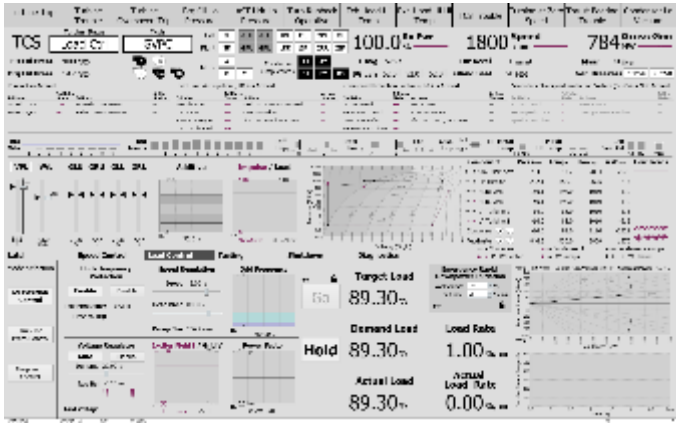
  - Connect full-scope simulator database variables to objects
  - Connect reduced order model (microworld) to objects

ANIME Continuum

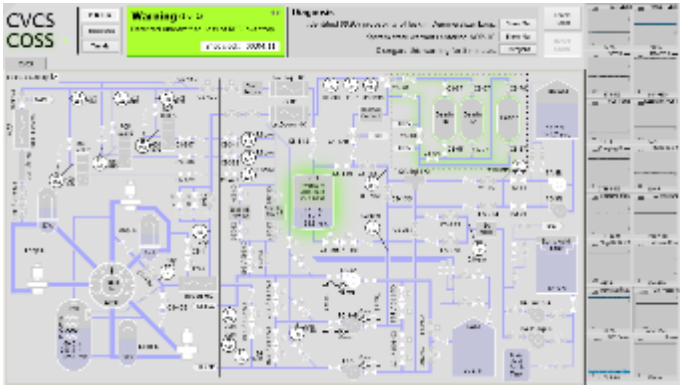


Standalone Microworld for Human Factors and Automation Research

Emulation of Conventional Distributed Control System HMI

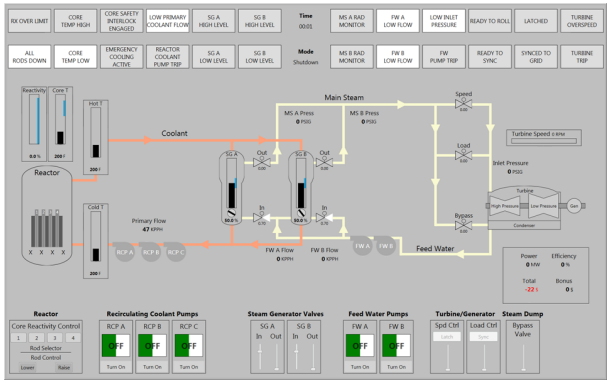


Conceptual Distributed Control System Prototype



Computerized Operatior Support System

ANIME Continuum



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Emulation of Conventional Distributed Control System HMI

We'll come back to this!

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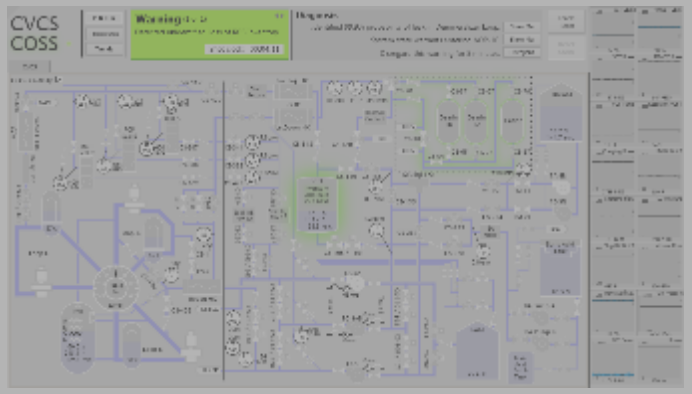

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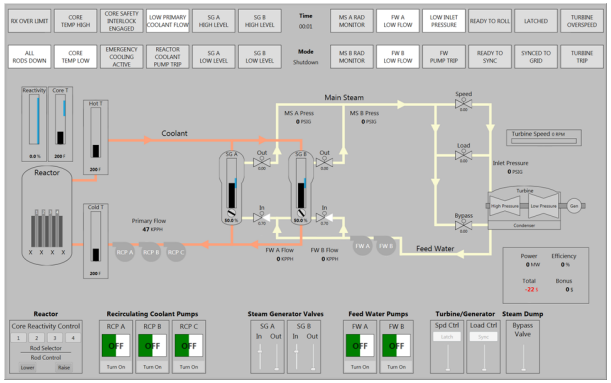

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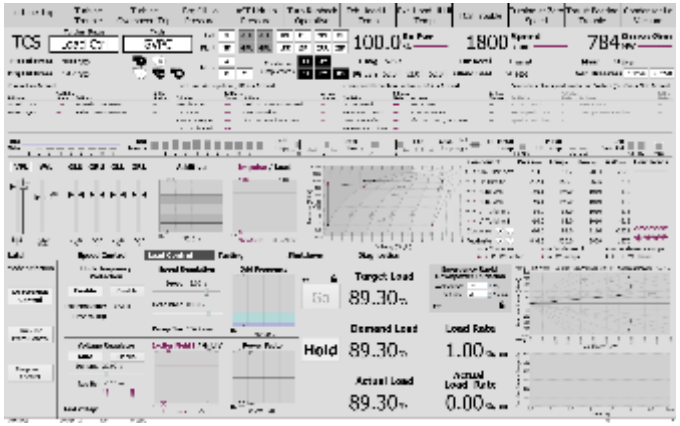

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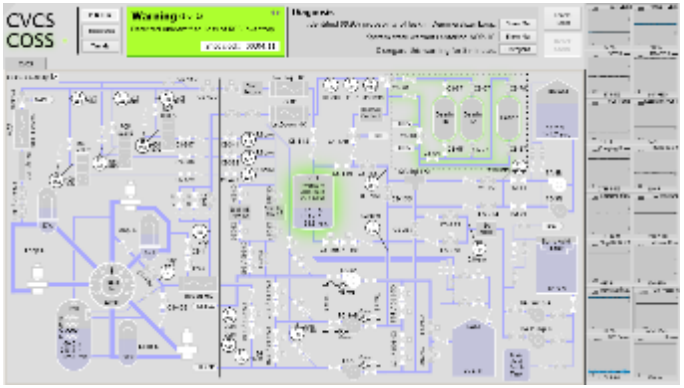
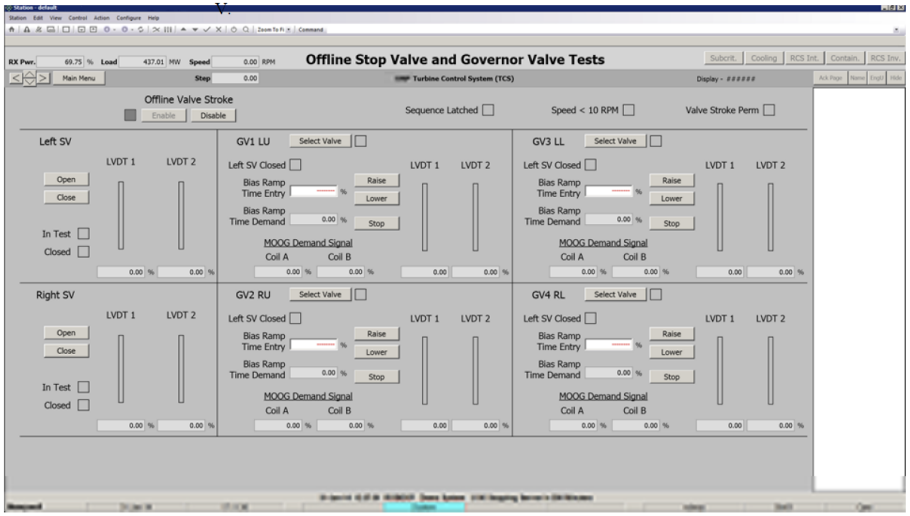


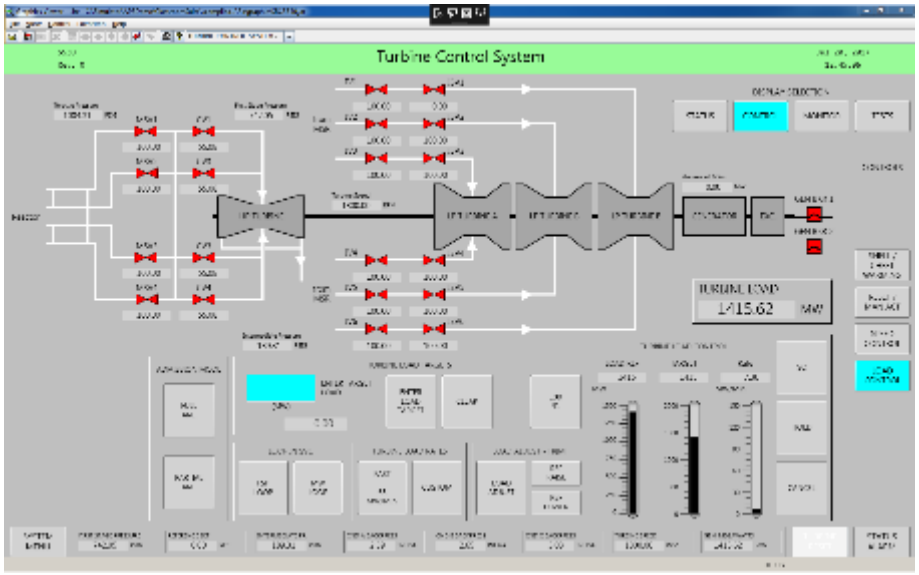
Computerized Operatior Support System

Distributed Control System (DCS) HMI Mimicking

Honeywell Experion Mimic



Westinghouse Ovation Mimic



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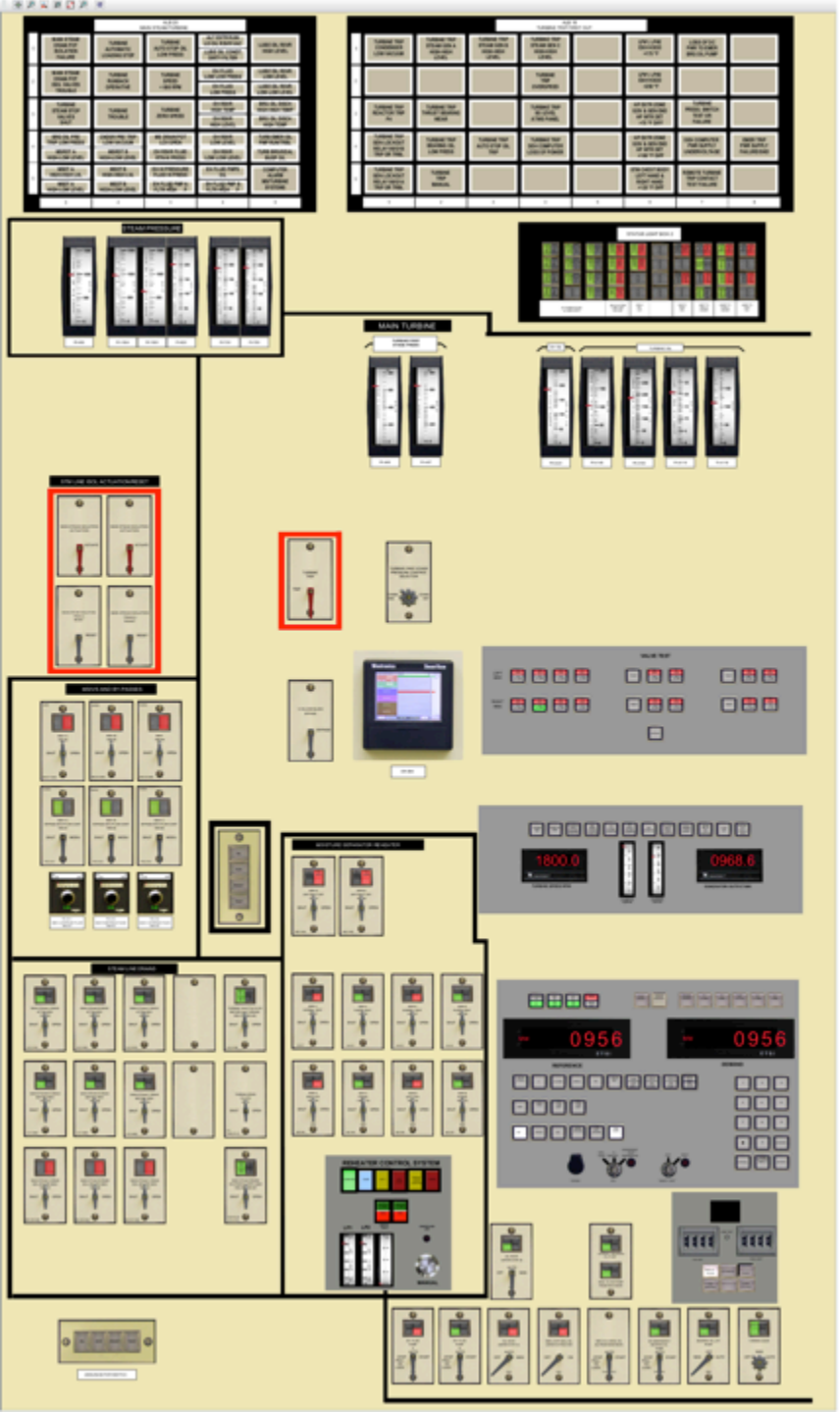
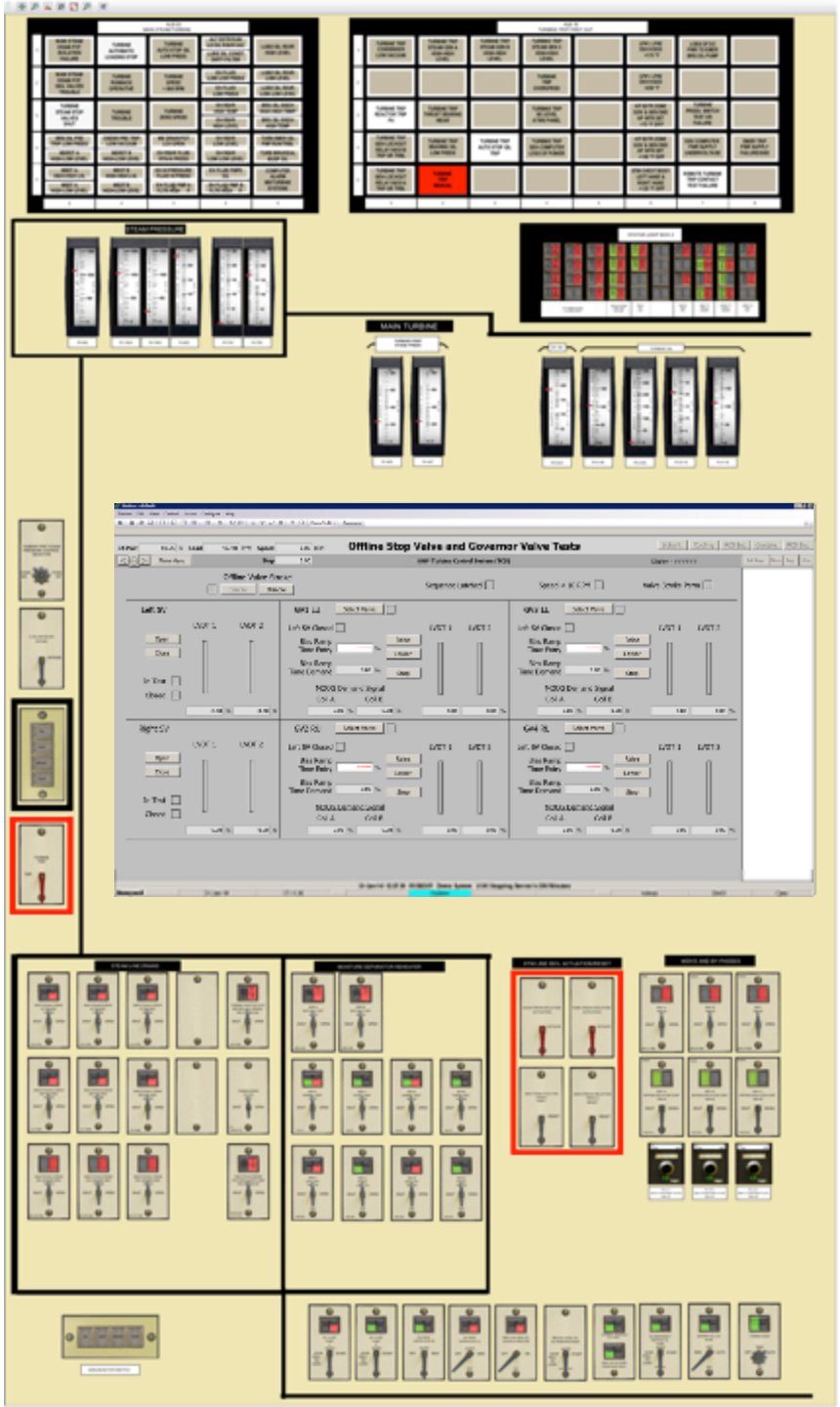
New >





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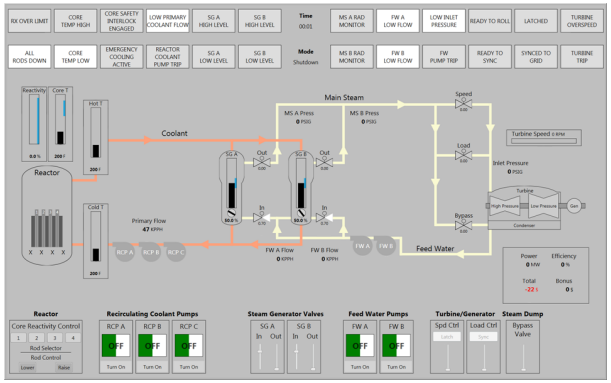

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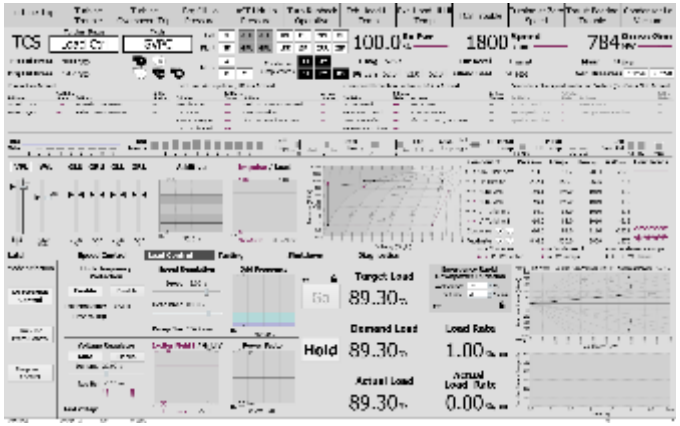

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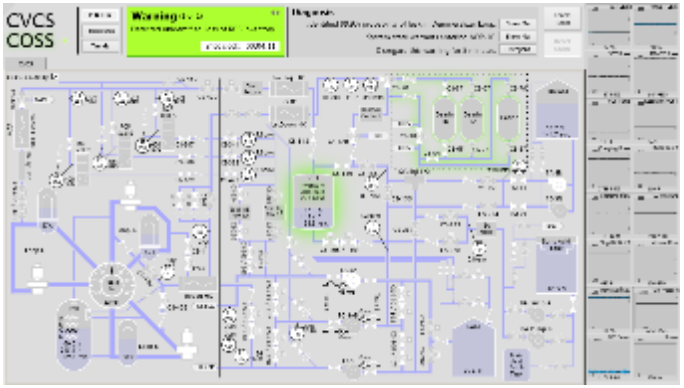

Computerized Operatior Support System

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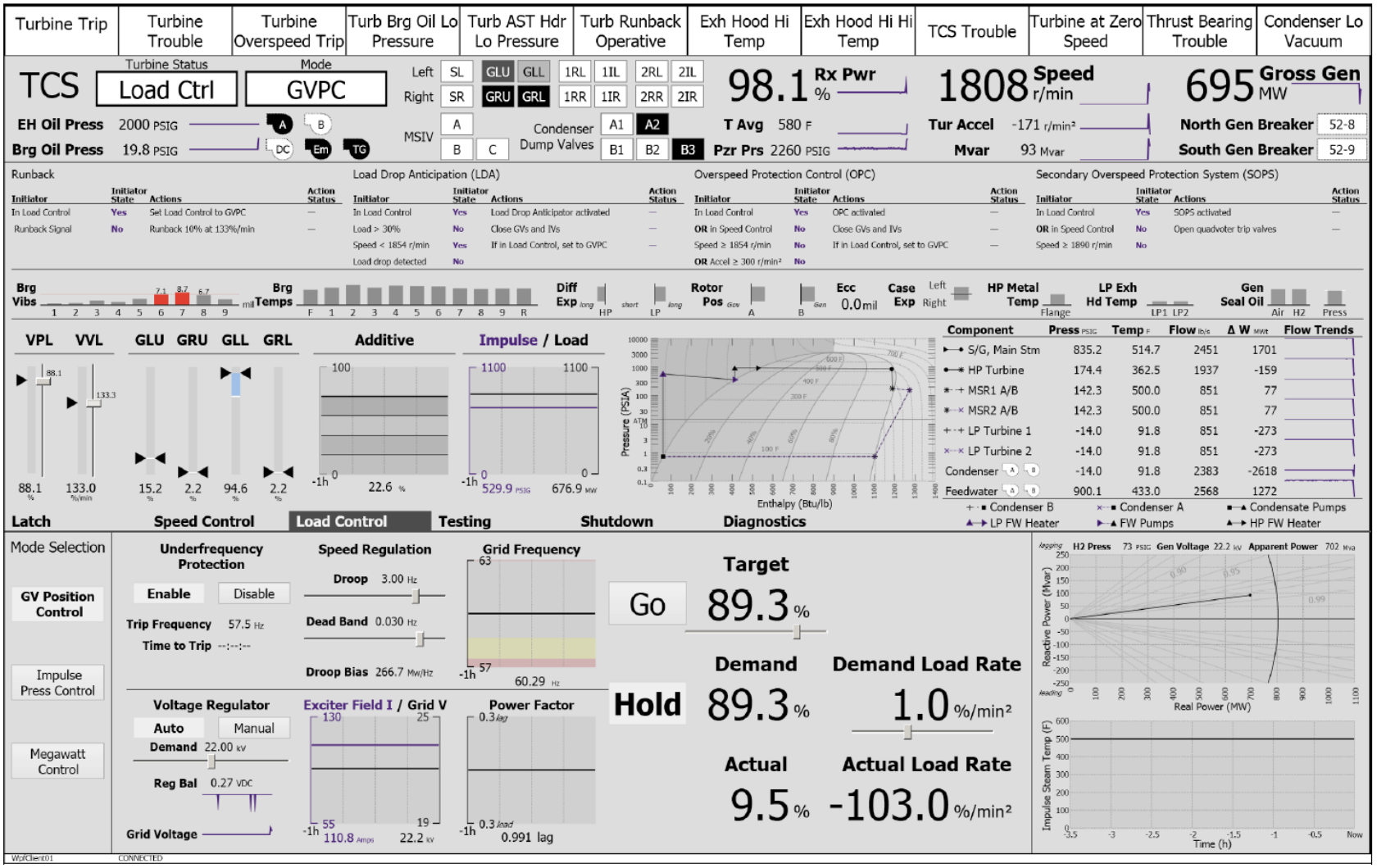
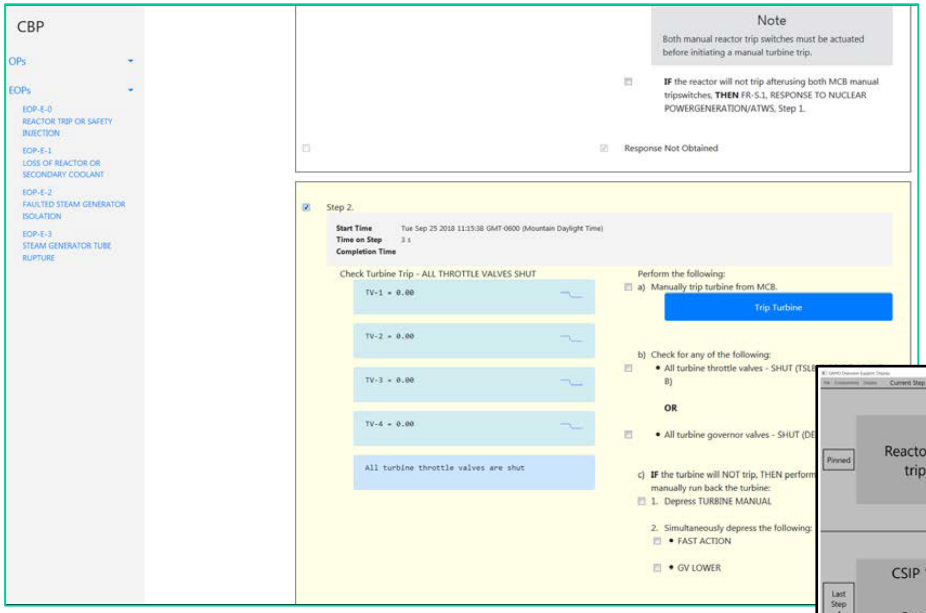
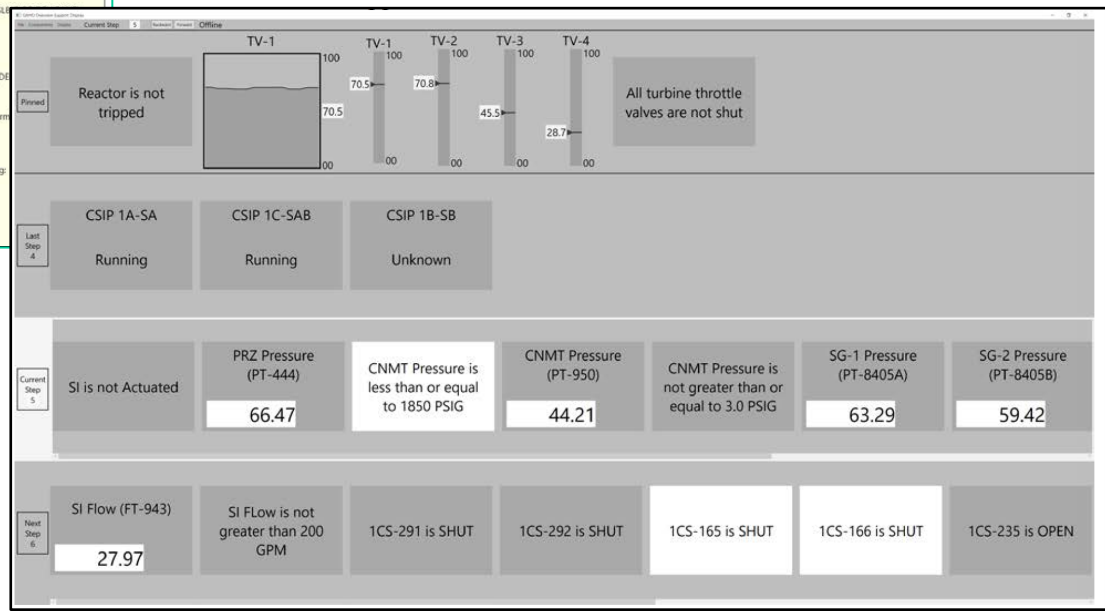
Advanced Turbine Control System Prototype



The Two-Screen Plant Control System Concept



Task Engine for Job and User Notification (TEJUN): A Tool for Building Computerized Procedures



Graphical Augmentation Interface for Yoked Overviews (GAIYO): A Tool for Building Overview Screens for Main Control Rooms

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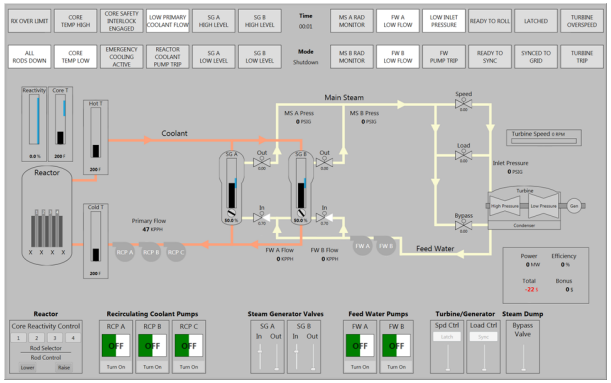
GAIN
Gateway for Accelerated Innovation in Nuclear

ANIME Continuum



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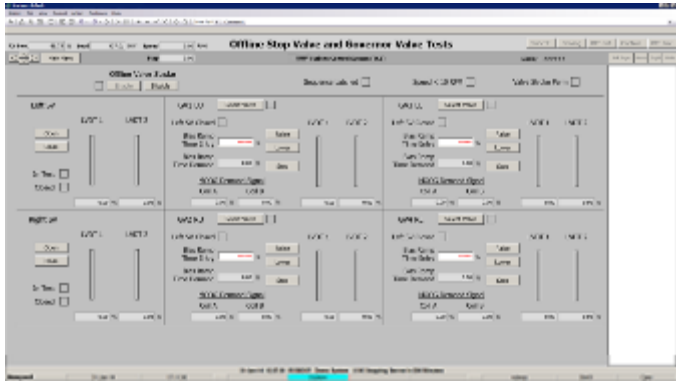

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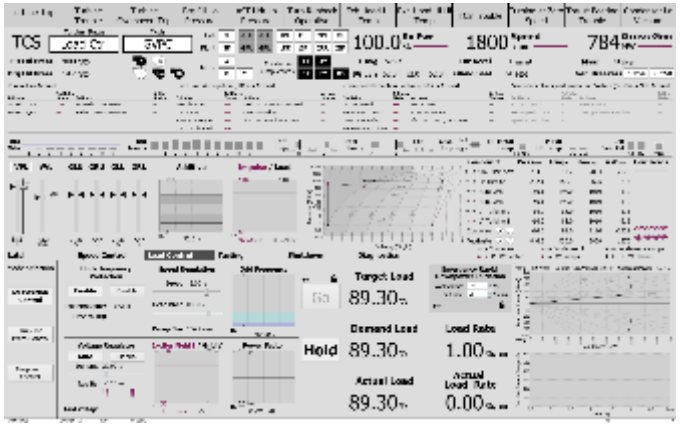

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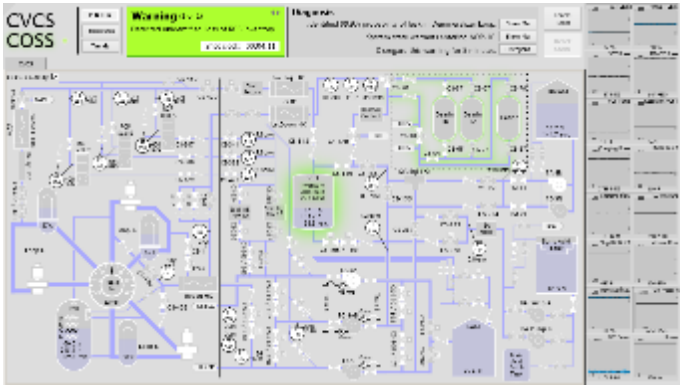
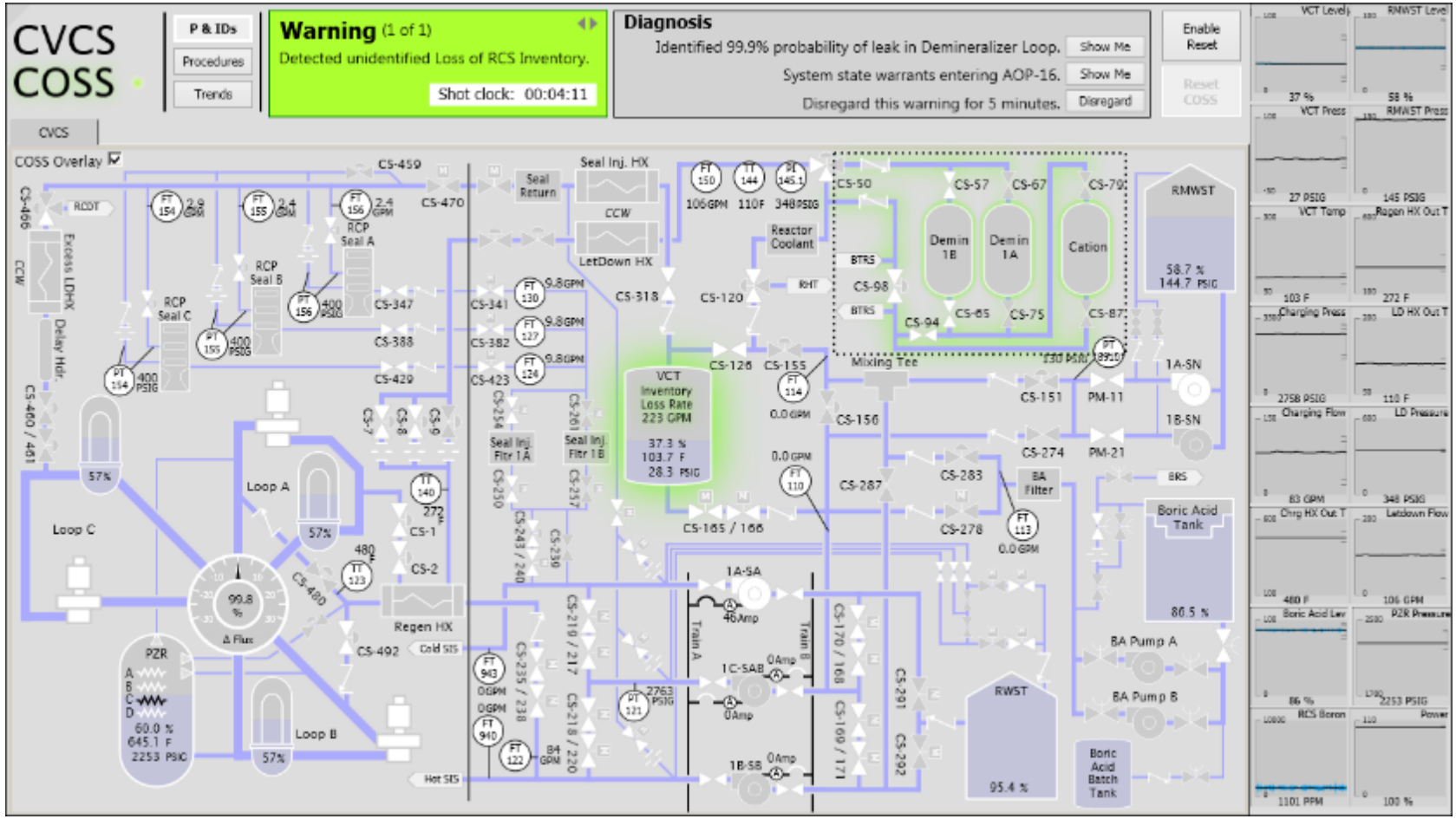


Computerized Operatior Support System

Computerized Operator Support System (COSS)

- Collection of technologies to assist operators in monitoring the plant and making timely, informed decisions



COSS: Computer-Based Procedures

CVCS
COSS

P & IDs
Procedures
Trends

Warning (1 of 1)
Detected unidentified Loss of RCS Inventory.
Shot clock: 00:03:29

Diagnosis
Identified 99.9% probability of leak in Demineralizer Loop. Show Me
System state warrants entering AOP-16. Show Me
Disregard this warning for 5 minutes. Disregard

Enable Reset
Reset COSS

AOP - 16

AOP-016 Excessive Primary Plant Leakage

Purpose
☑ Leakage from outside of CNMT (CVCS)

Entry Conditions
☑ Unexplained loss of RCS inventory

Status:
COSS identified 99.9% probability of a leak in the Demineralizer System.

Go to Step 1.

Operator Actions	Response Not Obtained
☐ 1. Check RHR in operation Status: RHR is not in operation.	☐ Go To Step 3. Go to Step 3.
☐ 2. Go To AOP-020 Loss of RCS Inventory Residual Heat Removal While Shutdown.	☐ Go To Step 3.
☐ 3. Refer To PEP-110 Emergency	☐ Go To Step 4.

Automatic Execution is not available

Clear Procedure
Procedures List

VCT Level 35 %
RMWST Level 58 %
VCT Press 29 PSIG
RMWST Press 144 PSIG
VCT Temp 104 F
Regen HX Out T 272 F
Charging Press 2764 PSIG
LD HX Out T 109 F
Charging Flow 84 GPM
LD Pressure 347 PSIG
Chrg HX Out T 481 F
Letdown Flow 106 GPM
Boric Acid Lev 86 %
PZR Pressure 2253 PSIG
RCS Boron 1104 PPM
Power 100 %

COSS: Trend Alarms

CVCS COSS

P & IDs | Procedures | Trends

Alarm (1 of 1)
CSIP A Trip or Close Circuit Trouble
Shot clock: 00:18:37

Diagnosis
Unable to identify cause of CSIP A Trip. Show Me
System state warrants entering APP-ALB-06. Show Me
Disregard this warning for 5 minutes. Disregard

Enable Reset
Reset COSS

ALB - 06

5. **Verify** charging has been restored

a. **Verify** CSIP B current between 25-50 amps.

Status:
CSIP drawing 45 amps.

b. **Verify** Charging header pressure between 2200-2750 PSIG.

Status:
Charging header pressure is 2703 PSIG.

c. **Verify** Charging header flow is between 90 - 105 GPM

Status:
Charging header flow is 90 GPM.

d. **Verify** RCP seal injection flows are between 8-13 GPM for each seal

Status:
Seal injection flows
are RCP A = 9.0 GPM, RCP B = 9.0 GPM, and RCP C = 9.0 (

Trip Reactor.

Automatic Execution is not available.

Clear Procedure | Procedures List

VCT Level 53 % | RMWST Level 59 %
VCT Press 29 PSIG | RMWST Press 143 PSIG
VCT Temp 104 F | Regen HX Out T 373 F
Charging Press 2627 PSIG | LD HX Out T 116 F
Charging Flow 122 GPM | LD Pressure 290 PSIG
Chrg HX Out T 528 F | Letdown Flow 93 GPM
Boric Acid Lev 86 % | PZR Pressure 2225 PSIG
RCS Boron 1172 PPM | Power 100 %

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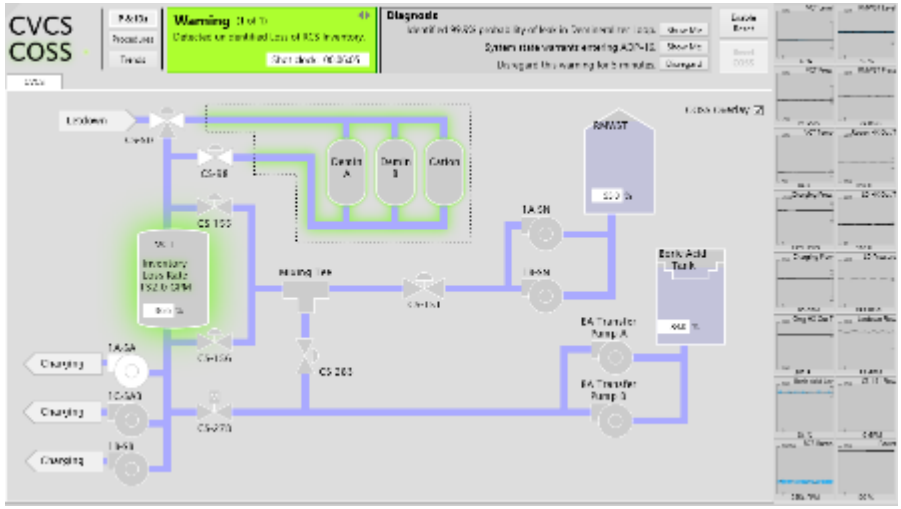
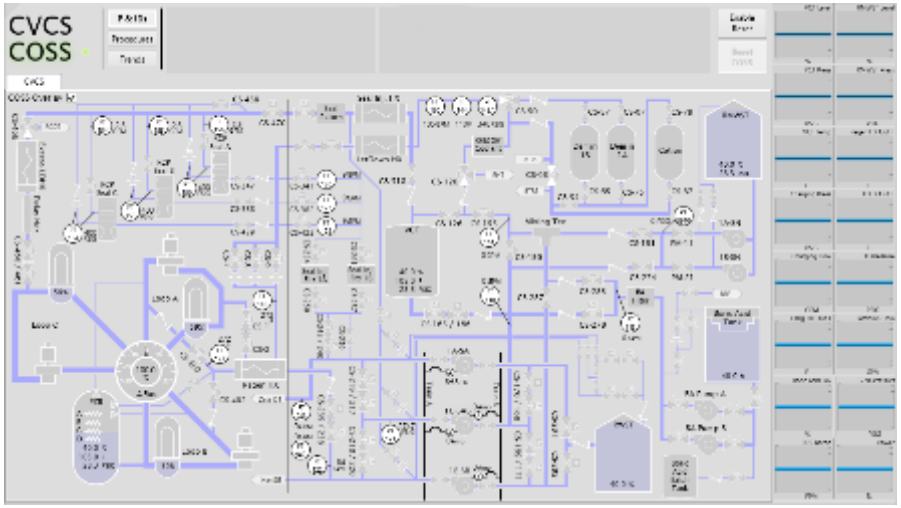
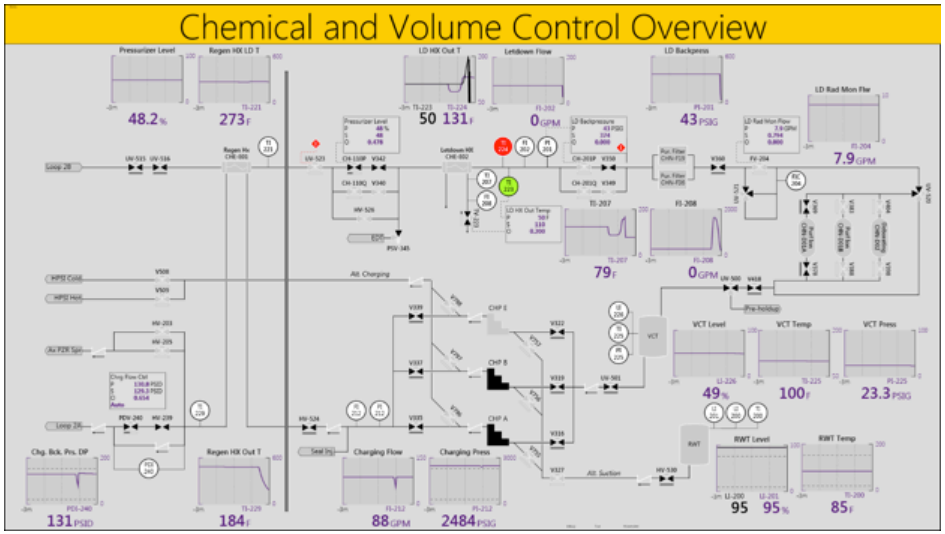
Iteration 1

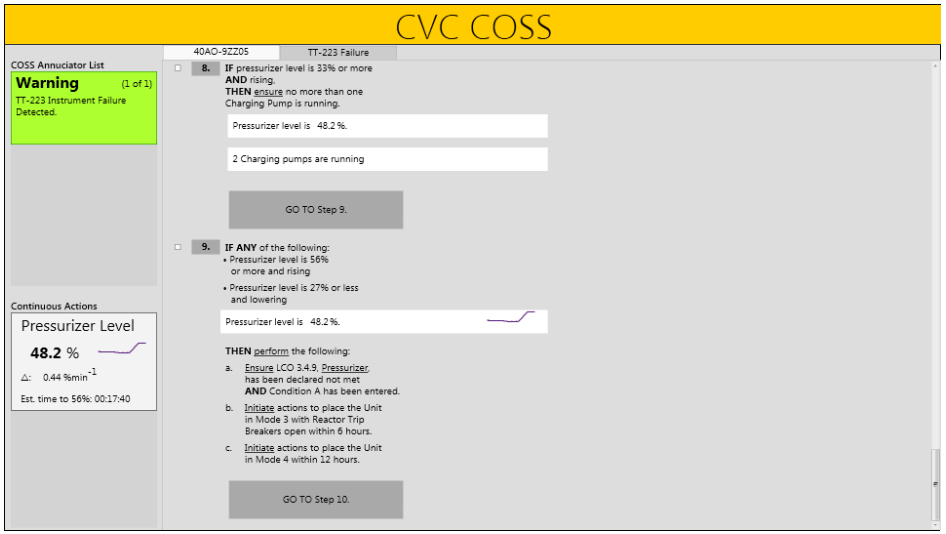


Iteration 2



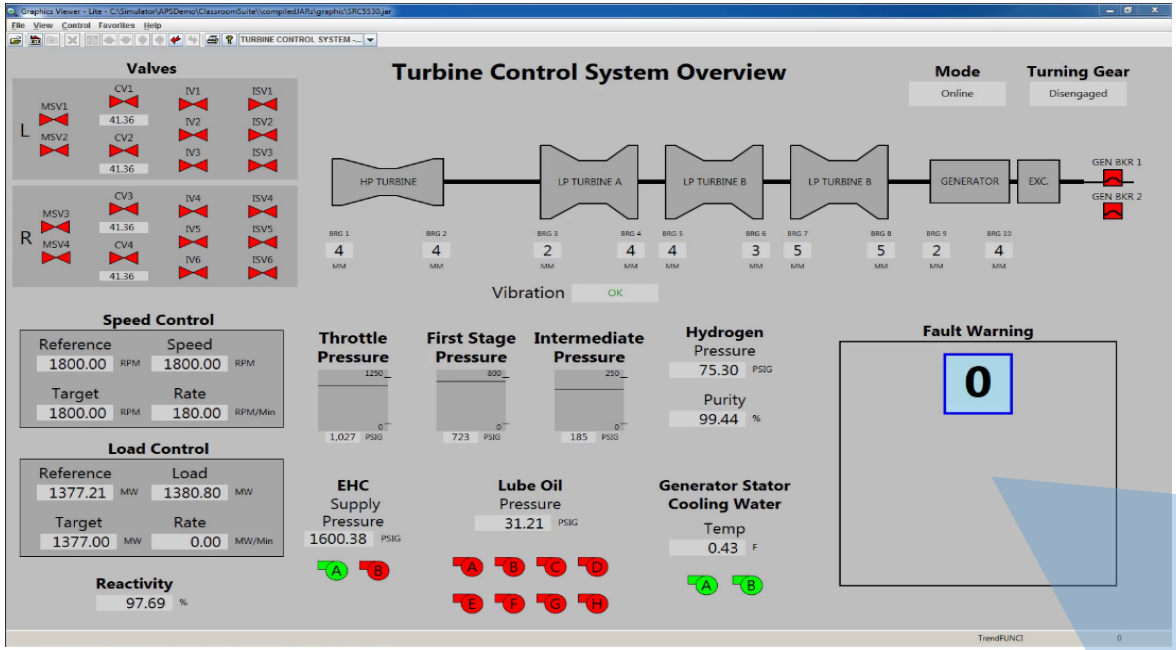
Iteration 3

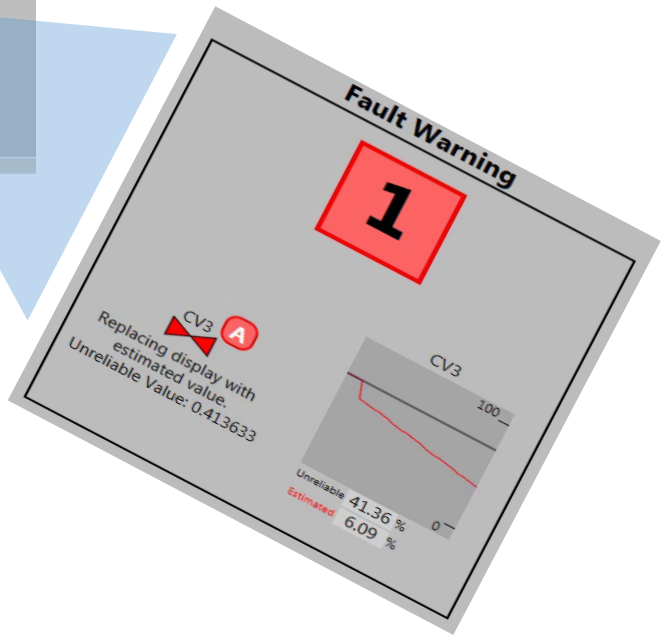




Example Multidisplay Upgrades

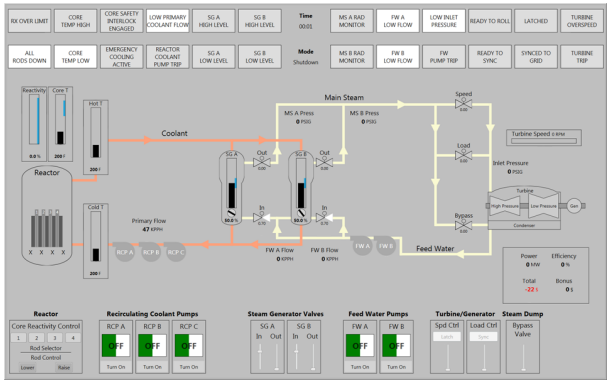
COSS: System Overview Display





The microworld prototypes for testing COSS concepts are called **COSSplay** of course!

ANIME Continuum

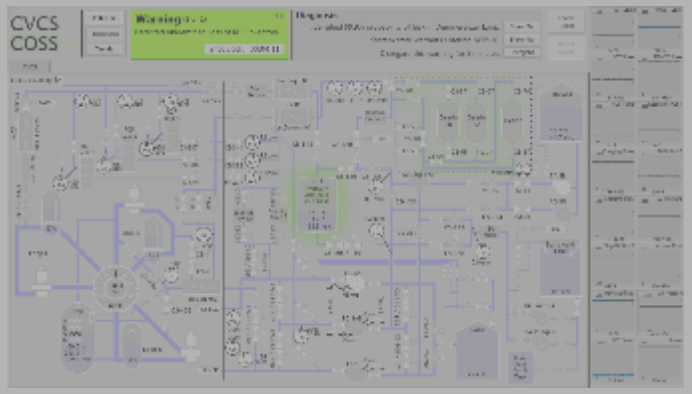


Standalone Microworld for Human Factors and Automation Research

Emulation of Conventional Distributed Control System HMI

Revisiting microworlds

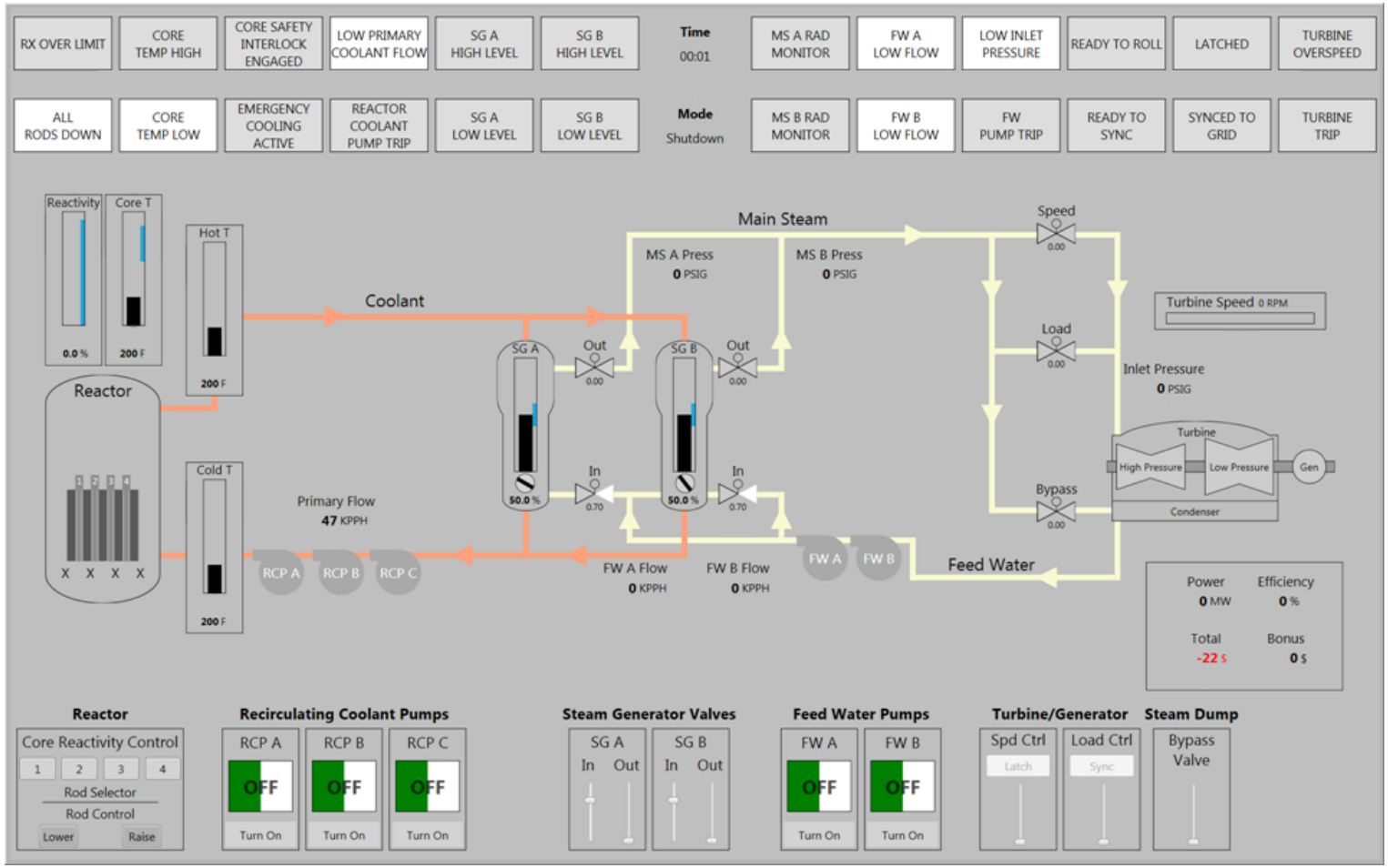
Conceptual Distributed Control System Prototype



Computerized Operatior Support System

Standalone Microworld for Research

- Decouple HMI from LWR simulator



Why a Standalone Simulator?

Simpler Design

- Robust reduced order model of a few hundred variables instead of hundreds of thousands of parameters in full-scope simulator
- Ability to train student operators
  - Assume some commonality for interfaces
  - Assume generalizability of some aspects of human performance to inform human reliability analysis

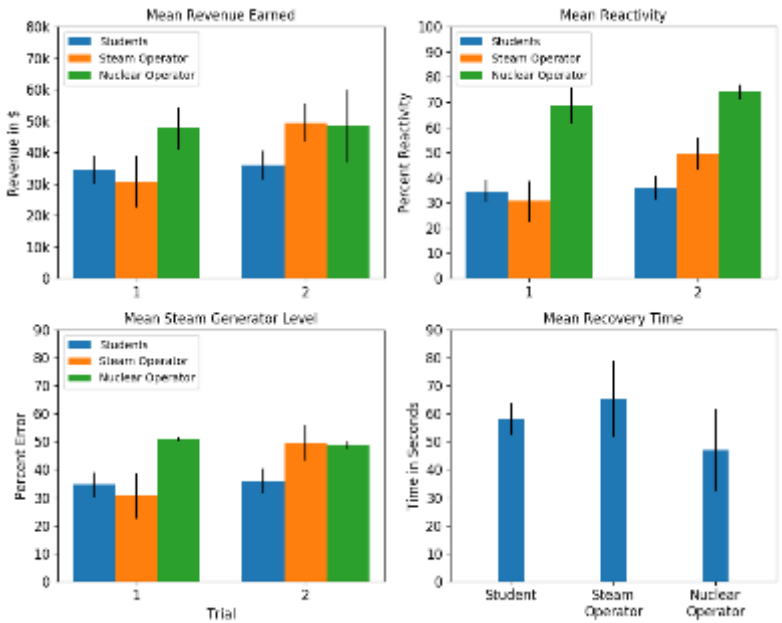
Greater Control

- Ability to automate features without legacy control systems
- Ability to present advanced visualizations and interfaces
- Ability to control evolution of events
  - Greater recovery to prevent runaway phenomena that renders human intervention irrelevant

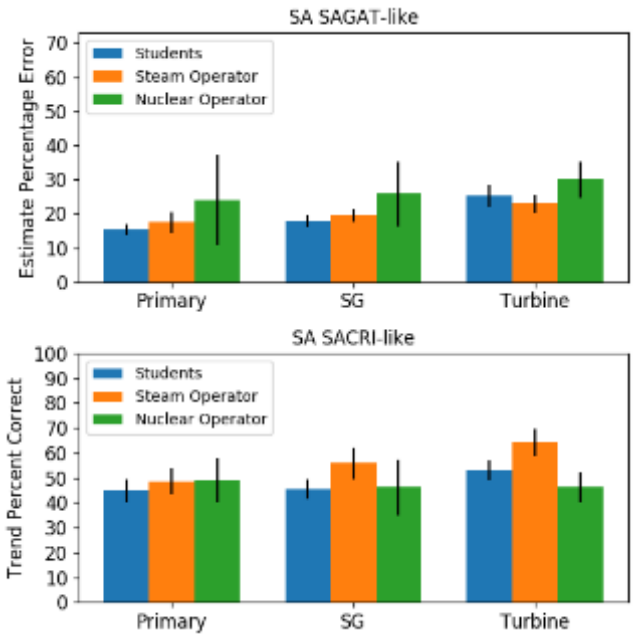
Rationale and Results

- Microworld gives greater experimental control than full control room
- Microworld can be administered to less experienced operators, allowing greater number of participants and more conclusive findings
- Studies to date compare how performance generalizes from students to operators

Performance Measures



Situation Awareness



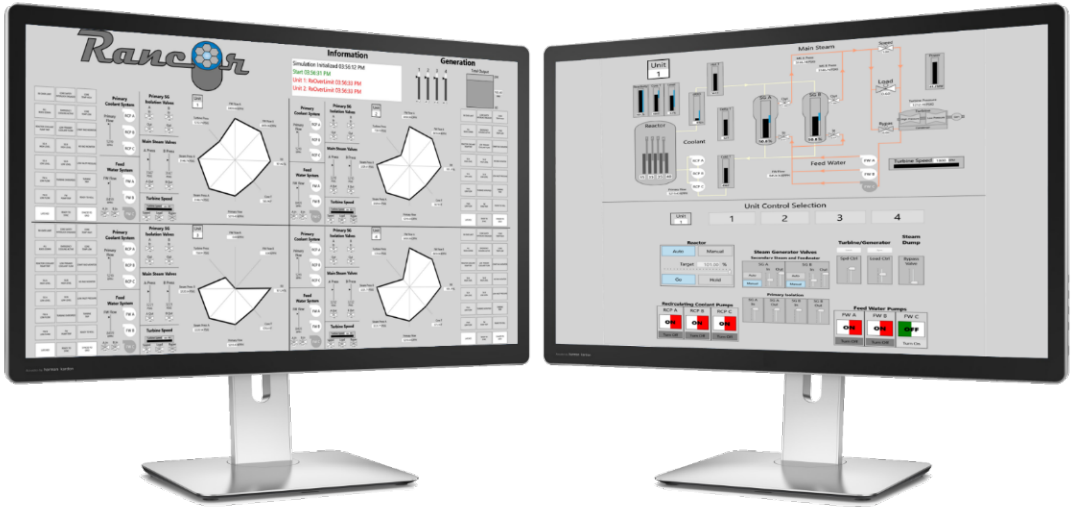
But, Wait…

Eureka Moment

- By reducing complexity of underlying plant model, we're able to prototype reactor concepts very quickly
  - Full-scope control room simulators require years of development and are usually built after the design is finalized
- Having a simpler prototyping tool serves allows **parallel development of plant and control room design**
  - Engineering tool
  - Establish and validate control room concept

Microworld simulators are a tool for developing the control interfaces for advanced reactors!

Advanced Nuclear
Power Plant Microworld
Simulation Framework



Demo

Faster and Cheaper
Proof of Concept
Control Room

Design

Agile and Iterative
Concept of Operations
Regulatory Licensing

Training

Hands-on and Instructional
System Familiarization
Operating Experience

New nuclear is about capital and science

Rancor uniquely supports both roles

DOE REACTOR

COMMERCIAL REACTOR VENDORS

UNIVERSITY COLLABORATORS

Other Future Directions

HSSL
a full-scope simulator for assessing operator performance across normal and abnormal operations

ANIME
a prototyping system for customizing the operator interface and introducing advanced visualization and automation

Microworld
a simplified simulator for evaluating non-expert operators and developing control rooms for advanced reactor concepts

Are we ready?

Do we have the tools?

Do we have the methods?

Are we ready?

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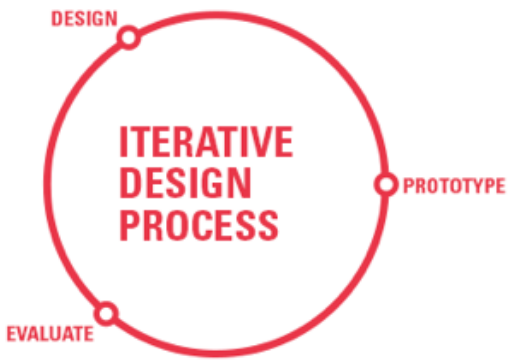
Do we have the methods?

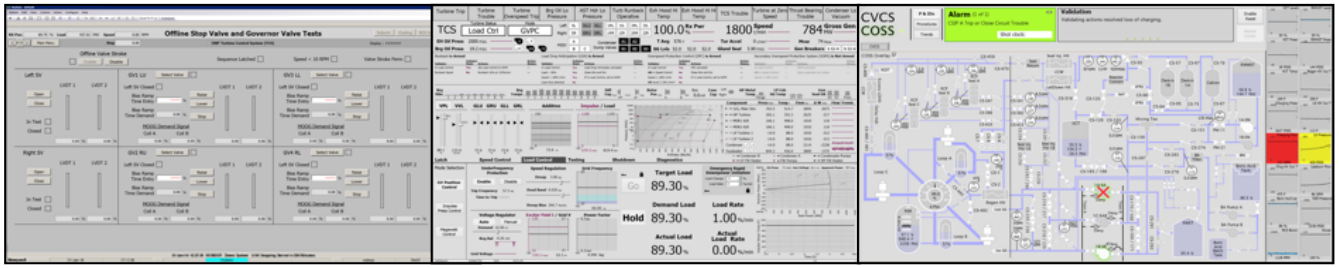
HSSL: Operator-in-the-Loop Design Studies



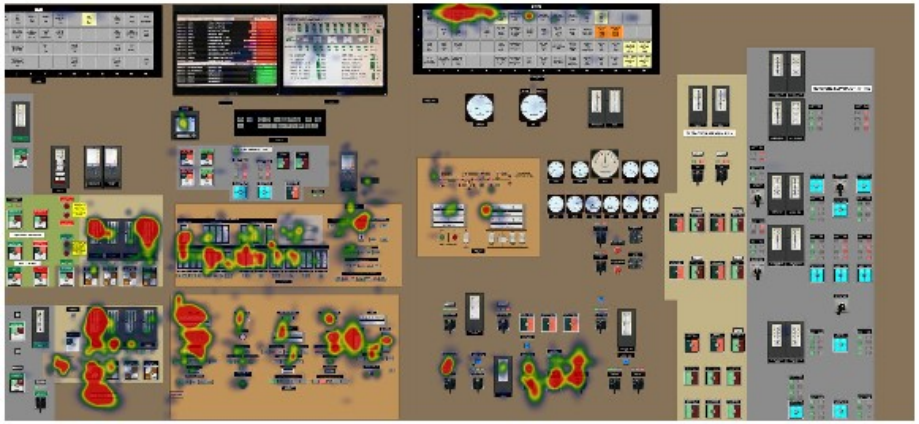
tools

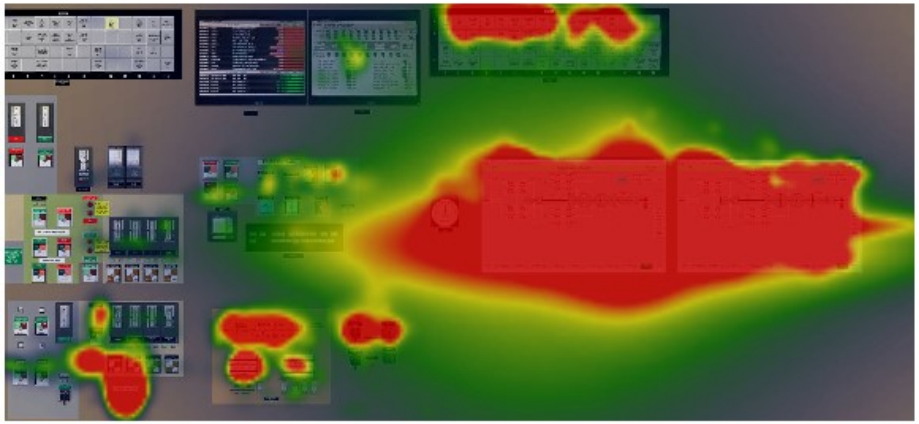
our team builds prototypes of control room upgrades that we then evaluate through operator-in-the-loop studies

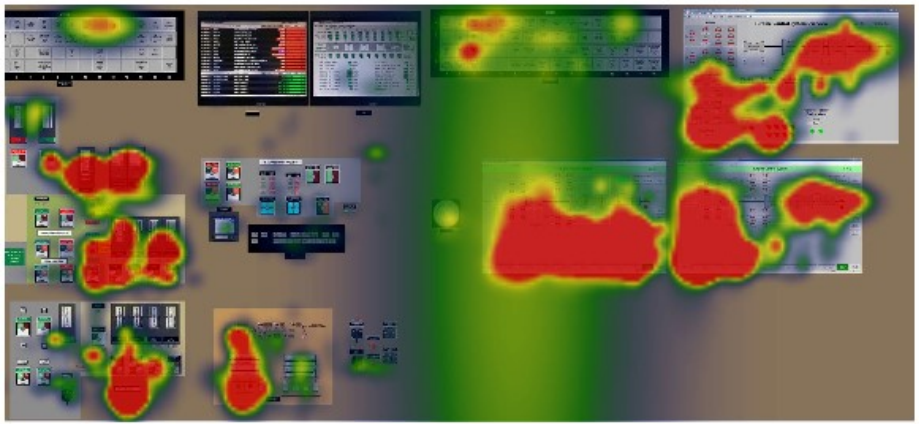
methods



Study on Digital Displays



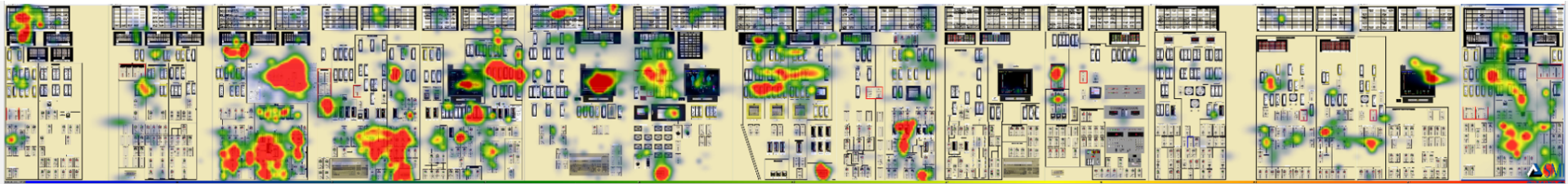




2018 Cyber Study with Sandia National Labs

Joint Pilot Study on Operators' Response to Cyber Attacks in Existing Nuclear Main Control Rooms

- Study run with analog boards, but assuming digital cross-layer that could be compromised
- Operators were not instructed there were cyber faults (among other faults)
- Examined effects of spoofed indicators and systems
  - Operators recognized spoofed indicators as "faulty"
  - Operators across all nine scenarios successfully brought plant to a safe state
  - Analyses are currently underway, but we are already seeing clear indicators of the spoofed indicators by the operator visual scanning patterns



Guideline for Operator Nuclear Usability and Knowledge Elicitation (GONUKE)

Evaluation Phase

Evaluation Type	Pre-Formative *(Planning and Analysis[1])*	Formative *(Design[1])*	Summative *(Verification and Validation[1])*	Post-Summative *(Implementation and Operation[1])*
Expert Review *(Verification)*	**[1]** Design Requirements Review	**[2]** Heuristic Evaluation	**[3]** System Verification	**[4]** Requalification against New Standards
User Study *(Validation)*	**[5]** Baseline Evaluation	**[6]** Usability Testing	**[7]** Integrated System Validation	**[8]** Operator Training
Knowledge Elicitation *(Epistemiation)*	**[9]** Cognitive Walkthrough (Task Analysis)	**[10]** Operator Feedback on Design	**[11]** Operator Feedback on Performance	**[12]** Operating Experience Reviews

[1]Corresponding Phases in NUREG-0711.

Guideline for Operator Nuclear Usability and Knowledge Elicitation (GONUKE)

Multi-stage evaluation

Evaluation Type	Evaluation Phase: Pre-Formative *(Planning and Analysis[1])*	Formative *(Design[1])*	Summative *(Verification and Validation[1])*	Post-Summative *(Implementation and Operation[1])*
Expert Review *(Verification)*	**[1]** Design Requirements Review	**[2]** Heuristic Evaluation	**[3]** System Verification	**[4]** Requalification against New Standards
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[1]Corresponding Phases in NUREG-0711.

Guideline for Operator Nuclear Usability and Knowledge Elicitation (GONUKE)

Typical usability evaluation

Evaluation Phase

Evaluation Type	Pre-Formative *(Planning and Analysis[1])*	Formative *(Design[1])*	Summative *(Verification and Validation[1])*	Post-Summative *(Implementation and Operation[1])*
Expert Review *(Verification)*	**[1]** Design Requirements Review	**[2]** Heuristic Evaluation	**[3]** System Verification	**[4]** Requalification against New Standards
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Guideline for Operator Nuclear Usability and Knowledge Elicitation (GONUKE)

Typical utility/ regulatory emphasis

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Guideline for Operator Nuclear Usability and Knowledge Elicitation (GONUKE)

That ignores a lot of chances to get the interface right

Evaluation Phase

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home work

In education, we test learning continuously and cumulatively

exam

Guideline for Operator Nuclear Usability and Knowledge Elicitation (GONUKE)

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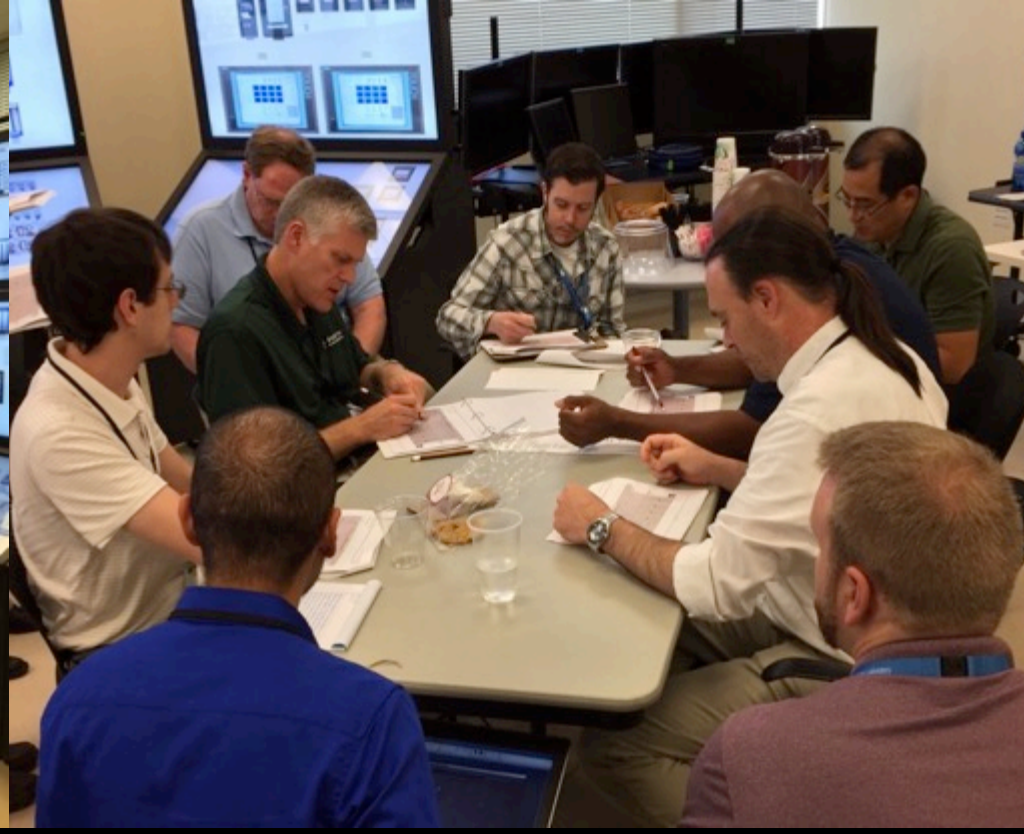

Epistemiation: Capturing Expert Operator Knowledge to Design New System

Do not leave control room design as a tail-end activity

Use simplified modeling and simulation (=simulator) tools to help guide the design of the operator interface

Use vetted human factors tools to validate the control room early in the design phase

ronald.boring@inl.gov