



Idaho National Laboratory

**You Have to Build It to
Evaluate It: Prototyping and
Evaluating Advanced Control
Rooms**

Ron Boring, PhD, FHFES

Manager & Distinguished Scientist
Human Factors and Reliability Department



Idaho National Laboratory (INL)



Idaho National Laboratory



*One of 9 large U.S.
Department of Energy (DOE)
multi-program Labs*

DOE's Lead Lab for Nuclear Energy

- Site of 52 historic prototype or test reactors*
- 4 reactors currently being developed*

*5,500 full-time
researchers and staff*

*Nearly \$2bn annual
budget*

*890 miles² (2300 km²) of
research facilities
across ca. 600
buildings*

Our Programs of National Importance

Nuclear Science & Technology

National & Homeland Security Science & Technology

Nuclear Nonproliferation

Critical Infrastructure Protection

Industrial Control Systems
Cybersecurity

Electric Grid Resiliency

Wireless National
User Facility

Armor &
Defense
Systems

A leader in critical infrastructure protection and homeland security



INL Wireless
USER FACILITY



Fuel Cycle R&D

LWR Sustainability
Program

Advanced Reactor R&D
ATR National Scientific
User Facility

Space Nuclear

NGNP R&D



MOOSE

Energy & Environment Science & Technology

Hybrid Energy Systems

Non-traditional Hydrocarbons

Battery & Energy Storage
Technologies

Clean Energy & Water

Bio-fuels & Synfuels

Energy Critical
Materials



A leader in developing solutions to energy, resources and infrastructure challenges in the State and Region

Research – Development – Demonstration – Deployment

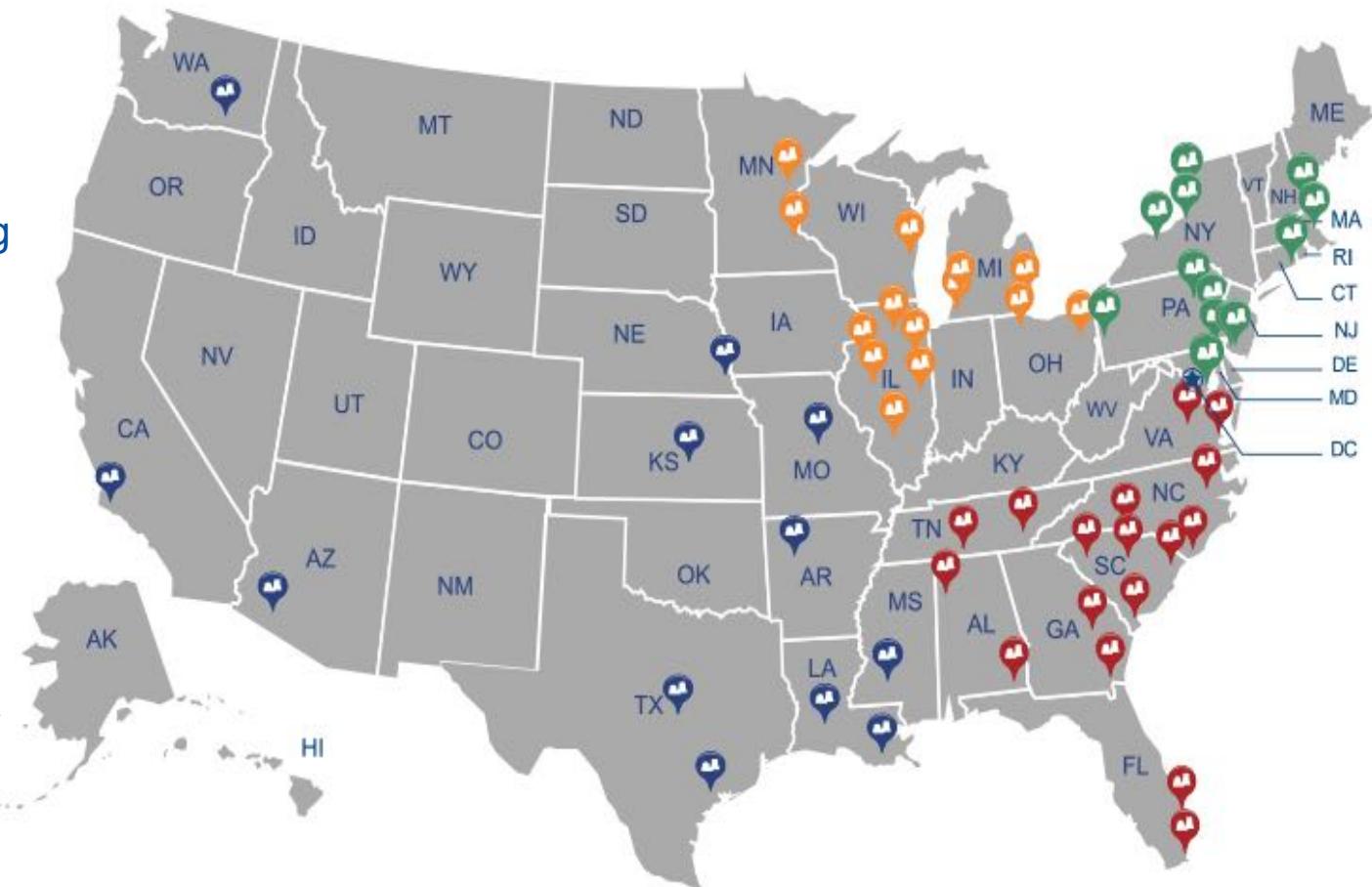
Why It Matters: Nuclear Power Plants in U.S.



October 2021

- 93 operating commercial reactors generating about 20% of U.S. electric supply
- 12 reactors shut down over past 10 years, reducing nuclear proportion of U.S. electricity generation by 5%
- Shutdown reactors largely replaced by natural gas plants
- Emissions have gone up!

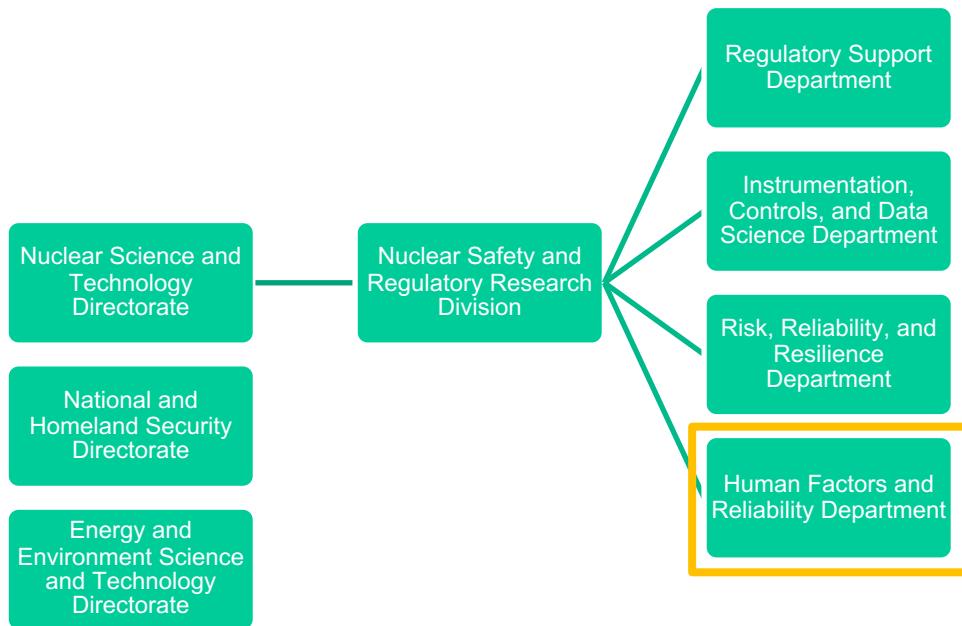
U.S. Operating Commercial Nuclear Power Reactors



Human Factors at INL

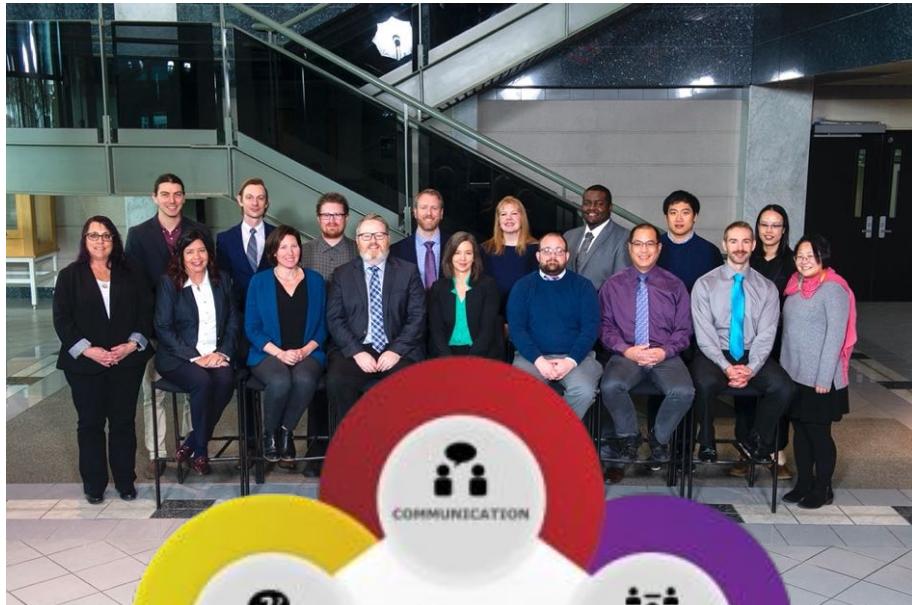
Human Factors and Reliability Department

INL Research Organizations



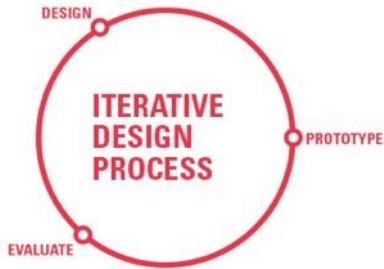
- Human factors employs design and evaluation methods to determine the optimal human-system interface
- Human reliability is the study of how to model and predict human performance to minimize human error and the contribution to overall risk
- These two capabilities are combined in the **Human Factors and Reliability Department** at INL
- Our mission is to ensure the safety of humans and the usability of systems they operate

Human Factors and Reliability Department



- **16 human factors staff and 2 support staff**
 - Primarily engineering psychologists involved in design and evaluation of control rooms
- **Practitioners**
 - Apply standards, guidance and principles within a regulatory framework
 - e.g., Help utilities apply with control room modernization using established tools and methods
- **Researchers**
 - Develop new tools and methods for human factors and reliability
 - e.g., Develop new computer-based procedure software

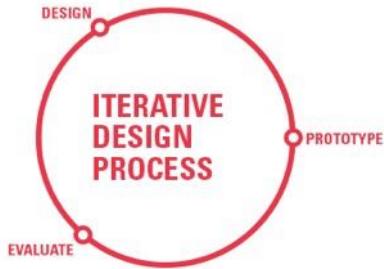
What Do We as Psychologists Do?



my team and I **build prototypes** of control rooms for nuclear power plants that we then **evaluate** through operator-in-the-loop studies



What Do We as Psychologists Do?



my team and I **build prototypes** of control rooms for nuclear power plants that we then **evaluate** through operator-in-the-loop studies

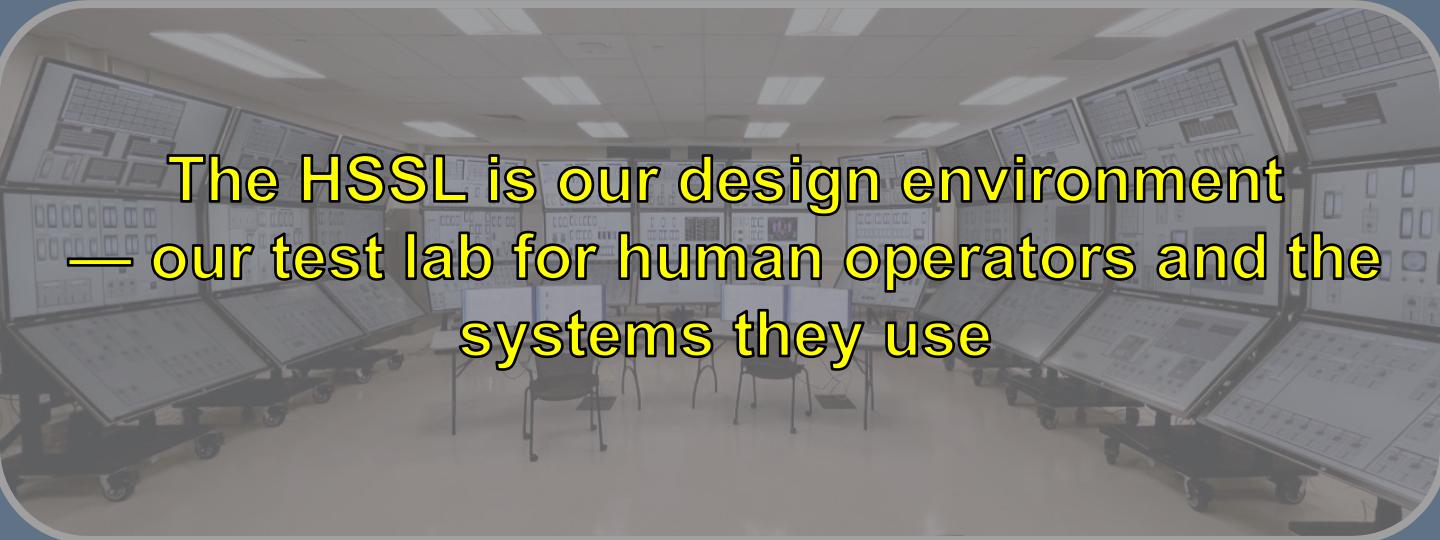


Human System Simulation Laboratory



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

Human System Simulation Laboratory



The HSSL is our design environment
— our test lab for human operators and the
systems they use

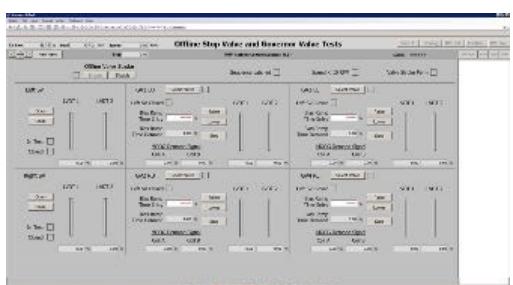
reconfigurable,
full-scale,
full-scope,
research simulator



ANIME advanced nuclear interface
modeling environment

*a development framework and sample
code library for process control*

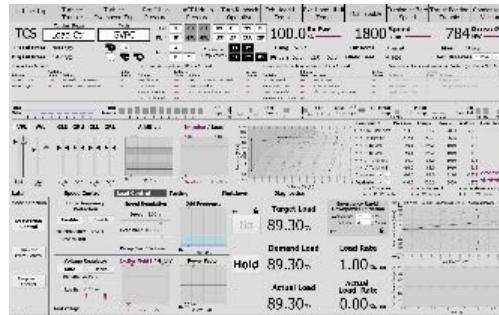
ANIME Continuum



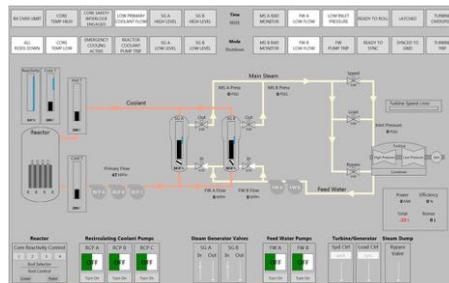
Emulation of Conventional Distributed Control System HMI



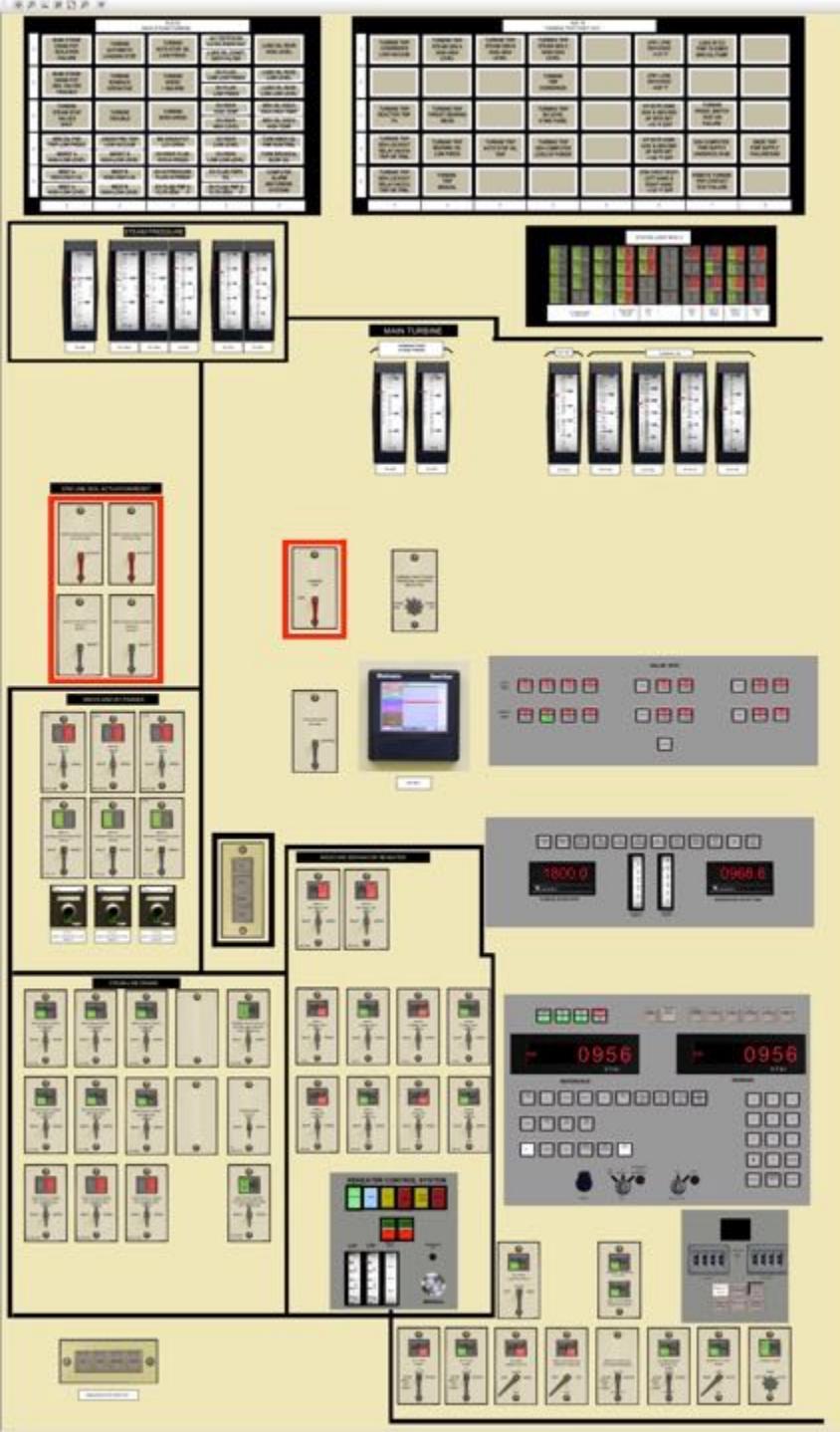
Computerized Operator Support System



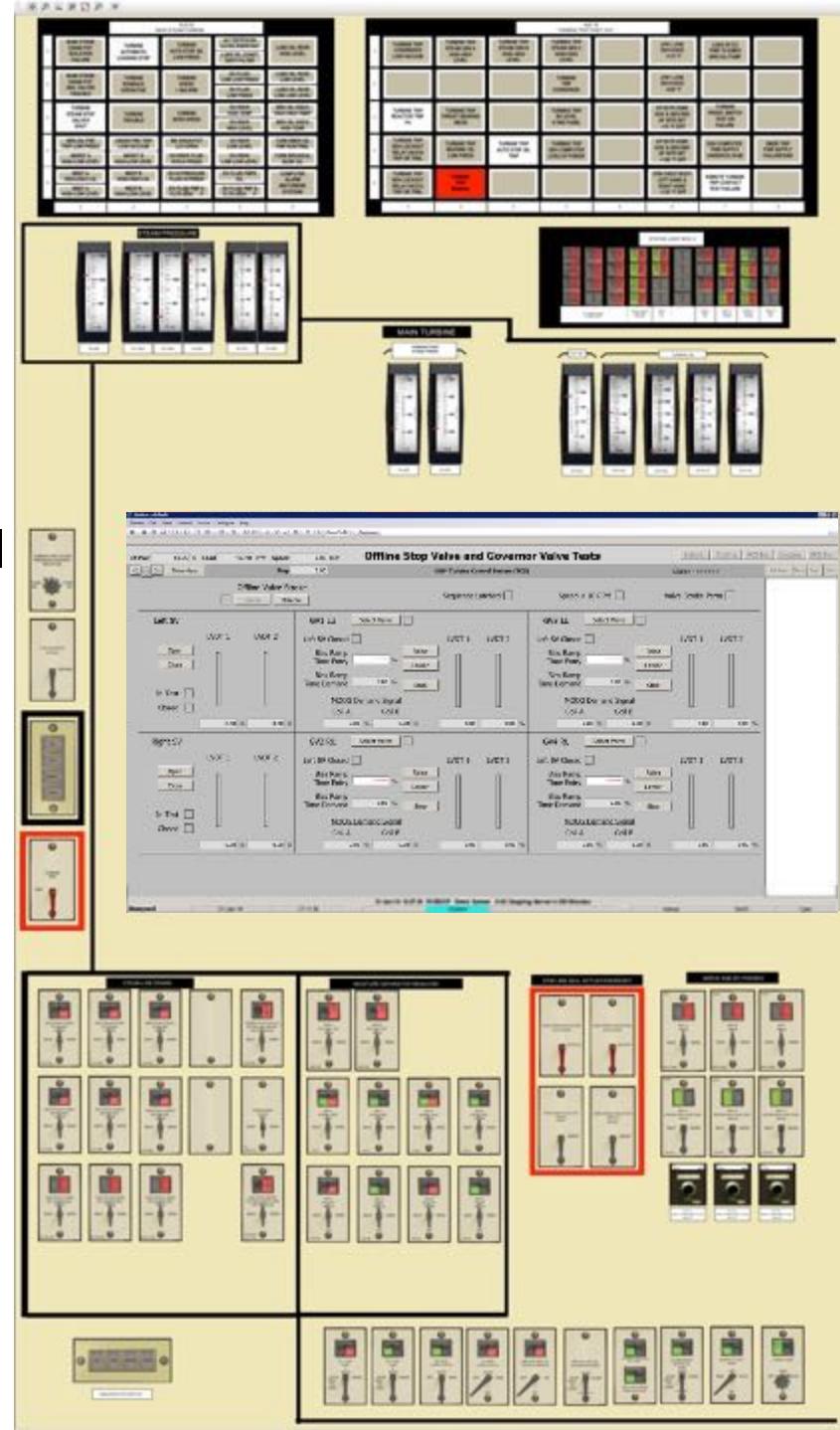
Conceptual Distributed Control System Prototype



Standalone Microworld for Human Factors and Automation Research

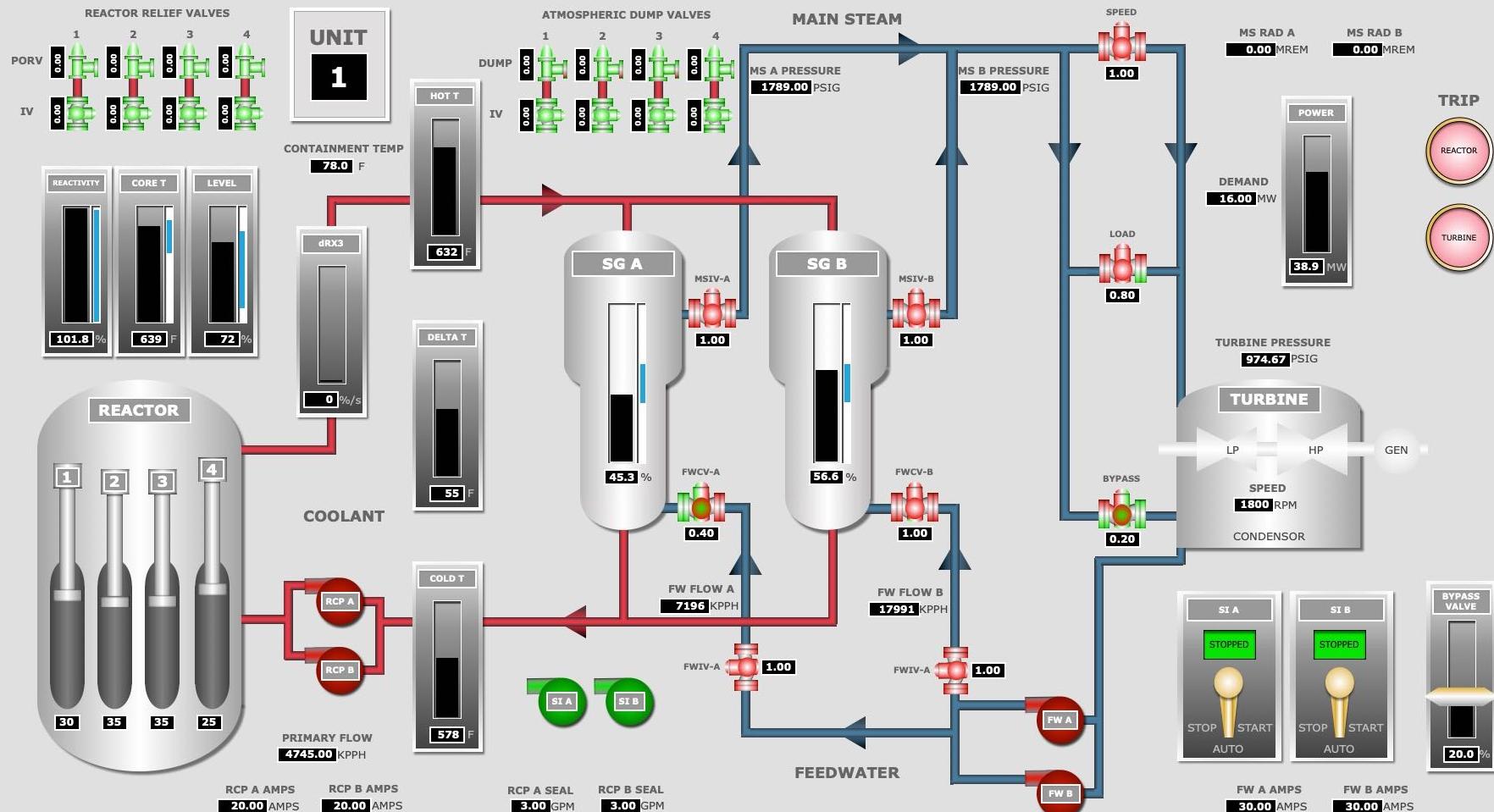


< Original

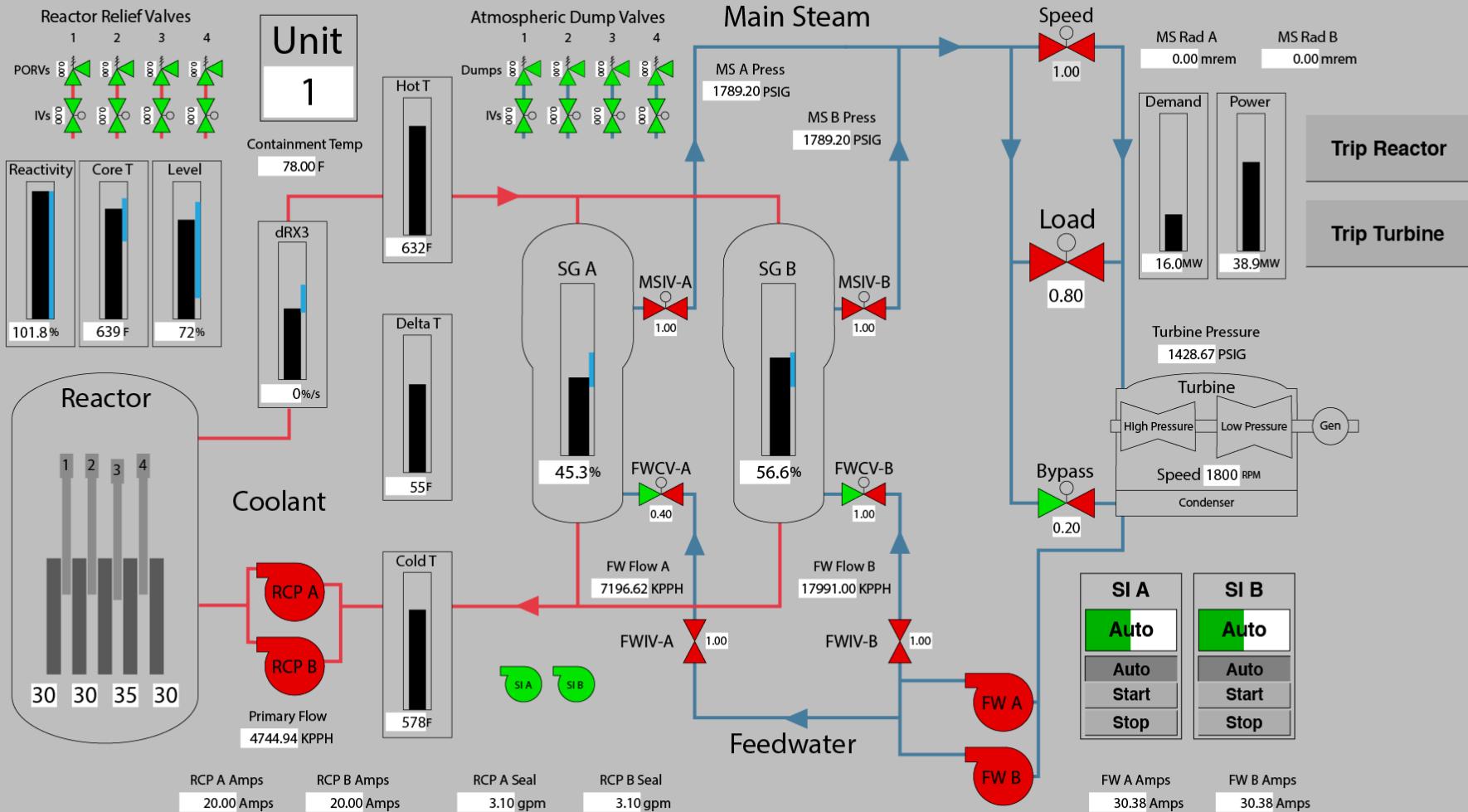


New >

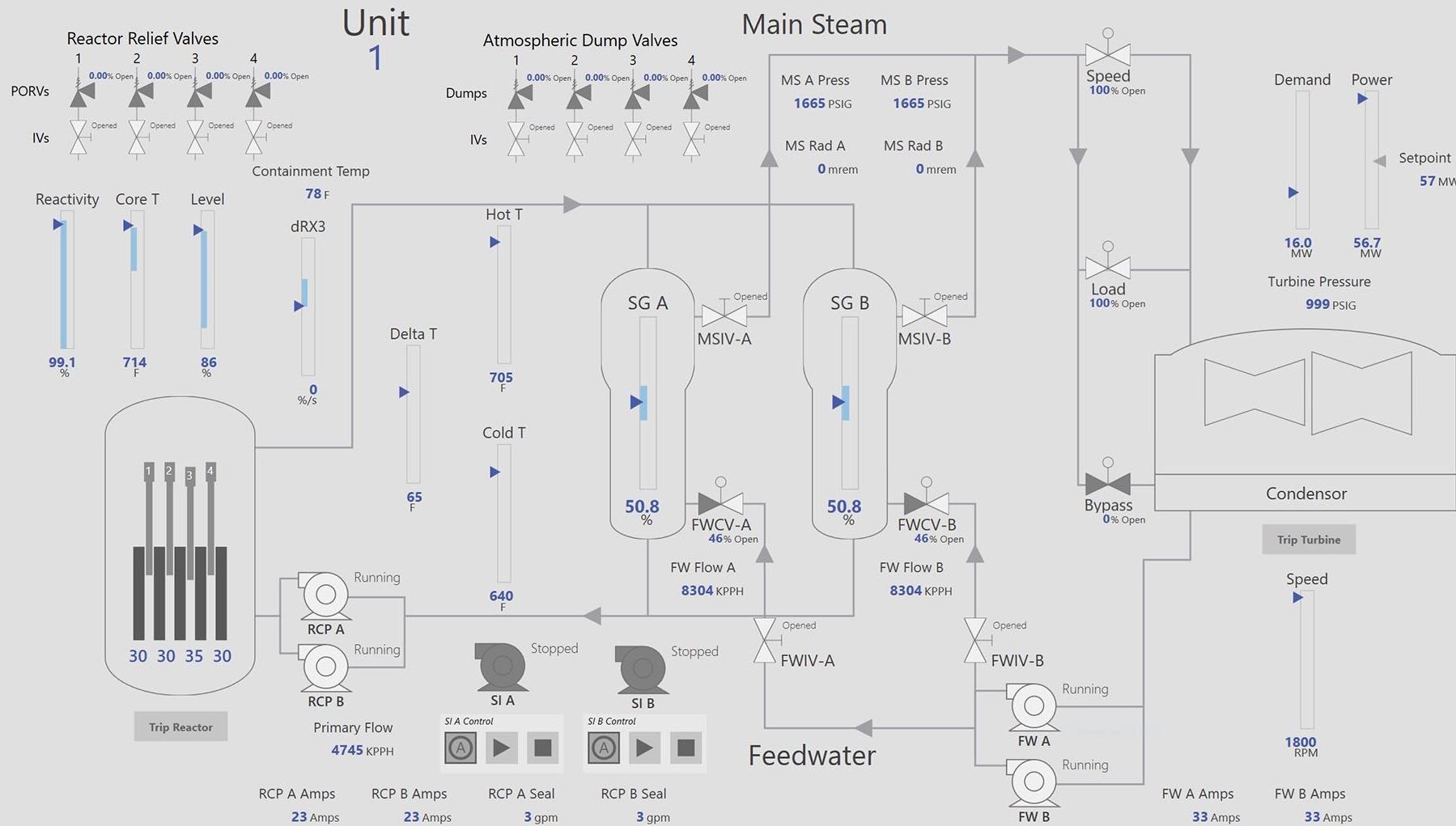
How about trying out different interfaces for same systems?



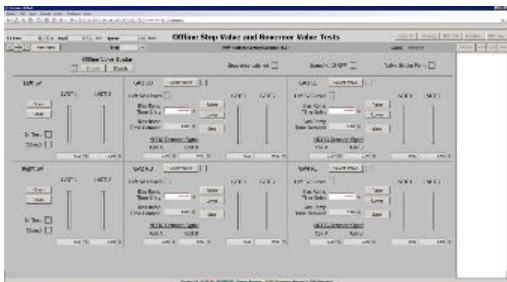
How about trying out different interfaces for same systems?



How about trying out different interfaces for same systems?



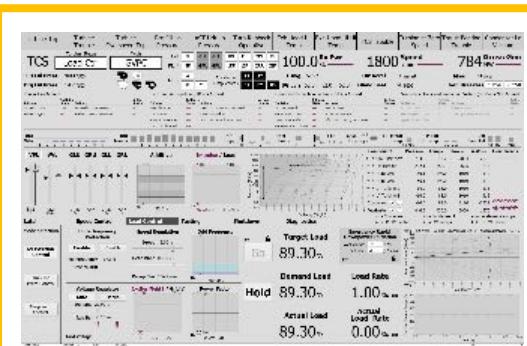
ANIME Continuum



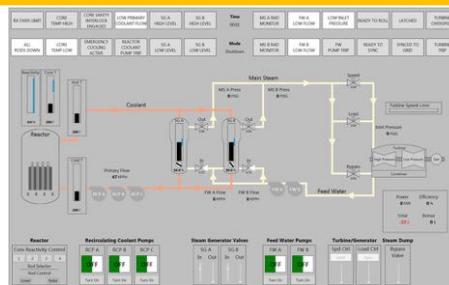
Emulation of Conventional Distributed Control System HMI



Computerized Operator Support System

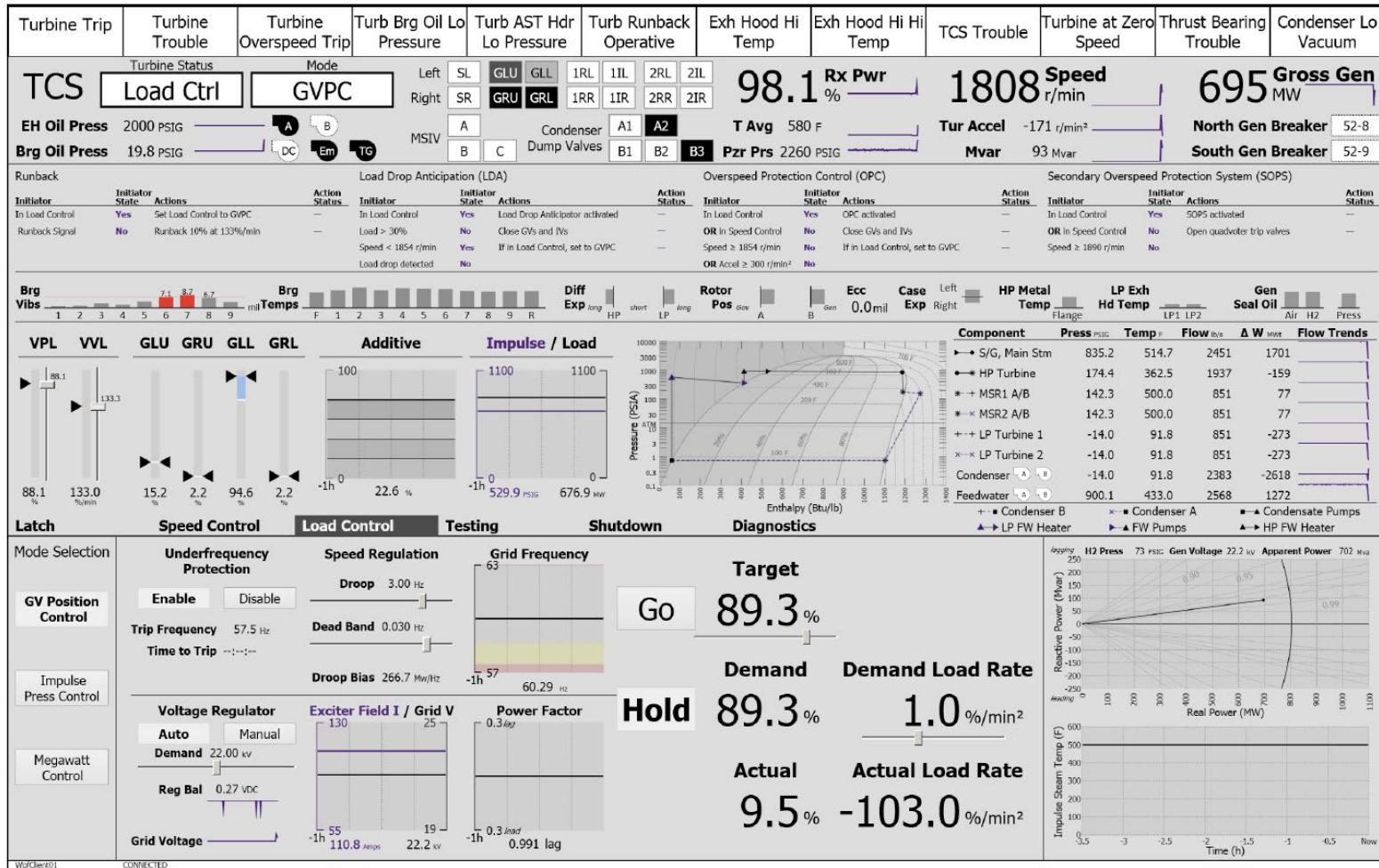


Conceptual Distributed Control System Prototype



Standalone Microworld for Human Factors and Automation Research

Advanced Turbine Control System Prototype



IDaho National Laboratory

The Two-Screen Plant Control System Concept

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

Note
Both manual reactor trip switches must be activated before initiating a manual turbine trip.

Step 2:
Start Time: Tue Sep 29 2015 11:05:08 GMT -0600 (Mountain Daylight Time)
Time on Step: 3 s
Completion Time:
Check Turbine Trip - ALL THROTTLE VALVES SHUT
TV-1 = 0.00
TV-2 = 0.00
TV-3 = 0.00
TV-4 = 0.00
All turbine throttle valves are shut

Perform for following:

- a) Manually trip the turbine from MCB
- b) Check for any of the following:
 - All turbine throttle valves = SHUT

OR

- c) If the turbine will NOT trip, THEN perform manually run back the turbine
 - 1. Depress TURBINE MANUAL
 - 2. Simultaneously depress the following
 - FAST ACTION
- d) GV LOWER

Reactor is not tripped

TV-1 TV-2 TV-3 TV-4

100 100 100 100

70.5 70.8 45.5 28.7

00 00 00 00

All turbine throttle valves are not shut

Control Panel Status:

CSIP 1A-SA	CSIP 1C-SAB	CSIP 1B-SB
Running	Running	Unknown

Process Parameters:

SI is not Actuated	PRZ Pressure (PT-444)	CNMT Pressure is less than or equal to 1850 PSIG	CNMT Pressure (PT-950)	SG-1 Pressure (PT-8405A)	SG-2 Pressure (PT-8405B)
	66.47		44.21	63.29	59.42

Bottom Row:

SI Flow (FT-943)	SI Flow is not greater than 200 GPM	1CS-291 is SHUT	1CS-292 is SHUT	1CS-165 is SHUT	1CS-166 is SHUT	1CS-235 is OPEN
27.97						

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



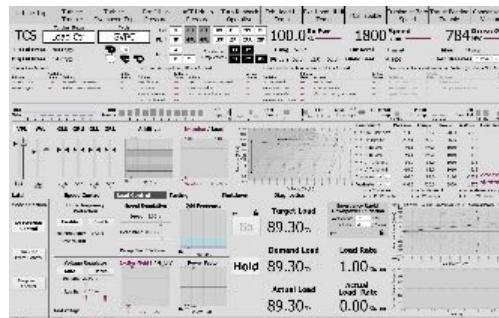
ANIME Continuum



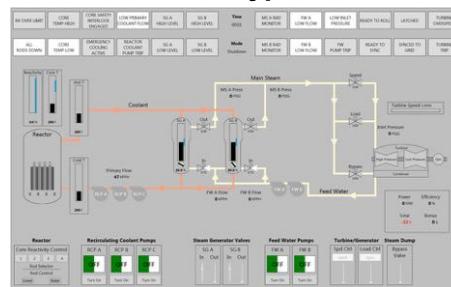
Emulation of Conventional Distributed Control System HMI



Computerized Operator Support System



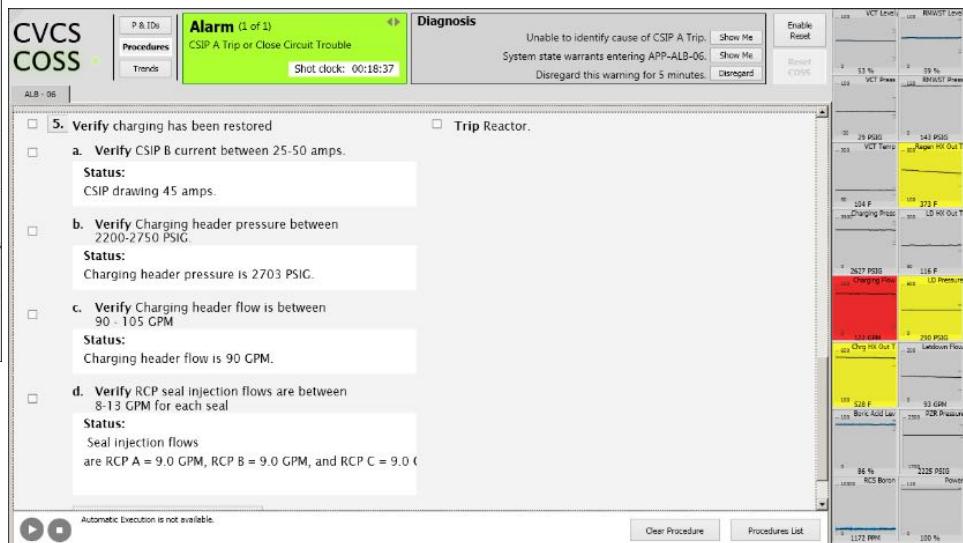
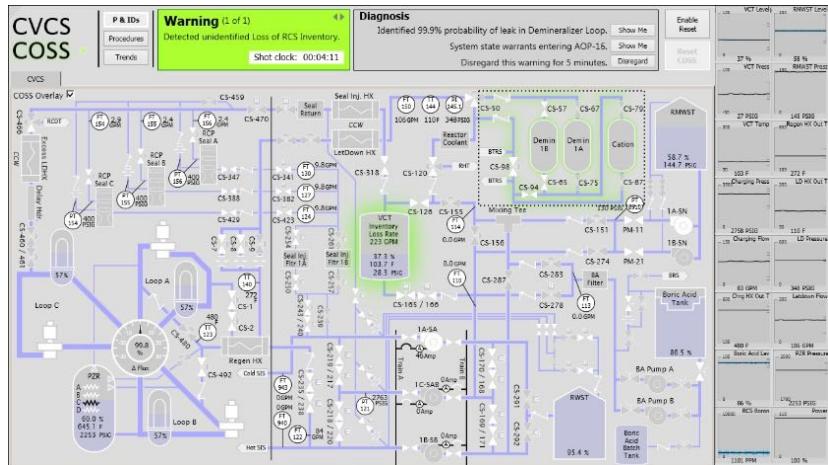
Conceptual Distributed Control System Prototype



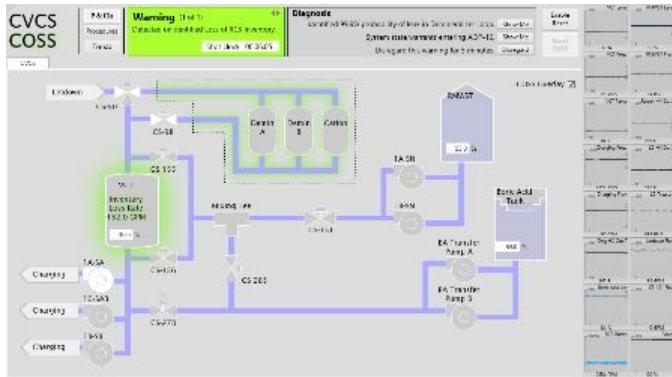
Standalone Microworld for Human Factors and Automation Research

Computerized Operator Support System (COSS)

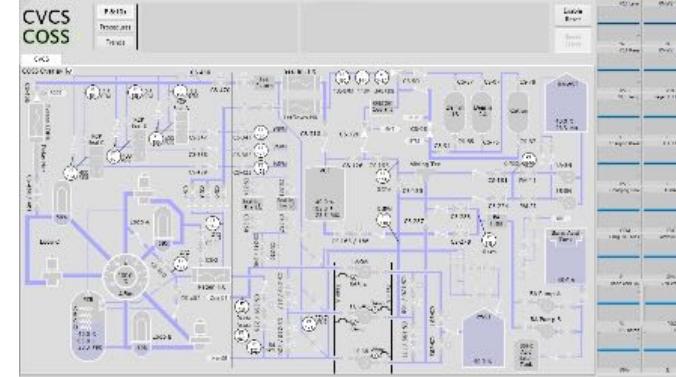
- Collection of technologies to assist operators in monitoring the plant and making timely, informed decisions



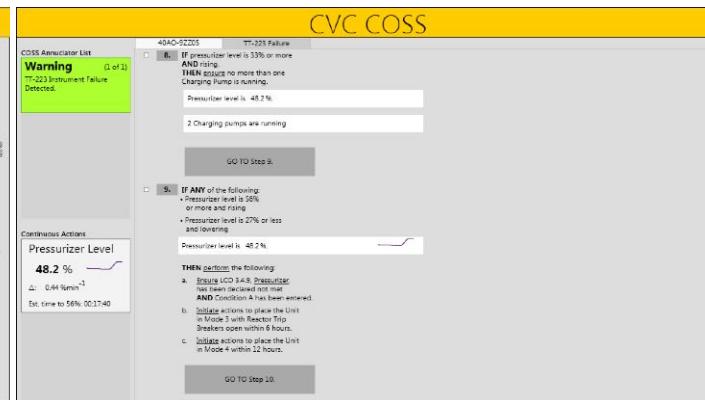
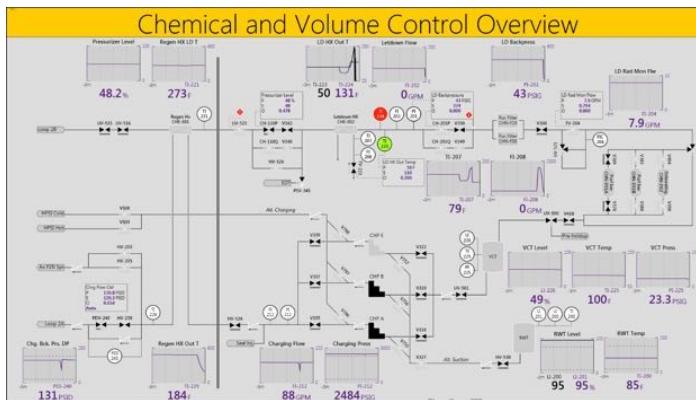
Iteration 1



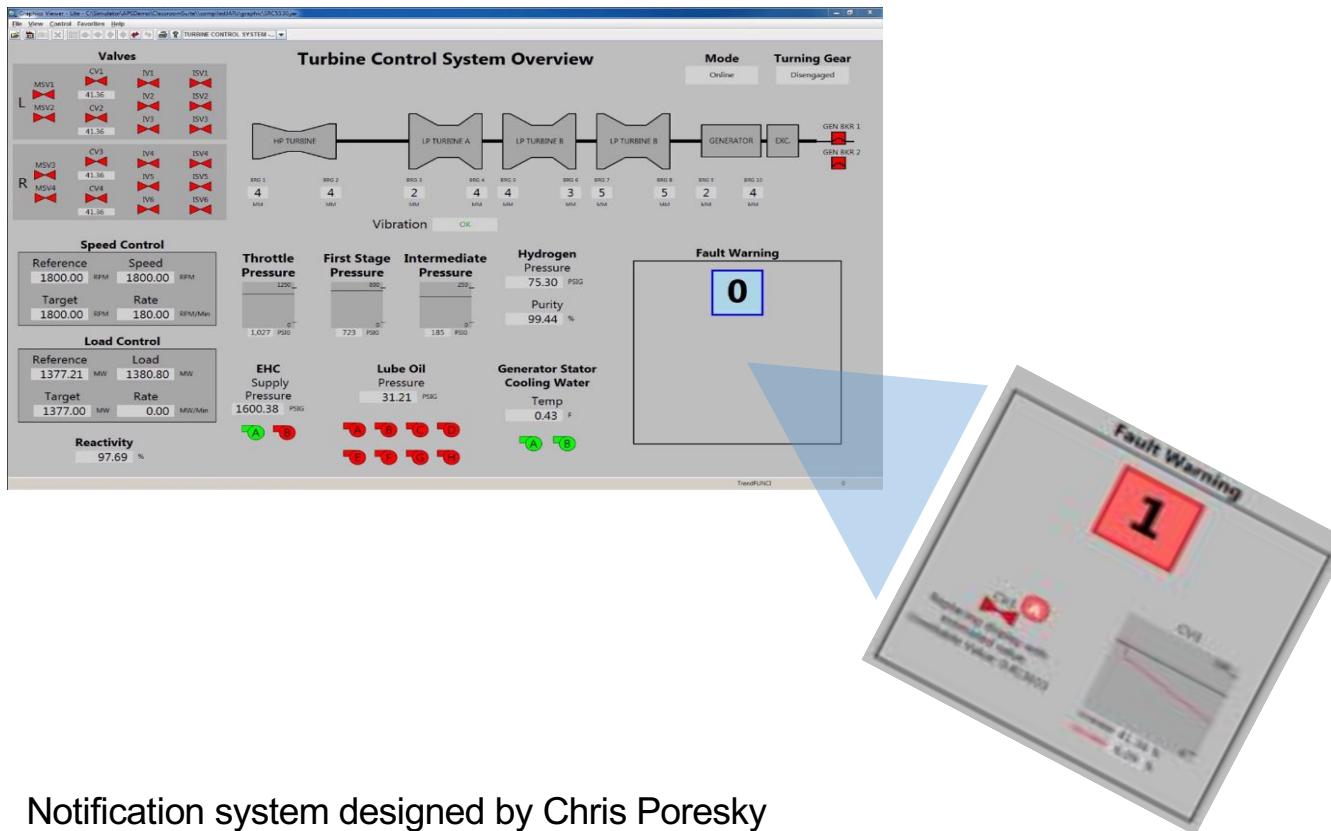
Iteration 2



Iteration 3



COSS: System Overview Display for Turbine



Notification system designed by Chris Poresky

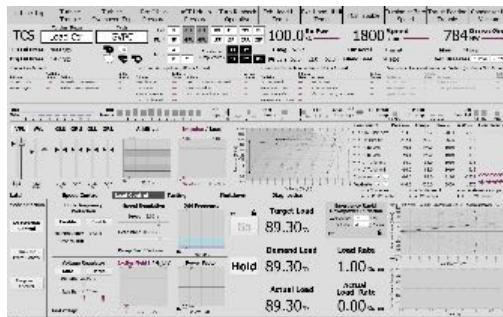
ANIME Continuum



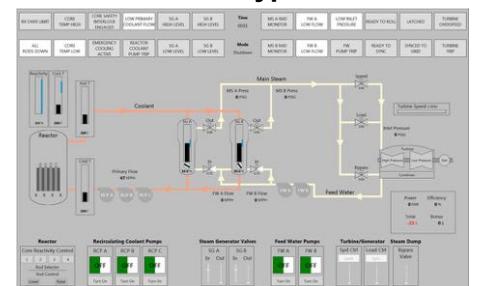
Emulation of Conventional Distributed Control System HMI



Computerized Operator Support System

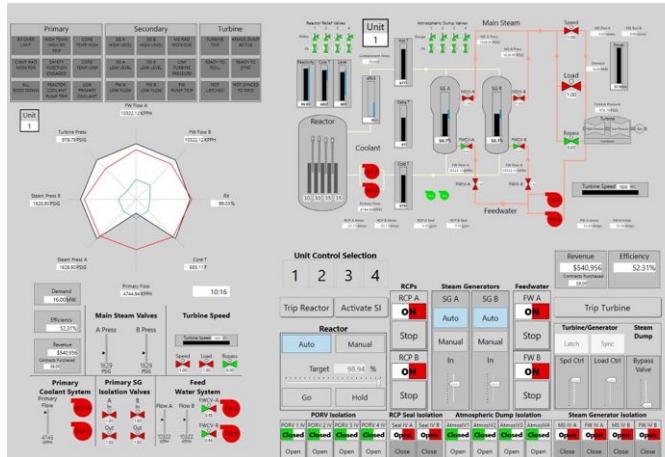


Conceptual Distributed Control System Prototype



Standalone Microworld for Human Factors and Automation Research

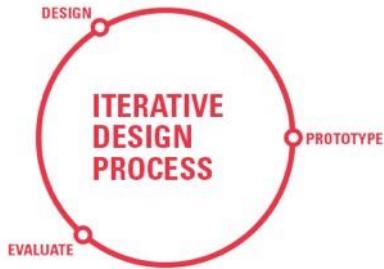
Standalone Microworld for Research



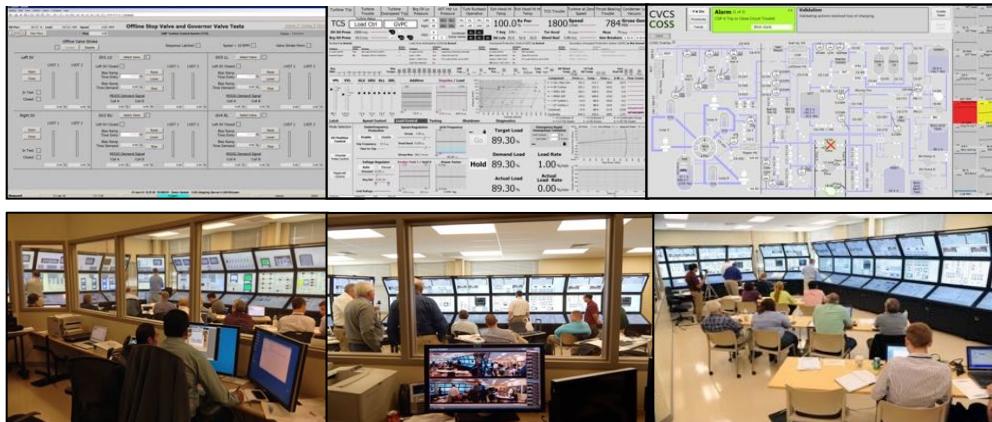
- Microworld = simplified simulator
 - Use reduced order physics model as backend instead of full-scope simulator
- Use for research
 - Human factors using students instead of operators
 - Optimal alarms
 - Prototyping advanced features and reactors not yet available in full-scope versions



What Do We as Psychologists Do?



my team and I **build prototypes** of control rooms for nuclear power plants that we then **evaluate** through operator-in-the-loop studies





humans as sources of data



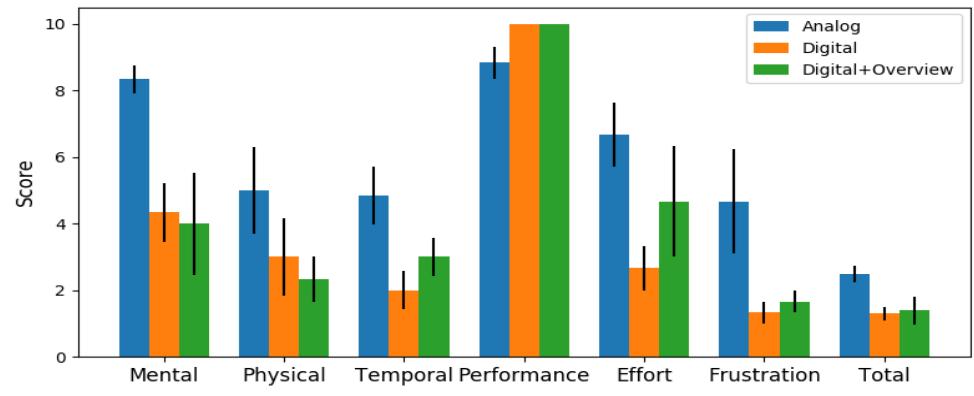
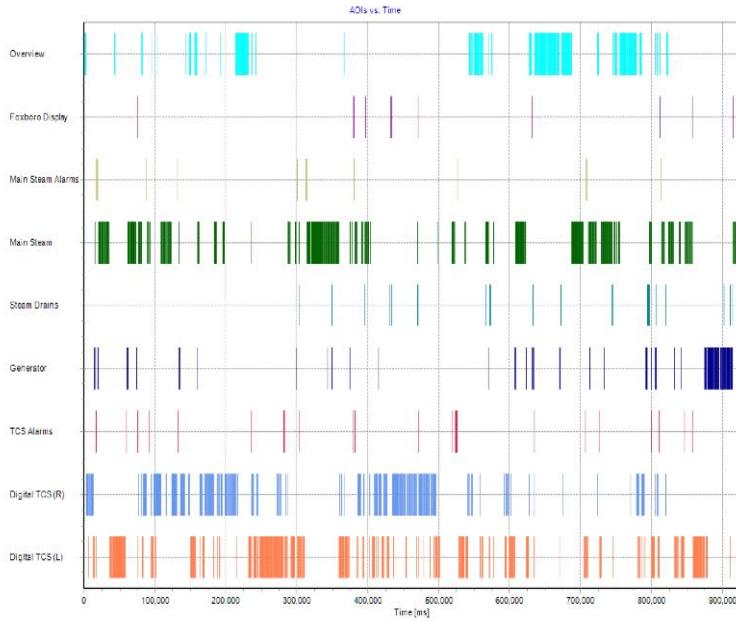
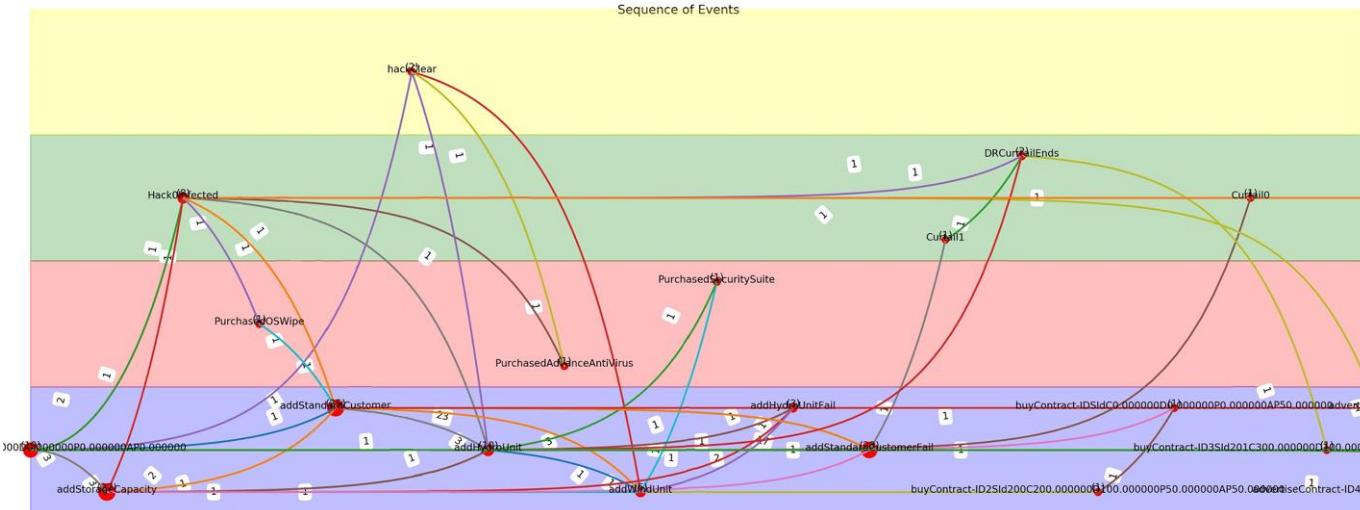


Operators Leave Traces

Procedure	Procedure			Failure Events			Time		
	Step	Substep	TLP	LOOP	LOGG	LOB	5th	Expected	95th
PTA	1	-	-	1	0	0	-	-	-
PTA	1	a	Rc	1	0	0	3.08	9.81	21.9
PTA	1	b	Rc	1	0	0	3.08	9.81	21.9
PTA	1	c	Rc	1	0	0	3.08	9.81	21.9
PTA	2	-	-	1	0	0	-	-	-
PTA	2	a	Cc	1	0	0	2.44	11.41	29.88
PTA	2	b	Cc	1	0	0	2.44	11.41	29.88
PTA	2	c	Cc	1	0	0	2.44	11.41	29.88
PTA	3	-	-	1	0	0	-	-	-
PTA	3	a	Rc	1	0	0	3.08	9.81	21.9
PTA	3	b	Rc	1	0	0	3.08	9.81	21.9
PTA	4	-	Rc	1	0	0	3.08	9.81	21.9
PTA	5	-	-	1	0	0	-	-	-
PTA	5	a	Cc	1	0	0	2.44	11.41	29.88
PTA	5	b	Rc	1	0	0	3.08	9.81	21.9
PTA	5	c	Rc	1	0	0	3.08	9.81	21.9
PTA	6	-	-	1	0	0	-	-	-
PTA	6	a	Rc	1	0	0	3.08	9.81	21.9
PTA	6	b	Rc	1	0	0	3.08	9.81	21.9
PTA	6	c	Rc	1	0	0	3.08	9.81	21.9
PTA	7	-	-	1	0	0	-	-	-
PTA	7	a	Rc	1	0	0	3.08	9.81	21.9
PTA	7	b	Cc	1	0	0	2.44	11.41	29.88
PTA	7	c	Cc	1	0	0	2.44	11.41	29.88
PTA	8	-	-	1	0	0	-	-	-
PTA	8	a	Rc	1	0	0	3.08	9.81	21.9
PTA	8	b	Rc	1	0	0	3.08	9.81	21.9
PTA	9	-	-	1	0	0	-	-	-
PTA	9	a	Rc	1	0	0	3.08	9.81	21.9
PTA	9	b	Rc	1	0	0	3.08	9.81	21.9
SBO	3	-	Rc	1	1	0	3.08	9.81	21.9
SBO	4	-	-	1	1	0	-	-	-
SBO	4	a	Cc	1	1	0	2.44	11.41	29.88
SBO	4	b	Ae	1	1	0	1.32	18.75	65.26
SBO	4	c	Ae	1	1	0	2.44	11.41	29.88
SBO	5	-	-	1	1	0	1.32	18.75	65.26
SBO	5	a	Cc	1	1	0	2.44	11.41	29.88
SBO	5	b	Ae	1	1	0	1.32	18.75	65.26
SBO	5	c	Cc	1	1	0	2.44	11.41	29.88
SBO	6	-	Rc	1	1	0	3.08	9.81	21.9
SBO	7	-	Sc	1	1	0	3.01	34.48	115.57
SBO	7	-	Rc	1	1	0	3.08	9.81	21.9
SBO	8	-	Sc	1	1	0	3.01	34.48	115.57
SBO	8	-	Cc	1	1	0	2.44	11.41	29.88
SBO	9	-	Ae	1	1	0	1.32	18.75	65.26



Operators Leave Traces



Guideline for Operator Nuclear Usability and Knowledge Elicitation (GONUKE)

<u>Evaluation Phase</u>				
	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

¹Corresponding Phases in NUREG-0711.

Guideline for Operator Nuclear Usability and Knowledge Elicitation (GONUKE)

		<u>Evaluation Phase</u>			
		Pre-Formative (Planning and Analysis ¹)	Formative (Design ¹)	Summative (Verification and Validation ¹)	Post-Summative (Implementation and Operation ¹)
Evaluation Type	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

¹Corresponding Phases in NUREG-0711.

Guideline for Operator Nuclear Usability and Knowledge Elicitation (GONUKE)

<u>Evaluation Phase</u>				
	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

¹Corresponding Phases in NUREG-0711.

Guideline for Operator Nuclear Usability and Knowledge Elicitation (GONUKE)

What the regulator requires

		<u>Evaluation Phase</u>			
		Pre-Formative (Planning and Analysis ¹)	Formative (Design ¹)	Summative (Verification and Validation ¹)	Post-Summative (Implementation and Operation ¹)
Evaluation Type	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

¹Corresponding Phases in NUREG-0711.

Guideline for Operator Nuclear Usability and Knowledge Elicitation (GONUKE)

Typical usability evaluation

		<u>Evaluation Phase</u>			
		Pre-Formative (Planning and Analysis ¹)	Formative (Design ¹)	Summative (Verification and Validation ¹)	Post-Summative (Implementation and Operation ¹)
Evaluation Type	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

¹Corresponding Phases in NUREG-0711.

Guideline for Operator Nuclear Usability and Knowledge Elicitation (GONUKE)

<u>Evaluation Phase</u>				
	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

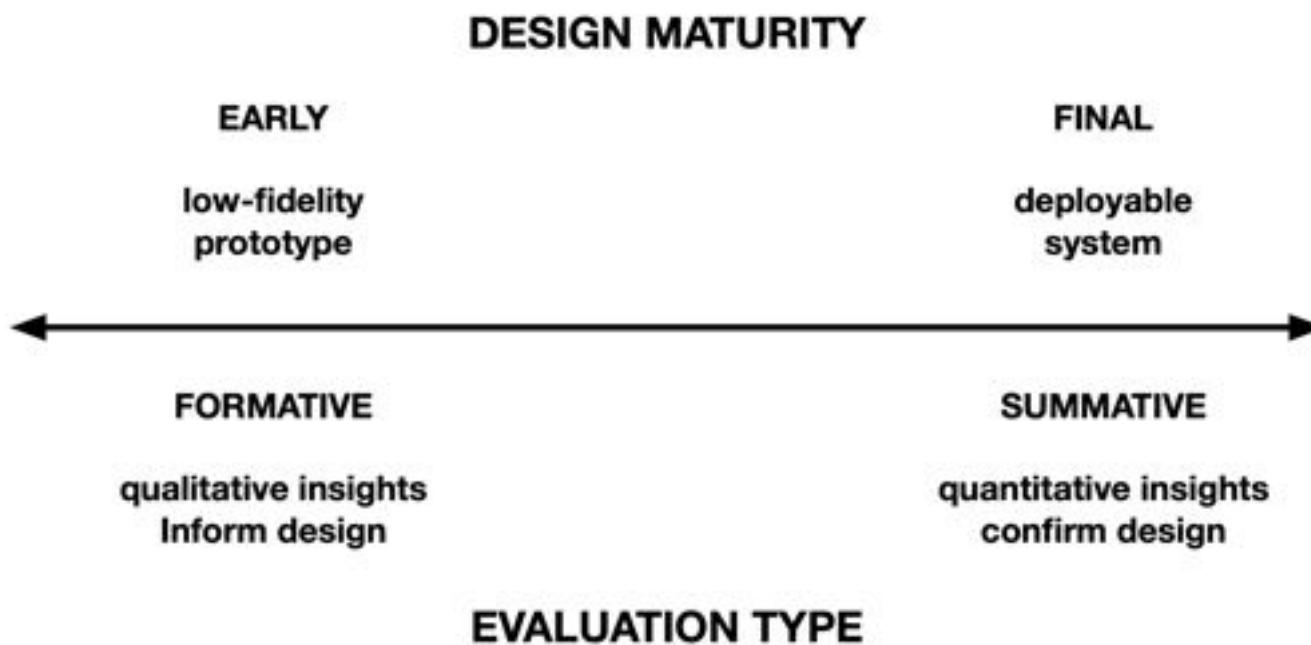
¹Corresponding Phases in NUREG-0711.



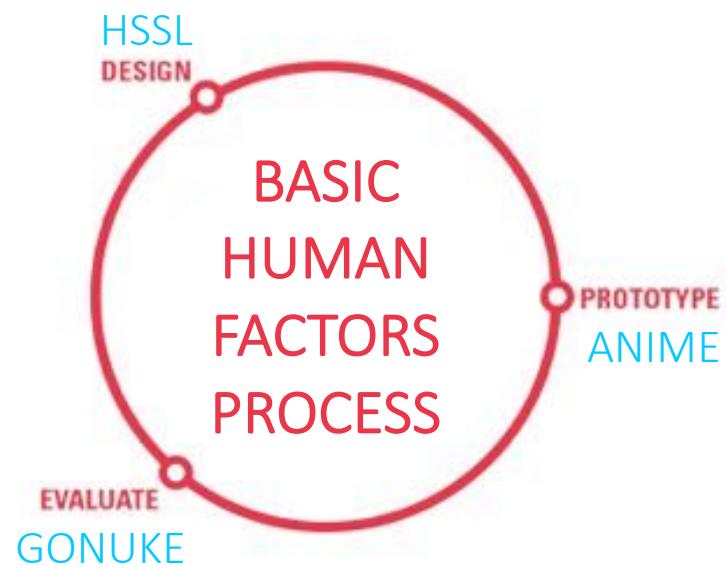
Epistemiation: Capturing Expert Operator Knowledge to Design New System



ALARA
As Low As Reasonable Assessment



NODOSE
Nuclear Oriented Detailed Operator-System Evaluation





IDaho National
Laboratory

70th
Anniversary

ronald.boring@inl.gov