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Light Water Reactor Sustainability Program

Preliminary Human-System Evaluation of Thermal Power Dispatch Concept of Operations

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Preliminary Human System Evaluation of Thermal Power Dispatch Concept of Operations

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EXECUTIVE SUMMARY

An initial thermal power dispatch concept of operations was evaluated to demonstrate and acquire lessons learned for coupling a nuclear power plant to a nearby hydrogen production plant. The project was sponsored by the Department of Energy's Light Water Reactor Sustainability (LWRS) Program under the Flexible Plant Operations and Generation (PFOG) Pathway. To perform the evaluation, GSE's generic pressurized water reactor (GPWR) full-scope simulator was modified by adding models for thermal power extraction from the main steam line and for delivering thermal power to an industrial heat user. The modified simulator is referred to as the Thermal Power Dispatch (TDP) GPWR Simulator. Procedures were developed for basic operating scenarios, which include evolutions to move from a Shutdown state to a Hot Standby state, from Hot Standby to an Online state, from Online to Hot Standby, and from Hot Standby to Shutdown. A prototype human-system interface (HSI) was developed to interact with the model and allow operators to execute the procedures to test the system running through basic operating conditions.

Four operators were recruited to perform the evaluation. Due to COVID-19 travel restrictions, and to maintain prudent safety precautions, the original in-person experimental design was restructured to support a remote operator evaluation. The remote operator evaluation was performed using a web meeting platform that supported screen control to allow the operators to take control and interact with the prototype HSI. Procedures for each of the four scenarios were provided to the operators in preparation for the study.

Due to the remote format and the technical limitations of the web meeting platform, running the prototype in tandem with a live GPWR simulation was not feasible. Instead, data were recorded from the Thermal Power Dispatch GPWR Simulator to provide system status and response at key points during the operating procedures for each scenario. The prototype HSI was then used to play recordings for the operators in tandem with the operators' walking through the procedures. The data were organized in timepoint snapshots, and the interface itself was functional in the sense that it supported navigation, provided updated values for each timepoint, and supported control interactions. However, the simulation was not live; therefore, the experiment can best be described as a static concept of operations evaluation. Each operator ran through the scenarios individually while performing a think-aloud protocol to narrate their experience and any issues they encountered while completing the procedures. A team of observers with expertise in human factors and nuclear power generation captured operator comments and behaviors.

Several significant outcomes stemmed from this evaluation of the system, HSI, and procedures. First, the evaluation indicated that this initial concept of operations is feasible for the preliminary design of the integrated energy system. The evaluation provided positive support for the initial concept of operations in that the operators reported they were comfortable with the system and could manage it without adverse impacts on reactor power in order to ensure plant safety and prevent equipment damage. There were a number of issues identified, and these will be addressed moving forward.

The HSI issues with clear solutions and consensus concerning those issues were implemented post-study and summarized in Section 3. A few of the updates

are mentioned here. The thermal power extraction line and thermal power delivery loop mode indicators were changed to show four separate indicators for Shutdown, Warming, Hot Standby, and Online. Only one indicator is illuminated to denote the mode. This scheme was much more salient than the text change used in the study (see Figure 27). Bar graphs indicating key parameters were removed because they were reported to be unhelpful. Removing the bar graphs resulted in a cleaner interface that made it easier to extract individual values from the data tables. The orientation and flow paths for the TPE-EHX-1 and TPE-EHX-2 heat exchangers were corrected. In the control display, controllers were updated to use a red and green color scheme. Values that had been entered, but not yet accepted by the system, are now shown in red. After the system accepts the values, the color of the values changes to green (see Figure 28).

Future efforts will expand on the basic suite of scenarios evaluated in this work to include abnormal, emergency, and maintenance activities. Furthermore, future work will begin coupling the simulations to physical test platforms to perform integrated human-in-loop and hardware-in-loop testing.

ACCOMPLISHMENTS

The following accomplishments were a result of the work described in this report:

1. A full-scope generic pressurized water reactor (PWR) simulator was modified to incorporate thermal power extraction
2. A prototype human-system interface was developed for the Thermal Dispatch Full-Scope Generic Pressurized Water Reactor Simulator
3. Mock procedures were written for four basic operating scenarios that captured processes to warm the thermal power dispatch systems and initiate system operation to extract thermal power for 5% thermal load
4. A preliminary proof of concept evaluation was performed for the Thermal Dispatch Full-Scope Generic Pressurized Water Reactor Simulator, the prototype human-system interface, and the mock procedures

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ACRONYMS

AOP	Abnormal Operating Procedure
APP	Annunciator Panel Procedure
DBA	Design Basis Accidents
DOE	Department of Energy
EOP	Emergency Operating Procedure
EPRI	Electric Power Research Institute
GP	General Procedure
GPWR	Generic Pressurized Water Reactor
HF	Human Factors
HSI	Human-System Interface
HSSL	Human Systems Simulation Laboratory
HTSE	High Temperature Steam Electrolysis
IES	Integrated Energy Systems
INL	Idaho National Laboratory
LWR	Light Water Reactor
LWRS	Light Water Reactor Sustainability
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
ONE	Office of Nuclear Energy
OP	Operating Procedure
OPT	Operations Periodic Test
P&ID	Piping and Instrumentation
PWR	Pressurized Water Reactor
R&D	Research & Development
TPD	Thermal Power Delivery
TEDL	Thermal Energy Delivery Loop; synonymous with TPD loop
TPD	Thermal Power Dispatch
TPE	Thermal Power Extraction
V&V	Validation & Verification

PRELIMINARY HUMAN SYSTEM EVALUATION OF THERMAL POWER DISPATCH CONCEPT OF OPERATIONS

1 INTRODUCTION

The LWRS Program is developing and testing nuclear power plant (NPP) simulators that include dispatching thermal and electric power to specific industrial processes, such as high temperature electrolysis for green hydrogen generation. With electricity grid operations undergoing rapid and far-reaching changes, NPP owners and utility companies need to understand the technical, operational, and human factors requirements for plant operations that involve varying energy output between electricity production for the grid and directly providing both thermal and electrical energy directly to an industrial partner. For example, the NPP could apportion electricity between the grid and an electrolysis plant that produces hydrogen or a water desalination plant that produces fresh water.

Due to market rules and conditions that favor power from wind and solar energy and natural gas power plants, NPPs in some regions may no longer be able to operate purely as baseload plants. Instead, they may need to dispatch power to the grid to make up the difference between grid demand and electricity provided by other sources, including intermittent renewable energy. With flexible operation and generation, nuclear power plants may distribute energy to an industrial process in a dynamic manner that optimizes the revenue of NPP owners. Studies have shown NPPs can competitively provide the energy required to produce hydrogen and other valuable chemical products (Boardman et al. 2019) (LWRS Program Plan 2020). Many NPPs could be used in this way, which would yield a more advantageous market and revenue position for utilities employed in this market (LWRS Program Plan 2020).

NPP simulators that include dispatching thermal and electric power to these industrial processes provide key information to stakeholders. These NPP simulators provide technical, operational, and human factors requirements that are needed to estimate the performance of the integrated system as well as the associated installation and operating costs, and potential revenues. These simulators are also valuable for addressing safety concerns that are needed for nuclear operating licensing amendments. In 2020, the LWRS Program modified a full-scope generic pressurized water reactor (GPWR) simulator from GSE Systems (Sykesville, MD) to include thermal power extraction and delivery to an industrial user (Hancock, Shigrekar, and Westover 2020). The boundary limits of the thermal power extraction simulator are shown by the dashed line in **Error! Reference source not found.**. The simulation includes: (1) a thermal power extraction (TPE) line that extracts steam from the main steam line and passes the steam through extraction heat exchangers before returning the steam to the condenser and (2) a thermal power delivery (TPD) loop that circulates synthetic heat transfer oil between the extraction heat exchangers and a set of heat exchangers at the site of the industrial user, which may be as far as one kilometer from the NPP. Rigorously simulating the modifications needed for electric power switching at the NPP switchyard and also simulating the complex dynamic behavior of the industrial user will be pursued in 2021.

A prototype human-system interface (HSI) was developed for the modified thermal power dispatch simulator, and mock procedures were written for startup, management, and shutdown of the dispatch of thermal and electric power to the hydrogen generation plant. Four former licensed NPP operators participated in operator evaluation of the modified thermal power dispatch simulator, the prototype HSI, and the mock procedures. The operators were able to successfully complete the operator scenarios, which involved executing the procedures related to the thermal power dispatch and simplified electric power dispatch described above. The success of the tests confirmed the validity of the approach for the prototype thermal power dispatch design and identified areas for future research and improvements. For example, incorporation of electric power dispatch and the dynamic behavior of the industrial user in future simulators will enable more precise identification of technical and operating limitations as well as specific engineering and human factors needs. Coupling future simplified simulators to physical hardware during operator tests will assist in identifying hardware requirements to address issues associated with human factors, automated controls, and cybersecurity vulnerabilities. This report documents efforts at Idaho National Laboratory (INL) to perform an evaluation of the thermal power extraction (TPE) line design, the thermal power delivery (TPD) loop system design,[a] and a human-system interface (HSI), collectively forming an initial concept of operations for dispatching thermal and electric power.

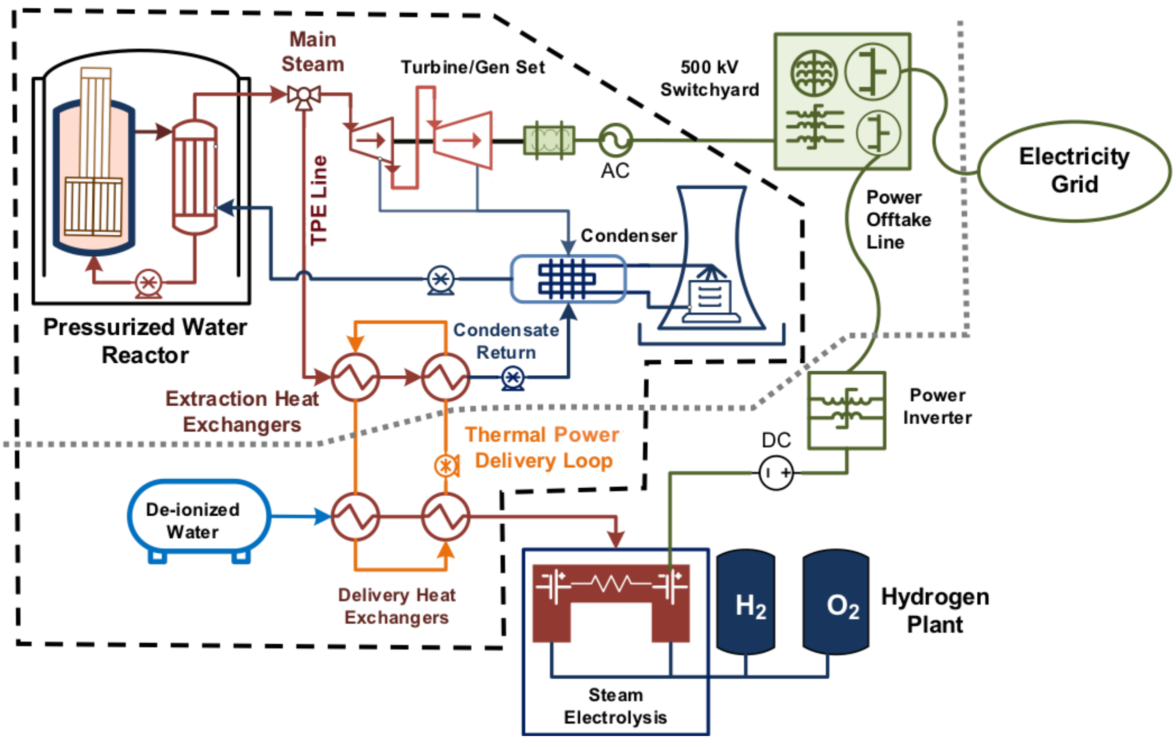

Figure 1. Boundary limits of the thermal power dispatch GPWR simulator (black dashed line) and site boundary of the nuclear power plant (grey dotted line).

An additional comment is that the Covid-19 pandemic created a particular challenge for the originally proposed work. The interface evaluation was originally planned to take place in the Human Systems Simulation Laboratory (HSSL) located at the INL. The HSSL is a full-scale, full-scope, simulator capable of virtually representing existing NPP main control rooms. The HSSL can represent any NPP control room that is able to provide the underlying system models and visual representations of the control boards. The original plan entailed using the modified GPWR simulator coupled with the prototype HSI in the HSSL. Due to the Covid-19 travel restrictions, the project was unable to host the operators at the HSSL to perform the study. As a result, the human factors research team put together a contingency comprised of a reduced scale study that could be performed remotely through a web meeting platform that is described below.

[a] During the operator tests, the TPD loop was referred to as the thermal energy delivery loop (TEDL) in the HSI and in the operating procedures. Consequently, in this report TEDL and TPD loop are synonyms.

2 HUMAN-SYSTEM INTERFACE DESIGN

This effort builds on the previous iterations of an HSI design for the dispatch of thermal and electric power operations. The design presented here demonstrates some key design choices made by the human factors team that sought to foresee potential operator needs and minimize the cognitive workload. Informed by past digital design efforts (Ulrich et al. 2014), the team developed a dull screen, flat display design with a piping and instrumentation diagram (P&ID) mimic and coordinated data tables for access of granular system information. The operators were given the option to select between several displays: a supervisory overview, controls, and isolation valve controls. In a traditional simulator study, these would have likely been displayed across separate displays, but some remote restrictions, which are described in more detail in subsequent sections, required a single screen instance and, therefore, a navigable set of displays to execute tasks.

User interface elements were modified from the standard set of icons present in the ANIME framework (Boring et al. 2017) and previous work in designing digital control system interfaces. Control actions and system behavior were informed by system engineering of a hypothetical thermal power extraction system and its impact on a generic NPP. A unique characteristic of this effort is the cooperative tasking between human factors researchers and thermal and electric power dispatch system engineers. Often human factors researchers are brought into a project at a date when the engineering design is solidified and human factors designs are intended to give a skin to the skeleton of the underlying system's design. However, in this project, the teams worked together in an iterative loop to ensure a high level of fidelity for HSI performance and the system characteristics. Additionally, the inclusion of a more diverse group of disciplines was valuable to increase the design quality (Boring et al. 2018).

Last, particular attention was paid to understanding the process control workflows and specific interactions present in the system. Interaction design is always present in HSI display design projects, but for this effort the team focused on how the interaction between the operator and the system would perform. This specific focus is somewhat novel in nuclear or process control designs but lays a foundation for developing systems that can interact with operators in a more intuitive fashion.

2.1 System-Based Human-System Interface Modifications

During this first year of the project, the team was tasked with first developing an initial HSI for the proposed integrated energy system comprised of the TPE line and TPD loop. The efforts to develop the initial prototype are documented in a report released in April titled, "An Integrated Energy Systems Prototype HSI for a Steam Extraction Loop System to Support Joint Electricity Hydrogen Flexible Operation" (Ulrich et al. 2020, INL/EXT-20-57880). The human factors process used to develop the interface is iterative and continued as the system design matured up to the operator testing study performed as part of this year's initial efforts. As such, the HSI was updated as the system design itself changed and was also modified to refine the human factors of the interface. The following sections detail the modifications made to the HSI and reflect the design that was used for the operator testing.

The system design changed after the initial HSI design was completed and, as a result, the HSI required updates to represent the underlying system accurately. The nomenclature used to refer to the different systems also changed during the development to select appropriate three-letter acronyms that are not already in use in nuclear plant systems. One consequence of these changes is that the TPD loop was referred to as the thermal energy delivery loop (TEDL) in the HSI and in the operating procedures during the operator tests. Therefore, for the purposes of this report, TEDL and TPD loop are synonyms.

The second major system design change was more impactful to the HSI design. The heat transfer fluid used in the TPD loop was changed from steam to synthetic oil (see Figure 2). This change was made to simplify the modelling of the heat exchangers for this initial design. Using synthetic oil as the heat transfer fluid also simplifies the design of the integrated system because it avoids phase changes in the TPD loop that greatly complicate operations of pumps and heat exchangers.

Individual system components were also changed in the system design, which resulted in an overall TPE system simplification and eliminated the need to represent several components within the simplified P&ID mimic included on the supervisory display of the HSI. The separation tank and the valves downstream of the tank were removed (see Figure 3). A hot-well tank performing a similar function to allow for condensed steam to accumulate was positioned downstream of the first heat exchanger in the TPE system (Figure 4). The number of steam traps, represented as boxes with a capital "T" designation, in the system was reduced from three to one, which further simplified the P&ID mimic of the TPE system. The original design included bypass valves throughout various parts of the system; however, these were determined to be unnecessary in all cases except for the bypass valve associated with the TPE-1 control valve because this bypass valve is required for TPE warming. The overall simplifications of the P&ID mimic resulting from the removal of these components allowed the design to accommodate also representing the TPD loop system without requiring a separate P&ID mimic. As can be seen in the original display design and the update, the navigation buttons to display the other P&ID mimics were removed, and the right portion of the P&ID mimic now contains portions of the TPD loop.

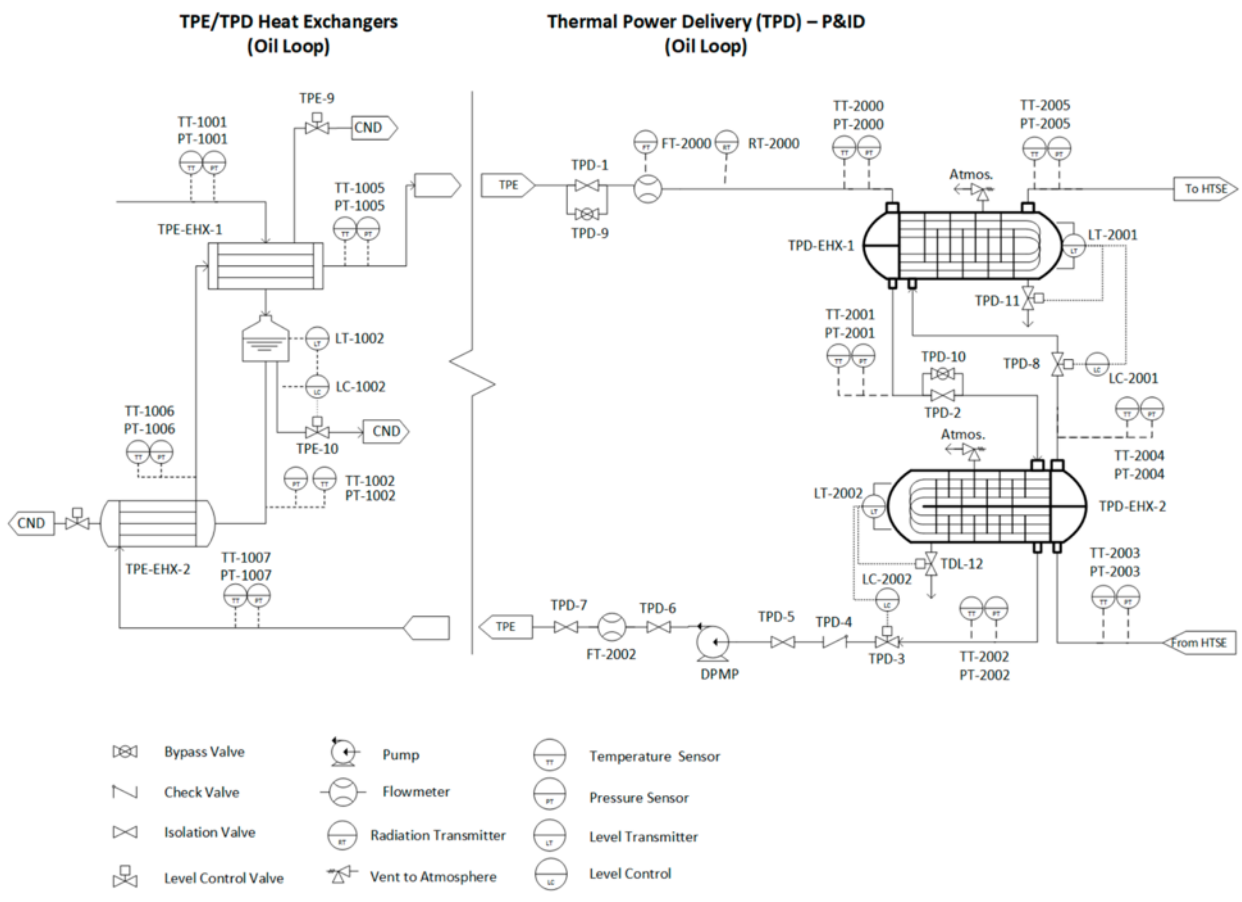

Figure 2. P&ID of the TPD loop with oil as the medium.

As the design of the system matures, it may be necessary to include a separate P&ID for the TPD loop. This initial concept of operations study focuses on the TPE system with less emphasis on the TPD loop. The hydrogen plant was modeled as an ideal heat sink that could immediately remove the intended amount of thermal power. Future research will incorporate a more realistic simulation of the hydrogen plant and will require greater attention to the dynamic response of the TPD loop.

There were some additional modifications made to the HSI control display, which added controllers for all the control valves within the system. These control valves not only regulate fluid flow rates throughout the system, but they also control the fluid level in the heat exchangers. The initial design included an automatic startup sequence that would allow the operator to push a button that would warm up the TPE without requiring manual valve manipulations (see Figure 5). For this initial concept of operations evaluation, the operators preferred to manually control the process. Consequently, it was decided that the automated controls would be tested and refined in future work. The updated HSI without automatic startup capability is shown in Figure 6. The separation tank positioned after EHX-2 was replaced with a hot well, and the controller terminology was updated on the control display along with the level and drain controller associated with the hot well. The terminology used to identify the controllers was updated to support better interactions and allow the operators to more easily link the controllers from the supervisory display to this control display.

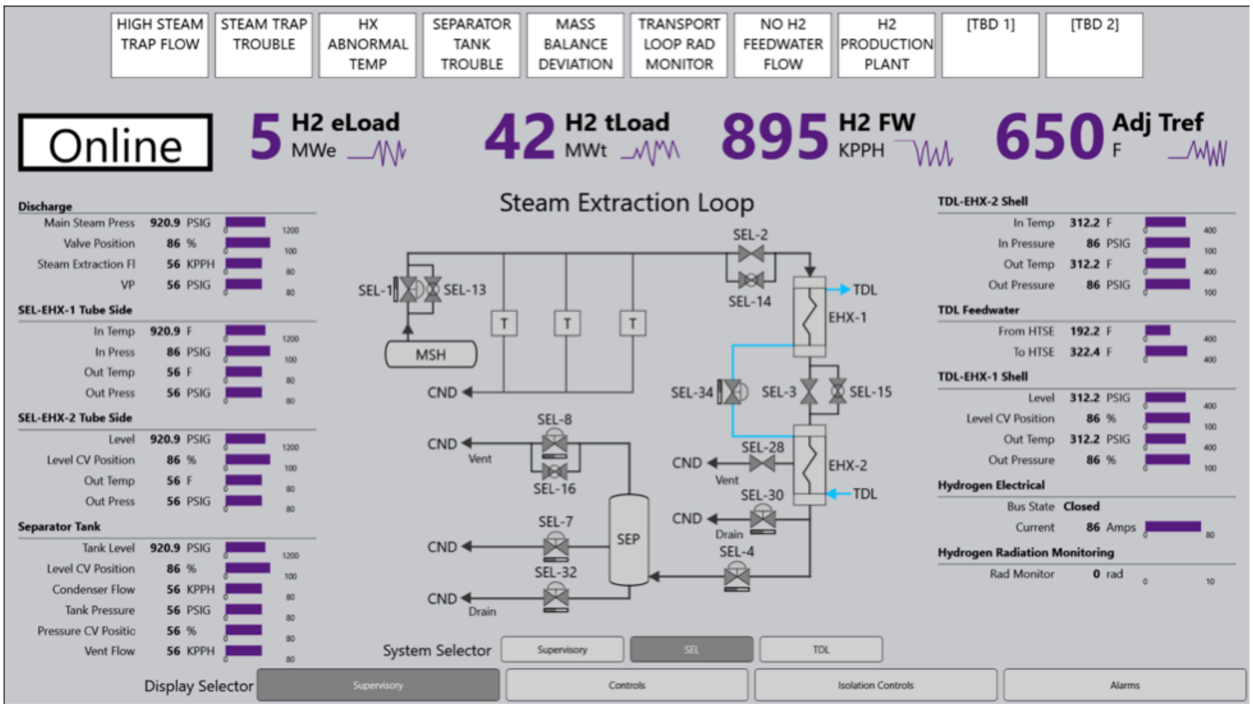

Figure 3. Initial HSI supervisory display design for the integrated energy system (IES) that represented the starting point for the human factors work documented in this report.

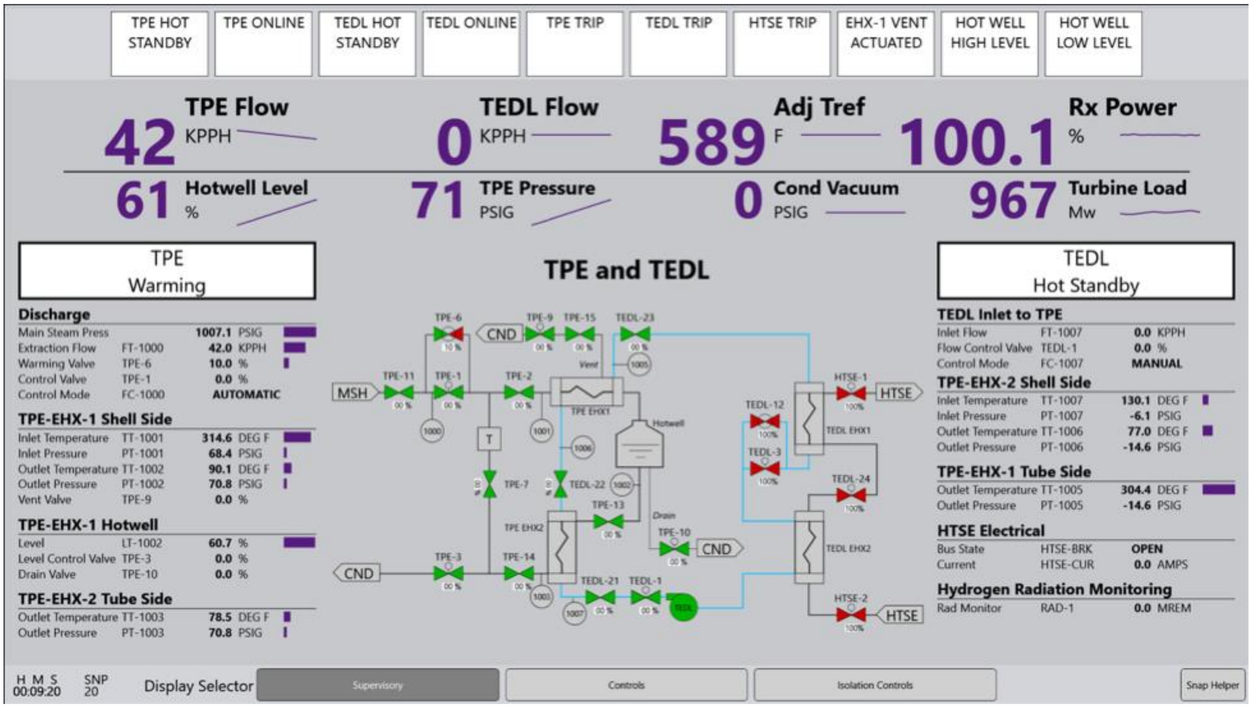

Figure 4. The updated HSI design used for the operator testing.

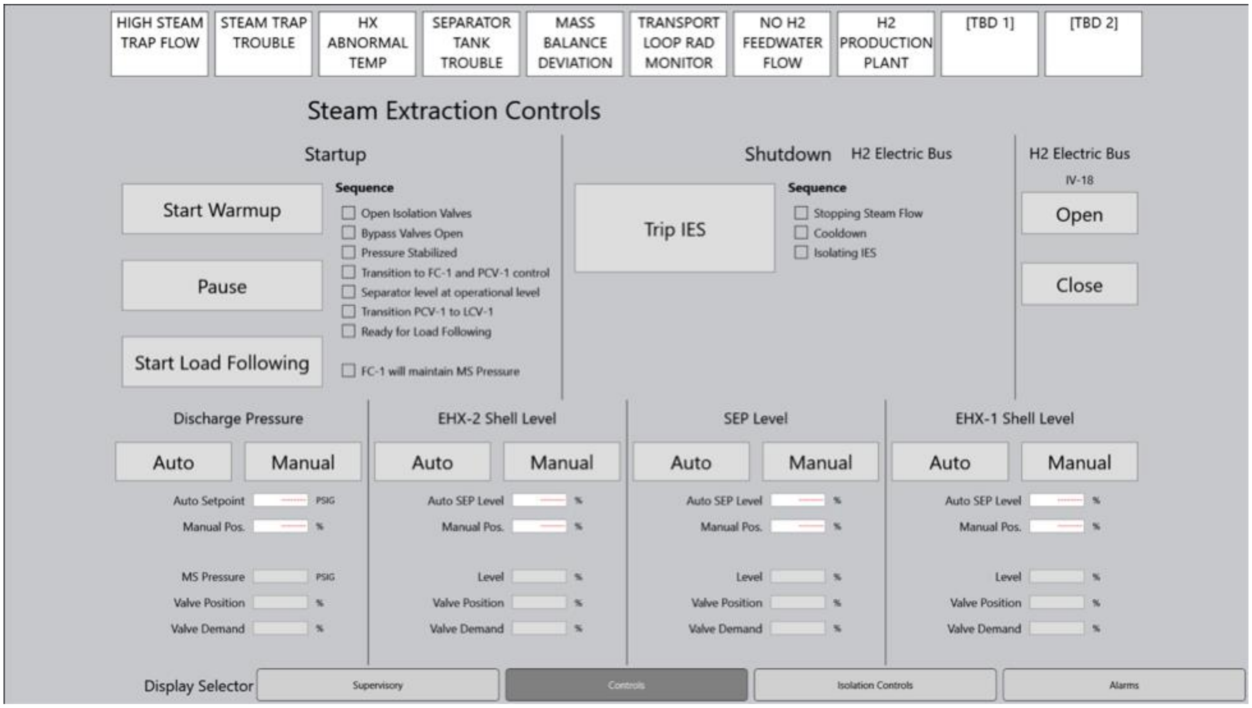

Figure 5. Initial HSI control display design for the IES system that represented the starting point for the human factors work documented in this report.

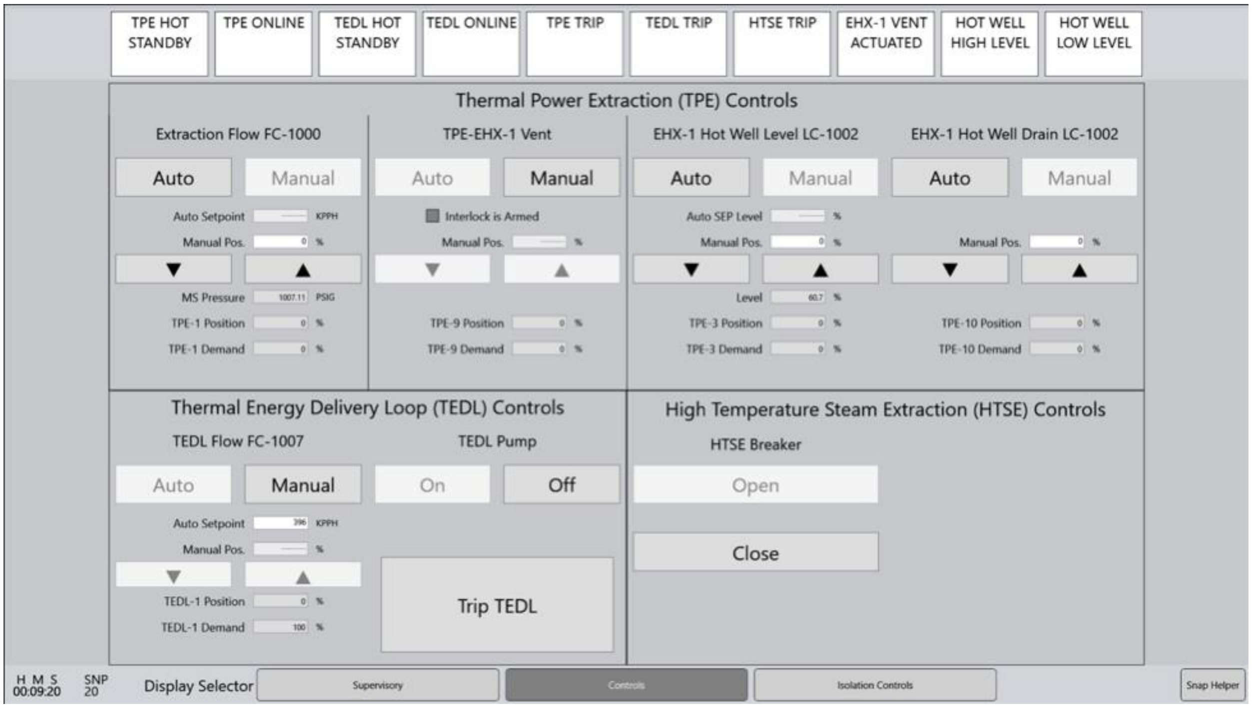

Figure 6. The updated HSI control display design used for the operator testing.

2.1.1 Display Interaction Modifications

In addition to the updates required to accurately reflect the system design, a number of HSI display elements were updated to improve the human factors of the initial design. In particular, the display elements governing the interactions between the operator and the HSI were the focus of the efforts to refine the design. This task was performed according to standard practice heuristics evaluations, in which an expert reviewer compares displays and systems against a defined standard, such as NUREG-0700 (O'Hara, 2020). As no defined interaction characteristics exist, save for general guidelines and recommendations in NUREG-0700, a documented and analytical approach was taken to vet the mock procedures against the displays. By using the mock procedures, the usability evaluation of the HSI displays was based on specific tasking provided to the operators through the procedures.

2.1.2 Workflow Assessment of Procedure and Displays

For the workflow assessment, a member of the human factors team attempted to complete each of the mock procedures that would be used by the operators in the actual study. The primary metric used to evaluate the display in this context was that the procedure steps be straightforward and simple to complete to maximize the accuracy of the actions with minimal cognitive workload for the operator. This approach, in which members of the human factors team internally tested the mock procedures, identified and corrected many issues prior to the final study with the licensed operators.

An additional component evaluated as part of this task was how the interactions between the user and the system performed. As stated, this project sought to highlight specific interaction design characteristics and ensure that the resulting design was intuitive and usable by operators. On this point, some interaction problems were highlighted, and design recommendations were issued. At this early stage, the system displays are not dynamic, so in many cases, potential interactions were absent. However, the walkthrough of these procedures also gave the team their first look at what the workflows for this system may look like and served to refine both the procedures and the HSI for the study.

2.2 Interaction Design in Process Control

Interaction design as a specific step in design tasking has not been a principal focus in analog process control, largely due to the relatively low numbers of possible interactions in many analog systems. Due to the analog nature of many process control systems, especially in the nuclear industry, there has not been much need to focus on interactions exclusively. While the systems present in these analog control rooms are highly complex as an integrated piece, the specific user controls and interaction vectors are minimal. Consider a switch, for example: it can be on or off. The complexity may arrive as a large number of switches are present, but the reality of these binary switches limits the interaction load to a relatively few levels. However, the number of potential interactions within digital designs increases rapidly with increasing complexity of the interface. Consequently, there is a much greater need for interaction design as a separate task for development of digital designs. For example, in digital designs it is more common to use control logic to introduce dependencies between multiple user inputs and the final system response.

In general, interaction design is concerned with behaviors of both the system and operator. A "good" interaction is one in which the behaviors of the users and systems are aligned and function in a sequence of expectations and satisfactory executions. As systems begin to include automation, machine learning, decision support, adaptive alarms, and more, the number of interactions and behaviors increase rapidly, and these systems can interact in ways that can lead to confusion and errors (Cooper et al. 2014).

The proposed method used here is one that views these interactions as a means of communication. Communication design is well-trod territory in nuclear and process control more generally. Three-way communication, plan of the day meetings, procedures, and structured walkdowns are all examples of prescriptive communication mandated across safety critical industries. As systems begin to achieve greater levels of interaction, human factors further improve interface designs to take advantage of new communication paradigms that effectively treat the system as a potential partner in the control room. As an example, a confirmation dialog is a form of three-way communication. The operator tells the system to do something via a button click, the system populates a message asking if the operator wants to undertake said action, and the operator confirms by clicking the affirmative button option. Understanding the operator's mental models of the actual tasking being performed, the steps being taken, and the responses expected are critical components of understanding how to design the interactions between the user and the system.

As the assessment of procedures and displays was performed, the evaluation focused on the informational context surrounding the specific procedure step being undertaken in order to understand the information needed to complete the step, the information present and its alignment with that need, and the operator's methods of reconciling the information with that need. By viewing the task steps as a part of a broader context and attempting to frame these steps within the broader aspects of communication between the system and user, interaction flaws and design options become immediately apparent. Historically, nuclear and process control relied on training, procedures, and other education or direction methods to guide operators through the performance of their task and to control error traps and likelihoods. Again, a limitation of analog systems is that they are relatively inflexible to modification. However, as digital systems are deployed, there are opportunities to improve intuitive interaction with the HSI. Digital systems can minimize error by being intuitive and support good communication and teaming with the systems.

2.2.1 Interaction Design Measures

Similar to general usability testing, when focusing on interaction design there are a large number of different measures and methods that can be employed by human factors practitioners in assessing the effectiveness of the interactions. For this study, several measures were initially planned. Potential interaction and usability measures are listed below:

1. Error/success rate

Error and success in a task are immediate identifiers of a design's effectiveness. When observing tasking during a study, it is important to use qualitative feedback from participants and map the path the user takes through the system. A well designed system should provide signposts, and navigation should be intuitive.

2. Time to completion

   Human factors designers can run through tasks to determine the standard time to completion for the primary tasks that will be measured. Users should have slower times than system engineers or system designers because familiarity with the system and HSI is much lower. However, large deviations are indicative of a design issue for the user as they execute the task. Additionally, as with error rates, it is important to note the path the participants take and identify flaws with the interactions present in the system. The displays should seamlessly communicate and guide the users through the requisite task.

3. Lost user/operator

   Users are lost when they are not sure how to progress in the task. This can be identified via observation of a user's not taking an action for an amount of time, or a user's directly statement of a lack of surety as to what to do next. The design of the workflow and relationships of the interface elements should always signpost eligible actions, and the system should be intuitive in a way that enables the next step. A lost state can be stem from a learnability problem in more complex systems, but a well designed interaction scheme should flatten any learning curve and communicate what tasks should be taken next.

4. Qualitative feedback of task

   Due to the intangible and inaccessible realities of cognitive actions and decision making, a robust and consistent debrief will help give context to the quantitative measures collected during testing. Understanding the error rate has value, but does not prescribe corrective actions to design teams. Only a thorough qualitative debrief can help develop the next steps and areas for improvement of the design for the operators. Each usability method should be coupled with a qualitative manner of knowledge elicitation so context is always available (Ulrich et al. 2018). Qualitative feedback provides the most tangible results that lead to meaningful improvements in the HSI display. By contrast, the error/success rate and time to completion provide quantitative metrics to rate the HSI, but do not readily provide tangible solutions to resolve issues.

5. False landings (erroneous destinations)

   False landings can be identified as instances in which a user enters a section of the interface and, prior to taking any actions or monitoring any value, immediately exits that section. This metric serves to grade the design's navigation, signposting, and directionality. A well-designed system should minimize false landings as much as possible through consistent information architecture and navigational research tasks. False landings can be one of the more frustrating user experiences in dealing with a digital system. They also interrupt the standard cognitive and decision-making process that a user undertakes and cause a feeling of being lost.

6. False starts (erroneous first actions)

   False starts are more difficult to detect in many instances. Tasking rarely will have an error on the first step taken, due to the malleability of digital displays and the presence of multiple ways to complete a task. However, in some instances, initial deviations from the prior "optimal mapping" completed by human factors personnel can be a preceding condition to an error. It is important to capture these issues. A user undertakes specific cognitive actions to initiate a task. Understanding the specific process that the participant undertook to complete the task can give insight into the signposting of the display at an initial position and ensure that navigation is structured in a way to enable success from the beginning.

3 STATIC SIMULATOR DYNAMIC INTERFACE EVALUATION BY OPERATORS

The operators were presented with a static simulator that was not running a live simulation model. Instead individual timepoints were recorded and played back to the operators while pausing at key points to allow them to execute procedure steps. The interface itself was dynamic and had full functionality that would be present if it were connected to a running simulator model. For example, the operator could navigate throughout the HSI and manipulate controls. The values portrayed within the HSI corresponded to actual simulator states, but any manipulations made by the operators would not affect any change to subsequent system states because the data itself was a static snapshot from a given moment. After completing a procedure step, the timepoint displayed within the HSI would be advanced, and then the operators could see the feedback for the intended actions following the correct execution of the procedures. Thus, if the operators made an error while executing a procedure, the observer acting as the trainer would stop the procedure, inform the operator of the error, and ask for a repetition of the step so that it was correctly performed. In this manner, operators were locked within a set path towards executing the procedure; in a dynamic simulation, incorrect actions would move the plant toward undesirable actions and could lead the operators toward different paths with varying levels of success or failure. The approach used has limitations, but proved useful in identifying issues with the concept of operations and does have a precedent in nuclear studies.

3.1 Generic Pressurized Water Reactor Simulator

The GSE GPWR simulator uses a model developed from an existing NPP and visually represents digital versions of the analog control boards. A fundamental aspect of this work entailed modifying the GPWR code by adding the TPE line and TPD loop, such that steam is extracted from the main steam header, thermal power is removed, and then liquid is returned to the main condenser. A detailed description of this process can be found in a related report released in June, titled “Incorporation of Thermal Hydraulic Models for Thermal Power Dispatch into a PWR Power Plant Simulator” (Hancock, Shigrekar, and Westover 2020). The GPWR simulator version used for this study contained the original GPWR code in addition to the TPE line and TPD loop systems. The modelling effort represents the initial thermal model and is not intended to be an end state model of the proposed system. Therefore, the nuclear engineer who built the model focused on capturing the critical aspect of reactor power feedback during dispatch of thermal and electrical power.

3.2 COVID-19 Considerations and Contingencies

As noted in Section 1, the interface evaluation was originally planned to take place in the Human Systems Simulation Laboratory (HSSL) located at INL. However, due to COVID-19 travel restrictions, the project was unable to host the operators at INL’s facility, so that it was necessary to remotely perform a reduced-scale study through a web-meeting platform. To the best of the author’s knowledge, this is the first entirely remote nuclear operator usability study. This research tread new ground and forced the team to derive new techniques to capture the human factors input required to assess the concept of operations for the thermal and electric power dispatching processes, which address human factors issues concerning the system itself, the procedures, and the HSI.

3.2.1 Remote Usability Characteristics

A number of unique characteristics were associated with the remote usability nature of the operator study. The research team has previously performed operator-in-the-loop studies, but int the subsections immediately following, we describe how this unique remote usability study differed from typical full-scale control room studies performed in the past.

3.2.1.1 Limited simulator scale

Because operators were not able to physically perform the scenarios within the HSSL, it was not possible to represent the control room in a full-scale form. Within analog control rooms, each indicator is ever present, which allows operators to adjust their gaze and, often, to walk to the board to check a value. There simply is no feasible way to represent the control room in its entirety over a web meeting in a manner that is usable to the operators. The GPWR simulator does, in fact, have a view in which the operator can scroll through the control room panels, but this is cumbersome and still requires a large display region to show even a single control board with sufficient resolution for the operators to be able to discern values. Indeed, one of the driving impetuses for the physical bay arrangement of the HSSL was to expand upon the single three-display trainer bay unit in a way that allows the entire control room to be displayed without requiring the operator to move the view of the simulator. The scenarios for this study could be completed without the use of the HSSL simulator only by having one of the researchers, acting as the simulator trainer, provide general plant parameter information when requested by the operators.

Beyond not being able to display the analog control boards, potential issues with the presentation of the prototype and accompanying procedures were also considered. Operators were remotely connected to the prototype his; therefore, the research team did not have experimental control over the operator’s computer hardware. For this reason, research team could not dictate how the operators displayed the prototype HSI and the procedures. To ensure visibility of the prototype, the operators were advised to print the procedures so that they could dedicate their display to the prototype while still being able to access the procedures as they performed the scenarios. Each operator reported that hard copies of the procedures were used during the tests, allowing for reasonable resolution of the HSI.

3.2.1.2 Recorded simulator data

Because the three-panel bays of the HSSL were not available for the tests, and due to potential technical issues associated with running a live simulator and prototype HSI over a remote connection, it was decided not to attempt to use the GPWR as a live simulator as we typically did in prior operator-in-the-loop studies (Ulrich et al. 2017). Instead, we developed an alternative approach in which we prerecorded the data from the modified GPWR simulation, including the TPE and TPD loop systems being used to execute the procedures. To create the recordings, we used one of the internal GPWR data logging tools, capable of recording multiple simulation points at a rate of 20 Hz. At this data logging rate, the scenario recordings yielded thousands of comprehensive timestep data snapshots, which in the nuclear simulator arena are referred to as “snaps.” Due to the high frequency of the snaps, many show from miniscule to no change across the majority of parameters. To extract snaps with meaningful change, a custom Python script was created to comb through the snaps and include a snap in the scenario recording only when at least one parameter exceeded a 3% value-change threshold. The prototype HSI was then configured to consume the data snaps to update all indication and controls based on each parameter within the snap file. This reduced the number of snaps for each scenario to roughly 40, with the exception of one that spanned several hours and contained approximately 580 snaps. Reducing this number to the minimum needed was advantageous because the operators were given control of the snaps such that they could move forward in time as they progressed through the procedures. Without this approach, the operators would have been forced step through thousands of miniscule changes that would have been tedious and provided little insight into an evaluation of the concept of operations. Operators controlled the snaps through additional controls embedded within the prototype HSI, which are described in the following section on modifications made to the prototype HSI to support a remote study.

3.2.1.3 Remote usability prototype HSI adaptations

In typical operator-in-the-loop experiments, the prototype is solely used for its process control purposes within the nuclear simulation. Due to this remote format, the simulator required a few modifications to support the ability to present the GPWR prerecorded data and to advance or regress through the timepoint snaps. This approach allowed the operator to move through the time sequence of the simulation and directly observe the system response represented by the prototype HSI. To support this capability, the prototype was modified to load a series of data files containing the parameter values and historical trending data for each of the simulation points. We then created a small graphical user interface (GUI) to allow the observer, acting as trainer, and the operator performing the scenario to change the timepoint of data portrayed within the HSI display (see Figure 7). This tool provided the ability to advance to the next snap as well as to advance ten snaps to provide a fast-forward feature. The fast-forward feature was really only used in the first scenario because the cold shutdown to hot standby scenario contained approximately 580 snaps to account for the several-hour period that is required for the warmup to take place.

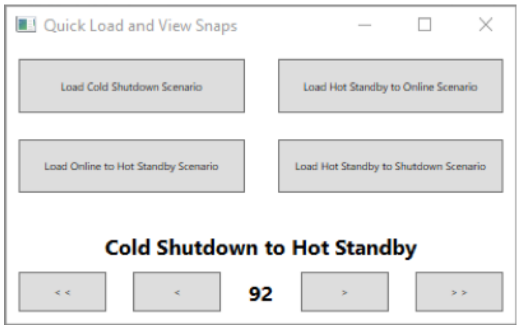

Figure 7. Snap tool created to allow the operators and the observer acting as the trainer to load each of the four scenarios and navigate through the data to update the display.

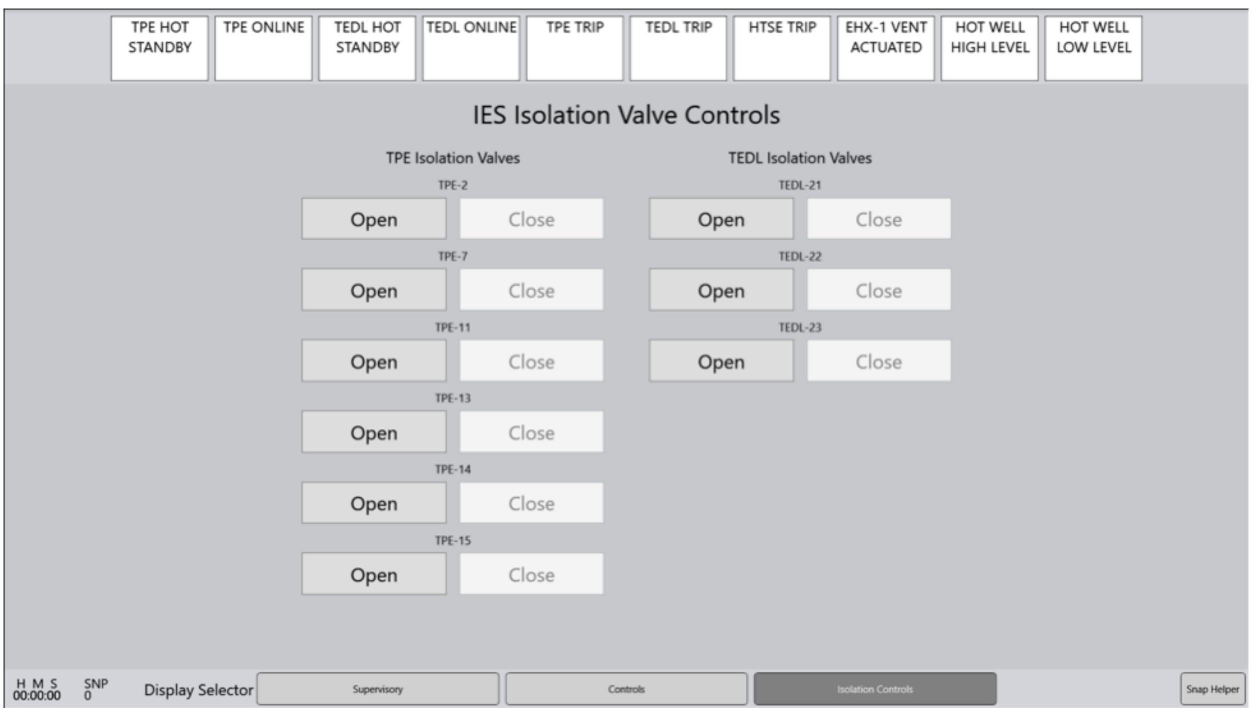

Figure 8. HSI display of the isolation valve controls. The isolation valves are envisioned to be manual, but this display ensured operators considered how a field operator would manipulate the valves when dispatched to do so by the operators in the main control room.

The model built within GPWR was pragmatic in that it represented only those components needed to test the simulation; therefore, many components were not modelled in the simulation itself. The prototype HSI was used to emulate these additional components. Most notably, the high temperature steam electrolysis (HTSE) breaker and isolation valves were included in the HSI, but not included in the model.

The model only uses a dummy load to represent the HTSE process. No breaker is currently implemented. When in their proper operating configuration, the isolation valves impose negligible impact on the simulation; thus, they were not included. To evaluate the concept of operations, it is still important to include these components to understand how they would be monitored and manipulated by the operators. In the case of the isolation valves, they are envisioned at this point in time as primarily manual. The operator would have to dispatch a field operator to manipulate them. For the purposes of capturing how an operator might manage their actuation, we included a basic display of isolation valves (see Figure 8) to allow the operator to change their states and then navigate back to the supervisory display to view their positions within the P&ID mimic. This was an artifact of the study, but was useful in capturing some of the interactions the operators would have with the isolation valves and ensuring they consider those valves while performing the procedure, as opposed to superficially noting a field operator would manipulate them and then moving on to the next activity in the procedure. For this purpose, isolation valve implementation was effective because it allowed observation of issues with labels and the order of operations during the evaluation. The details concerning the isolation valve issues are presented in a subsequent section.

3.2.2 Web-Meeting Platform

To support the remote nature of the study, a web-meeting platform was required. The challenge was to identify a platform that would support the ability to allow operators to take screen control of the computer running the prototype HSI. The second requirement was to provide a high degree of reliability, defined for the purpose of this study as maintaining connectivity without dropping attendees, but with uninterrupted and clear audio and video. Two of the participating operators were retired and did not have any restrictions on the web-meeting platform they could use, but two of the operators were from the Electric Power Research Institute (EPRI) and required consent from their organization to use any web-meeting platform. Given these restrictions, the three web-meeting platforms that were identified as possible solutions included Microsoft Teams, Bluejeans, and Web-EX. Of these three platforms, Bluejeans was selected because it provided the ability to perform screen-sharing control, which allows a research team member to take control of the desktop of a participant's computer to support the operators in manipulating the prototype HSI. While Teams also allowed for sharing control of the screen, testing revealed inconsistent availability of the function between INL and EPRI team members. Furthermore, Bluejeans proved to be quite reliable based on past use by the research team. The testing revealed that the lag in manipulating the prototype stemming from the remote connection was negligible and did not interfere with the operators' ability to interact with the prototype. The testing also revealed that an overlay button to adjust the view of the Bluejeans application occasionally obscured the time display on the prototype HSI, but this was a minor difficulty and did not appear to interfere with the ability of any operator to complete any scenario.

3.3 Procedure Development

Although thermal dispatch operations have been performed at nuclear power plants in other countries, such as Russia, China, and Canada, such operations are new in the United States. Therefore, the research team developed mock procedures to support thermal dispatch operations. To ensure the mock procedures adhered to nuclear standard practices, the research team identified and outlined NPP procedure structures, standards, and style guides. This section begins first by describing some basic characteristics of procedures used in NPPs and then describes the efforts to develop mock procedures and integrate them within the existing suite of procedures provided for the GSE GPWR simulator.

3.3.1 Nuclear Power Plant Procedures

NPP operations are highly proceduralized to maintain high safety standards. There are formal mechanisms in place to track procedures from their conception to their deployment and revision within the plant. NUREG-0711, Rev. 3, "Human Factors Engineering Program Review Model," provides specific guidance on the activities that must be performed (O'Hara and Fleger 2012). Verification and validation (V&V) that the system can function properly requires that an accompanying set of procedures is available to support the operators as they perform their tasks with any new system. This research team has been involved with past V&V activities for turbine control system upgrades (Boring 2014). The method effectively ensures that a high-quality and usable HSI and accompanying procedures have been developed. The research team adopted the V&V strategy as part of the effort to develop an HSI and procedures for the thermal and electric power dispatch concept of operations. Procedures developed for the system were evaluated in tandem with the interface during the operator study. Before describing the process of how the procedures were developed, it is first necessary to provide some useful background on procedures used in existing NPPs.

Procedures used in NPPs can largely be considered in three categories: 1) administrative procedures, 2) plant operating procedures, and 3) severe accident management guidelines, as shown in Figure 9. The administrative procedures refer to administrative controls and those for control of operational activities by the plant staff (U.S. NRC 2007). The plant operating procedures are used for operating NPP systems in any condition: startup, steady state, shutdown, or abnormal and emergency operations. The severe accident management guidelines provide guidance to limit the effects of an accident that results in significant damage to the fuel.

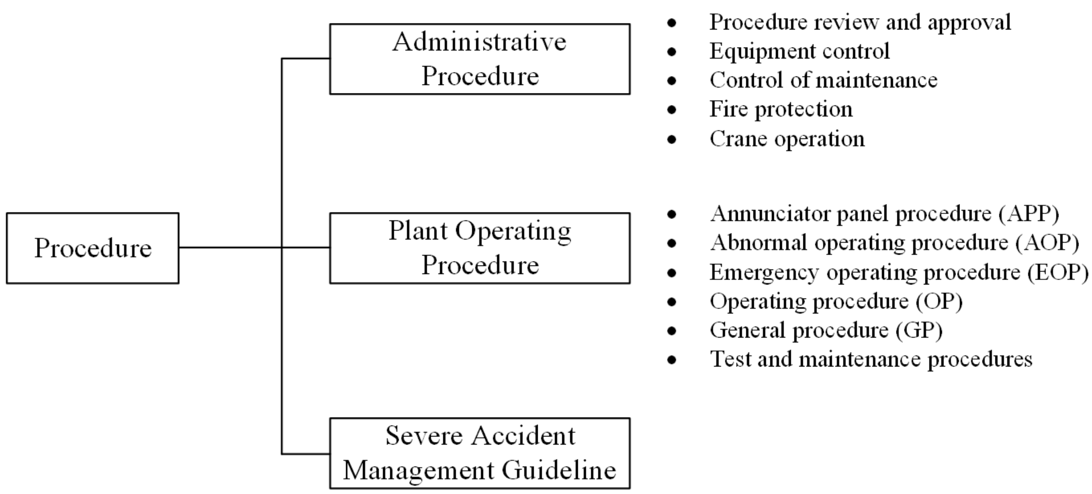

Figure 9. Different types of procedure used in NPPs.

The procedure development described here mainly focused on plant operating procedures. Here, too, there are several types of procedures: 1) annunciator panel procedures (APPs), 2) abnormal operating procedures (AOPs), 3) emergency operating procedures (EOPs), 4) operating procedures (OPs), 5) general procedures (GPs), and 6) test and maintenance procedures. Each procedure type has its own purpose and treats specific NPP conditions. The following sections describe the major content and the detail structure on each procedure type.

3.3.1.1 Annunciator panel procedure

An APP prescribes operator actions in response to individual alarms within alarm panels. When a parameter reaches a critical value threshold, the system automatically provides an alarm related to the value so that operators can rapidly identify the issue and perform proper actions. For example, when a steam generator's water level is above a certain threshold, an alarm will trigger to alert the operator. Figure 10 shows the basic structure of APPs. The APP includes the entire alarm panel available in the main control room and provides specific information that is required for treating an alarm, such as work devices, alarm set point, operator actions, causes, and references.

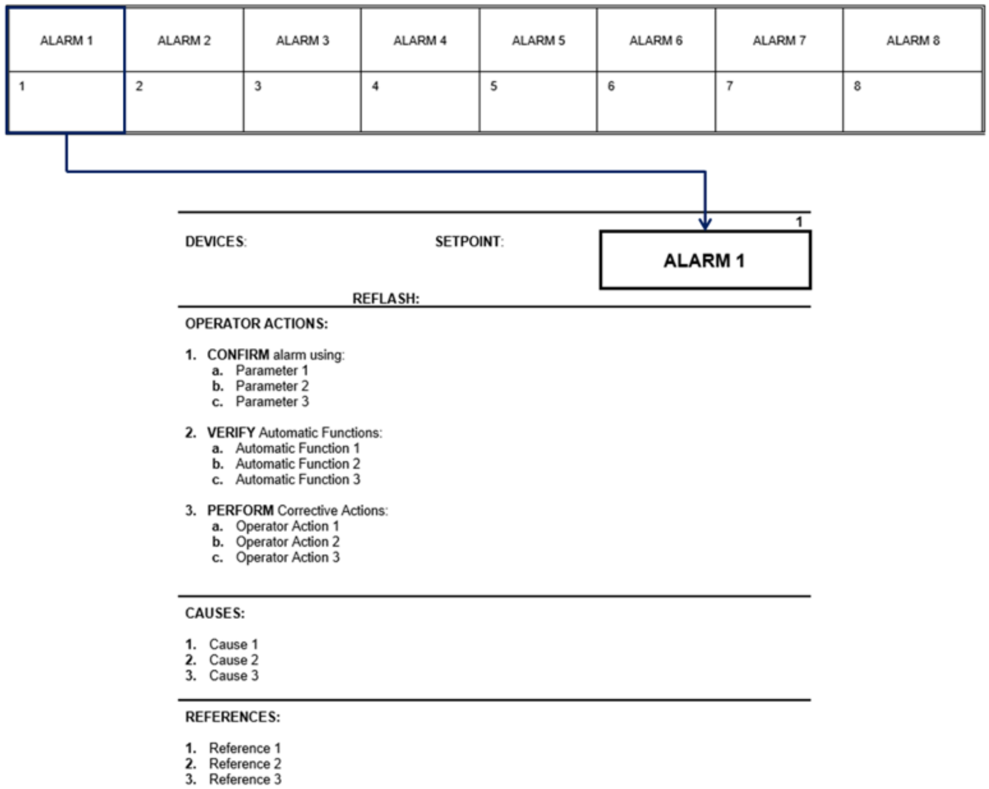

Figure 10. Basic structure of an APP to illustrate how this type of procedure is constructed and organized.

3.3.1.2 Abnormal operating procedure

An AOP is designed to stabilize and control an abnormal event prior to a reactor trip. A reactor coolant pump's failing is an example of an abnormal event that requires the use of an AOP. The procedure normally suggests a method to restore failed components. However, if it is expected that the components are not recoverable, the procedure deliberately leads to less conservative actions, such as a reactor trip to shut down the reactor, ensure NPP safety, and allow for maintenance work on the failed components. The contents of the AOP include its 1) purpose, 2) entry conditions, and 3) operator actions. There is variation between plants, but one common approach and the one employed for the GPWR simulator reference plant, organizes AOP steps in a two-column format of 1) instructions and 2) response not obtained. Operators mainly perform the instructions column while the steps corresponding to the response not obtained are used when the steps for the instructions are unsatisfactory. The two-column organization is also found in emergency operating procedures.

3.3.1.3 Emergency operating procedure

The EOP is used to shut down the reactor and conduct long-term cooling to ensure a stable plant state when an emergency event occurs. An emergency event can be characterized as a design basis accident (DBA)—i.e., the postulated accidents that a nuclear facility must be designed and built to withstand without loss to key systems, structures, and components. Examples include a loss of coolant accident or steam generator tube rupture. EOPs consist of the two types: 1) event-based EOPs and 2) symptom-based EOPs. An event-based EOP suggests a way for operators to treat an event by focusing on a couple of emergency events among a well-defined set of events anticipated. These are usually limited to the list of DBAs for the plant. EOP procedures begin with diagnostic criteria that identify the type of event and then provide the most appropriate procedure in response to the event identified. In contrast, a symptom-based EOP focuses on symptoms, with one or more measurable plant parameters available to the operator in the main control room. It is used when a specific event is not diagnosed or an accident, combined with more than two emergency events or failures, occurs. The major strategy suggested in symptom-based EOPs focuses on recovery of critical safety functions.

3.3.1.4 General procedures and operating procedures

The GP and OP provide instructions for startup, normal operations, shutdown, and infrequent operations. The GP procedure type pertains to changing the plants mode of operation—e.g., hot standby to power operation)—while the OP supports the use of the GP by providing specific instructions to operate specific systems. The contents of the GP and the OP include 1) purpose, 2) reference, 3) prerequisites, 4) precautions and limitations, and 5) procedure steps.

3.3.1.5 Test and maintenance procedures

NPPs consist of a huge number of subsystems and components. To ensure that the NPPs work properly, these should be periodically tested and maintained. The test and maintenance procedures provide adequate procedural methods for the subsystems and the components in NPPs. Operations periodic test (OPT) procedures are representative for the type of test and maintenance procedures.

3.3.2 Procedure Development Process

The thermal and electric power dispatch systems are novel. Therefore, a new set of mock procedures was drafted to prescribe the process for specific evolutions. However, before these specific procedures were drafted, GPWR procedures were reviewed to identify where they would need to be modified to account for new processes. Existing procedures require additional or modified steps to link them with the new procedures, as applicable. For example, rod control, main steam, turbine control, and condenser systems are all relevant to TPE and TPD loop operations and have implications for how these systems might be operated. Therefore, it is important to identify these common points across the entire procedure set for GPWR to ensure we have a comprehensive set of procedures to cover all situations.

An initial review identified 20 existing GPWR procedures relevant to this study that would require significant modifications due to thermal and electric power dispatch operations. shows summary results of the procedural review for the 20 existing GPWR procedures related to TPD evolutions. Five procedures—EOP-EPP-044, GP-002, GP-004, GP-005, and GP-006—have been determined to require revision to link them with TPD operations. The other procedures were not directly related to the TPD and required no revisions for this work. For EOP-EPP-044, to achieve the original EOP strategy introduced in the previous section, it should include procedural steps to shut down the TPD system. On the other hand, GP-002, GP-004, GP-005 and GP-006 need to include contents for manipulating the system in tandem with NPP mode changes.

Table 1 shows summary results of the procedural review for the 20 existing GPWR procedures related to TPD evolutions. Five procedures—EOP-EPP-044, GP-002, GP-004, GP-005, and GP-006—have been determined to require revision to link them with TPD operations. The other procedures were not directly related to the TPD and required no revisions for this work. For EOP-EPP-044, to achieve the original EOP strategy introduced in the previous section, it should include procedural steps to shut down the TPD system. On the other hand, GP-002, GP-004, GP-005 and GP-006 need to include contents for manipulating the system in tandem with NPP mode changes.

Table 1. A summary of procedure review result for 20 existing GPWR procedures related to thermal and electric power dispatch evolutions.

No.	Procedure Type	IES Related GPWR Procedure		Review Result
1	Annunciator panel	APP-ALB-014	Main control board (Steam generator annunciator panel)	No revision required

No.	Procedure Type	IES Related GPWR Procedure		Review Result
	procedure (APP)	APP-ALB-020	Main control board (Main steam / Turbine)	No revision required
2	Abnormal operating procedure (AOP)	AOP-012	Partial loss of condenser vacuum	No revision required
		AOP-028	Grid instability	No revision required
		AOP-035	Main transformer trouble	No revision required
		AOP-038	Rapid downpower	No revision required
3	Emergency operating procedure (EOP)	EOP-EPP-004	Reactor trip response	Revised
4	Operating procedure (OP)	OP-104	Rod control system	No revision required
		OP-107.01	CVCS boration, dilution, and chemistry control	No revision required
		OP-126	Main steam, extraction steam, and steam dump systems	No revision required
		OP-130.01	Auxiliary steam and condensate system	No revision required
		OP-131.01	Main turbine	No revision required
		OP-131.04	Moisture separator reheater	No revision required
		OP-134	Condensate system	No revision required
		OP-136	Feedwater heaters, vents, and drains	No revision required
5	General procedure (GP)	GP-002	Normal plant heatup from cold solid to hot subcritical (mode 5 to mode 3)	Revised
		GP-004	Reactor startup (mode 3 to mode 2)	Revised
		GP-005	Power operation (mode 2 to mode 1)	Revised
		GP-006	Normal plant shutdown from power operation to Hot Standby (mode 1 to mode 3)	Revised
6	Operations periodic test (OPT)	OPT-1014	Turbine valve test semi-annual interval modes 1-5	No revision required

Second, new procedures directly supporting the TPE and TPD loop systems operations have been developed based on the existing GPWR procedure format and following guidance from NPP procedure writing good practices (Wieringa and Farkas 1991, Wisconsin Public Service Corporation 1993) and

NUREG-0711 (O’Hara and Fleger 2012). Table 2 shows a summary of the new procedures developed for supporting the TPD system. In reference to the prototype HSI for thermal and electric power dispatch operations and the result of the functional requirements analysis, functional allocation, and task analysis for the thermal and electric power dispatch introduced in prior research (Ulrich et al. 2020, INL-EXT-20-57880), the procedures were first drafted by matching the style and formatting of the GPWR procedures and following the GPWR procedure format and procedure writing good practices. As shown in Table 3, the guide suggests how to specifically format procedures that are technically accurate, concise, consistent, and easy to perform with respect to four topics of the guideline—i.e., procedure format, instructions, and graphics and writing mechanics. Then, the early drafts were reviewed by the criteria suggested in NUREG-0711 (O’Hara and Fleger 2012).

Table 2. A summary of new procedures developed for supporting the TPD system

No.	Procedure Type	Procedure number	Title
1	Annunciator panel procedure (APP)	APP-ALB-IES	Integrated energy system board
2	Abnormal operating procedure (AOP)	AOP-IES	Integrated energy system trouble
3	Operating procedure (OP)	OP-IES-001	TPE and TEDL operation (shutdown to hot standby)
		OP-IES-002	TPE and TEDL operation (Hot Standby to online)
		OP-IES-003	TPE and TEDL operation (Online to Hot Standby)
		OP-IES-004	TPE and TEDL operation (shutdown)
4	Operations periodic test (OPT)	OPT-SEL	Steam extraction loop valve test

Table 3. Major considerations required for writing procedures

Topic of guideline	Contents
Procedure format	Page size, margins, spacing, typography, header blocks, procedure organization, date performed line
Procedure instructions	Instruction format, signoffs, initial lines, verifications, equipment nomenclature, conditional statements, data blocks, precautions, notes, cautions and warnings, multiple objects and lists, acceptance criteria, limits, rates, measurements, tolerances, calculations and formulas, infrequently performed tests and evolutions
Procedure graphics	Criteria, selecting graphics, providing legibility and consistency, placing graphics, unacceptable graphics, tables
Writing mechanics	Punctuation, methods of emphasis, spelling, grammar, vocabulary, numerals and units of measure, abbreviations / acronyms / symbols, reference

Third, new procedures must be tied to existing procedures such that operators can appropriately know when and what conditions should be met to begin performing them. For EOP-EPP-044, procedure steps to shut down the TPD system have been added after major post trip actions in the EOP because the procedure steps for the TPD are less important than the actions in EOPs. For GP-002, GP-004, GP-005, and GP-006, procedure steps for transferring to the new procedures; OP-IES-001, OP-IES-002, OP-IES-003, and OP-IES-004 have been added in each procedure. In addition, the other procedures newly developed for the TPD operations, but not directly linked with the existing GPWR procedures, have connections, or cross-references, to one another within the new procedures. For example, APP-ALB-IES has a step for transferring to AOP-IES according to alarms or other symptoms.

Finally, after the initial draft of the procedures were written specifically for the thermal and electric power dispatch system, the procedures were shared with the operators to provide comments, then these were revised based on the operator comments. This was not part of the study itself, but was performed months in advance to ensure the procedures were prepared correctly. Table 4 shows a classification of operator comments that were received during the procedure preparation process. Operator comments were classified by the four topics introduced in Table 3. For example, in the first comment, details on how a valve works were not specifically provided in the procedure. Most of the comments were related to the procedure instruction category.

Table 4. Classification of operator comments into procedure writing issue categories

No.	Operator comment	Category
1	Does a valve have a controller with an M/A station or is it closed because it shut when level reached it’s low setpoint?	Procedure instruction
2	Operating Procedures have an attachment in the back for Electrical Lineups and Valve Lineups. These attachments would list the position of breakers and valves when a system is shutdown. If we had this you wouldn’t need to be listing valves required to be in a certain position because an initial conditions would say attachments 1 and 2 of this procedure are completed.	Procedure instruction
3	What is this component supplying power to? Is this the proper place for it?	Procedure instruction
4	Remove “If” after “Determine”	Writing mechanics
5	The note before step 5 should be before step 3.	Procedure format
6	Appears to be a duplicate step to step 10.	Procedure format
7	You say ensure which to me implies something is happening automatically. Valves are shown as manual valves. You should say perform the following when discussing positioning manual valves. What physically occurs when the Start Warmup button is depressed?	Procedure instruction
8	Does the warmup of EHC-1 & 2 occur due to steam going to condenser through SEL28? I can see that EHC-1 will warmup quickly but EHC=2 may take a while. Is there flow from the TPD loop through the tubes of EHC-2 at this time? If the level in EHC-2 is above the tubes how much condensing will you get in the heat exchanger and will level actually increase to cause SEL-4 to open. The bypass valves are not mentioned. Do we not use the bypass valves?	Procedure instruction
9	Clearly define the manual valves on the drawing so they agree with the procedure.	Procedure instruction
10	The valve lineup on page 6 would work better if manual valves were OPEN that need to be open to provide a flow path for warmup and operation.	Procedure instruction

No.	Operator comment	Category
11	Controllers should normally be in AUTO I believe. SEL-1 should be in MANUAL and closed when the system is shut down.	Procedure instruction
12	I would expect SEL-13 to be the warmup valve from a cold start. Slowly, manually, open SEL-13 to warm up and equalize the pressure around SEL-1 to prevent water hammer. Then OPEN SEL-1 or place in AUTO. Then CLOSE SEL-13	Procedure instruction
13	Pressing the START WARMUP BUTTON in steps 8 and 10 needs to be figured out. Is a start warmup button needed? If a valve and controller lineup is performed prior to startup then manually opening SEL-13 will warm the loop and basically put it in standby when SEL-1 is eventually opened.	Procedure instruction

3.4 Scenarios

For this initial concept of operations evaluation with operators, a basic set of scenarios was selected. The TPE system itself was the focus of this particular evaluation because this system interacts directly with the main steam system of the simulated NPP. The TEDL and the hydrogen plant were included in the evaluation, but only to enable testing of the TPE. As such, the TEDL was assumed to be in the correct configuration for each scenario and required few manipulations. The hydrogen plant was only included as a dummy heat sink within the simulation to provide a destination for extracted thermal power. Furthermore, electrical interconnectivity was only modeled as a simple control to close the breaker between the NPP switchyard and the hydrogen production plant. With those limitations noted, the scenarios spanned the basic set of evolutions required to transition the TPE from a cold shutdown state to 5% thermal power extraction supplied to the hydrogen plant and then back to a shutdown state. These evolutions all fall under normal operations. Future studies will examine more nuanced and abnormal scenarios.

3.4.1 Shutdown to Hot Standby

In the shutdown state, the TPE and TEDL systems both have zero flow and are at ambient temperature. The transition from shutdown to hot standby can take a significant amount of time (several hours) to achieve because the long delivery pipelines must be pressurized and heated. In this scenario, operators first verify whether the initial state for valves and pumps in the TPE and TEDL systems are ready for the warmup evolution. The operators also determine 1) target temperatures and hot-well water levels for TPE-EHX-1 and TPE-EHX-2 and 2) target turbine control system (TCS) demand and ramp rate for thermal power extraction pressurization based on technical specifications provided in procedures. Next, the TPE system is pressurized using a bypass valve. This is a manually operated valve to allow the operator to ensure acceptable pressurization of the system. The scenario is concluded when the target temperatures, the hot-well water levels, the target TCS demand, and the ramp rate reach a stabilized state within the predetermined target ranges.

3.4.2 Hot Standby to Online

The hot standby state refers to the TPE and TEDL systems operating with minimal flow to maintain hot conditions in both the TPE and TEDL. The transition from hot standby to online state is an important task to evaluate because it may occur frequently and is associated with substantial and rapid changes in thermal power flow that must be achieved while maintaining the NPP at near full reactor power. In this scenario, operators manipulate the TCS, TPE, and TEDL systems until target flow rate and TCS demand

and ramp rate for thermal power extraction reach the values required for the online state. It is advisable that prior to initiating the transition to online from hot standby state, reactor power be slightly reduced to avoid unintentionally causing the reactor power to exceed 100%. The mass flow of oil in the TEDL system should also not change significantly. Another issue is the potential for low temperature zones in the heat transfer fluid in the TEDL system, which could interfere with subcooling of the condensate in the TPE system and also cause excessive pipe stress and other problems.

3.4.3 Online to Hot Standby

The transition from online to hot standby state is the reverse of the hot standby to online evolution. The operator reduces the flow rate through the TPE while diverting steam back to the turbine. This evolution may also occur frequently, perhaps even daily, in response to grid demand fluctuations. To perform the evolution, the operators reduce flow through the TPE to move from an online to hot standby state, such that the thermal power is diverted back to the turbine to restore full electrical power generation. The operators reduce flow through the TPE to a predetermined minimal target flow rate and, in tandem, ramp the turbine to normal flow rates and demand for electrical power generation. The mass flow of the TEDL system is maintained to ensure constant thermal heat reduction to HTSE system while the flow is reduced in the TPE.

3.4.4 Hot Standby to Shutdown

It is anticipated that the hot standby to shutdown evolution will be performed infrequently for maintenance purposes and prior to NPP outages, during which the NPP itself goes into shutdown. Hot standby to shutdown is the reverse evolution of shutdown to hot standby described above. In tandem, the operators open the bypass valve and close the main control valve for the TPE, which causes an initial and substantial flow reduction. The operators then use the bypass valve to further reduce flow to zero by closing the bypass valve. Once the bypass valve has been closed, isolation valves are closed to prevent any flow into the condenser, and the system is allowed to cool. Once the systems has cooled to ambient temperature, the system can be drained, and maintenance can be performed.

3.5 Remote Static Operator Evaluation Protocol

3.5.1 Collaboration with EPRI—Operators and Another Human Factor

This study was performed in collaboration with EPRI. In prior research efforts, such as the initial HSI development and the system design, EPRI reviewed and provided expertise and guidance. For this research activity, EPRI provided two formerly licensed pressurized water reactor (PWR) operators as participants for the study and a boiling water reactor (BWR) operator who served as a member of the observation team. The BWR operator possessed expertise in nuclear operations, but also in human factors. Therefore, he was uniquely suited to serve as part of the research team, making observations while the PWR operators performed the scenarios. His observations were invaluable in assisting the INL human factors observers to reconcile discrepancies between operators.

3.5.2 Operator Demographics and Persona Characteristics

Four operators participated in the evaluation study, and results were anonymized for privacy. All were male, all had previously held a license to operate a commercial NPP, and all had held multiple operations and leadership roles in the nuclear power industry. The table below shows the years of experience in nuclear, as well as their years of experience as a licensed operator.

Table 5. Operator Demographics

Operator ID	Years of experience in Nuclear	Years of experience as licensed operator
Alpha	44	18
Bravo	43	28
Charlie	33	6
Delta	47	22
Average	41.75	18.5
Median	43.5	20

A unique component of this study was the consideration of personas after the fact. Often personas are generated prior to user testing and are intended to represent abstracted or idealized potential users. The purpose of personas is to attempt to capture the majority of needs, wants, and overall characteristics to ensure that initial designs are suitable and beneficial to those users. Due to the relatively low population of nuclear operators, this form of general user study exercise is not often undertaken in nuclear applications. Additionally, the development of personas after the fact is not generally considered a proper use of the method; however, in this case, they were found to be informational and contributed to the qualitative interpretation of the findings.

During the study, it became apparent that one of the operators was approaching the tests in a different manner than the other three. Potentially due to an absence of defined instruction, this difference yielded interesting information about the characteristics of the participating operators and could be an initial step in identifying governing characteristics of nuclear operators more generally. Various complications and the early stage of the design have been discussed as limitations of the system in particular; therefore, the displays were not in a state that can represent a realistic instance of the system during operation. Similar to other training or research simulations, this stage of development required the operators to extend a certain degree of suspension of disbelief in order to test the display components and the overall system as it is performing. As the concept of a hydrogen production system integrated with an NPP is hypothetical at this point, the underlying model and displays are also an exercise in the design of hypothetical systems. Three of the four operators approached the task with this mindset and were able to negotiate the study and scenarios with the assumption that it represented a realistic instantiation of a potential system. The operators were able to take actions, identify problems, and make recommendations related to the display design and various alternative components of the design.

The fourth operator approached the study from a position of validation of the model and displays as-built and as a potentially existing system. As a result, the majority of recommendations and problems identified by the fourth operator were related to the underlying model, system performance, and overall realism of the representation. This was a unique experience for the human factors team and resulted in two very distinct types of operational methods that can be captured using two personas. One operator persona performed the procedures as written, identifying problematic areas, but attempting to perform the tasks in the present context and respond according to that context. This operator persona successfully spotted areas of concern or problematic values, but managed to move on to complete the tasks. The second operator persona approached the procedures more from an engineering context. Strict adherence to variable fidelity and concern for variables that were perceived to be outside the normal range was high for this operator persona and could be an obstacle to completing the procedures. Additionally, this operator required a full understanding of potential system response prior to taking any specific action. Due to the novelty of the hypothetical system and the realities of model refinement and development, this need can create a difficulty for an operator reconciling current states and procedural steps.

As persona development was not undertaken as a part of the early design stages, these observations do not constitute any validation or findings that are generalizable to nuclear operations as a whole. However, the different approaches were a characteristic that the team had not considered in designing the scenarios. A further area of research may be a deeper dive into the operational psychology of nuclear operators and carefully tailored scenarios which are intended to draw these specific approaches out of participants in order to capture specific types of operators. All nuclear operators are expert performers in their specific area; however, the differences between operators may be a ripe area for research as standard OPs and training regimens may have previously blurred these differences.

3.5.3 Experimental Protocol

This section describes the protocol used to guide each of the operators through the study. A detailed account of each activity performed and how it was performed is included.

3.5.3.1 Session 1: orientation and discoverability exercise

The first session was primarily to orient the operators to the use of the online format and become familiar with the prototype HSI so that they would be able to focus on executing the scenarios, as opposed to learning the nuances of the displays while attempting to perform the scenarios.

3.5.3.1-1 Overview of study

The INL researchers presented the operators with an overview of the study, detailing the background and goals of the research.

3.5.3.1-2 Operator packet

Participants were presented with the operator packet which included the procedures needed to carry out the four scenarios along with the required informed consent form. This form is a standard requirement for research involving human subjects to ensure participants are notified of their rights as subjects and any harm that could arise from their participation. Operators were asked to read the informed consent form and provide verbal consent that they understood the risks involved and would like agreed to participation in the study. This took place directly before the onset of Session 1.

3.5.3.1-3 Usability survey

Following completion of the operator packet, participants were asked to access and complete a usability survey on the Qualtrics survey platform.

3.5.3.1-4 Check connection issues/screen control

The operators were asked to check for any web-meeting platform connection issues and whether the situation was deemed satisfactory to request screen control and begin the scenario.

3.5.3.1-5 Think-aloud discovery exercise

The operators were asked to navigate the interface in a think-aloud protocol—that is, audibly detailing their actions for a duration of thirty minutes. The observation team collected this information via handwritten and computer-based notes.

3.5.3.1-6 Debrief

After each session of orientation and discoverability, the four operators then separately participated in follow-up debriefs as well. The observation team collected this information via handwritten and computer-based notes.

3.5.3.1-7 Follow up

Following the Session 1 scenario tests, operators were provided with a summary regarding some issues encountered with the interface. Clarification was made that the P&ID that had been shared with the operators was a proof of concept model with limitations. It was stressed that operators should ask for clarification if needed during the scenario runs. Additionally, the operators were then supplied with P&IDs of the underlying TPE and TEDL systems.

3.5.3.2 Session 2: individual walkthroughs and debriefs

Session 2 consisted of four-hour-long blocks, during which each of the four operators individually participated in running the four scenarios. The four scenarios included:

1. Scenario 1: Shutdown to Hot Standby (Start at Shutdown)
2. Scenario 2: Hot Standby to Online (Start at Hot Standby)
3. Scenario 3: Online to Hot Standby (Start at Online)
4. Hot Standby to Shutdown (Start at Hot Standby)

Each scenario evaluated was scheduled for 30 minutes, followed by a 15 minute debrief. The debriefs allowed the observers to capture valuable insight and feedback regarding issues with the interface. Observers collected this information via handwritten and computer-based notes.

3.5.3.2-1 Remote usability online format debrief

Following the four scenario runs, a remote usability online format debrief was carried out by the operators.

3.5.3.3 Session 3 - Group Debriefs

Session 3 entailed a collective study debrief. The two former Harris operators participated in one group debrief, and the three EPRI operators participated together in a separate group debrief. From these collective debriefs, the operators provided INL researchers with valuable feedback regarding:

- Interface issues
- System issues
- Challenges performing the study remotely
- Future directions
- INL researchers collected the debrief data via handwritten and computer-based notes.

3.5.3.3-1 Offline Debrief Questionnaire

Following the operator group collective debrief, an offline debrief questionnaire was administered to the operators.

3.5.4 Measures

3.5.4.1 Observation notes

During each session of the study, several observers recorded what the operators self-reported as well as capturing their own independent observations. Self-reports are inherently subjective and, therefore, participants do not always accurately report their experience, but rather a perception of their behaviors and experience that is fallible both due to memory, situation awareness, and biases held by the participant. The independent observations made by the observers supported a more objective account of the operators' experience while performing the discoverability and scenario exercises. Each observer was free to record anything of note, but several individual observers were tasked with focusing on particular elements to ensure all aspects of the evaluation were captured. A dedicated observer was tasked with capturing any issues within the following topics:

1. Procedures
2. HSI information presentation
3. HSI and operator interactions (i.e., navigation, control manipulations, information drill downs, etc.)
4. Prototype HSI technical issues
5. System modelling
6. Nuclear operations.

The combined self-report and more objective observations made by the observers captured a comprehensive account of each operator's experience and yielded a number of issues that are reported in the Section 3.6 of this document. This is an applied study, and the focus is on identifying and reporting the issues with the concept of operations. Therefore, the source of the issue identification is not as important as the issue itself, and the Section 3.6 is organized from an issue perspective.

3.5.4.2 Questionnaires

The study included a questionnaire that was given to the participants in pre- and post-test formats. Operators completed the initial questionnaire shortly after the completion of the initial think-aloud and discovery exercise. A second instance of the questionnaire was completed after all four scenarios were completed, but prior to the team debriefs. The questionnaire primarily comprised binary Yes/No questions with an opportunity to explain some answers and several Likert scales. The goal of the repeated questionnaire was to capture any learning effects that were present as operators became more familiar with the prototype HSI after using it to complete the scenarios. It was hypothesized that this learning effect would be present, with operators reporting that the displays made more sense and were clearer after completing the tasks. Pre- and post-test comparisons were completed, as were comparisons across the individual operators. A second instance of the questionnaire was completed after all scenarios were completed, but prior to the team debriefs.

3.6 Results

The results from this study are primarily qualitative in nature. Due to the remote format of the study, the research team was not able to capture some performance measures, such as situation awareness and workload. Fortunately, for the purposes of evaluating the initial concept of operations including the system design, supporting HSI, and procedures to prescribe thermal and electric dispatching evolutions, the qualitative results are of critical importance. Indeed, as our previous research efforts using the HSSL with the capability to record performance metrics, such as eye tracking and process parameters, the most informative data collected to improve the concept of operations was qualitative in nature (Ulrich, Boring, and Lew 2018). The qualitative data from this study came from operators themselves, as well as from the human factors expert observers.

3.6.1 Remote Usability

As this was the first remote usability study performed by this research team, and possibly the first for the commercial nuclear power domain, the format of the study was assessed. The operators were asked specifically to report on their experience performing the scenarios in the remote format using the static display supported by snaps from the GPWR simulator. Overall, the operators reported that this approach was effective for the purposes of the study to evaluate the concept of operations. Operators reported no issues with the web platform itself, aside from one noting that the Bluejeans control overlay would occasionally obscure a portion of the prototype HSI, though they didn't experience issue with this occurring beyond the initial surprise of experiencing it the first time.

Operators did comment on the snap method of providing the simulator data to the interface as they moved through the scenario. Operators were provided with the ability to control the snaps themselves, and three of the four operators elected to do so. One operator was not as comfortable moving the simulation and requested that the observer acting as the trainer move the snaps for him. The observation team noted that, on several occasions, the operators advanced through the snaps beyond the appropriate timepoint to perform several of the procedure actions, and the observer acting as the trainer had to prompt the operator to move back to the appropriate snap in order to have the correct state of the simulation portrayed within the prototype to support executing the particular procedural step. Though none of the operators reported the snaps were overly burdensome, they were the largest point of confusion in the entire study. To the best of the authors' knowledge, this is the first study of its kind; thus, the method to record and deliver the snaps was admittedly unrefined and can be improved in future studies. In particular, one scenario had snaps in which several procedural steps were completed within a single snap, but in the procedures, they were called for in a sequence in which the operator would be able to verify procedural actions for each step. Unfortunately, their combination into one snap eliminated this feedback, making the actions of an operators simultaneous and requiring the operator to execute steps before receiving feedback. This was an artifact of simulator data recordings and was purely an error in the data recording method that will be corrected in future work.

Beyond the specific step order issue, the snap navigation in general was challenging for the operators and required prompting from the observer acting as the trainer to stop the operator before he advanced too far in the scenario for a given procedure step. To provide a more straightforward navigation scheme for the snaps, two recommendations were captured to improve their delivery for subsequent studies. One operator recommended that the procedures should have a second column to denote the correct snap for performing that procedure step. Another operator recommended that each procedure or sub-procedure step should have a single snap associated with it such that, after completing each procedure, the operator could then advance exactly to the next snap without advancing too far.

3.6.2 Findings and Issues

This section of the results describes both positive findings and issues that were identified through the reports by the operators performing the think-aloud protocol and the observations themselves and from the research team. The findings refer to observations and self-reports concerning aspects of the HSI, procedures, and system that were effective in enabling the operators to perform the tasks within the procedures. These findings serve as validation that the concept of operations is an effective approach for thermal and electric power dispatch. The observations and self-reports also identified issues with the HSI, procedures, and system that made it more challenging for the operators to perform the tasks within the procedures. The findings and issues are broken into display and procedure categories and then further divided into subcategories within those.

3.6.2.1 System design and modelling issues

There was no feedback from the operators suggesting that the system design was flawed in a gross or fundamental manner. These issues had been addressed during previous activities; therefore, the types of issues anticipated during this study were more nuanced. There were a number of issues identified in the modelling of the system itself. First, during the shutdown to hot standby scenario, several of the pressures within the TPE and TEDL systems displayed negative pressure values (i.e., vacuum conditions). All operators reported this issue because the procedure for the first scenario explicitly instructs the operators to check that the pressure value for TPE-PT-1002 be above 50 psig. However, that pressure remained negative until the loop began to warm. This was a modelling limitation from cooling down a closed system that would not occur in the actual system. While constructing the simulation, designers did not know how the system would be depressurized when put into a shutdown state. The operators reported that the system would be drained and vented to atmosphere. This was simply not an activity that the simulation was designed to support; therefore, the issue was noted, and future modelling will expand the scope and fidelity of the simulation to support this system condition for future concept of operations testing.

A few key parameters were reported as erroneous values. The turbine load value displayed in the key parameters section was reported as inaccurate by at least one operator in that it was approximately 50 MW higher in magnitude than what was expected by the operator. Several of the operators reported the adjusted Tref parameter was confusing. The adjusted Tref represents the actual Tref with the bias included to prevent the rods from stepping to account for the loss of steam and thermal power due to the operation of the new system. The operators report that the adjusted Tref is not that useful and, instead, they would rather have the bias displayed in conjunction with Tref so that they can see how the new system is affecting larger plant operations.

One operator noted the rad monitor indication in the TEDL data table and questioned how that was used and whether it was necessary. This led to a discussion between the operator and the research team in which the issue of whether a radiation monitor should be placed within the TPE or TEDL or should even be included anywhere in the system. The main steam system already has radiation indicators, and those would be triggered to alert the operator of an issue before any radiation indicator in the thermal and well before any alarm in the electric power dispatch systems would detect the radiation. The question was posed to all operators during the debriefs, and one operator pointed out that even though other indication would be more informative during a radiation event, the addition of radiation indication in the new systems would be useful for cleanup activities after the event. In the end, the decision to include a radiation indication comes down to the cost-benefit tradeoff. It should be noted that no accident or abnormal scenarios were evaluated during this scenario. Thus, the radiation indication was not used in these scenarios. Future expanded testing with abnormal and accident scenarios will inform the decision as to whether radiation indication should be included.

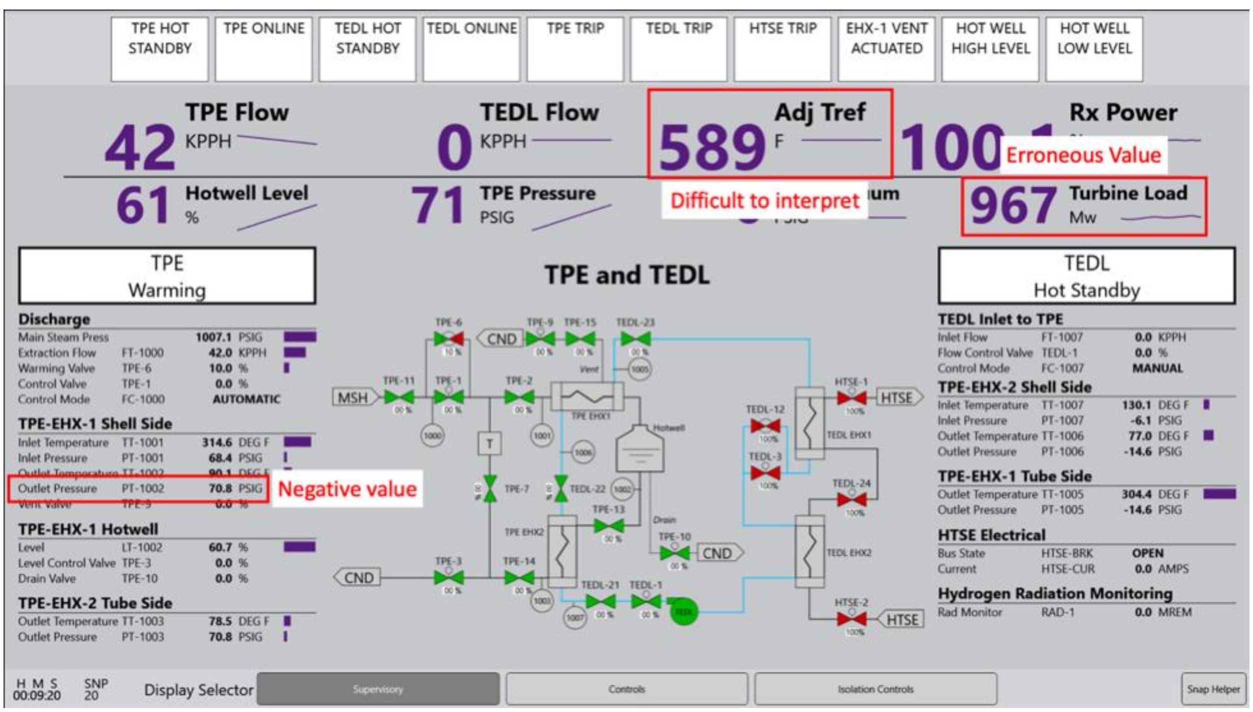

Figure 11. HSI supervisory display depicting the system design and modelling issues reported by the operators and noted by the observation team.

3.6.2.2 Display findings and issues

Fortunately, the preparation and testing performed before the study eliminated any issues that would prevent operators from executing procedure actions with the control and information in the display. The study did yield a number of findings and issues for the prototype HSI display.

3.6.2.2-1 General

The P&ID mimic was updated to reflect system changes, and one error that was identified was the incorrect location of TEDL-24. More importantly, the incorrect orientation of the TPE heat exchangers was reported. The data tables had the correct relationships, but the graphic was displaying an incorrect relationship between the flow paths in terms of the shell and tube sides of both heat exchangers. Interestingly, this was not discovered until the final operator was run through the scenarios. This highlights the value in having multiple participants during a usability study to ensure the maximum number of issues are identified. Virzi (1992) found that five users can identify 85% of the usability issues within a design. This highlights the diminishing returns from increasing the number of users in usability studies. Considering that this study only employed four participants, it may have yielded less than 85% of the usability issue. However, it is likely that the gross issues were captured, and the remaining undiscovered issues are likely minor. Because the observers also evaluated the interface while the operators performed the scenarios, the argument can be made that there were actually more than five users evaluating the HSI and with reasonable confidence the bulk of the issues were successfully identified. Furthermore, this design is still under development and with additional reviews any lingering usability issues will be identified through the verification and validation approach.

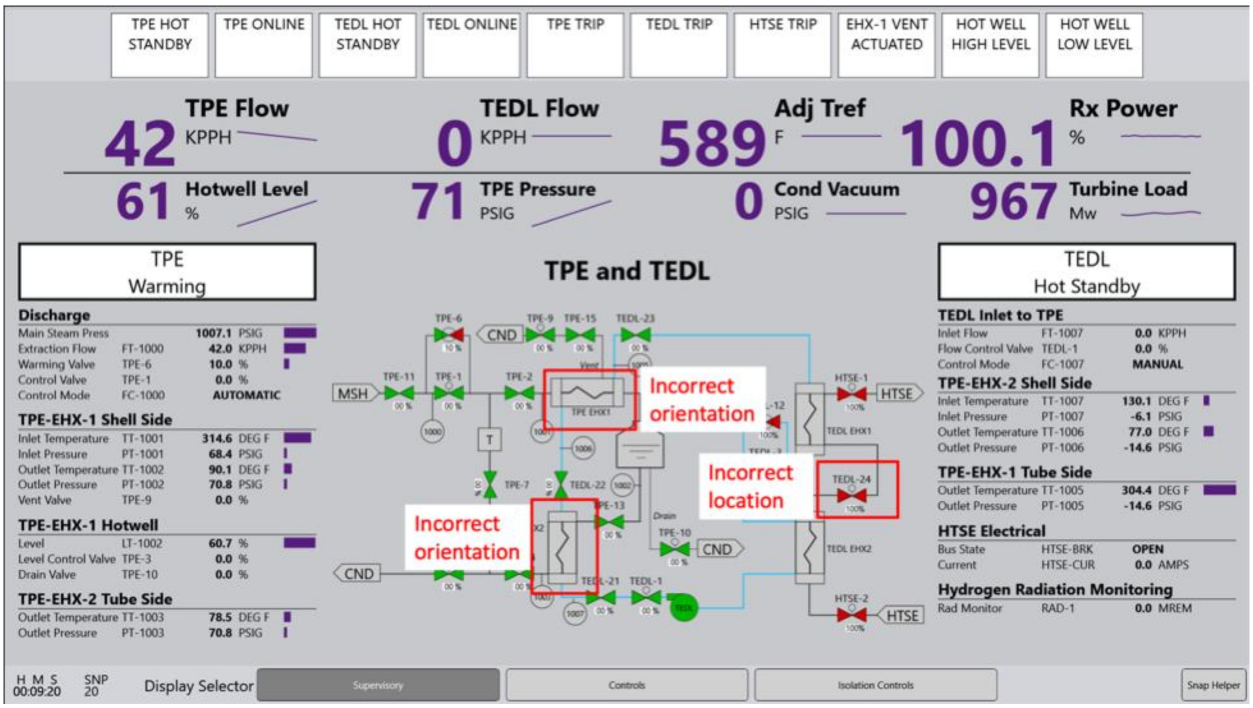

Figure 12. HSI supervisory display depicting the incorrect orientation of the heat exchangers and valve TEDL-24 in the wrong location in the P&ID mimic.

3.6.2.2-2 Nomenclature

Nomenclature was a category of notable findings and issues identified during the evaluation. In particular, the nomenclature for the instrument and valve names was discussed several times throughout the study and explicitly addressed during the final study debrief performed for each of the two groups of operators. Central to the nomenclature is identifying a naming convention that is consistent and easy to interpret. Two of the operators were from the same NPP, but the remaining operators, including the BWR operator included on the research team, all reported different naming conventions for their components. Within the HSI, the primary confusion observed and reported was linking the controller and associated sensor instrumentation to a corresponding valve. For example, TPE-1 in the HSI supervisory display refers to the valve itself, while FC-1000 refers to the flow controller that manipulates the valve position of TPE-1. Based on the various suggestions provided by operators and to make this relationship more explicit, the general consensus for a solution was to add the flow controller instrument designation in the P&ID mimic directly below the corresponding valve. For example, FC-1000 would be labelled directly below the TPE-1 valve in the P&ID mimic.

The nomenclature "TPE-EHX-1 Vent Interlock is Armed" was confusing to operators (see Figure 13). The correction for this issue was to remove the interlock terminology and use the auto and manual mode for the vent to denote whether it will trigger at the setpoint value or whether it is controlled manually. This also reduces the iconography required to display the interlock status and eliminates clutter on the display because this is redundant information to the auto and manual state denoted in the controller.

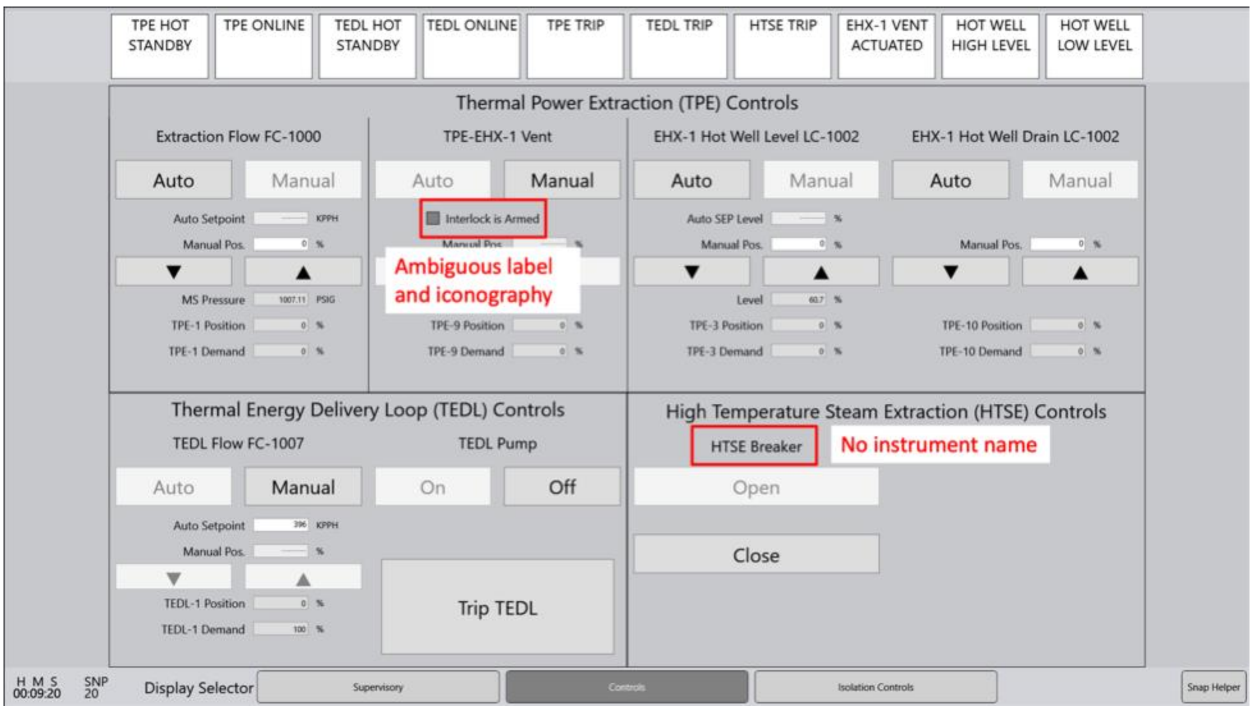

Figure 13. HSI control display showing the ambiguous "Interlock is Armed" status indicator.

The operators also reported a few issues with the nomenclature of the key parameters section of the HSI supervisory display. The TPE Flow label does not clearly convey where flow is being measured; it should be relabeled to TPE Extraction Flow and should match the data table label as well. The same issue was identified for the TPE Pressure key parameter since it was unclear where in the system this pressure was measured. The label should be revised to TPE-EHX-2 Outlet Pressure to convey its location. Last, the operators requested the inclusion of the turbine status because it is used in tandem with valve manipulations during several of the scenarios evaluated, as can be seen in Figure 14.

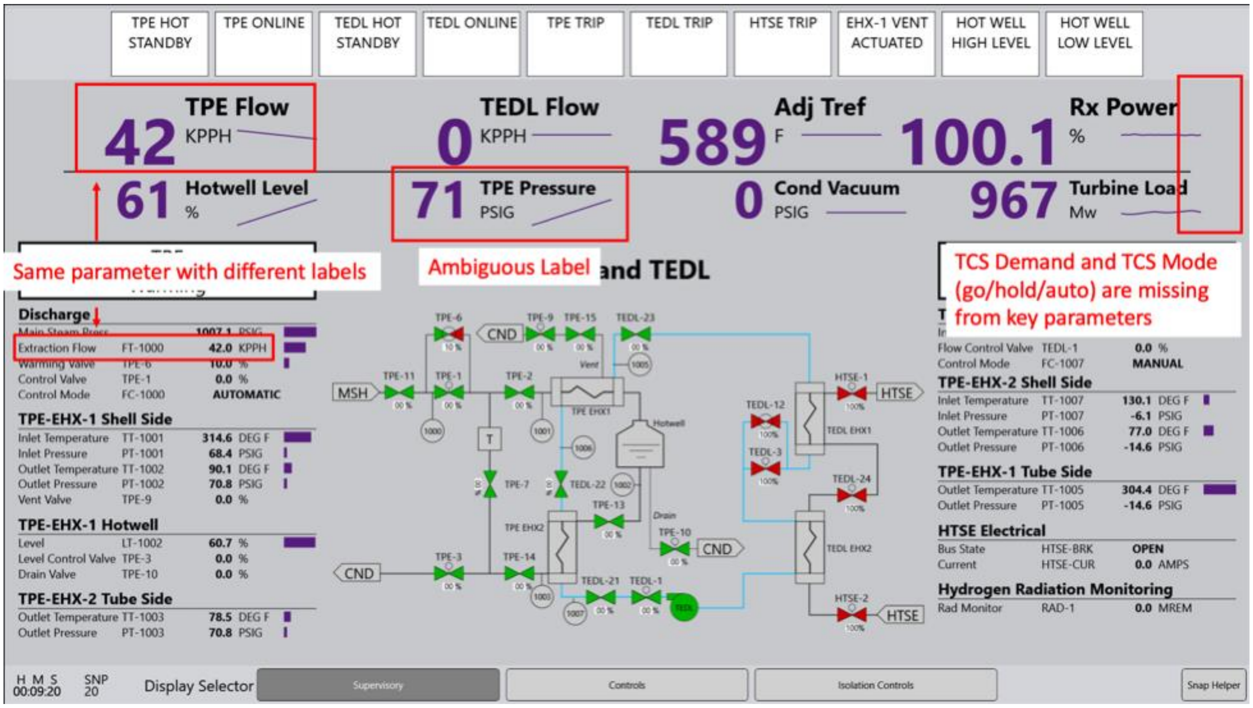

Figure 14. HSI display depicting ambiguous and inconsistent labeling with missing TCS demand and mode indication.

3.6.2.2-3 Consistency

To meet the expectations of the operators and convey information in a manner they are accustomed too, it is important to use consistent styles across display elements of the same type. Consistency should be applied across the interface, and deviations should only be made judiciously. The study identified several issues with consistency. The first issue, as can be seen in Figure 15, pertains to numerical precision consistency for parameters within the display. The data tables contain a single decimal place precision while P&ID mimic valve position indicators have integer percentage precision, and key parameters have integer parameter precision with the exception of Rx Power. As mentioned previously, consistency should be strictly adhered to unless there is a strong reason to deviate from it. In the case of the key parameters, the precision difference was not an issue because these are meant to serve as at-a-glance indicators; therefore, integer precision was adequate. Rx Power is an important key parameter. In particular, having a single decimal value precision is desirable because the plant operates near 100%, but any deviation above 100% is a potentially serious situation. Operators must be aware of the Rx Power to a greater accuracy. The operators were directly asked whether the inconsistent decimal precision was an issue for the key parameters, and none reported an issue with the current configuration.

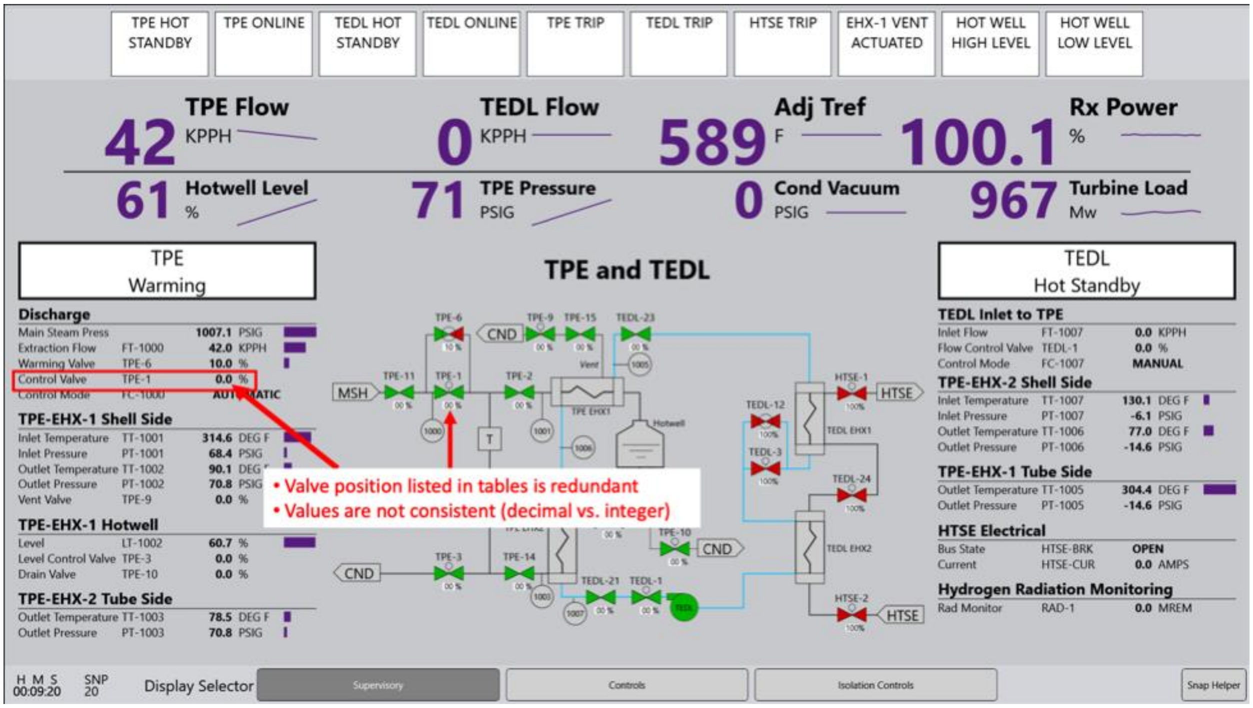

Figure 15. HSI depicting the ambiguous correspondence between the valve position in the data table and the valve position as represented in the P&ID mimic.

The data table and P&ID mimic inconsistency were noted by several operators as a source of confusion. The original intent of data tables was to provide an indicative summary of groups of instrumentation depicted on the P&ID mimic. For example, the P&ID mimic depicts the instrumentation associated with the discharge section in the TPE data table with a “1000” in a grey circle. All associated indication for that region of the system are grouped so the operator can identify all parameters quickly in the data table when they are referenced in the procedure. The simulation is calculated and the accuracy that it can provide values is beyond what actual instrumentation might be able to reliably provide. Furthermore, there are some minor changes to these parameters that the decimal level precision is useful for detecting. Unfortunately, the inclusion of valves within the data tables with a different level of precision confused at least two of the operators. One reported that he did not realize the valve represented in the data table was the same as the valve in the P&ID mimic. To alleviate this confusion, the same level of precision should be used for the valves in the data tables and the P&ID mimic. The operators also reported that the valves in an actual plant never provide accuracy beyond 0.5% increments and commonly only provide accuracy to a single percent. Therefore, to maintain consistency throughout the display, all valves will have no decimal place, but rather whole-number percentage level precision.

3.6.2.2-4 Iconography

The iconography refers to the usage of pictorial symbols to represent components and their states. As was the theme throughout the study, the iconography was reported as adequate, but several issues with the were identified.

The operators reported no issue with the use of the red and green colors to represent the valve position, with the exception that at least one operator asked what the color coding represented on this display during the discoverability exercise. Once it was explained that green represented closed valves while and red represented open valves, the operators did not report any further difficulty, and no observations were made concerning the operator confusing the states of the valves. Indeed, the red and green color usage is common throughout the nuclear industry, and its application here is consistent with that usage. During the first scenario, in which the operators were monitoring the interface to observe the use of the TPE-6 bypass valve to warm the TPE system, several operators missed the opening of TPE-6 because the threshold for the dual red and green color coding to indicate partially open (see Figure 16) was set to a threshold of 10% valve position. When asked what the threshold for indicating partially opened at their plants, the operators provided two responses. One noted that the plant they worked at used any registerable reading above zero percent to indicate partially opened. The rest of the operators report that a threshold of 3% or 5% is typical. After debriefing with the operators, a general consensus was formed to use the 3% threshold to show a partial valve position. Interestingly, one operator noted that even with the reduced threshold, the operators shouldn't rely on the dual color change to detect a change in state for the valve, but should independently use the process value and other process parameters to verify the overall process state.

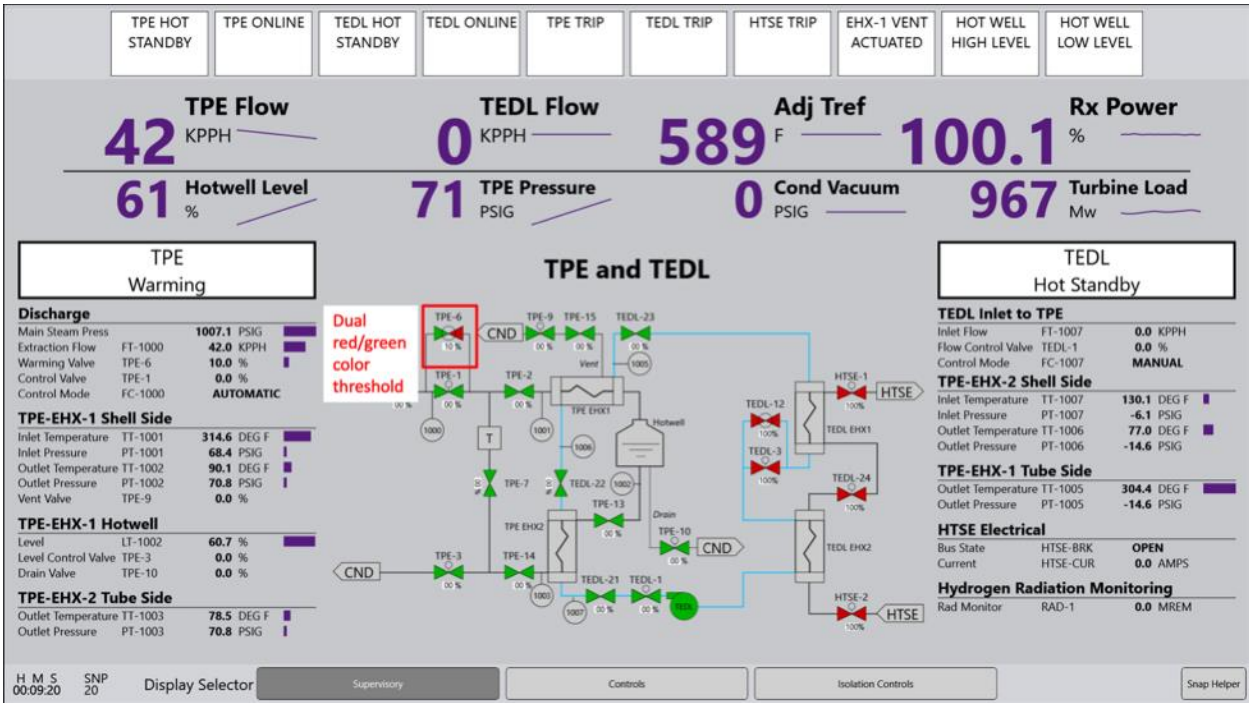

Figure 16. HSI depicting the dual red and green valve position indication to convey that a valve is in a partial state between fully closed and fully open.

Each of the interval parameters represented in the data table has a bar graph to depict the relative range of the value across the span of a control's operational band. The operators never reported using these, and there were no observed instances of the operators using these during any of the scenarios. The original intent was to create a rapid capability to assess the relative levels of the system and provide emergent features that would allow for at-a-glance identification of system health. However, in practice these bar graphs proved unhelpful and will be removed.

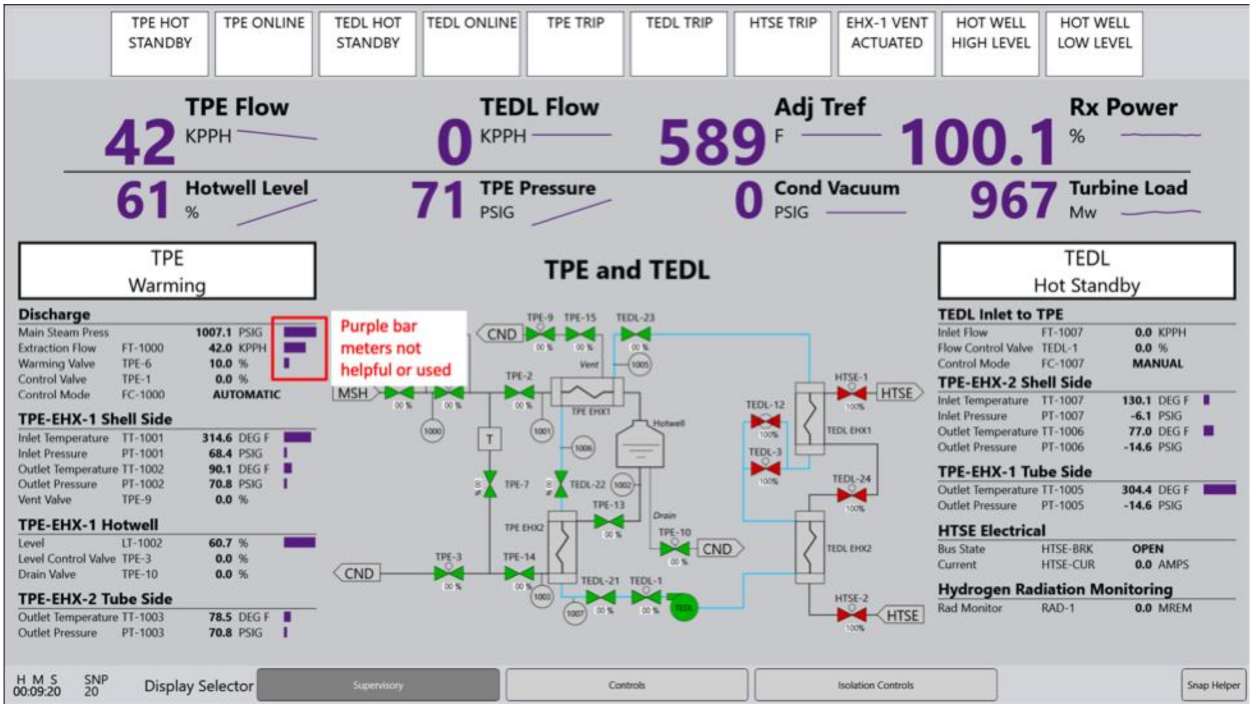

Figure 17. HSI display highlighting the bar graphs used to convey the relative position of each parameter within the data table.

The sparklines used to convey the historical trends for the key parameters was the overall most universally and positively regarded aspect of the HSI design (see Figure 18). The operators noted the trends, and several vocalized their approval of the approach explicitly. The operators were not told what time scale was represented by the sparklines, and when asked, they each reported different time lengths. One operator accurately reported the time span as 20 seconds; another reported the timespan as 2 minutes. The other two reported much larger time spans of 10 and 20 minutes. In all cases, the operators weren't that confident as to the actual time span. This lack of confidence stems from the snapshot nature of the study. After being informed that the actual time span is 20 seconds, all operators reported that the time span should be lengthened, and a general consensus was between 10–20 minutes.

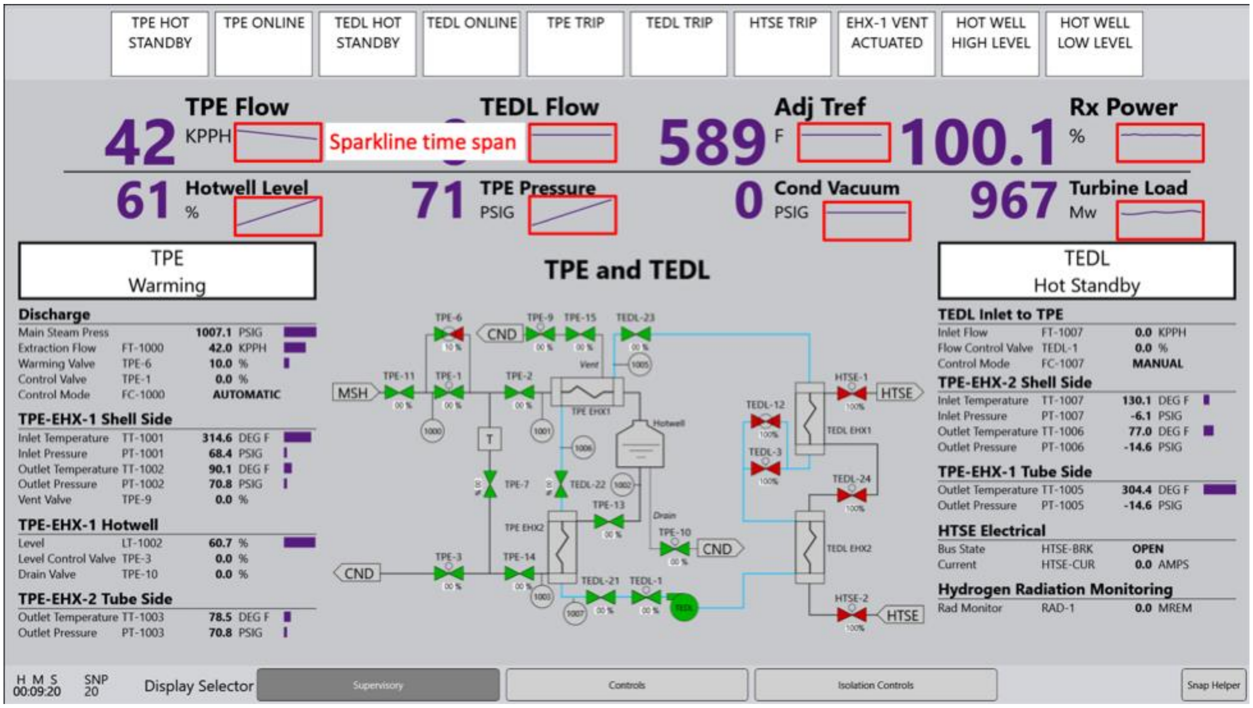

Figure 18. HSI supervisory display depicting the use of sparklines for the key parameters, including along the upper portion of the display.

3.6.2.2-5 Organization

The general structure of the supervisory display included a P&ID mimic in the middle and data tables with supporting indication for the TPE and TEDL systems on each side of the P&ID mimic (see Figure 19). The design was intended to support the operators in using the P&ID mimic to orient themselves grossly within the system, and then they can move to the data tables to find more detailed information concerning the indication positioned near each of the valves and denoted in the P&ID mimic with a grey circle and number associated with the cluster of instruments. In practice, this workflow was not observed. Instead the operators tended to treat the P&ID mimic and data tables as separate entities. Some operators did use the P&ID mimic and data tables as was intended and reported they liked the organization, but others reported it was cumbersome. Additional formats were elicited, with the most advantageous concept being an expanded P&ID mimic with the information embedded in the P&ID itself. This could result in cluttered P&ID in which identifying a specific value becomes challenging; therefore, additional recommendations were made to use a hover-on or click feature in which any element in the P&ID can be selected to display the additional indication. This concept will be explored in future research and iterations of the HSI.

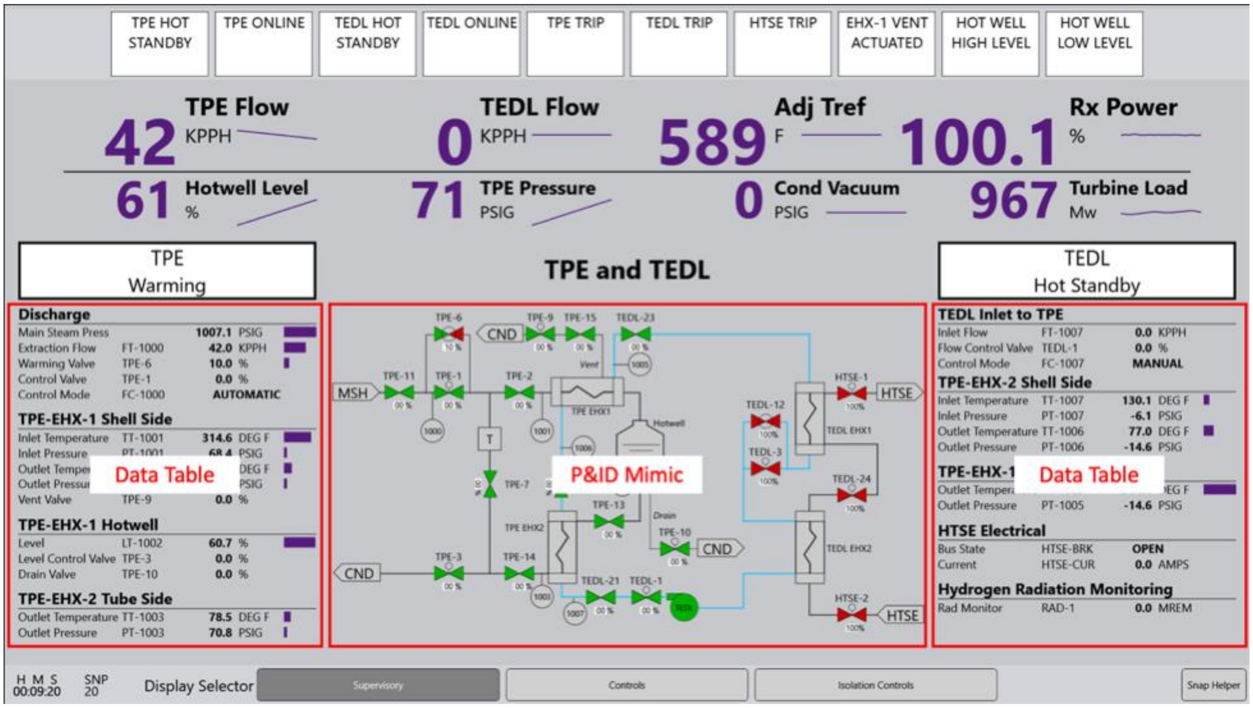

Figure 19. HSI supervisory display depicting the layout of with the P&ID mimic presented prominently in the middle and flanked on either side by data tables of supporting indication.

3.6.2.2-6 Alarms and status indication

The alarms along the top of the display were included as placeholders for future testing for abnormal and emergency scenarios (see Figure 20). As a result, they were not the focus of this study, and the simulation data did not have corresponding points for those alarms, which rendered them nonfunctional within the prototype. This in itself is not an issue as it was known to the research team. It did factor into the evaluation because several operators confused the alarms for the mode indicators referenced in the procedure instructions to check the state of TPE and TEDL. There were several contributing reasons for this confusion. First, the mode indicators are quite similar in appearance to the alarms as they both have near white shading for their backgrounds with black text. Second, the mode indicators used a change in the text underneath the TPE and TEDL labelling to denote the mode as Shutdown, Warming, Hot Standby, and Online. The text change went unnoticed by several operators and, as a result, it was not clear that these were indicators. They were confused for column headers to denote the tables of data below them and were associated with the TPE and TEDL systems respectively.

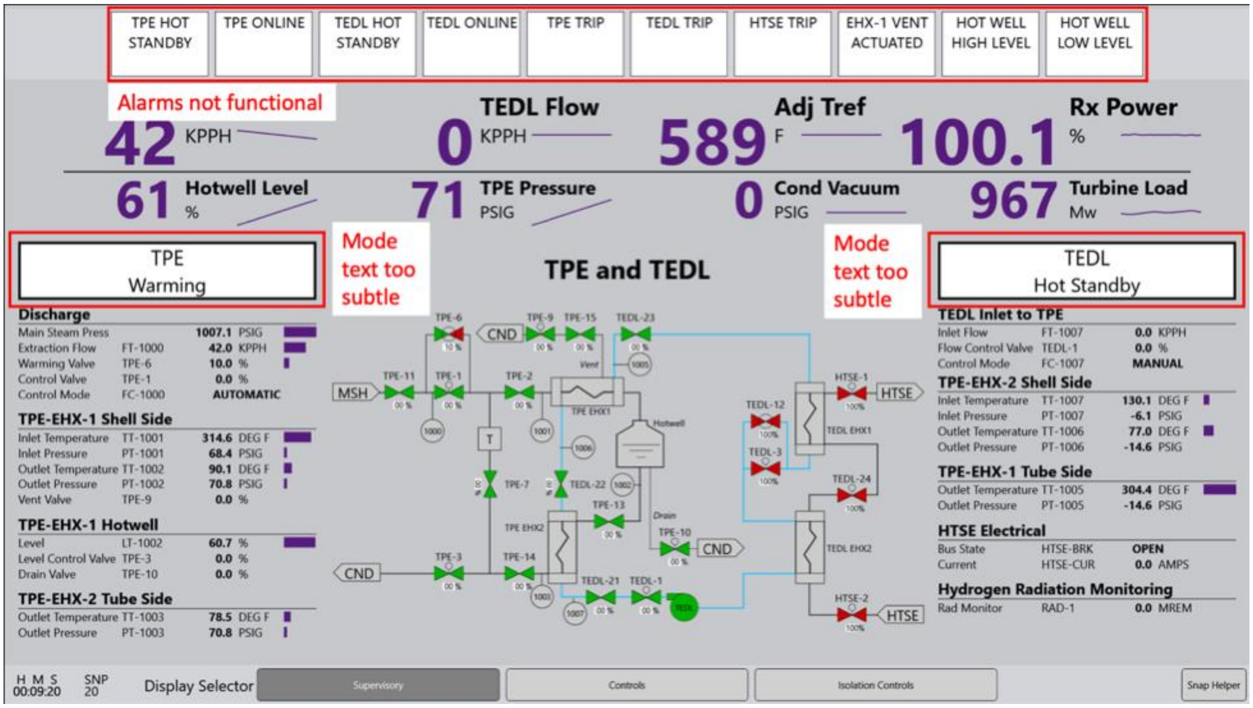

Figure 20. Prototype HSI depicting the non-functional alarms and the mode indicators, which were confused by the operators.

3.6.2.3 Controls

The controls display contains flow and level controllers for the control valves used to manipulate flow in the TPE and TEDL systems. The operators reported that the layout of the control grouping was logical and organized in a manner they easily understood. However, the operators and observers noted several issues with the controls display. The bulk of the issues pertain to the configuration of the controllers themselves (see Figure 21). Each controller has an automatic and manual mode of operation. In automatic mode, the operator can enter the desired setpoint value and activate the control by pressing the enter key. A confirmation dialog is presented to confirm the desired action and to enter the setpoint into the system. To make the mode of operation more salient, the auto setpoint or manual position for each controller was greyed out when in the manual or auto mode respectively. As a result, the operators were forced to place the controller into auto mode and input the desired setpoint. As reported by all operators, this is the reverse of how the interaction should take place because the last auto setpoint entered will be the value towards which the system begins to move when it is placed in auto. This might not be the value that the operator desires. Therefore, both entry fields for auto setpoint and manual will be able to receive input at any time. The setpoint and manual entry fields were part of another issue. It was difficult for the operators to discern if a value had been registered by the system. One recommendation that was provided and adopted is to color code the numeric entry text so that when a number is typed into the field, it remains red to indicate it has not been accepted into the control logic. After confirming the entry, the text changes to green to denote that the system has accepted the value and is using it to control the process.

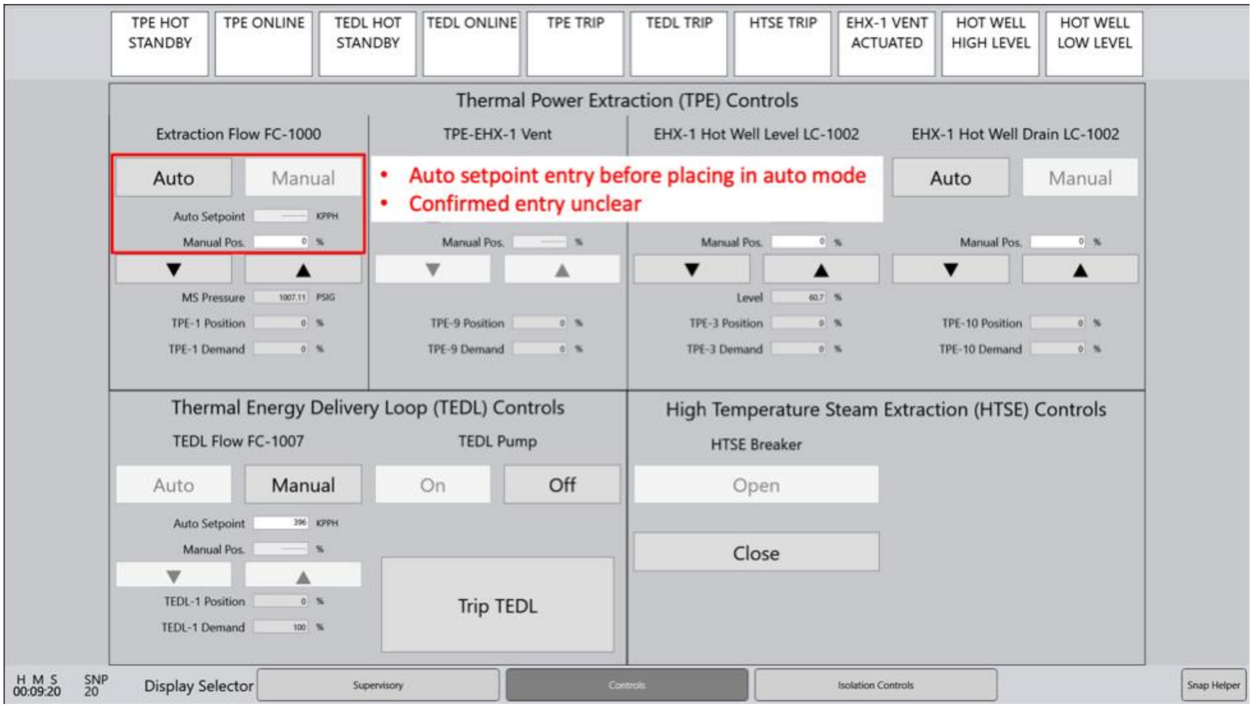

Figure 21. HSI control display depicting issues associated with the configuration of the controllers themselves that did not align with the interaction expected by the operators to manipulate controller.

The operators also reported that the MS Pressure indicator parameter in the Extraction Flow FC-1000 controller was the wrong process parameter and should be replaced by the FT-1000 flow rate indicator. Similarly, the operators reported that they would like the process parameter for TEDL Flow FC-1007, which is the FC-1000 flow rate indicator, included in the control so the process could be monitored without having to return to the supervisory display to see the feedback from the controller.

Figure 22. HSI control display depicting indication reported as necessary to monitor the feedback of the process being controlled by the controller.

3.6.2.3-1 Interactions

At the time of the study, some specific observational measures of interaction described in Section 2.2.1 were largely excluded in favor of purely observational measures. Due to the quasi-static nature of the snap and time series functions of the prototype HSI, operators were not given the freedom to interact with the display in a way that would enable the tracking of false starts and landings. There were several instances during each scenario where operators were unsure as to how to proceed to the next step and needed guidance from the observer acting as the trainer. In most participant lost instances, the procedures required the operators to validate a specific variable or perform a task based on a particular condition; however, the condition was not met due to the operator's incorrectly advancing to the wrong snap for that procedural step. The observer acting as the trainer would then intervene to move the operator to the correct snap location. Due to this structured form of guidance, false starts and landings were not possible to measure. Likewise, this approach ensured operators did not fail to complete a task due to unavoidable issues associated with the remote nature of the tests, such as the need to snap through timepoints and navigate the HSI using a single remote display.

However, there still were findings related to the interactions present in the display, taken primarily from comments made during the study. The concept of interactions, which are defined as communication between system and user, operates at a foundational level in the overall display design. For example, as discussed above and shown in Figure 13, the "Interlock is Armed" status indicator was ambiguous, causing a user interface element design issue. However, the interface element is a design issue primarily due to the fact that it is a poor means of communicating the current state of the particular component—in this case, the interlock. In the case of the "Interlock is Armed" status indicator (Figure 13), prior to giving a command to change the state of the interlock, an operator must first verify the current state. In a conversation, the operator would first ask what the current state is, and that is something that should be readily communicated by the inherent design of the element. In the case of the interlock, a standard checkbox design should readily communicate the state in a way that most users are familiar with.

At a fundamental level, the display should communicate necessary information to take any actions required or show a clear and intuitive navigation path to find the information. During the study, issues were raised regarding consistency of values and designs, relative value measures such as the bar charts in the data tables. In each instance, these show an obstacle to task completion in a way that can be solved by focusing at a baseline level of what communication we are trying to facilitate. As this system is a novel system and is digital, these displays are a significant detour from common nuclear analog operations, so this study was a great opportunity to better understand what communications the operators require to complete tasks using these displays.

In future designs, efforts will be made to reduce the duplicative communication of information without a specific demand and will seek to develop intuitive and simple paths for operators to access more information, as needed. Controls will be co-located with specific process variables that respond to that control's actions in order to enable operators to better assess system response to a control action. Competition for information was a particular problem between the data tables and P&ID representation, so these particular elements will need to be tested further to attempt to understand which is a better modality of information communication. As more complexity is added to the system, the design team will need to better integrate workflows and consider the possible interactions needed versus the interactions provided to ensure a resilient and optimized interface.

3.6.2.4 Procedure findings and issues

At the time of the study, the mock procedures had gone through several iterations. They were initially drafted by the human factors team, then they were reviewed by the operators who participated in this study. This solidified the format and general flow of the procedures in alignment with the existing GPWR procedures and with the terminology for action verbs within the procedures. The procedures were revised as the system was modified and the interface was modified. As a result, the procedures required another iteration of review by the operators during this evaluation. Following the V&V process prescribed by NUREG-0711 (O'Hara, Higgins, and Fleger 2012) and augmented by the guidance from Boring et al. (2014), the evaluation by the operators served as a valuable validation process that extends beyond simply reviewing procedures, as was performed in the prior verification activities for this project. Here, they executed the procedures, which highlighted issues and ensured that the procedures were worded and ordered appropriately, and complete in their prescriptions of the process.

In a typical validation activity, operators have reviewed and practiced using the procedures with the new HSI through training provided to them in a classroom and simulator. As this study is part of the system design, and not the implementation of the system, the operators did not have this prior training, though they each were familiar with the system as they had assisted in its design. As a result, this is not a true V&V process. Some aspects of the procedures have not been populated, in part because the project technical readiness level has not advanced to maturity sufficient that the information can be provided. For example, the cautions and constraints are sparse because we are performing the initial concept of operations validation. These will be refined; indeed, this study assisted in identifying some of this content as part of the study outcome.

The validation of the mock procedures can be termed a success for the evaluation as the majority of the operators reported the procedures adequate, given the stage of the project, with the obvious caveat that there are issues that shall be resolved as the project continues. The revised procedures represent a significant outcome that directly contributes to the concept of operations for coupling an NPP to a hydrogen production plant. These procedures provide a formalized documentation of the concept of operations associated with the system and describe the process of performing the evolutions associated with the TPD. Therefore, the four revised procedures are included as appendices to this report. The following sections describe the issues identified by the observers and the operators' self-reports while performing the scenarios and the post-scenario debriefs.

3.6.2.4-1 General

There were several issues that fall under the general category in that they pertain to all the procedures and not a specific instance of an issue necessarily. One of the most prominent issues illustrates this general concept. The manner in which the instruments were referenced within the procedure was not consistent and led to confusion. Most often, instruments are referred to by their tag or instrument name (e.g. TT-1001). Because operators were new to the system, they did not know whether the instrument was part of the TPE or TEDL system. To remedy this issue, the procedures should always provide the system and description—e.g., TPE-EHX-1 Shell Outlet Temperature, in addition to the tag.

The tag enumeration of the control valves is not consistent with the enumeration of the controllers. Operators expected these to be consistent. For example, operators expected FC-1000 to control TPE-1000. Operators familiar with the GPWR control room noted that the plant maintains two designations in such cases. TPE-1 would also be referred to as TPE-FCV-1000 to clearly indicate what controller is modulating the valve.

5. **VERIFY** TPE-1 (TPE-FCV-1000) is closed.

Figure 23. Depiction of how control valves should be referenced in the procedure.

At the end of these procedures the temperatures and pressures may not be exactly at the setpoint. The procedure should allow for temperatures and pressures to move “gradually in the upward direction” for Procedure 1 and “gradually in the downward direction” for Procedure 4.

We also discovered that Procedure 1 was missing several place-keeping marks (check offs or initial boxes).

For specific installations it should be possible to define criteria for when a system is shutdown, warming, in hot standby, or online. This will allow the criteria and the target values to be written into the procedure. This would also be useful because the final monitoring at the end of the procedure would not require operators to refer back to target values set early on in the procedure.

Segmenting procedure steps to ensure that only a single action is contained within each step is critical to preventing the error in which the operator misses one the of the steps. For example, Procedure OP-004, Step 5 is written as can be seen in Figure 24. This step should be split into multiple steps so that each action has its own place-keeping.

The header of the procedures did not list the procedure number or the current revision.

5. **PLACE** FC-1000 and FC-1007 in manual mode.

Figure 24. OP-IES-004 depicting two actions incorrectly combined within a single procedure step.

3.6.2.4-2 Order

The order of items within the procedure was found to be incorrect in several instances. The attachments for valve lineups found at the end of each procedure did not list the valves in the order that operator Alpha would prefer to open them. The valves should be listed in that order or a logical order that is consistent with the way a field operator would check them or manipulate them.

Instead of having a step to change reactor power, reactor power at or below a certain level can be made a prerequisite. Then the shift supervisor and the operators can decide how to meet the desired reactor power requirement prior to completing the procedure. Otherwise, operator Alpha felt that the procedure was dictating how reactor power and turbine load were controlled as opposed to allowing the crew to determine the most appropriate strategy.

When shutting down the TPE and TEDL from online operations to hot standby, the HTSE breaker should not be opened until the thermal power extraction is ramped down. This allows the HTSE system to continue producing hydrogen during the shutdown procedure. If the breaker is closed early in the procedure, the HTSE system would have to deal with the excess heat by some other means.

In Procedure OP-003, the note regarding TPE Flow and TEDL flow if pressure drops below 200 PSIG should precede placing the TCS in go (see Figure 25). Generally, operators should know these sorts of contingencies before moving the plant; however, it should be moved before Step 10 in the procedure, as can be seen in Figure 26.

10. **PLACE** TCS in GO. _____

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11. **CONTINUE TO LOWER** FC-1000 as turbine load increases while keeping reactor power at or below 99.5%. _____

> **NOTE**: If at any point the pressure of PT-1003 drops below 200 PSIG, immediately perform steps 12 and 13.

12. When the TPE target flow rate OR target turbine demand are reached **SET** FC-1000 setpoint to target flow rate and **PLACE** FC-1000 in auto mode. _____

13. **SET** FC-1007 to target flow rate. _____

Figure 25. Steps 10-13 of Procedure 3 used in the workshop. The note should precede Step 10.

NOTE: Once the TCS is placed in GO the TPE-EHX-2 tube outlet pressure (PT-1003) and TPE target flow should be monitored according to Step 10.

9. **PLACE** TCS in GO. _____

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10. **WHEN** TPE target flow rate is reached
OR Turbine target demand is reached,
OR at any point TPE-EHX-2 tube outlet pressure (PT-1003) drops below 200 PSIG
THEN PERFORM the following

    a. **SET** TPE Extraction Flow FC-1000 setpoint to target flow rate and **PLACE** FC-1000 in auto mode. _____

    b. **SET** TEDL Inlet Flow FC-1007 setpoint to target flow rate and **PLACE** FC-1000 in auto mode _____

Figure 26. Revised placement of note and procedure logic.

In Procedure OP-004, the TEDL pump should be turned off before setting the TEDL-FC-1007 to 0 and closing TEDL-1 (TEDL-FCV-1007). Procedure OP-004 has the operators close TPE-1 and TEDL-1 valves before looking for verification. The sequence has been altered to support action and verification for each of these actions in sequence.

3.6.2.4-3 Missing Content

Whenever a procedure requires directing an entity to prepare for something, the procedure should have another step to verify the entity is ready.

Procedure 1 does not direct the HTSE plant to prepare for startup of TPE and TEDL.

In Procedure OP-004 when informing the HTSE plant that the TPE will be shutdown, the procedure should also informs the HTSE plant that the TEDL will also shutdown.

The attachment to place all valves in the shutdown state at the commencement of Procedure OP-004 is missing. There should be a step stating to complete Attachment 1 to return valves to their shutdown state along with the accompanying attachment at the end of the procedure.

3.6.2.4-4 Typographic Error

The title of Procedure OP-003 is inconsistent with the other procedures. The title should be made consistent by having the evolution description in parentheses.

In Procedure OP-004, the purpose is to transition from “Hot Standby to Shutdown” and not “Shutdown to Hot Standby” as currently stated in the procedure.

3.6.2.4-5 Nomenclature

Reactor power should be referred to as reactor power and not reactivity.

The terminology “Vent Interlock is Armed” was confusing to operators. Because the armed functionality is redundant with the vent controller mode being in auto verses manual, the terminology can be replaced with “Vent Controller is in Auto.”

The interface refers to the HTSE electric bus, but the procedures use the terminology “H_2 electric bus.” The procedures should be changed to be consistent with the interface.

3.6.3 Questionnaire

Because the questionnaire primarily asked participants closed-ended questions with the opportunity for comments there is little in the way of quantitative results to discuss. However, there are distinct qualitative trends across the two operator categories and some interesting results that were consistent across all operators. The hypothesis for the questionnaire and the purpose of the pre- and post-test configuration was to capture specific learning characteristics. It was assumed that the operators would report more affirmatives on questions related to the display making sense, its usability, and its overall function. It is a reasonable assumption that these aspects of an interface would be learned, and the subsequent assessment would reflect that familiarity. However, what makes the questionnaire results interesting is that all four participants actually reported the opposite. This pattern of results suggests that, with additional experience and after learning more about the functionality, the operators began dissecting the HSI more thoroughly and were able to identify issues that they previously had not when they had little experience with the interface. Pre-test responses were notably more positive regarding the usability and other functional questions when compared with the post-test, and across the entire group of participants, more confusion and reticence was reported. While, observationally, the participants were clearly more comfortable toward the end of the scenarios than they were during the discoverability exercise, the responses show that they were focusing on the bigger picture of the experience and operating the system in a realistic environment. The critical nature of their post-test opinions was interesting and matched the team’s observations across the scenarios. In many instances, the questionnaire responses reported the same concerns or issues that they stated during the tasks, as well as the difficulties that the human factors team noted in the evaluations of their performance. Collectively, this pattern of results provides evidence that our approach was valid in providing a thorough examination of the HSI.

In some disciplines, a user evaluation that appears to get worse with familiarity would be considered a negative outcome. However, in human factors, the goal is to get at the mental models and honest opinions of the users. The questionnaire responses in this study were a success in that the team was able to capture the operator mental models, workflows, and clear design issues and recommendations. Additionally, it is a demonstration of the solid understanding of the research protocol that participants and human factors team members were aligned across the self-report measures, qualitative feedback, and observational data. These results also highlighted specific design recommendations for the next iterations of the prototype HSI and future research to support the concept of operations for thermal and electric power dispatch. Additionally, the results provided specific element level feedback, which enables the human factors team to focus on specific design improvements at the micro level, as well as the macro level of the integrated display scheme. Finally, a successful result from the questionnaires was their alignment with observational findings. The questionnaires were able to validate the team’s observations and the qualitative feedback from the operators. This reinforces the experimental design and ensures that the observations were accurate when compared with the actual self-reports from the operators.

3.7 Discussion

3.7.1 Concept of Operations Evaluation Outcomes

In this study, four operators participated in a prototype HSI evaluation project within the context of a concept of operations for a hypothetical system coupling an NPP with a nearby hydrogen production plant. Several significant outcomes stemmed from this evaluation of the system, HSI, and procedures. First, the evaluation indicated that this initial concept of operations is feasible for the preliminary design of the integrated energy system. The operators reported that they were able to perform the evolutions without significant difficulties. There were a number of issues identified, and these will be addressed moving forward. The issues noted in the system model will be examined and addressed during the future activities. The HSI issues with clear solutions and consensus concerning those issues were implemented post-study, and the updated displays are presented below.

The updates to the interface are many, and details can be found in section 3.6 on the HSI, but a few are worth highlighting here. The TPE and TEDL mode indicators were changed to show four separate indicators for Shutdown, Warming, Hot Standby, and Online. Only one indicator is illuminated to denote the mode. This scheme was much more salient than the text change used in the study (see Figure 27). The bar graphs were removed because they were reported to be unhelpful and to create a less cluttered and cleaner interface and make it easier to extract an individual value from the data tables. The orientation and flow paths for the TPE-EHX-1 and TPE-EHX-2 heat exchangers were corrected. In the control display, controllers were updated to use a red and green color scheme. Values that had been entered, but not yet accepted by the system, are now shown in red. After the system accepts the values, the color of the values changes to green to indicate the system acceptances entered (see Figure 28). Furthermore, the interlock indication was removed in leu of the auto and manual mode indication to remove ambiguity and maintain consistency.

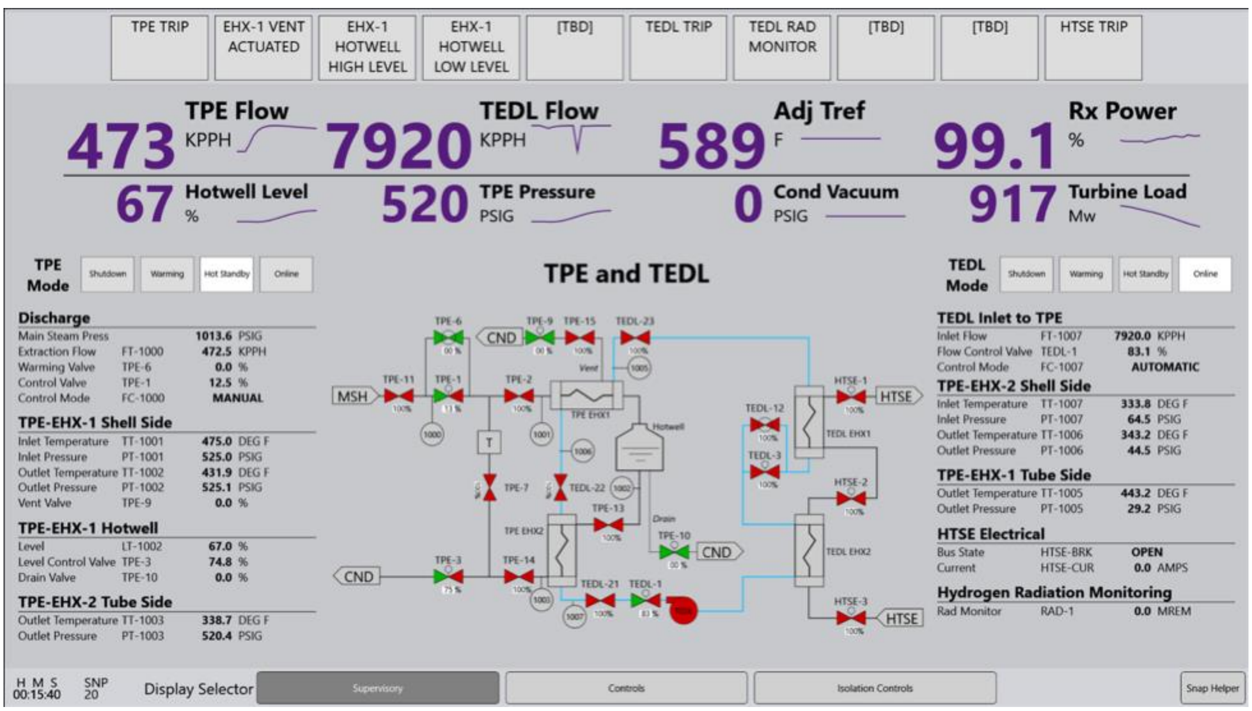

Figure 27. HSI supervisory display with updates made based on the operator study.

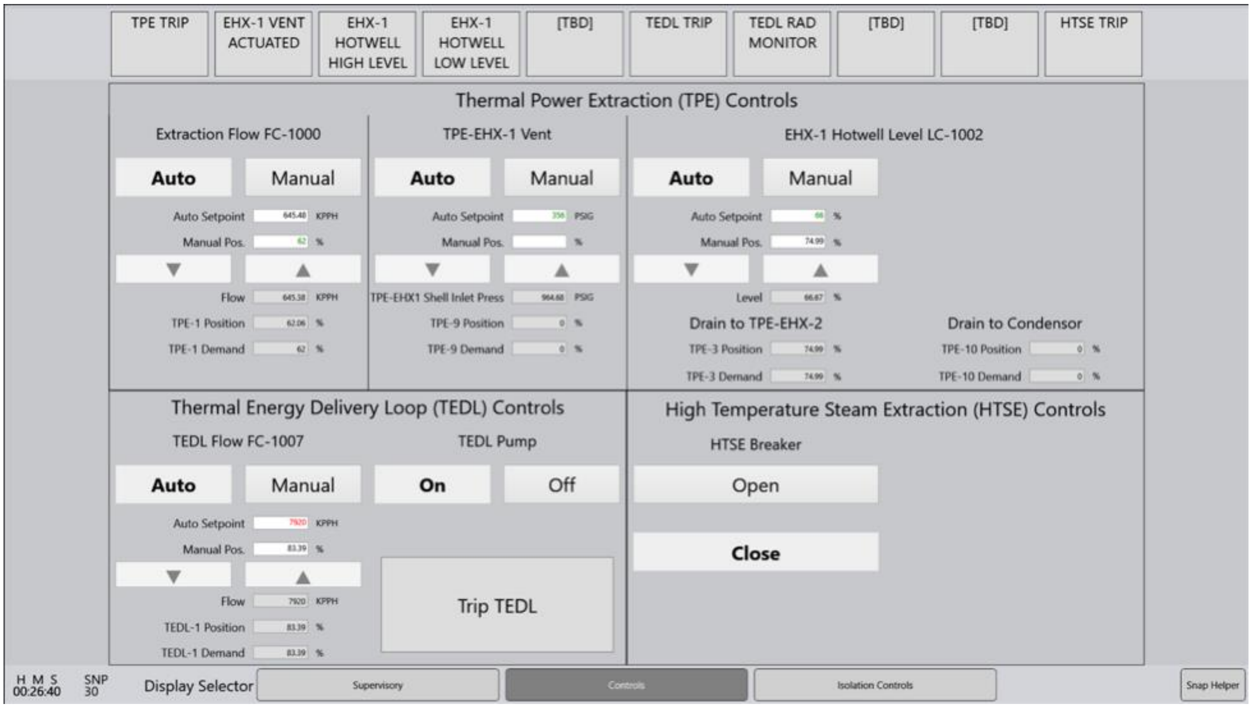

Figure 28. HSI control display with updates made based on the operator study.

The methodology to capture findings and issues was effective. Furthermore, the complementary sources, including the operator self-reports, observations, and questionnaire responses, served as form of cross-validation and captured overlapping issues. This ensures that issues are identified and identified consistently.

The remote testing format was helpful in identifying issues with the HSI and in improving understanding of the interactions between the different systems during operations, but it cannot supplant in-person testing that should be performed to evaluate the thermal and electric power dispatch capability integrated within the main control room simulator. While remote testing suffered some difficulties, as mentioned, it was still a successful way to undergo preliminary interface evaluations. The recorded data approach had some *ad hoc* or clunky characteristics, but it was also more successful than a purely static approach and could be improved with more refinement in how operators progress through data snaps. The remote testing format was effective in testing specific interface concepts or elements and could yield more design iterations and improvements through the relative ease of constructing a scenario when compared with setting up a full study in person and requiring participants to travel.

Succeeding iterations of the system will be able to incorporate these foundational structures in a way that ensures that interactions are more intuitive and expected by the operator mental models. The complementary measures used were extremely effective in the elicitation of the operator mental models. As mental models and cognitive tasking can be difficult to elicit, the protocol here was successful in providing a clear foundation for what to expect in future studies. It is important to remember, as mentioned in Section 2.2, that interaction design as a standalone concept is often overlooked in nuclear process control. This interface suffered in some instances from this process, but the results gave the team clear guidance on how to move forward in designing these interactions and validate them as well.

3.7.2 Future Directions

The present study gave the team significant insight into design choices and recommendations moving forward, as it tested some novel concepts such as remote testing and interaction design methods. As with most experiments, it also generated more questions for the team to answer in future research activities. Some of the specific questions the team will seek to pursue are:

- Element level testing of particular components
- Understanding and establishing the integrated communication platforms for the grid, hydrogen, and nuclear relationships
- Enhanced scenario design and testing, specifically with abnormal and emergency situations
- Overall interaction design of the interface and the operator characteristics involved
- Integration with future physical test platforms
- More iterative small-scale remote testing and interface evaluation
- Exploration of the feasibility of more remote testing platforms and live streaming of simulations via GPWR, the Rancor microworld or physical test platforms, all of which explore the concept of a remote operations
- Possible collaboration with other remote monitoring capabilities, such as the Monitoring, Diagnostic, and Automation Laboratory located at INL

The results from this study demonstrate that there are different preferences and expectations from the particular data visualizations employed in the prototype HSI. Some elements are clearly more effective as interface components than others. However, in some cases, it is not clear which components are the most effective. In particular, it is not yet clear whether the data table format is a more effective means of summarizing equipment status than are indicators in the P&ID mimics. The team will seek to explore different design concepts and test some elements in order to understand the differences between the cognitive influence that each element has on an operator's understanding.

The scenarios designed for this study were normal OPs. The scenarios represented movement from one particular system state to another, rather than specific maintenance activities, abnormalities, or emergencies. The team will seek to design these abnormal or emergency evolutions to begin testing future concepts of operations at a greater depth of information and to understand whether the interface enables operators to perform well under duress. These abnormal circumstances are critical to testing the resiliency of the operators within the context of the particular system and can yield additional design insights that are not considered during normal operations.

Future iterations of the systems will explore the behavior and communications of the system and operator relationship and seek to understand the complexity of the digital interface and workflows involved in the performance of the system. Iterations of the system will attempt to pay particular attention to the results from this study and how an operator's mental models performed as they used this novel system within a purely hypothetical concept of operations. The team will seek to identify and define some foundational interaction aspects that are present throughout the system's performance.

Due to the success of the remote testing of the TPD interface system, the team will consider leveraging this capability with future work on the TPD concept of operations. In traditional control room design, the team builds to one larger single final evaluation to test the ideas generated throughout the design phases. However, remote testing offers opportunities to use preliminary tests to provide multiple operator feedback events and iterate on various design concepts. This ability should greatly increase the effectiveness of each iteration as user feedback will be more frequent and less time and effort will be spent on designs that are less than optimal.

As part of the focus on an increased frequency of user involvement, the team will also seek to research and establish more real-time or live instances of the simulation. This study was particularly limited and required the use of pre-recorded data, but to truly test the interface and operators, a live simulation is needed. The team will work inside INL and with vendors, as needed, to develop the capability to test designs with a live simulation environment within a GPWR concept, a microworld environment such as Rancor, or a physical system model.

With the remote testing of the TPD interface, the team realized that this was an initial test of a remote operations interface. Regardless of the reality of the use of pre-recorded data, the operators were controlling an interface remotely with success. This direction closely aligns with some other work being done in nuclear to explore the feasibility of remote monitoring of systems with advanced sensors. This work is being undertaken within the newly established Monitoring, Diagnostic, and Automation Laboratory at INL, and the team will seek to collaborate as remote operations are explored. By creating a link between the TPD system interface and a live simulation environment, the team can explore and validate operation capability while operating a live simulation remotely.

In terms of the overall TPD project, the research team has a number of future efforts. The most critical aspect of this integrated energy systems concept is to create an effective method to coordinate between the NPP main control, the electrical grid, and the hydrogen production plant to support the capability to transition between hydrogen production and pure electrical generation modes of operation. In order to evaluate this coordination, the system design and the simulation modeling capabilities to represent the design must be expanded to include the switch yard, the electrical grid, and the HTSE plant. In addition to expanding the simulation to incorporate these additional aspects, there is also a thrust to include equipment-in-the-loop testing with physical test platforms, such as the Thermal Energy Delivery System (TEDS) at INL. Including hardware-in-the-loop will increase the fidelity of the concept of operations and will offer opportunities to identify additional operator and system interactions that cannot be identified in a purely simulated environment.

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Appendix A

OP-IES-001 Post Evaluation

Appendix A
OP-IES-001 Post Evaluation

GSE POWER SYSTEMS

Continuous Use

GPWR NUCLEAR PLANT

PLANT OPERATING MANUAL

PROCEDURE TYPE: OPERATING PROCEDURE

NUMBER: **OP-IES-001**

TITLE: **TPE and TEDL Operation (Shutdown to Hot Standby)**

TABLE OF CONTENTS

Section

1.0 PURPOSE

1. This procedure provides operating instructions to transition the Integrated Energy System (IES) from a shutdown to hot standby state. The IES consists of the following systems:

    a. Thermal Power Extraction (TPE)

    b. Thermal Energy Delivery Loop (TEDL)

2.0 REFERENCES

2.1 Plant Operating Manual Procedures

1. N/A

2.2 Technical Specifications

1. N/A

3.0 PREREQUISITES

1. The plant AC Distribution System is in operation per OP-156.02. _____
2. The plant DC Distribution System is in operation per OP-156.01. _____
3. The Compressed Air System is in operation per OP-151.01. _____
4. The Main Condenser Air Removal System is in operation per OP-133._____
5. The Condensate System is in operation per OP-134. _____
6. Valve Testing has been performed per OP-IES 5.3 _____
7. Reactor power is over 70%. _____
8. Turbine load is over 70%. _____
9. TPE is in a cold shutdown state:

    a. TPE-EHX-1 shell side inlet temperature TPE-TT-1001 is below 200 °F _____

    b. Attachment 1 of this procedure is complete _____

4.0 PRECAUTIONS AND LIMITATIONS

1. Thermal Power Extraction (TPE)

   a. Maximum of 5% is currently planned for total TPE extraction when operating at full power.

   b. Increasing steam diverted through the TPE will cause reactor power to increase.

2. Thermal Energy Delivery Loop (TEDL)

   a. N/A.

5.0 PROCEDURE

NOTE : General flow of the startup process for the IES is the following:

- Warm up TPE
- Warm up TEDL
- Engage and maintain thermal energy supply to hydrogen plant

BEGIN TPE AND TEDL WARMUP EVOLUTION

1. **DIRECT** HTSE plant to prepare for TPE and TEDL warming to hot standby. _____
2. **OPEN** isolation valves:
   a. Direct a field operator to align valves using Attachment 2 - Valve Alignments for TPE and TEDL Hot Standby and Online State Checklist _____
3. **VERIFY** TPE-EHX-1 shell side outlet pressure TPE-PT-1002 is stable and above 50 PSI _____
4. **VERIFY** TPE FC-1000 is in manual control mode. _____

NOTE: During warming, hot standby, and online modes EHX-1 Hotwell Level should be operated between 60 and 70%.

5. **VERIFY** TPE-1 (TPE-FCV-1000) is closed. _____
6. **VERIFY** TPE-LC-1002 is in manual mode. _____
7. **VERIFY** TPE-3 (TPE-LCV-1002) is closed. _____
8. **VERIFY** TPE-EHX-1 Vent is in auto mode. _____
9. **TURN ON** the TEDL Pump. _____

10. **DETERMINE** target temperatures and hotwell water level for TPE-EHX-1 and TPE-EHX-2

    a. temperature

        (1) TPE-EHX-1 shell side Inlet temperature TPE-TT-1001 470 °F _____

        (2) TPE-EHX-2 tube side outlet temperature TPE-TT-1003 300 °F _____

        (3) TPE-EHX-2 shell side Inlet temperature TEDL-TT-1007 300 °F (oil) _____

        (4) TPE-EHX-1 tube side outlet temperature TEDL-TT-1005 470 °F (oil) _____

    b. Water level

        (1) TPE-EHX-1 Hotwell Level 66 % _____

11. **DETERMINE** target TCS demand and ramp rate for thermal power extraction pressurization

    a. TCS Demand 926 MW _____

    b. TCS Ramp Rate 5 MW/min _____

12. **VERIFY** HTSE plant is ready for TPE and TEDL startup. _____

13. **PLACE** TCS in GO. _____

14. **DIRECT** a field operator to **SLOWLY OPEN** the TPE Warming Valve TPE-6 to 10% to pressurize TPE. _____

15. **VERIFY** TPE Extraction Flow TPE-FT-1000 is below 45 KPPH. _____

16. When TPE-EHX-1 Hotwell Level TPE-LT-1002 reaches target 66%:

    a. **SET** TPE Hotwell TPE-LC-1002 setpoint to target _66_% and **PLACE** TPE-LC-1002 in auto mode. _____

b. **VERIFY** the TPE Hotwell Level control valve TPE-3 (TPE-LCV-1002) opens and TPE Hotwell Level TPE-LT-1002 approaches setpoint. _____

17. **SET** TPE Extraction TPE-FC-1000 setpoint to target <u>32.4</u> KPPH and **PLACE** FC-1000 in auto mode. _____

18. **WHEN** TPE-EHX-2 tube side outlet pressure TPE-PT-1003 is at or above 100 PSIG,
THEN DIRECT a field operator to slowly close the TPE Warming Valve TPE-6. _____

19. **VERIFY** TPE Extraction Flow Control Valve TPE-1 (TPE-FCV-1000) OPENS to maintain TPE Extraction Flow TPE-FT-1000 at target setpoint flow rate.
_____

20. **SET** TEDL inlet flow TEDL-FC-1007 setpoint to target <u>396</u> KPPH and **PLACE** TEDL-FC-1007 in auto mode. _____

21. **VERIFY** TEDL-1 (TEDL-FCV-1007) OPENS to maintain FC-1007 target setpoint flow rate. _____

NOTE: When TEDL flow starts TPE pressure will momentarily drop and recover over time as TEDL warms up.

22. **MONITOR** until the following conditions are met: _____

a. TPE Extraction Flow TPE-FT-1000 stabilizes. _____

b. TPE-EHX-1 shell side Inlet temperature TPE-TT-1001 is at or above target temperature of 470 °F. _____

c. TPE-EHX-1 shell side temperature TPE-TT-1001 is stable or trending slowly in the upward direction. _____

d. TPE-EHX-2 tube side outlet temperature TPE-TT-1003 is at or above target temperature of 300 °F. _____

e. TPE-EHX-2 tube side outlet temperature TPE-TT-1003 is stable or trending slowly in the upward direction. _____

f. TPE Hotwell Level TPE-LT-1002 at operational level between 60-70%. _____

g. TPE-EHX-2 shell side oil inlet temperature TT-1007 is at or above target of 300 °F. _____

h. TPE-EHX-2 shell side oil inlet temperature TT-1007 is stable or trending slowly in the upward direction. _____

i. TPE-EHX-1 tube side oil outlet temperature TT-1005 is at or above target of 470 °F. _____

j. TPE-EHX-1 tube side oil outlet temperature TT-1005 is stable or trending slowly in the upward direction. _____

k. TPE-EHX-1 shell side inlet pressure TPE-PT-1001 is stable or trending slowly in the upward direction. _____

l. TPE-EHX-2 tube side outlet pressure TPE-PT-1003 is stable or trending slowly in the upward direction. _____

m. TPE-EHX-1 tube side oil outlet pressure TEDL-PT-1005 is stable or trending slowly in the upward direction. _____

n. TPE Hot Standby Indicator is illuminated. _____

o. TEDL Hot Standby Indicator is illuminated. _____

6.0 ATTACHMENTS

Attachment 1 – Valve Alignments for TPE and TEDL Cold Shutdown State Checklist

Attachment 2 – Valve Alignments for TPE and TEDL Hot Standby and Online State Checklist

Attachment 1 – Valve Alignments for TPE and TEDL Cold Shutdown State Checklist

This attachment verifies that the TPE and TEDL isolation valves are aligned for cold shutdown.

Sheet 1 of 2

(Independent Verification Required As Indicated)

Person(s) Performing Checklist

Initial	Name (Print)	Initials	Name (Print)

Remarks – Indicate any component not in the prescribed position

____

____

____

____

____

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____

____

Checklist started by ____________________ Time ________ Date __________

Checklist completed by ____________________ Time ________ Date __________

Approved by ____________________ Time ________ Date __________

Unit Supervisor

After receiving the final review signature, this OP Attachment becomes a QA RECORD.

Attachment 1 – Valve Alignments for TPE and TEDL Cold Shutdown State Checklist

Sheet 2 of 2

(Independent Verification Required As Indicated)

NO.	COMPONENT NUMBER	COMPONENT DESCRIPTION	POSITION	CHECK	VERIFY
1	TPE-11	Main Steam IV	OPEN		
2	TPE-2	TPE-EHX-1 shell side inlet IV	OPEN		
3	TPE-7	TPE Steam Trap IV	OPEN		
4	TPE-15	TPE-EHX-1 shell side Vent	OPEN		
5	TPE-13	TPE-EHX-1 tube side outlet IV	OPEN		
6	TPE-14	TPE-EHX-2 tube side outlet IV	OPEN		
7	TEDL-23	TPE-EHX-1 tube side outlet IV	OPEN		
8	TEDL-22	TPE-EHX-1 tube side inlet IV	OPEN		
9	TEDL-21	TPE-EHX-2 shell side inlet IV	OPEN		

Attachment 2 – Valve Alignments for TPE and TEDL Hot Standby and Online State Checklist

This attachment verifies that the TPE and TEDL isolation valves are aligned for hot standby or online operations.

Sheet 1 of 2
(Independent Verification Required As Indicated)

Person(s) Performing Checklist

Initial	Name (Print)	Initials	Name (Print)

Remarks – Indicate any component not in the prescribed position

Checklist started by ____________________ Time __________ Date ___________

Checklist completed by ____________________ Time __________ Date ___________

Approved by ____________________ Time __________ Date ___________

Unit Supervisor

After receiving the final review signature, this OP Attachment becomes a QA RECORD.

Attachment 2 – Valve Alignments for TPE and TEDL Hot Standby and Online State Checklist

Sheet 2 of 2
(Independent Verification Required As Indicated)

NO.	COMPONENT NUMBER	COMPONENT DESCRIPTION	POSITION	CHECK	VERIFY
1	TEDL-21	TPE-EHX-2 shell side inlet IV	OPEN		
2	TEDL-22	TPE-EHX-1 tube side inlet IV	OPEN		
3	TEDL-23	TPE-EHX-1 tube side outlet IV	OPEN		
4	TPE-14	TPE-EHX-2 tube side outlet IV	OPEN		
5	TPE-13	TPE-EHX-1 tube side outlet IV	OPEN		
6	TPE-15	TPE-EHX-1 shell side Vent	OPEN		
7	TPE-7	TPE Steam Trap IV	OPEN		
8	TPE-2	TPE-EHX-1 shell side inlet IV	OPEN		
9	TPE-11	Main Steam IV	OPEN		

Appendix A
OP-IES-002 Post Evaluation

GSE POWER SYSTEMS

Continuous Use

GPWR NUCLEAR PLANT

PLANT OPERATING MANUAL

PROCEDURE TYPE: OPERATING PROCEDURE

NUMBER: **OP-IES-002**

TITLE: **TPE and TEDL Operation (Hot Standby to Online)**

TABLE OF CONTENTS

Section

1.0 PURPOSE

1. This procedure provides operating instructions to transition the Integrated Energy System (IES) from a hot standby to online state. The IES consists of the following systems:

   a. Thermal Power Extraction (TPE)

   b. Thermal Energy Delivery Loop (TEDL)

2.0 REFERENCES

2.1 Plant Operating Manual Procedures

1. N/A

2.2 Technical Specifications

1. N/A

3.0 PREREQUISITES

1. Reactor power is over 70% and below 99%.

2. Turbine load is over 70%.

3. TPE is in a Hot Standby:

   a. TPE-EHX-1 vent valve TPE-6 is closed _____

   b. Steam extraction flow at TPE-FT-1000 at 32.4 KPPH _____

   c. TPE-EHX-1 shell inlet temperature at TPE-TT-1001 is greater than 400 °F and stable or trending slowly in the upward direction. _____

   d. TPE-EHX-1 shell inlet pressure at TPE-PT-1001 is greater than 500 PSIG and stable or trending slowly in the upward direction. _____

   e. TPE-EHX-1 Hotwell level at TPE-LT-1002 is between 60-70% and stable. _____

   f. TPE-EHX-2 tube outlet temperature at TPE-TT-1003 is greater than 300 °F and stable or trending slowly in the upward direction. _____

   g. TPE-EHX-2 tube inlet pressure at TPE-PT-1003 is greater than 500 PSIG and stable or trending slowly in the upward direction. _____

h. TPE Hot Standby Indicator on the IES display is illuminated. _____

4. TEDL is in Hot Standby:

a. TPE-EHX-2 shell oil inlet temperature at TPE-TT-1007 is greater than 300 °F and stable or trending slowly in the upward direction. _____

b. TPE-EHX-2 shell oil inlet pressure at TPE-PT-1007 is greater than 20 PSIG and stable or trending slowly in the upward direction. _____

c. TPE-EHX-1 tube oil outlet temperature at TPE-TT-1005 is greater than 450 °F and stable or trending slowly in the upward direction. _____

d. TPE-EHX-1 tube oil outlet pressure at TPE-PT-1005 is greater than 10 PSIG and stable or trending slowly in the upward direction. _____

e. TEDL Hot Standby Indicator is illuminated. _____

5. EHX-1 Vent Interlock is armed. _____

4.0 PRECAUTIONS AND LIMITATIONS

1. Thermal Power Extraction (TPE)

    a. Maximum of 5% is currently planned for total TPE extraction when operating at full power.

    b. Increasing steam diverted through the TPE will cause reactor power to increase.

2. Thermal Energy Delivery Loop (TEDL)

    a. N/A.

5.0 PROCEDURE

NOTE : General flow of the startup process for the IES is the following:

- Warmup TPE (OP-IES-001)
- Warmup TEDL (OP-IES-001)
- Engage and maintain thermal energy supply to hydrogen plant (OP-IES-002)

BEGIN HOT STANDBY TO ONLINE EVOLUTION

NOTE: Manual control is desired for TPE evolutions using the TPE-1 (TPE-FCV-1000) flow control valve. After stable flow rates have been achieved, automatic flow control using TPE-FC-1000 can be used.

1. **DETERMINE** target TPE flow rate for thermal power extraction
   a. TPE Flow Rate 645.5 KPPH. ______
   b. TEDL Flow Rate 7920 KPPH. ______
2. **DETERMINE** target TCS demand and ramp rate for thermal power extraction pressurization
   a. TCS Demand ____ MW ______
   b. TCS Ramp Rate ____ MW/min ______
3. **VERIFY** TPE Hotwell TPE-LC-1002 is in auto mode and setpoint is between 60-70%. ______
4. **DIRECT** HTSE plant to prepare to receive thermal and electrical energy delivery. ______
5. **CLOSE** HTSE Electric Bus Breaker. ______
6. **RECORD** the time that HTSE Electric Bus is closed.

   Time _____ CLOSED _____

7. **VERIFY** TEDL-FC-1007 is in auto mode. _____

8. **SET** TEDL-FC-1007 setpoint to target flow rate and **PLACE** TEDL-FC-1007 in auto mode. _____

9. **PLACE** TPE-FC-1000 in manual mode. _____

10. **PREPARE** TCS for load change by performing the following

    a. **SET** TCS target demand _____

    b. **SET** TCS ramp rate _____

    c. **PLACE** TCS in Hold _____

11. **VERIFY** HTSE plant is ready for transition from online to hot standby _____

12. **PLACE** TCS in GO. _____

13. **SLOWLY RAISE** TPE-FC-1000 as turbine load decreases until target flow rate is achieved. _____

14. **SET** TPE-FC-1000 setpoint to target flow rate and **PLACE** FC-1000 in auto mode. _____

15. **MONITOR** until the following conditions are met:

    a. TPE extraction flow TPE-FT-1000 stabilizes. _____

    b. TPE-EHX-1 shell inlet temperature TPE-TT-1001 stabilizes. _____

    c. TPE-EHX-1 shell inlet pressure TPE-PT-1001 stabilizes. _____

    d. TPE-EHX-2 tube outlet pressure TPE-PT-1003 stabilizes. _____

    e. TPE-EHX-1 tube oil outlet pressure TEDL-PT-1006 stabilizes. _____

    f. TPE Online Indicator is illuminated. _____

    g. TEDL Online Indicator is illuminated. _____

16. **ADJUST** turbine load until desired reactor power is achieved. _____

Appendix B
OP-IES-003 Post Evaluation

GSE POWER SYSTEMS

Continuous Use

GPWR NUCLEAR PLANT

PLANT OPERATING MANUAL

PROCEDURE TYPE: OPERATING PROCEDURE

NUMBER: **OP-IES-003**

TITLE: **TPE and TEDL Operation (Online to Hot Standby)**

TABLE OF CONTENTS

Section

1.0 PURPOSE

1. This procedure provides operating instructions transition the Integrated Energy System (IES) from an online state to hot standby. The IES consists of the following systems:

   a. Thermal Power Extraction (TPE)

   b. Thermal Energy Delivery Loop (TEDL)

2.0 REFERENCES

2.1 Plant Operating Manual Procedures

1. N/A

2.2 Technical Specifications

1. N/A

3.0 PREREQUISITES

1. TPE is Online
2. TEDL is Online
3. Reactor Power is below 99%

4.0 PRECAUTIONS AND LIMITATIONS

1. Thermal Power Extraction (TPE)

    a. Maximum of 5% is currently planned for total TPE extraction when operating at full power.

    b. Increasing steam diverted through the TPE will cause reactor power to increase.

2. Thermal Energy Delivery Loop (TEDL)

    a. N/A.

5.0 PROCEDURE

BEGIN TPE AND TEDL ONLINE TO HOT STANDBY EVOLUTION

1. **DETERMINE** target TPE and TEDL flow rates and TCS demand and ramp rate for Hot Standby
   a. TPE Flow Rate 32.4 KPPH. _____
   b. TEDL Flow Rate 396 KPPH. _____
2. **VERIFY** LC-1002 is in auto mode and setpoint is between 60-70%. _____
3. **VERIFY** EHX-1 Vent is in auto. _____
4. **DIRECT** HTSE plant to prepare for transition from online to hot standby. _____
5. **PLACE** FC-1000 in manual mode. _____
6. **DETERMINE** target TCS demand and ramp rate for thermal power extraction pressurization
   a. TCS Demand 926 MW _____
   b. TCS Ramp Rate 7 MW/min _____
7. **PREPARE** TCS for load change by performing the following
   a. **SET** TCS target demand _____
   b. **SET** TCS ramp rate _____
   c. **PLACE** TCS in Hold _____
8. **VERIFY** HTSE plant is ready for transition from online to hot standby _____

> **NOTE**: Once the TCS is placed in GO the TPE-EHX-2 tube outlet pressure (PT-1003) and TPE target flow should be monitored according to Step 10.

9. **PLACE** TCS in GO. _____

10. **WHEN** TPE target flow rate is reached
OR Turbine target demand is reached,
OR at any point TPE-EHX-2 tube outlet pressure (PT-1003) drops below 200 PSIG
THEN PERFORM the following

    a. **SET** TPE Extraction Flow FC-1000 setpoint to target flow rate and **PLACE** FC-1000 in auto mode. _____

    b. **SET** TEDL Inlet Flow FC-1007 setpoint to target flow rate and **PLACE** FC-1000 in auto mode _____

11. **VERIFY** HTSE plant is ready for HTSE Electric Bus to open. _____

12. **OPEN** HTSE Electric Bus Breaker. _____

13. **RECORD** the time that HTSE Electric Bus is OPENED.

    Time _____ OPENED _____

14. **MONITOR** until the following conditions are met:

    a. TPE Extraction Flow FT-1000 stabilizes. _____

    b. TPE-EHX-1 shell inlet temperature TT-1001 stabilizes or is trending slowly in the downward direction. _____

    c. TPE-EHX-1 shell inlet pressure PT-1001 stabilizes or is trending slowly in the downward direction . _____

    d. TPE-EHX-2 tube outlet pressure PT-1003 stabilizes or is trending slowly in the downward direction . _____

    e. TPE-EHX-1 tube outlet oil pressure PT-1006 stabilizes or is trending slowly in the downward direction. _____

    f. TPE Hot Standby Indicator is illuminated. _____

    g. TEDL Hot Standby Indicator is illuminated. _____

15. **ADJUST** turbine load until desired reactor power is achieved. _____

Appendix C
OP-IES-004 Post Evaluation

GSE POWER SYSTEMS

Continuous Use

GPWR NUCLEAR PLANT

PLANT OPERATING MANUAL

PROCEDURE TYPE: OPERATING PROCEDURE

NUMBER: **OP-IES-004**

TITLE: **TPE and TEDL Operation (Shutdown)**

TABLE OF CONTENTS

Section

1.0 PURPOSE

1. This procedure provides operating instructions to transition the Integrated Energy System (IES) from hot standby to shutdown. The IES consists of the following systems:

    a. Thermal Power Extraction (TPE)

    b. Thermal Energy Delivery Loop (TEDL)

2.0 REFERENCES

2.1 Plant Operating Manual Procedures

1. N/A

2.2 Technical Specifications

1. N/A

3.0 PREREQUISITES

1. TPE is in a Hot Standby or Online
2. TEDL is in Hot Standby or Online

4.0 PRECAUTIONS AND LIMITATIONS

1. Thermal Power Extraction (TPE)

    a. Maximum of 5% is currently planned for total TPE extraction when operating at full power.

    b. Increasing steam diverted through the TPE will cause reactor power to increase.

5.0 PROCEDURE

BEGIN SHUTDOWN EVOLUTION

1. **IF** TPE and TEDL are online, complete OP-IES-003 and then continue this procedure. _____
2. **VERIFY** that TPE is in Hot Standby. _____
3. **VERIFY** that TEDL is in Hot Standby. _____
4. **DIRECT** HTSE plant to prepare for shutdown of TPE and TEDL. _____
5. **VERIFY** HTSE plant is ready for shutdown of TPE and TEDL. _____
6. **PLACE** TPE-FC-1000 in manual mode. _____
7. **LOWER** TPE-FC-1000 position to reduce TPE-FT-1000 flow rate to 0 KPPH. _____
8. **VERIFY** steam flow at TPE-FT-1000 is 0 KPPH. _____
9. **VERIFY** TPE-1 (TPE-FCV-1000) is closed. _____
10. **PLACE** TEDL pump in off position. _____
11. **PLACE** TEDL-FC-1007 in manual mode.
12. **LOWER** TEDL-FC-1007 position to reduce FT-1007 flow rate to 0 KPPH. _____
13. **VERIFY** oil flow at TEDL-FT-1007 is 0 KPPH. _____
14. **VERIFY** TEDL-1 (TEDL -FCV-1007) is closed. _____
15. **PLACE** TPE Hotwell TPE-LC-1002 in manual mode. _____
16. **LOWER** TPE Hotwell TPE-LC-1002 position to 0%. _____
17. **VERIFY** TPE Hotwell outlet pressure TPE-PT-1002 begins to trend downward. _____
18. **DIRECT** HTSE plant that TPE and TEDL have been shutdown. _____
19. **DETERMINE** target flow rate and TCS demand and ramp rate for thermal power extraction shutdown mode
    a. TCS Demand 926 MW. _____

b. TCS Ramp Rate 7 MW/min. _____

20. **PLACE** TCS in GO. _____

21. **MONITOR** until the following conditions are met:

a. TPE-EHX-2 tube outlet temperature TEDL-TT-1003 stabilizes. _____

b. TPE-EHX-2 tube outlet pressure TEDL-PT-1003 stabilizes. _____

c. TPE-EHX-1 tube outlet oil temperature TEDL-TT-1007 stabilizes. _____

d. TPE Shutdown Indicator is illuminated. _____

e. TEDL Shutdown Indicator is illuminated. _____

22. **CLOSE** isolation valves:

a. Direct a field operator to align valves using Attachment 1 - Valve Alignments for TPE and TEDL Cold Shutdown State Checklist _____

23. **ADJUST** turbine load until desired reactor power is achieved. _____

Attachment 1 – Valve Alignments for TPE and TEDL Cold Shutdown State Checklist

This attachment verifies that the TPE and TEDL isolation valves are aligned for cold shutdown.

Sheet 1 of 2

(Independent Verification Required As Indicated)

Person(s) Performing Checklist

Initial	Name (Print)	Initials	Name (Print)

Remarks – Indicate any component not in the prescribed position

____
____
____
____
____
____
____
____

Checklist started by ____________________ Time ________ Date _________

Checklist completed by ____________________ Time ________ Date _________

Approved by ____________________ Time ________ Date _________

Unit Supervisor

After receiving the final review signature, this OP Attachment becomes a QA RECORD.

Attachment 1 – Valve Alignments for TPE and TEDL Cold Shutdown State Checklist

Sheet 2 of 2

(Independent Verification Required As Indicated)

NO.	COMPONENT NUMBER	COMPONENT DESCRIPTION	POSITION	CHECK	VERIFY
1	TPE-11	Main Steam IV	OPEN	________	________
2	TPE-2	TPE-EHX-1 shell side inlet IV	OPEN	________	________
3	TPE-7	TPE Steam Trap IV	OPEN	________	________
4	TPE-15	TPE-EHX-1 shell side Vent	OPEN	________	________
5	TPE-13	TPE-EHX-1 tube side outlet IV	OPEN	________	________
6	TPE-14	TPE-EHX-2 tube side outlet IV	OPEN	________	________
7	TEDL-23	TPE-EHX-1 tube side outlet IV	OPEN	________	________
8	TEDL-22	TPE-EHX-1 tube side inlet IV	OPEN	________	________
9	TEDL-21	TPE-EHX-2 shell side inlet IV	OPEN		

6.0 ATTACHMENTS

N/A

6.0 ATTACHMENTS

N/A

6.0 ATTACHMENTS

N/A