Thomas Ulrich, PhD
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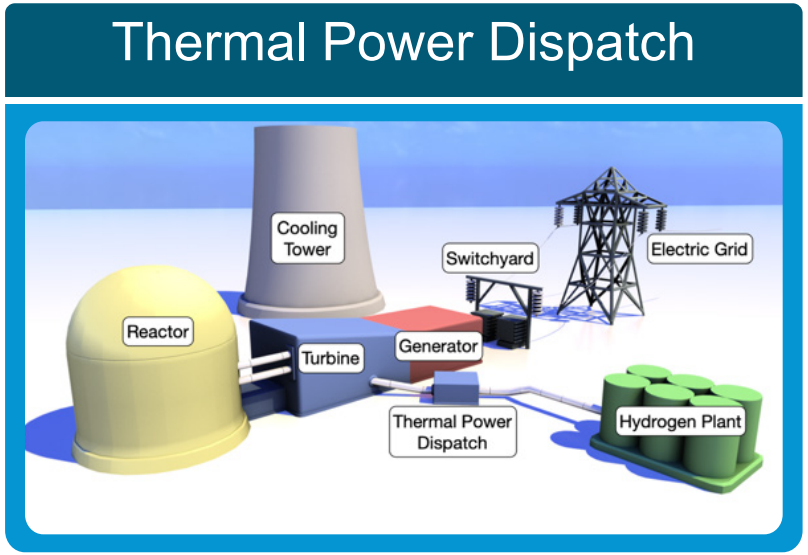
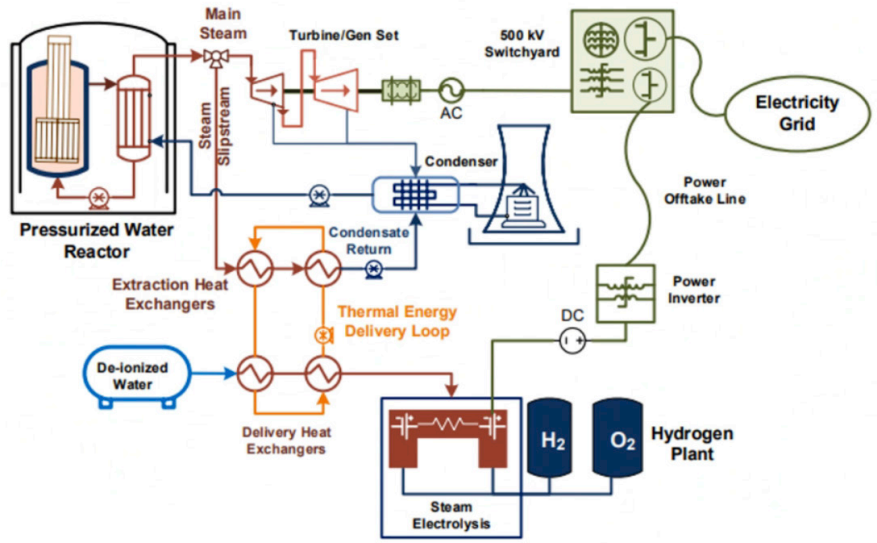
Flexible Power Operations and Generation Control Interfaces for Thermal Power Dispatch

Concepts of Operations Development and Demonstration

Thermal Power Dispatch Concept of Operations

- **Flexible Hybrid operations**
  - Dispatch electricity (spinning and nonspinning reserve) between grid and industry user
  - Store thermal energy for later grid use (electrolyzer)
  - Dispatch thermal energy and electricity to industrial user
- **Develop and Demonstrate Concept of Operations (ConOps) for Thermal Power Dispatch**
  - *Develop*, *evaluate*, and specify human system interfaces, work flows, procedures, inter-organizational coordination
  - Ensure safety and feasibility as these new operations are incorporated into existing operations
    - Provide control system interface implementation design schemes and mock procedures
    - Provide evidence and adoption roadmap for utilities to reduce regulatory uncertainty



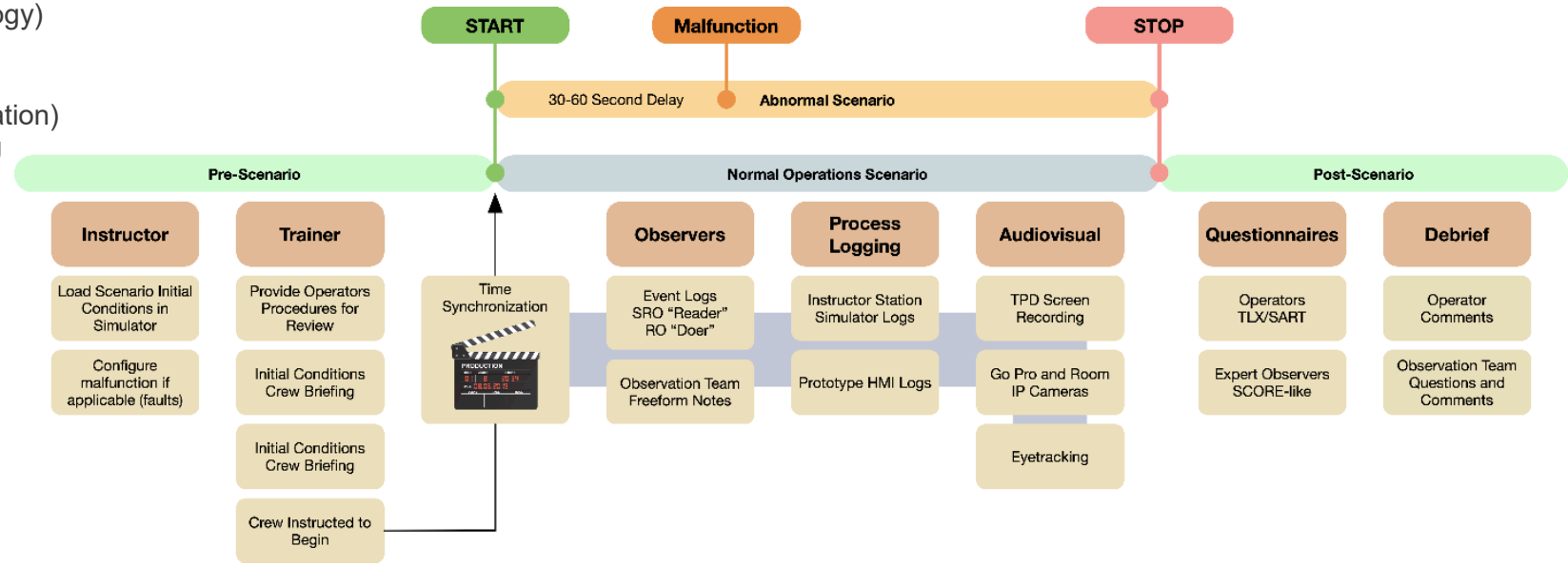


Simulator-based ConOps Development and Testing

A human-in-the-loop approach entails simulating representative scenarios with operators to **develop and evaluate new concept of operations**, identify operational impacts, and ensure the new concept of operations is safe, efficient, and reliable.

Use **human and system performance data** to evaluate the effectiveness of the engineered system design, HSI, and procedures (empirical evidence for licensing under **NUREG-0711 Human Factors Engineering Program Review Model**)

- **Multi-day evaluation workshop** (NUREG-0711 methodology)
- **Representative scenarios**
  - Benchmark (steam-generator tube rupture)
  - Normal operations (operational time course determination)
    - System startup, shutdown, engage, disengage, testing
  - Abnormal (ensure minimal workload increases)
    - Existing plant faults → TPD impacts on operations
    - TPD specific faults → TPD operations
- **Data Driven System Performance Metrics (evidence)**
  - Crew debriefs – "what worked and what didn't"
  - Track plant parameters within the context of operator actions – margins to technical specifications
  - Usability
    - Paper surveys post-trial
    - Eye Tracking
    - Expert observers
    - TomLogs



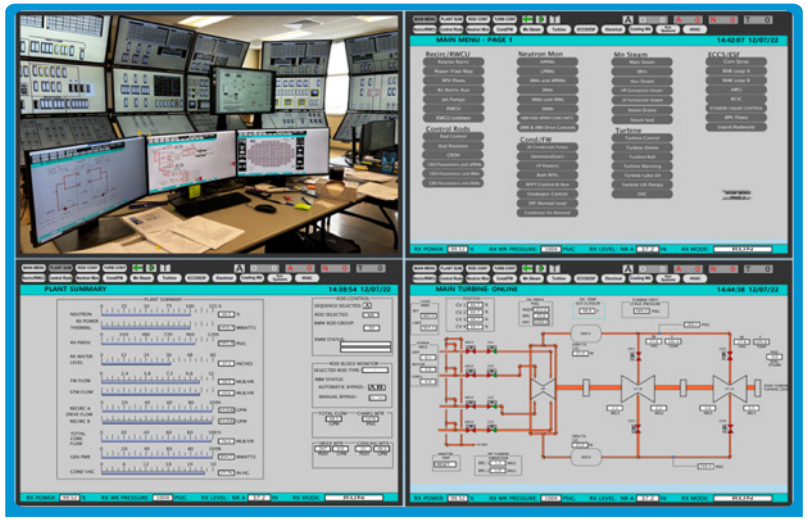
Human System Simulation Laboratory *v2* (2021)

a more reconfigurable,
new capacitive touch 4k displays

How do we use the simulator for Human Factors?

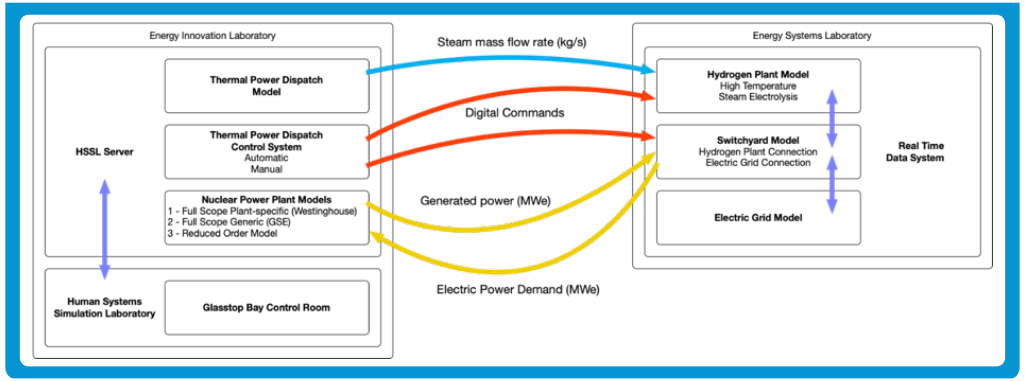
Simulation Capabilities

- **GSE Generic Pressurized Water Reactor (GPWR) training simulator**
- **GSE GBWR training simulator**
- **Westinghouse Three-Loop PWR (W3LPWR)**
  - Developed through collaboration with Westinghouse Electric Company
  - Established A/E Firm Industrial Grade Control System
  - Serves as a reference plant simulator
- Co-simulations with human operator-in-the-Loop (HOIL) and hardware-in-the-loop (HIL) testing
  - *Data connection between the Human Systems Simulation Laboratory (HSSL) and physical equipment in the Energy Systems Laboratory (ESL)*

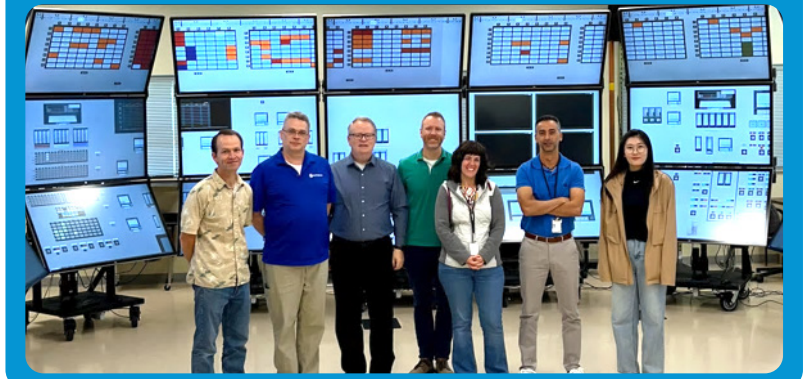


GSE Systems Inc. Modified Boiling Water Reactor in the Human Systems Simulation Laboratory

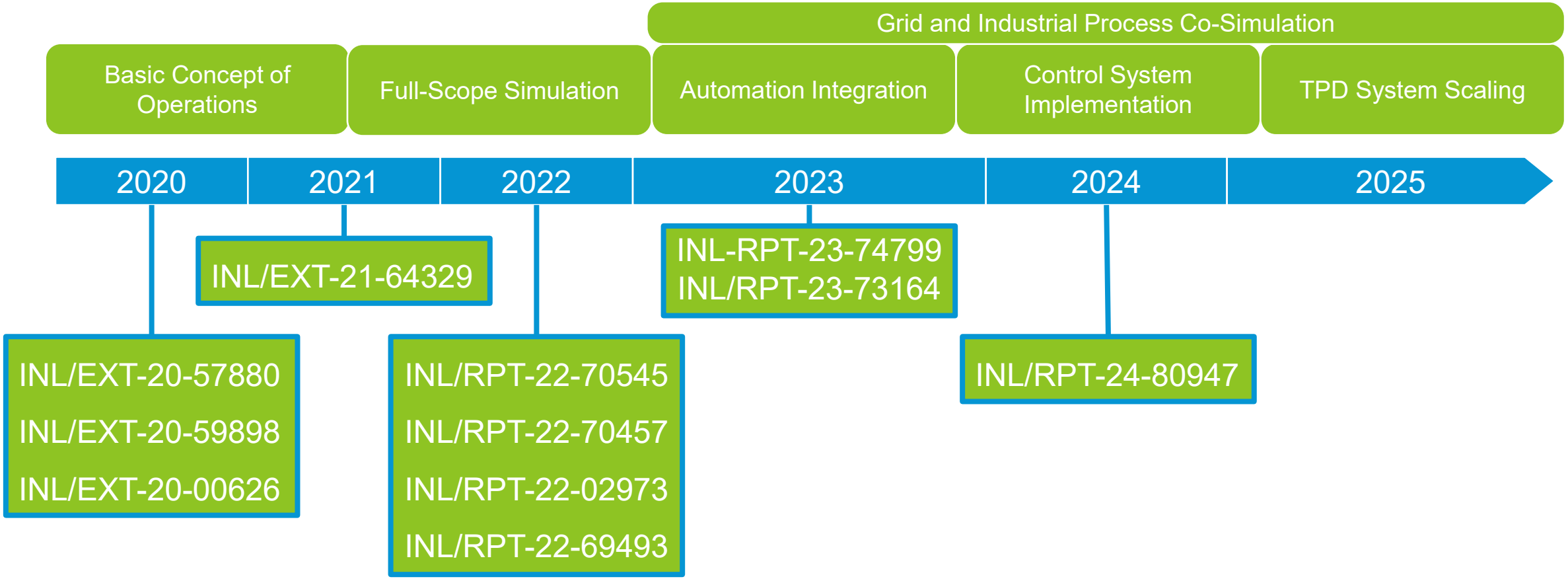
Data connection between the Human Systems Simulation Laboratory (HSSL) and physical equipment in the Energy Systems Laboratory (ESL)



Westinghouse Electric Company Simulator Installation in the Human Systems Simulation Laboratory (August 2023)



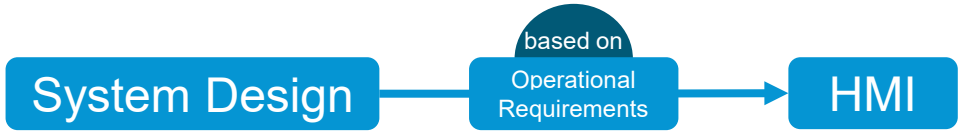
TPD ConOps Project Activities and Timeline

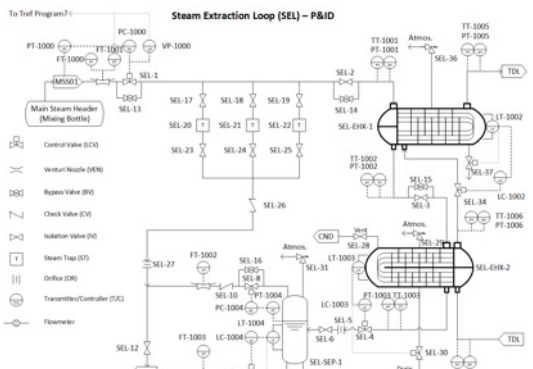


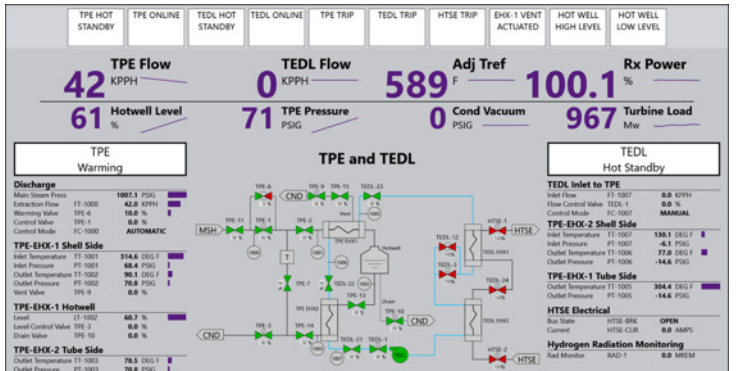
https://lwrs.inl.gov/flexible-plant-operation-and-generation-reports/

Initial Concept of Operations Development

- Prototype Human-machine interface (HMI) developed using in-house prototyping software
  - Preconceptual thermal power dispatch design
    - ***Steam-to-oil*** *single-phase heat exchanger* design supporting up to **15% TPD extraction** from ***main steam header****, oil as secondary delivery line medium*
    - GiiNET API to facilitate communication between HMI and GPWR simulator
- Procedures modified to accommodate responses account for the thermal power dispatch operation
  - Basic workflow for normal operations using a manually configured control system
- Remote operator evaluation of functional prototype using recorded GPWR scenarios



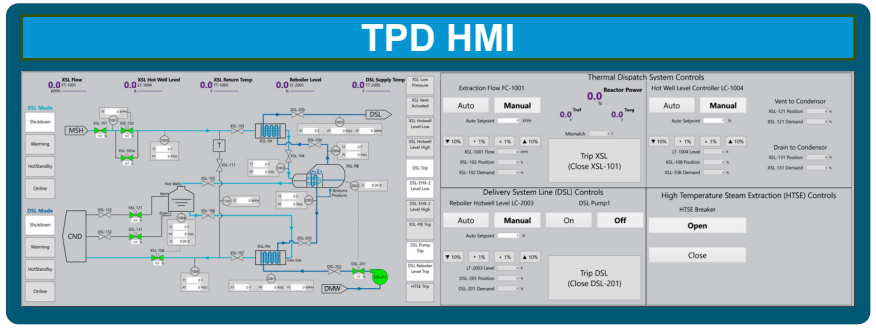




Full-Scope Simulation Testing

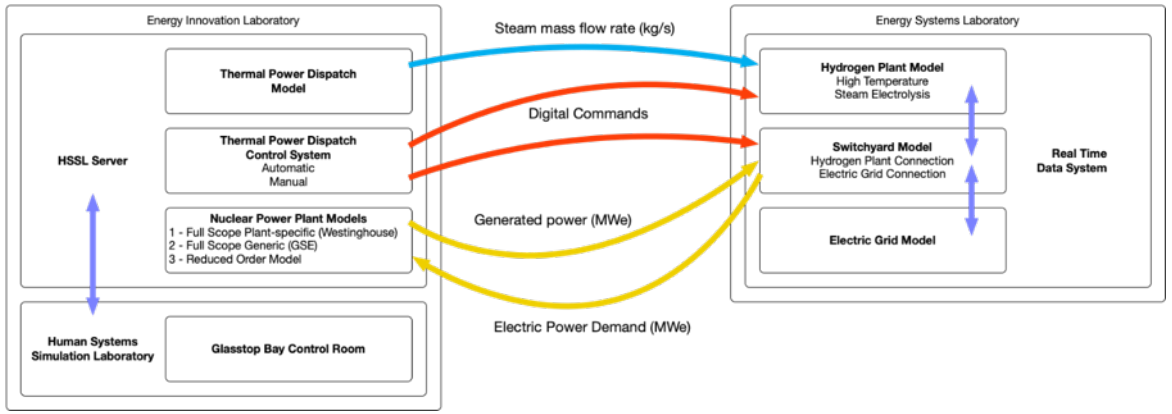
- ***Demonstration of basic concept of operations for safe and reliable TPD operations***
  - Steam-to-steam two-phase heat exchanger design supporting up to 15% steam extraction from main steam header
  - Crew performed scenarios acting as SRO (reader) / RO (doer) roles with mock procedures
  - Basic operating scenarios - routine operations key to system adoption business case
  - Automatic isolation linked with turbine trip signal required to minimize any thermal dispatch impacts (emergency response)
- ***Outcomes***
  - ***Automatic load transfer is a necessity - eliminate the need for additional operator during thermal dispatch evolutions***
    - Manual transfer of steam via turbine load and thermal dispatch load adjustments deemed too workload intensive and time consuming
  - ***Developed a multiyear plan to support integrated testing***
    - Identified need for co-simulation

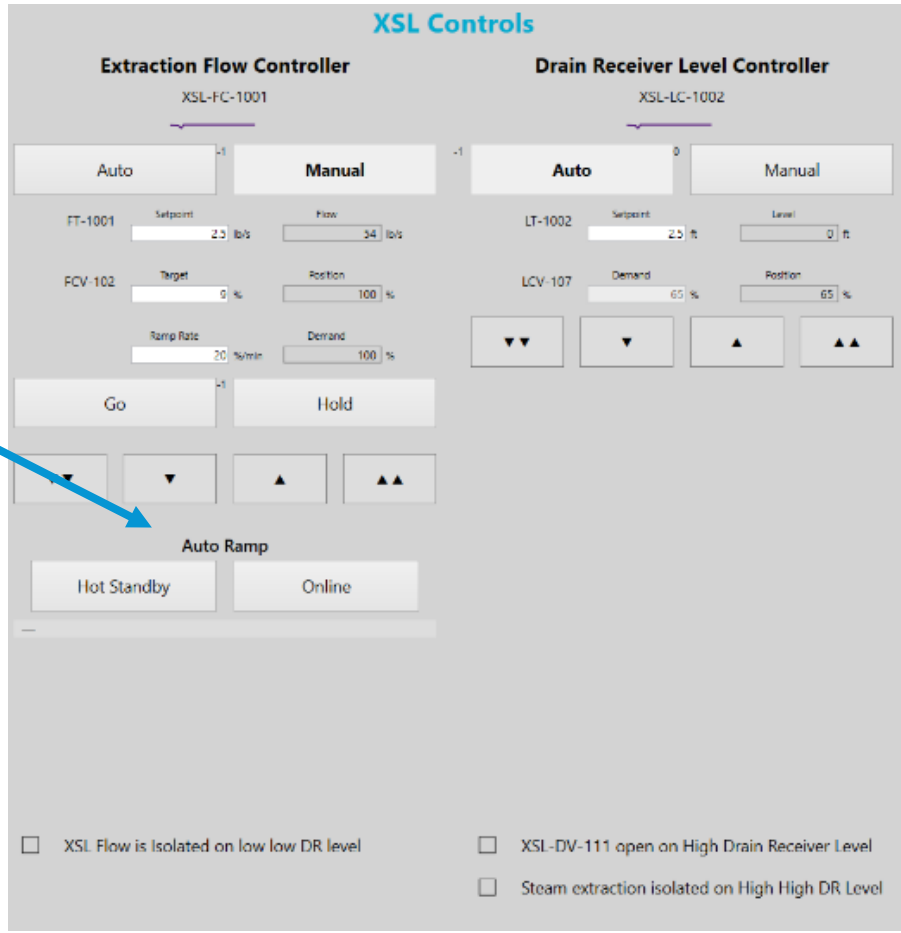
Block	Scenario	Description	Procedure	
1	1	SGTR using GPWR without the TPD in operation	AOP-16, EOP-E-0	Emergency response TPD impacts on existing operations
1	2	SGTR with TPD Failed Manual Trip	AOP-16, EOP-E-0	
1	3	SGTR with TPD Automatic Trip	AOP-16, EOP-E-0	
1	4	SGTR with TPD Manual Trip	AOP-16, EOP-E-0	
2	5	Hot Standby to Online at 5 mw/min ramp	OP-TPD-002	Target 10 min TPD engage/disengage
2	6	Hot Standby to Online at 15 mw/min ramp	OP-TPD-002	
2	7	Online to Hot Standby at 10 mw/min ramp	OP-TPD-003	
2	8	Online to Hot Standby at 20 mw/min ramp	OP-TPD-003	
3	9	TPD steam line leak	No Procedure	Fault diagnosis and response
4	10	Load Rejection GPWR (GV fail close)	AOP-15	
4	11	Load Rejection (GV fail close) with TPD	AOP-15	
4	12	Load Rejection (GV fail close) with TPD	AOP-15	
4	13	Load Rejection GPWR (GV fail close)	AOP-15	
5	14	Hot Standby Failed CV (looks like main steam leak)	OP-TPD-002	
5	15	Hot Standby evolution interrupted with load rejection	OP-TPD-002, AOP-15	



Automatic TPD Ramping – Daily Dispatching

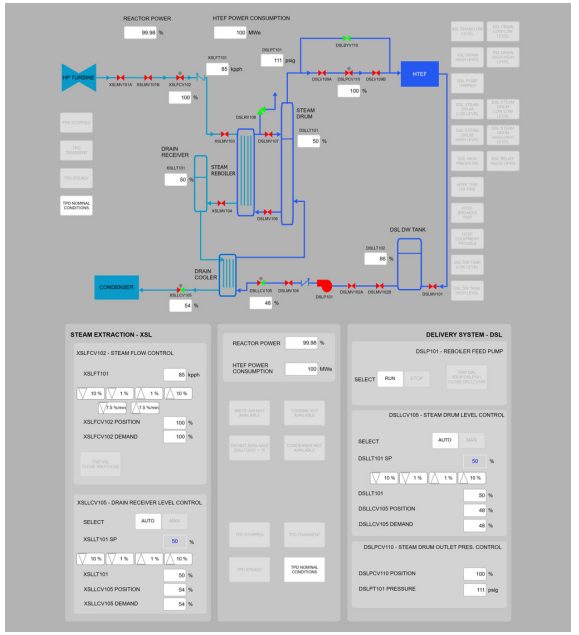
- *Dual Train, Steam-to-steam two-phase heat exchanger* design supporting ~1% thermal extraction ***after the high-pressure turbine***
- **Automatic engage and disengage program**
- **Improved annunciator alarms**
- Procedures revised by operations expert
  - Updated prerequisites and initial conditions to align with DOE Procedure Writers Guide guidelines
- **Deployed a fiber connection between ESL and EIL**
  - Established communication protocol though API between HSSL simulator infrastructure and RTDS
  - Participated as the nuclear power plant for the Superlab 2.0 demonstration

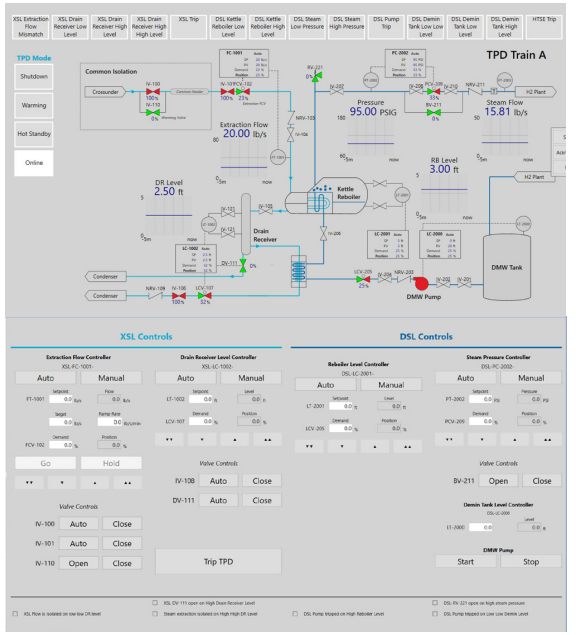




Control System Validation with Higher Fidelity Testing

- Two simulators and two different TPD implementations
  - Based on Sargent and Lundy design with **<1% extraction after the high-pressure turbine**
- **Key Outcomes – No significant safety implications**
  - Small TPD system size and extraction point limited plant impacts beyond what was observed with the 5-15% pre-turbine design
  - Operators reported relatively low TPD system priority system
  - Automatic control system in GSE HMI significantly reduces complexity and attention requirements
  - Successfully diagnosed all faults to specificity afforded by available indication – **key parameter relationships identified**
- **Westinghouse collaboration**
  - Validated operations with A/E Firm Industrial Grade Control System implemented in W3LPWR simulator





WEC W3LPWR	GSE GPWR
Westinghouse proprietary simulator	GSE Solutions more publicly accessible simulator to share results
High fidelity, industry grade turbine control system with reactor control system feedback	Matured INL ANIME HMI design (High performance-like HMI)

Next Steps

- **Integrated Testing Fidelity**
  - No grid induced load rejection capability → Used governor valve or feedwater pump trip
    - Malfunction impacts disrupt testing beyond realistic scenario
  - Better grid models and integration
    - RTDS RSCAD models being developed for ***switchyard, small grid***, and HTEF or ***industrial process***
    - Crucial for FY25 wind and solar emphasis
- **Scale system to support 30-100% Thermal Power Dispatch**
  - Much greater impacts on existing operations
  - Mixed thermal and electric dispatch for multiple industrial users
    - ($^{te}HTEF_{large}$, $^{te}HTEF_{small}$, $^{t}generic$)
  - Control System Interfaces
    - Automatic ramp integrated with *digital* turbine control system
    - Digital procedure (computerized operating procedures)

thomas.ulrich@inl.gov

We are **actively seeking collaboration opportunities** to support thermal power dispatch concept of operations development and deployment strategies.

Sustaining National Nuclear Assets

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