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Control Room Design and Modernization

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NPIC HMIT 2019

11th Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies

Control Room Design and Modernization

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LWRS LIGHT WATER REACTOR SUSTAINABILITY

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Outline

- Biographical Sketch
- U.S. DOE Light Water Reactor Sustainability
- Control Room Design and Modernization
- Current Work and Collaborating Utility Partners

Biographical Sketch

- Jeffrey C. Joe is a Senior Human Factors Research Scientist at Idaho National Laboratory (INL).
- Principal Investigator/technical lead for multiple projects under the DOE Light Water Reactor Sustainability (LWRS) program.
- Master’s Degree in Psychology.

U.S. DOE Light Water Reactor Sustainability Program

A Programmatic Solution to Sustaining Existing Commercial Nuclear Power Plants (NPPs)

- Partner with utilities to safely extend the life of currently operating NPPs
- Broad area focus, including Human Factors Research and Development (R&D) and Human Factors Engineering (HFE)
- Specific Focus on Control Room Design and Modernization

LWRS LIGHT WATER REACTOR SUSTAINABILITY

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Control Room Modernization – Human Factors

- LWRS Program researchers conduct Human Factors R&D on control room modernization approaches to:
  - Evaluate the impact of modernization activities on human-system performance.
  - Establish the technical bases for upgrade decisions.
- Human factors experts:
  - Collaborate with industry partners by evaluating designs to ensure human-system performance is not impacted.
  - Research a variety of data collection methods to provide the basis for design decisions and provide evidence of human performance impacts of design.
  - Develop principles and create state-of-the-art guidance on control room modernization to inform the LWR fleet.

Current Collaborations and Utility Partners

- Duke Energy
- Exelon ⏭
- Arizona Public Services – Palo Verde
- Dominion

Duke Energy Control Room Modernization

- Duke Energy entered into a collaboration with the U.S. DOE, LWRS Program, and INL to support Duke's digital upgrades
- The collaboration specifically focused on the HFE aspects of the turbine control systems (TCS) upgrades at four nuclear units at three different sites:
  - H.B. Robinson (1970)
  - Brunswick Unit 2 (1974), Unit 1 (1976)
  - Shearon Harris (1986)

HFE Basis – NUREG-0711 – Phases and Elements

Planning and Analysis	Design	Verification and Validation	Implementation and Operation
HFE Program Management	Human -System Interface Design	Human Factors Verification and Validation	Design Implementation
Operating Experience Review	Procedure Development		Human Performance Monitoring
Function Analysis & Allocation	Training Program Development		
Task Analysis			
Staffing & Qualification			
Treatment of Important Human Actions			

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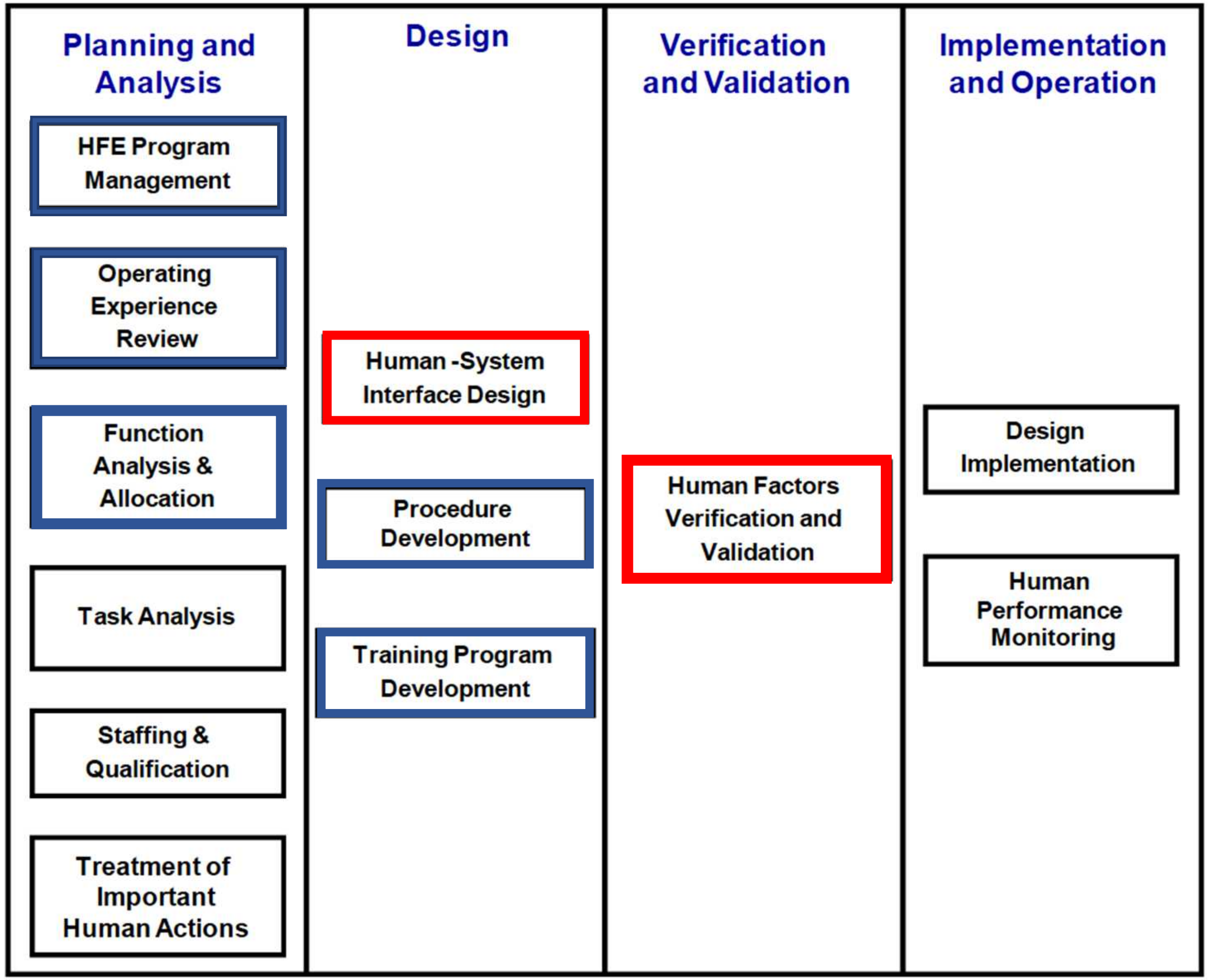


Human Systems Simulation Laboratory (HSSL)

Human Systems Simulation Laboratory (HSSL)

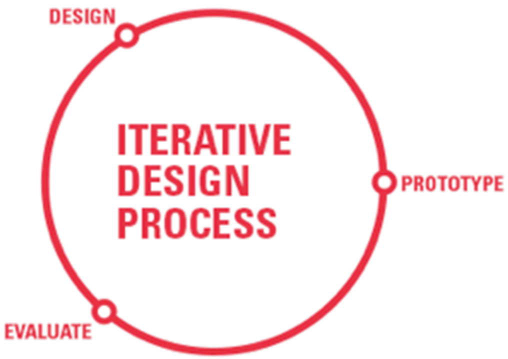
- Reconfigurable
- Full-Scale
- Full-Scope
- Research

Simulator

Early (Formative) Evaluations of the TCS HSI

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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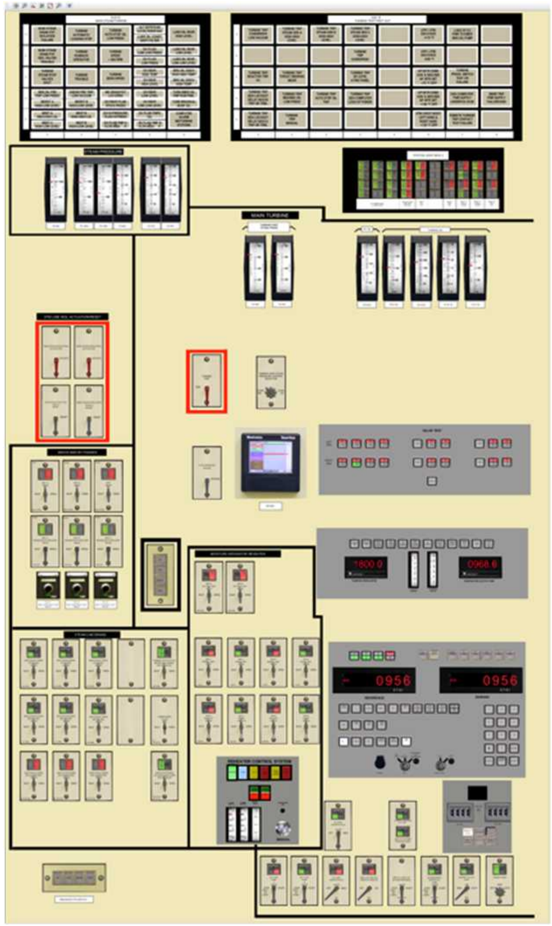
Example of Upgrades: Harris Turbine Control



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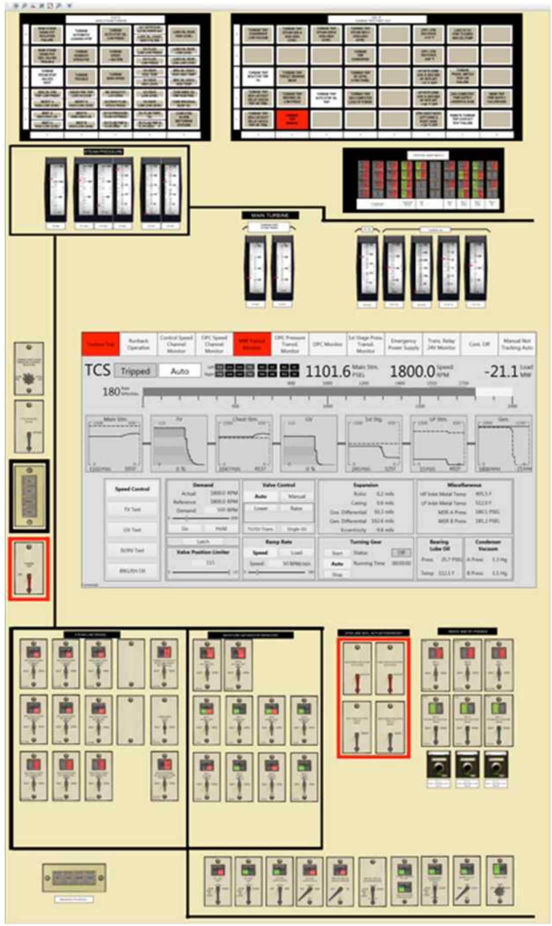

Human Factors Verification & Validation

Purpose of the Integrated Systems Validation (ISV)

- Does the new TCS HSI sufficiently support the control room team in their tasks and responsibilities
- Evaluate that no weakness or degradation is introduced by the modernization
- Validation of HSI includes
  - Interfaces
  - Procedures
  - Operator Proficiency

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Applied NUREG-0711 as the ISV Guideline

- NUREG-0711 Human Factors Engineering Program Review Model (Rev. 3), Chapter 11: Human Factors Verification and Validation.
  - Adapted to include safety and plant availability issues
- Applied a graded approach
  - TCS is a sub-system not the whole control room
  - We made some interpretations and adaptions of the guide to fit the scope of the TCS validation
    - Scenarios concentrated on TCS
    - Measures / Observations appropriate for ISV
    - Limited number of participants

Independence of ISV Evaluation Team

- The evaluation team did not directly participate in the actual design of the TCS
  - INL
  - Expert HFE Consultant
  - Fleet Design Engineering
  - Major Projects

- HFE experts from Norway (Halden Reactor Project) planned and the evaluation team executed the ISV

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ISV Process

- Scenarios – INL, Simulator Group, and Major Projects (Operations background) developed test scenarios relevant to TCS upgrade
  - Covered most of the main TCS formats and selected parts of most main procedures including these examples:
    - Turbine startup
    - Sync to grid
    - Online and offline valve tests
    - High bearing vibration - requiring Turbine trip
    - Card failure
    - Turbine runback
    - Rapid downpower

ISV Process

- Walked through scenarios in the glasstop simulator with plant operators (CRS and RO)
- Evaluated Results and identified Human Engineering Discrepancies (HEDs)

Evaluation Methods

- Human factors and operations expert observers
- Checklists and protocols
- Operator questionnaires
- Interviews and debriefs

Goal: Identify and classify Human Engineering Discrepancies (HEDs)

Human Engineering Discrepancies (HEDs)

- HED Definition - Elements of the HFE design that do not conform with the design specifications, task requirements, or performance standards necessary to ensure safe operation and plant availability

- HEDs were identified by agreement among expert observers based on
  - Observing and assessing detailed task performance
  - Discussing and assessing by the validation team
  - Interviews with participating operators

- Note: expert observers involving both human factors, subject matter expertise, training, and engineering

Classification of HEDs

- Priority 1: Have direct, indirect, or potential major safety or plant availability consequences and requires *Resolution*
- Priority 2: Potential significant consequences to plant performance / operability or personnel performance. Must be *Dispositioned*
- Priority 3: Other (not meeting priority 1 and 2 criteria) HEDs that should be documented for possible future resolution

- The validation team determines the priority and the plant is responsible for resolution or disposition

Overall Preliminary Results

- Operators reported many advantages of the new TCS
  - More detailed information readily accessible support decision making and better system awareness
  - Automation provided by new TCS reduced workload
  - More detailed information provided better transparency (allows operators to understand TCS actions and alarms)

- HEDs were identified…

Duke Energy Control Room Modernization

- Upgraded turbine control systems for Robinson, Harris, and Brunswick
- Conducted three phases of operator workshops to optimize the HSI design
  - Initial benchmark using static mockups
  - Benchmark using fully functional dynamic prototypes
  - Integrated system validation using deployed system

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Duke Energy Control Room Modernization

- The collaboration provided the opportunity to train operators and work with the new system at scale to see how it will integrate with other plant control systems before modifying the plant. Early learning provided the opportunity to modify the design and further improve plant safety and efficiency prior to implementation
- Initial vendor design proved to have numerous issues
- By the time of factory acceptance test and integrated system validation, no outstanding design issues

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Exelon Control Room Modernization

- In 2016, a collaboration between LWRS and Exelon started to perform cost-shared R&D activities.
- Exelon was in the process of upgrading the non-safety related (NSR) nuclear steam supply systems (NSSS) and balance of plant (BOP) systems at Byron and Braidwood.
- Although the utility had properly maintained and upgraded the NSR NSSS and BOP systems with like-for-like replacement parts, the systems had been in service for more than 30 years, and upgrading them to a new digital I&C system presented an opportunity to improve equipment reliability, reduce the likelihood of plant transients, and in general improve safety margins.

Exelon Control Room Modernization

For this upgrade, the changes to the control room included:

1. The addition of video display units to the control boards for the digital control system (DCS) soft controls and indications
2. The deletion of a number of analog controls and indicators
3. Changes to procedures, the conduct of operations, and training

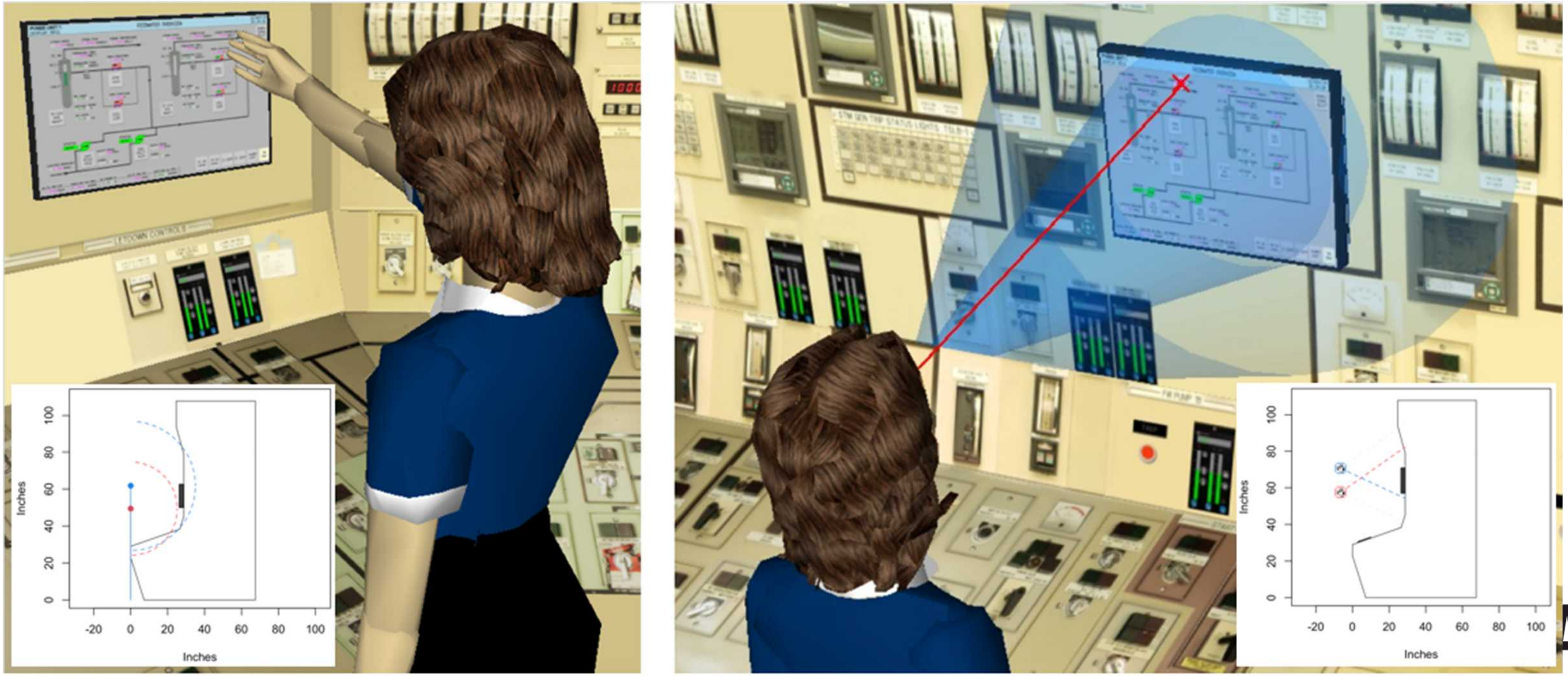
Exelon Control Room Modernization

Summary of Technical Activities

- 3D Modeling
- HSSL Development – Installed the Braidwood Simulator
- Conducted operator-in-the-loop simulator workshops to identify potential HFE issues with the planned upgrades

3D Modeling of the Braidwood Main Control Room

Ergonomic and HFE analyses of I&C hardware and human system interface to help identify and prevent the introduction of new human error traps with this DCS upgrade.



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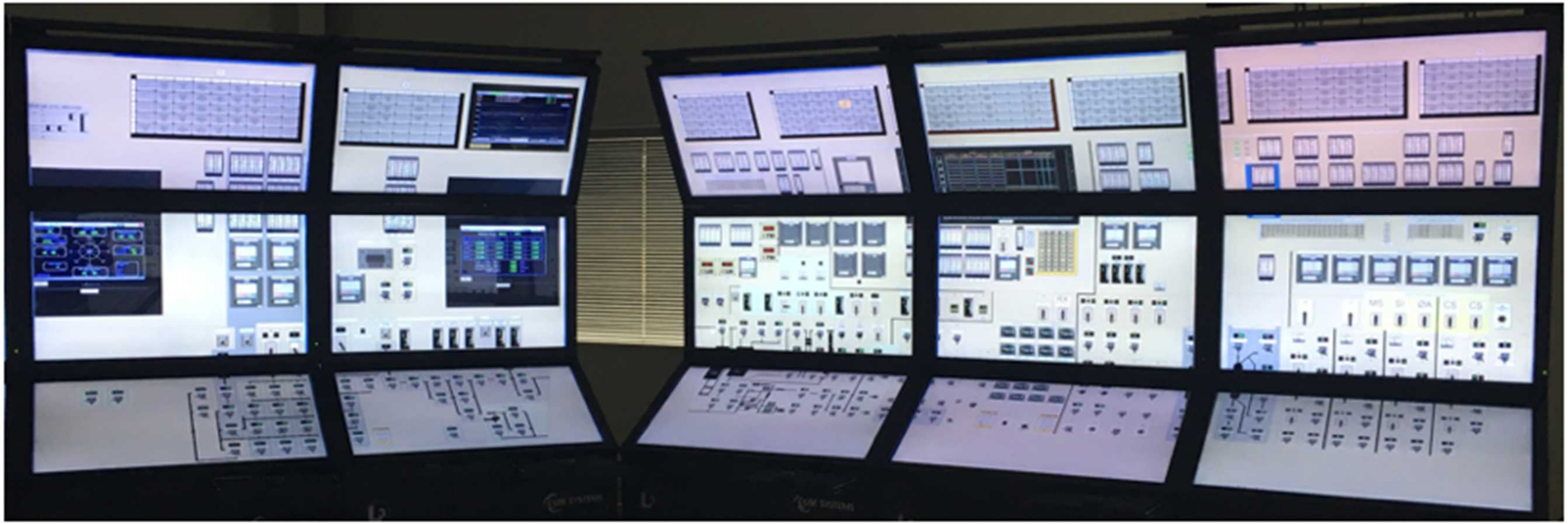
Installation of Braidwood Simulator in HSSL



The HSSL configured as the Braidwood main control room so the effect of upgraded digital I&C on operator and overall system performance can be evaluated.

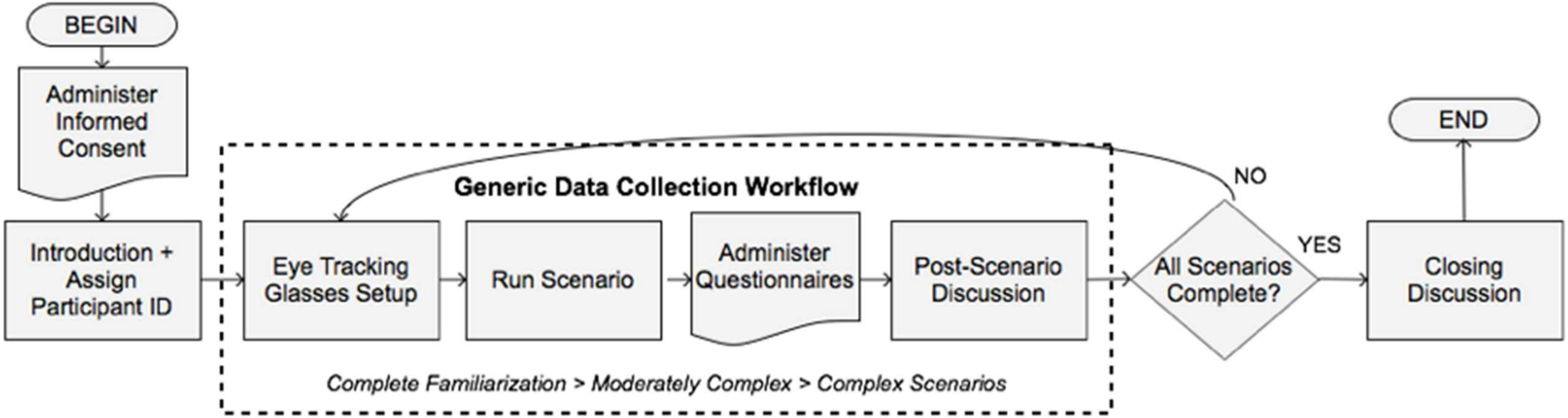
Operator-in-the-Loop Workshops

- The purpose of the workshops was to conduct HFE validation assessments of the planned control room I&C upgrades in order to identify potential HFE issues prior to installation in the main control room

- Normal, abnormal, and emergency scenarios were designed to evaluate the functional ergonomic and human factors aspects of the existing and upgraded I&C systems
  - Particular emphasis on the ability of the new I&C system to support operators’ cognitive processes and their ability to facilitate the operators’ ability to perform the correct control actions

Operator-in-the-Loop Workshops

- The operator-in-the-loop workshops entailed direct observations and assessments of key operator interactions with the existing and new HSIs.



Workshop Results

- Operators' ability to perform their expected monitoring and control functions during emergency operations was not challenged by the upgrade.
- In Emergency Conditions, operators were:
  - Able to successfully complete the tasks correctly, completely, and without confusion or misunderstandings.
  - Sufficiently alerted, provided with usable controls, and received adequate feedback from the system interfaces.
- Operators were also sufficiently supported by operating procedures, and training.

Workshop Results

- A few medium and low level human factors issues were identified that affected normal and abnormal operating conditions, but no issues were safety significant.
- HFE issues identified and documented helped Exelon get some legacy issues in the I&C solutions changed
  - Exelon expressed their thanks in being able to provide part of the technical basis to get the legacy I&C solutions changed

Control Room Design and Modernization – *Why does it matter? Why do it?*

Human Factors Technical Improvements

- Reduce operator workload and mental burden.
- Automate sequences of activities to reduce tedious manual control and associated human error.
- Assist the operator in integrating plant information to make diagnosis of plant upsets.
- Provide operators with early warnings

Control Room Design and Modernization – *Why does it matter? Why do it?*

Human Factors Technical Improvements	Improvements in Operations Performance Outcomes
• Reduce operator workload and mental burden. • Automate sequences of activities to reduce tedious manual control and associated human error. • Assist the operator in integrating plant information to make diagnosis of plant upsets. • Provide operators with early warnings	• Fewer safety challenges due to operators failure to detect off-normal conditions. • Quicker responses to plant transients resulting in less severe plant deviations and better outcomes. • Allow operators to perform ancillary duties without concern for ineffective plant monitoring.

Control Room Design and Modernization – *Why does it matter? Why do it?*

Human Factors Technical Improvements	Improvements in Operations Performance Outcomes	Improved Key Performance Indicators (KPIs)
• Reduce operator workload and mental burden. • Automate sequences of activities to reduce tedious manual control and associated human error. • Assist the operator in integrating plant information to make diagnosis of plant upsets. • Provide operators with early warnings	• Fewer safety challenges due to operators failure to detect off-normal conditions. • Quicker responses to plant transients resulting in less severe plant deviations and better outcomes. • Allow operators to perform ancillary duties without concern for ineffective plant monitoring.	• Higher Capacity Factor. • Reduced Forced Loss Rate. • Reduced O&M Cost. • Reduced Dose. • Improved Regulatory Ratings.

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