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Light Water Reactor Sustainability Program

Lessons Learned from Performing a Human Factors Engineering Validation of an Upgraded Digital Control System in a Nuclear Power Plant Control Room

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EXECUTIVE SUMMARY

The fleet of nuclear power plants (NPPs) in the United States (U.S.) have exceeded their original 40-year licenses, so many are seeking license renewals to continue future operations. To support their efforts, the U.S. Department of Energy's (DOE's) Light Water Reactor Sustainability (LWRS) Program provides assistance for utilities to maintain and upgrade their power production capabilities. Control room modernization is one focus area, which aims to modernize existing analog control rooms with digital controls and human system interfaces (HSIs). The turbine control system (TCS) is a non-safety-related system undergoing modernization efforts at multiple plants and utilities. Considerable human factors research efforts—comprised of expert reviews and operator-in-the-loop studies—were performed to develop TCSs that are human factors-compliant and more user-friendly. This report documents the final phase of the human factors engineering program used to design and validate new digital TCS. According to NUREG-0711, one of the last steps of the human factors engineering (HFE) program prior to implementation is human factors validation. This report details the methods, results, and conclusions from the human factors validation study of a collaborating utility's TCS slated to be implemented in one of their plants.

A team consisting of two control room supervisors and two reactor operators participated in the validation. All had previously participated in the utility's TCS training program prior to the TCS validation. Performance measures included task performance, situation awareness, and workload, as well as expert observations of any negative influences of HSI features on control room team performance and interviews with the participating operators. Performance criteria were based on the performance scores and the topics identified by interviews and expert observations.

The results showed that the crew using the new TCS could clearly achieve their overall objectives in the test scenarios with sufficient situation awareness. Compared to the old system, the new TCS provided clear improvements of the control room work regarding shell and chest warming and valve and other system testing. However, a number of human engineering discrepancies (HEDs) were identified. HEDs were prioritized (e.g., category 1, 2, or 3) according to potential safety, plant availability, operability, or personnel performance consequences.

Since no priority 1 HEDs were identified, no HFE reason exists to not continue implementation of the TCS. The TCS upgrade is acceptable if the priority 2 HEDs are resolved and dispositioned in a satisfactory way. Priority 3 HEDs should be noted and considered for future modifications.

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ACRONYMS

A/V	audio/visual
BPV	bypass valve
DOE	U.S. Department of Energy
EHC	electro-hydraulic control
EOP	Emergency Operating Procedure
ETS	emergency trip system
HED	human engineering discrepancy
HFE	human factors engineering
HSI	human system interface
I&C	instrumentation & control
IFE	Institute for Energy Technology
INL	Idaho National Laboratory
ISO	International Organization for Standardization
ISV	integrated system validation
LWRS	Light Water Reactor Sustainability
MCR	main control room
NASA	U.S. National Aeronautics and Space Administration
NASA TLX	NASA task load index
NPP	nuclear power plant
NRC	Nuclear Regulatory Commission
NUREG	NRC technical report designation
OECD	Organisation for Economic Cooperation and Development
OEM	original equipment manufacturer
PASU	process awareness and situation understanding
RO	Reactor Operator
SA	situation awareness
SART	situation awareness rating technique
SCORE	Supervisory Control Rating and Evaluation
SS	Shift Supervisor

TCS	turbine control system
TPS	turbine protection system
TVCS	turbine valve control system
U.S.	United States
V&V	verification and validation

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1. INTRODUCTION

1.1 Background for the TCS Human Factors Validation

In collaboration with Idaho National Laboratory (INL) and the Institute for Energy Technology (IFE), a nuclear power plant (NPP) is performing modernization efforts to upgrade their existing analog electro-hydraulic control (EHC) turbine control system (TCS)—originally installed during the initial commissioning of the plant—to a new, state-of-the-art digital system built on the Triconex® "Tricon" platform. This retrofit will help resolve reliability, obsolescence, and parts availability problems, as well as minimize single-point vulnerabilities associated with the original equipment manufacturer's (OEM's) outdated systems.

The collaborating NPP and its parent utility company has applied a human factors engineering (HFE) process to this TCS upgrade. The HFE plan included a human factors validation of the final TCS solution.

1.2 Human Factors Validation of the NPP TCS – NUREG-0711

Human factors design guides and standards from the International Organization for Standardization (ISO) and the Electric Power Research Institute (EPRI) (e.g., ISO 11064 [ISO, 2006] and EPRI 3002004310 [EPRI, 2015]) outline an iterative evaluation process, including design testing and verification and validation (V&V) activities. The primary purpose of this process is to both support in the design and development of a usable product, and to provide evidence of acceptable human performance. Regulatory guidance tends to emphasize the latter.

The TCS upgrade does not require full HFE validation as outlined in NUREG-0711, "Human Factors Engineering Program Review Model;" however, the NPP TCS upgrade project has chosen to use NUREG-0711 as its validation guide. The U.S. Nuclear Regulatory Commission (NRC) originally developed NUREG-0711 as a review standard in new nuclear reactor commissioning, but later versions of the guide have been expanded with additional HFE aspects to implement in plant modifications. As such, it is fair to state that the guide more easily fits larger plant upgrades than the NPP TCS upgrade.

The TCS upgrade will take place in a relatively minor part of the control room and the plant systems involved are not classified as safety systems. This motivated a graded application of NUREG-0711, which meant that the NPP TCS validation adapted the guidance according to the scope and safety significance of the upgrade.

While NUREG-0711 does not explicitly address plant availability and equipment damage, its plant safety validation principles can be used for plant availability. Analogues to the validation of safety tasks, the validation of plant availability needs to identify the relevant tasks, specify a relevant sample of test scenarios, and measure to what extent task performance can be achieved with sufficient situation awareness and within reasonable workload limits.

NUREG-0711 includes a chapter on "Human Factors Verification and Validation" (O'Hara et al., 2012). The guide defines integrated system validation as follows: "Integrated System Validation (ISV) is an evaluation, using performance-based tests, to determine whether an integrated system's design (i.e., hardware, software, and personnel elements) meets performance requirements and supports the plant's safe operation." Further, the guide describes that human engineering deficiencies (HEDs) "are identified if performance criteria are not met." (p. 73)

Regarding NRC's project review, the guide states the following HFE objectives:

- The applicant validated, using performance-based tests, that the integrated system design (i.e., hardware, software, procedures and personnel elements) supports the safe operation of the plant.
- The applicant has: (1) evaluated HEDs to determine if they require corrections; (2) identified design solutions to address HEDs that must to be corrected; and (3) verified the completed implementation of these HED design solutions.

Of special relevance to the validation were Sections 11.4.1, "Sampling of Operational Conditions," and 11.4.3, "Integrated System Validation." For some aspects, the guide also describes, "Additional Considerations for Reviewing the HFE Aspects of Plant Modifications."

Section 11.4.3 provides:

- The scenarios for ISV should be performed using a simulator, or other suitable representation of the system, to determine the complete design's adequacy to support safe operations.
- The applicability and scope of the ISV may vary in reviewing the HFE aspects of plant modifications. An ISV should be reviewed for all modifications that may: (1) change personnel tasks; (2) change tasks demands, such as changing the task's dynamics, complexity, or workload; or (3) interact with or affect HSIs and procedures in ways that may degrade performance.
- The applicant should describe how the team performing the validation has independence from the personnel responsible for the actual design.

2. VALIDATION TEAM AND INDEPENDENCE

Concerning the independence of validation, NUREG-0711 has a conservative perspective, as seen in Section 11.4.3.1, "Validation Team:"

> "The applicant should describe how the team performing the validation has independence from the personnel responsible for the actual design. *Additional Information*: The members of the validation team should have no responsibility for the design (i.e., they should never have been part of the design team). While they may work for the same organization, their responsibilities must not include contributions to the design, other than validating it." (p. 85)

Independence as outlined by the guide is generally difficult to achieve in practice. Individuals who are part of the design team have invaluable knowledge of how the new design functions and have knowledge about specific control room issues that would be important to include in testing. As we understood it, the intention of the guide regarding independence is, for example, to assure that validation is not limited to addressing tasks, scenarios, interfaces, and operator competences that have been used as design basis and not to bias the validation towards the advantageous elements of the design only.

To balance independence and the involvement of needed TCS upgrade expertise, the project was organized with one validation lead team and one validation support team. The validation lead team had no involvement in previous HFE efforts regarding design and testing prior to ISV. For ease of reference, the report refers to these two groups as the full validation team. The composition of each team is listed in Table 1 and Table 2.

Table 1. Validation Lead Team Personnel.

Company	Person	Role/Contribution
IFE	Håkan Svengren	operation, human factors validation methodology, expert observer
IFE	Per Øivind Braarud	human factors validation methodology, validation leader

Table 2. Validation Support Team Personnel.

Company	Person	Role/Contribution
NPP Utility	Matt W.	operation, measurement specification, scenarios, training instructor, simulator technology
NPP Utility	Matt K.	expert observer
NPP Utility – Corporate	Paul H.	corporate oversight, expert observer
Independent Consultant	Lew Hanes	human factors expertise, validation methodology, expert observer
INL	Jeffrey Joe	project manager, human factors expertise, validation methodology, expert observer
INL	Ron Boring	human factors expertise, validation methodology, expert observer
INL	Thomas Ulrich	human factors expertise, validation methodology, expert observer

The validation support team provided valuable feedback regarding the planned upgrades to the plant systems and control room, as well as operational expertise, simulator and training expertise, and human factors and validation expertise to support the development of adequate scenarios and specific content of scenario performance measures.

To support a sufficient level of independence, the development of the validation plan was organized and performed as follows:

- The IFE independently developed first version draft scenarios based on project material provided by INL and the utility. These drafts were thereafter discussed with the validation support team, modified, and expanded upon to ensure TCS upgrade relevance.
- IFE independently proposed a set of performance measures and developed the first version of the draft measures based on project material provided by INL and the NPP utility. The set of measures and drafts were thereafter discussed with the validation support team, modified, and expanded upon to assure TCS upgrade relevance.
- IFE made final decisions with regard to all elements of the ISV.

3. VALIDATION APPROACH

3.1 TCS Validation Objectives

3.1.1 NUREG-0711

NUREG-0711 Section 11.4.3, "Integrated System Validation," states: "*The applicability and scope of the ISV may vary in reviewing the HFE aspects of plant modifications. An ISV should be reviewed for all modifications that may: (1) change personnel tasks; (2) change task demands, such as changing the task's dynamics, complexity, or workload; or (3) interact with or affect HSIs and procedures in ways that may degrade performance. ISV may not be needed when a modification involves only minor changes to personnel tasks such that the modification reasonably may be expected to have little or no overall effect on workload and the likelihood of error.*" (p. 85).

This section further instructs an applicant to develop detailed test objectives and provide evidence the integrated system adequately supports plant personnel in safely operating the plant by including the following:

- Validation that the design has adequate capability for alerting, informing controlling, and feedback such that personnel tasks are successfully completed during normal plant evolutions, transients, design-basis accidents, and also under selected, risk-significant events beyond-design basis, as defined by sampling operational conditions.
- Validation that specific personnel tasks can be accomplished within the time and performance criteria with effective situational awareness and acceptable workload levels that balance vigilance and personnel burden.
- Validation that the HSIs minimize personnel error and assure error detection and recovery capability when errors occur.
- Validation that the personnel can effectively transition between the HSIs and procedures in accomplishing their tasks, and that interface management tasks, such as display configuration and navigation, are not a distraction or an undue burden.

3.1.2 Objectives

The objectives included evaluations where:

- Operators are able to complete TCS tasks successfully (i.e., correctly, completely, and without confusion or misunderstandings) using the new TCS.
- Operators are sufficiently alerted, provided with usable controls and adequate feedback from the system.
- The control room team is sufficiently supported by modified control room interfaces (i.e., alarms, process displays, system and function displays, etc.), operating procedures, conduct of operation, competence/training to control the plant with the upgraded TCS system, and that interface management tasks, such as display configuration and navigation, are not a distraction or an undue burden.
- Situation awareness and workload are within acceptable bounds.
- TCS upgrades support operators in ordinary operation tasks (i.e., startup, shut down, and "operation fine tuning"), surveillance and monitoring of status, identification and diagnostics of deviations, maintenance and testing of systems and components.
- HSIs minimize personnel error and support error detection and recovery when errors occur.

These objectives pertained to both plant availability and plant safety. Generally, the performance of TCS tasks resulting in turbine trip, and subsequently reactor trip, relate to both plant availability and plant safety. TCS tasks involved in accident sequences are directly relevant for plant safety.

3.2 Performance Criteria

Validation usually applies to one or both of the following criteria:

1. Requirements-Based Approach. These criteria are based on the requirements for safe and efficient operation. Functional requirements, systems specifications, and concept of operation provide the basis for the development of these criteria. Operations expertise often needs to be involved in the specification of detailed human factors criteria for specific scenarios and the assessment of performance against criteria often involve expert assessment.
2. Benchmark Approach. The measured performance in the pre-modernized control room (or with a reference system) is used as a baseline for the modernized control room. For test events where the tasks and conditions are similar between the old and modernized control rooms, a baseline represents adequate criteria for the modernized control room.

For the TCS validation, the requirements-based approach was deemed to be the most suitable. The benchmark approach has advantages when it is difficult or costly to develop criteria by a requirements-based approach. For example, it can be difficult to specify acceptable bounds for mental workload. A baseline from a previously accepted reference system can provide a useful basis for specification of workload criteria (Selcon, Taylor, and Kortias, 1991). However, there are several challenges of using a baseline (Braarud and Strand, 2011). Differences in HSI technology and plant systems between the modernized control room and the reference system (e.g., the old control room) might imply that tasks are not comparable between the modernized control room and the baseline, such as the mental workload required of manual TCS valve testing being used as the baseline for automated valve testing. Often, performance differences between the old and modernized control rooms have to be interpreted according to the similarities and differences regarding tasks, plant systems, and operational concepts. There is also the difficult question of how much the human performance of a modernized control can differ from a baseline before it is judged as either worse or better than the baseline. This is referred to as practical significance (e.g. Kirk, 1968). For some applications, robust criteria can be developed by a combination of both requirements-based and baseline approaches (a sort of triangulation). This might be warranted for large safety relevant modernizations.

For the TCS upgrade, having a relatively limited scope, the validation project chose a requirements-based approach. In general, the requirements-based approach directly addresses the upgraded control room and often provides the most useful results for deciding about acceptability and identifying HEDs.

3.3 Scenario Design

3.3.1 Scenarios Challenging the Control Room Work

Regarding safety, plants usually implement defense-in-depth principles (IAEA, 1996). Plant systems have redundant and reliable instrumentation and control (I&C), most important information has redundant presentations in the control room (e.g., component indications, alarms, trends, and overview information), procedures have been refined from simulator trails, and operators have extensive specialized training including highly realistic simulator training. Therefore, the validation of nuclear control rooms need to include challenging scenarios.

To evaluate the TCS upgrade for potential vulnerabilities or cognitive traps, challenges were included from the point of view of the operators controlling the plant; however, the TCS was a relatively limited part of the control room. As such, many of the potential failures either led to tripping the turbine or canceling the actual TCS tasks. This situation would then lead to no further use for the TCS system until the failure cause was resolved. When compared to other test scenarios for a fully modernized plant and control room, the potential failures for the TCS upgrade were relatively limited.

3.3.2 Targeted Scenarios

A realistic scenario can be described as progressing with all steps and timewise close to real operation. For example, some startup scenarios might last for several hours. Some of the scenario phases might include very simple tasks for the control room team—scenario phases or tasks that were expected to provide limited information regarding performance aspects of the TCS upgrade—or tasks that did not relate to the upgraded TCS.

Therefore, to focus on the most valuable performance evaluations, the project strategically concentrated on scenario phases being informative for the influence the TCS upgrades were expected to have on team performance. The project utilized project documentation review, design work expertise, and training to develop targeted scenarios for the TCS validation. For example, instead of running one "continuous" startup scenario containing phases of less relevant operation, the project developed targeted shorter scenarios addressing the tasks mostly influenced by the TCS upgrade. Also, the startup procedure had clearly defined plant states (e.g., shell warming, chest warming, turbine roll, and grid connection) that provided realistic scenario start points. Basically, the validation included skipping phases of startup that did not contain operation related to the upgraded TCS system.

In addition, shorter targeted scenarios had the advantage of ensuring that observers could concentrate on evaluating just the few tasks needing to be observed at the time, while both team performance and assessments were not influenced by subsequent scenario phases. Shorter targeted scenarios also tend to make operator ratings and interviews relevant to operator performance that is significant, and do not include performance measurements that do not provide opportunities for operator performance problems to develop.

3.3.3 NUREG-0711, NUREG/CR-6393, and EPRI 3002004310 Scenario Guidance: Plant Conditions, Personnel Tasks, and Situational Factors

As stated in Section 3.1.1, NUREG-0711 primarily fits new builds and large safety-oriented plant modifications. This is especially evident regarding the scenario guidance, which does not directly fit a limited upgrade like the TCS upgrade. However, the guide provided some considerations regarding plant modifications.

NUREG-0711 (O'Hara et al., 2012), NUREG/CR-6393 (O'Hara et el., 1997), and EPRI 3002004310 (EPRI 2015) describe a set of operational conditions that should be covered by ISV activities. NUREG-0711 describes a sample of operational conditions representative for the range of events that could be encountered during operation of a plant. NUREG/CR-6393 suggests that operational scenarios can be developed along dimensions grouped into three broad categories—plant conditions, personnel tasks, and situational factors—that are known to challenge human performance. Several dimensions may also be represented in a given scenario.

The selection of operational scenarios for validation should be directed towards the scope of the utility's TCS modernization. Special considerations for plant modernization programs are mentioned in NUREG-0711 and are relevant for this project: "*When evaluating plant modifications, the following factors should be addressed when identifying operational conditions:*

1. *The operational conditions should reflect tasks that involve the modification, rather than the entire range of topics discussed in the guide for Personnel Tasks.*
2. *For integrated system validation, the operational conditions should address the transfer of learning effects on personnel performance when a modification replaces an old HSI or procedure (Negative transfer of learning effects may occur when the new and old components are different and impose different demands on personnel).*

3. *For integrated system validation, when both old and new versions of the same HSI components with different means of presentation and methods of operation are permanently present in the HSI, evaluations should provide reasonable assurance that personnel can alternate their use of these HSI components without degrading their performance* (p. 80).

Guidance was present in NUREG/CR-6393 and NUREG-0711 on how to prioritize among the scenario dimensions. For plant conditions and selecting malfunctions, these standards state that consideration should be given to the role of the equipment in achieving plant safety functions (p. 5-10). For the TCS validation, this could also be applied to plant availability. In addition, Emergency Operating Procedures (EOPs) can be prioritized (p. 5-11). For the range of human decision-making activities, knowledge-based activities are stated as particularly important. The validation should include scenarios that require personnel to use their plant knowledge to analyze, for example, contradictory evidence and to diagnose faults (p. 5-12). For situational factors, the specific tasks selected should reflect the operating experience for this type of plant (p. 5-13).

3.4 TCS Project and Plant Basis for Scenario Items

The overall main purpose of the existing main turbine analog electro-hydraulic control (EHC) system was to position the sixteen (16) high pressure (HP) and low pressure (LP) turbine steam admission valves and the four (4) turbine bypass valves (BPVs) in order to regulate the flow of steam through the turbine. The system provided automatic or manual control of the valve position, and thereby steam flow, to control turbine speed from turning gear to synchronization and generator load from synchronization to full-load. The new digital TCS will replace the existing EHC control and protection systems at the plant.

The new TCS architecture will also be comprised of a Triconex (Tricon) platform hardware in a configuration of two independent Version 11 (V11) Tricon subsystems—one for steam admission valve and BPV control (TVCS Tricon) and the other for turbine protection (TPS Tricon). The TVCS and TPS are together referred to as the Tricon TCS system. The TCS subsystems are integrated into a single engineered control platform, divided among dedicated and independent controllers. The new TCS closely replicates the functionality of the existing EHC system with additional enhancements and improvements.

The TCS system for the main turbine will operate independently and will have fault tolerant capability for online repair of critical components without affecting unit load performance, pressure control regulation, speed control, or protection functions. The HSI/DCS will also allow users to view active trips, make setpoint changes, initiate valve tests, view current and historical alarms, view historical data, and perform additional functions.

The new TCS will provide an increased level of automation, and thereby change the way certain operator tasks are performed (e.g., valve testing).

3.4.1 Main Tasks

Based on the review of project material and discussion with the validation support team, the validation identified the main tasks of the TCS system. The utility's training program gave an overview of the knowledge and abilities required by the utility's control room teams to safely and efficiently operate the TCS system. Through further discussion with the validation support team, the scenarios covered instances of all main TCS tasks, including "respond to DOME pressure control failures," "navigate the HSI," "interpret information displayed on the HSI," "operate the HSI," "perform TCS valve testing at the HSI," and "respond to TVCS and TPS alarms on the HSI."

By review of the procedure set, the TCS relevant procedures were identified as:

- Perform High Pressure Turbine Shell Warming per OP-26.
- Perform Control Valve Chest Warming per OP-26.
- Roll the Main Turbine to Rated Speed per OP-26.

- Startup the Main Generator per 1OP-27.
- Perform Turbine Overspeed Trip Test per 1PT-40.2.6.
- Perform Turbine Control Valve/Stop Valve Closure Test per PT-40.2.9.
- Perform Main Turbine Stop Valve Test per OP-26.
- Bypass Valves Operability Test per 1PT-40.2.12.
- Perform Combined Intermediate Valve Testing per OP-26.
- Swap between Dome Pressure Control and PAM Pressure Control per 1OP-25.
- Respond to PAM or DOME pressure control Instrument/Channel Failure per Alarm Response Procedures.
- Establish heatup using pressure ramp rate.
- Establish cooldown using pressure ramp rate.

The most relevant scenario tasks for testing the validation of the new TCS from the above overview were included.

3.4.2 Upgraded Plant Systems

The new TCS closely replicates the functionality of the existing EHC system with additional enhancements and improvements.

- The TVCS Tricon Sequence program is organized into a series of operating modes, called “Steps,” which define the progressive stages of the startup and any special considerations involved with the execution of a given stage. The steps are based on a system of modes that control the operation of the turbine and maintain pressure control functions and progress in sequence as follows:
    - Step 1 – Bypass Valve Operations
    - Step 2 – Shell/Chest Warming
    - Step 3 – Turbine Roll
    - Step 4 – Generator Synch
    - Step 5 – Turbine Online.

These steps are automatically selected depending on operating conditions and are interlocked so the next step can only be entered when entry conditions from the previous step is correct. This ensures an orderly progression through the steps. The Turbine Sequence Step is shown at the HSI:

- In the new TCS, Turbine Trips are a function of both the Turbine Valve Control System (TVCS) the Turbine Protection System (TPS) and the Secondary Overspeed Protection System (SOPS). The TPS and TVCS are subsystems of the TCS and include a TVCS Tricon and a TPS Tricon. In addition, an independent Secondary Overspeed Protection System is provided as a backup to primary overspeed protection. The TPS performs its functions by monitoring critical parameters and closing turbine steam admission valves when parameters are exceeded by sending a signal to de-energize all solenoid valves on the Quadvoter, which in turn depressurizes the emergency trip system (ETS) header thereby causing fast closure of all steam admission valves through their disk dump valves.

3.4.3 Control Room Interfaces

Three new screens have been placed in the panel, while some equipment has been removed. The TCS displays are described in Z10R0 1121877-BNP1-910 Rev 0 (HSI O_M Manual), *Turbine Control System (TCS) Human System Interface (HSI) Operations and Maintenance Manual*. Three new display screens (HSIs) are also provided on the control boards. The changes in the control panels are described in EC 287406, *Unit 1 DEHC Main Control Board Design Changes & Installation Engineering*.

TCS alarms are integrated in utility's alarm system (and philosophy). The current TCS has a number of high priority alarms. The new TCS utilizes existing announcer panel (panel 1-UA-23) and adds some new nearby indicators (e.g., "E MOIST SEP DRAIN TANK LEVEL-HIGH," "Turbine Bypass Valves Open,") as shown in Figures 1–4.

AS LEFT With Backlight	1	2	3	4	5	6	7	8
1		EXH HOOD TEMP 225	TURB BYPASS VALVES OPEN	TURBINE MASTER TRIP	TURB BRG TEMP HIGH	RFP BRG TEMP HIGH	250V BATT A UNDERVOLTAGE	250V BATT B UNDERVOLTAGE
2	EXH HOOD A VACUUM LOW	EXH HOOD A TEMP 175		E MOIST SEP DRAIN TANK LEVEL-HIGH	W MOIST SEP DRAIN TANK LEVEL-HIGH	MAIN STEAM LINE RAD HI	250V BATT A CHARGER TROUBLE	250 V BATT B CHARGER TROUBLE
3	EXH HOOD B VACUUM LOW	EXH HOOD B TEMP 175		E MOIST SEP LEVEL-LOW	W MOIST SEP LEVEL-LOW	MAIN STEAM LINE RAD HI-HI/INOP	250V BATT A GROUND	250V BATT B GROUND
4	TCS LOSS OF COMMS	TCS ABNORMAL	TCS TROUBLE	E REHEATER FIRST STAGE LEVEL HI LO	W REHEATER FIRST STAGE LEVEL HI LO		48V BATT A UNDERVOLTAGE	48V BATT B UNDERVOLTAGE
5	TSI VIBRATION HI-HI	TSI ABNORMAL	TSI TROUBLE	E REHEATER SECOND STAGE LEVEL HI LO	W REHEATER SECOND STAGE LEVEL HI LO	BPV CLOSED - LOW VACUUM	48V BATT A CHARGER TROUBLE	48V BATT B CHARGER TROUBLE
6	TURBINE VIBRATION HIGH	RFP VIBRATION HIGH		E MOIST SEP LEVEL- HIGH	W MOIST SEP LEVEL- HIGH	VOLT BALANCE RELAY A OPERATION	VOLT BALANCE RELAY B OPERATION	NEG PHASE SEQUENCE ALARM

1-UA-23

AS FOUND	1	2	3	4	5	6	7	8
1	TURBINE VACUUM TRIP	EXH HOOD TEMP 225	TURBINE OVERSPEED TRIP	TURBINE MASTER TRIP	MOIST SEP LEVEL-HIGH TRIP	TURB OR RFP BRG TEMP HIGH	250V BATT A UNDERVOLTAGE	250V BATT B UNDERVOLTAGE
2	EXH HOOD A VACUUM LOW	EXH HOOD A TEMP 175	BACKUP OVERSPEED TRIP	E MOIST SEP DRAIN TANK LEVEL-HIGH	W MOIST SEP DRAIN TANK LEVEL-HIGH	MAIN STEAM LINE RAD HI	250V BATT A CHARGER TROUBLE	250 V BATT B CHARGER TROUBLE
3	EXH HOOD B VACUUM LOW	EXH HOOD B TEMP 175	OVERSPEED TRIP LOCKED	E MOIST SEP LEVEL-LOW	W MOIST SEP LEVEL-LOW	MAIN STEAM LINE RAD HI-HI/INOP	250V BATT A GROUND	250V BATT B GROUND
4	EXH HOOD BELLOWS FAILURE	E MOIST SEP LEVEL-HIGH	TURBINE OVERSPEED TRIP RESET	E REHEATER FIRST STAGE LEVEL HI LO	W REHEATER FIRST STAGE LEVEL HI LO	EHC 125VDC GROUND	48V BATT A UNDERVOLTAGE	48V BATT B UNDERVOLTAGE
5	TURB BYPASS VALVES OPEN	EHC SYSTEM LOST SPEED SIGNALS	W MOIST SEP LEVEL-HIGH	E REHEATER SECOND STAGE LEVEL HI LO	W REHEATER SECOND STAGE LEVEL HI LO	BPV CLOSED - LOW VACUUM	48V BATT A CHARGER TROUBLE	48V BATT B CHARGER TROUBLE
6	TURBINE VIBRATION HIGH	EHC SYSTEM LOST DC POWER	TSI HIGH VIBRATION TRIP	TURB THRUST BRG WEAR TEST	EHC ELEC MALFUNCTION	VOLT BALANCE RELAY A OPERATION	VOLT BALANCE RELAY B OPERATION	NEG PHASE SEQUENCE ALARM

1-UA-23

Figure 1. Annunciator UA-23, located on 1-XU-1 (“As-Found” and “As-Left”) with New Window Etchings.

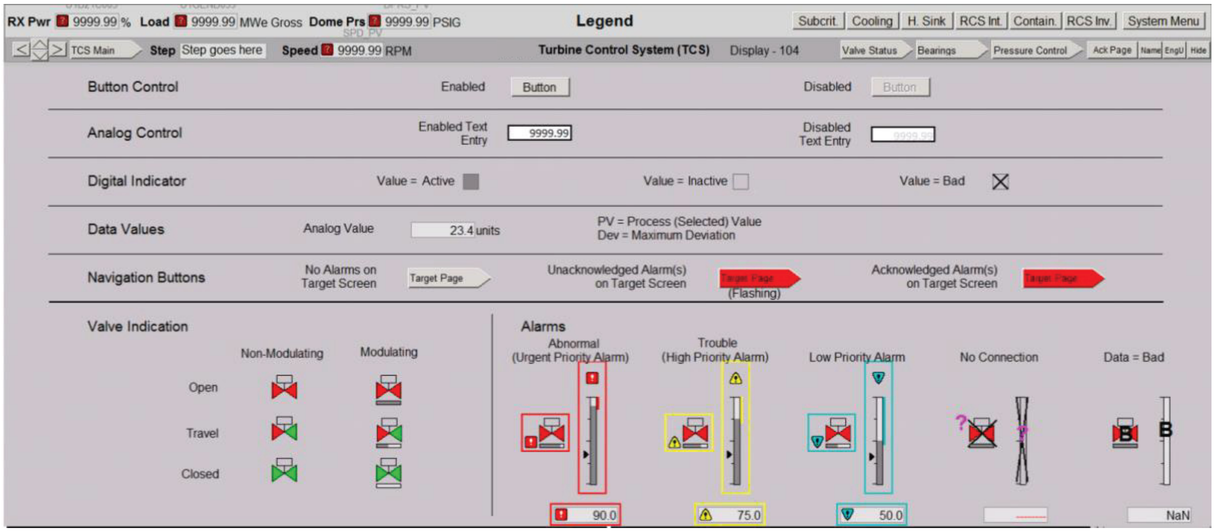

Figure 2. TCS Screen (from Z10R0 1121877-BNP1-910 Rev 0 (HSI O_M Manual)).

Figure 3. Two TCS screens (lower left of picture).

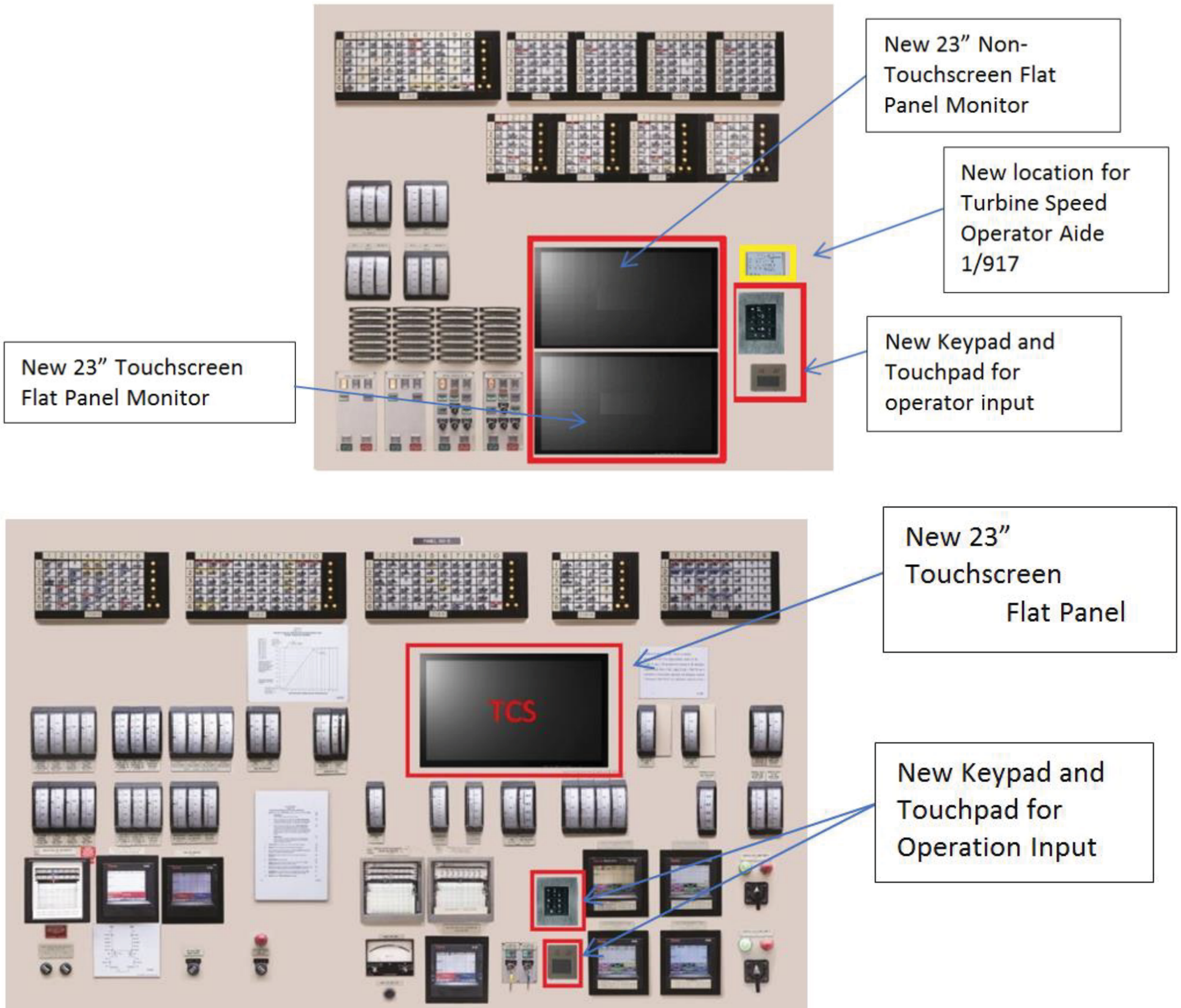

Figure 4. Placement of TCS screens shown in illustrations from the design work.

3.4.4 Procedures

The main procedures being modified are:

- 1OP-25 Main Steam system operating procedure
- 1OP-26 Turbine system operating procedure
- 1OP-27 Generator and exciter system operating procedure
- 1PT-40.2.6 Turbine Overspeed Trip Test
- 1PT-40.2.9 Turbine Control Valve/Stop Valve Closure Test
- 1PT-40.2.10 Turbine Control Valve/Stop Valves Tightness Test
- 1PT-40.2.12 Bypass Valves Operability Test
- 1PT-40.2.14 Turbine Control System Quadvoter Test.

3.4.5 Staffing and Concept of Operation

The TCS upgrade has no planned changes to the concept of operation or control room staffing.

3.4.6 Scenarios Used During Design and in Training for the TCS Upgrade

These validation activities planned to avoid identical scenarios to those used during the design work, previous V&V activities, or in the TCS upgrade training. Using identical scenarios could bias the validation results towards specific versions of scenarios either designed for or trained on. Main tasks, procedures, and interfaces obviously need to be covered by training. However, this validation aimed at developing different versions of scenarios previously applied in training or during design.

However, the TCS is a limited system, and it was difficult to identify completely new scenarios for the validation. A limitation was also the limited simulator malfunctions available for the early version of the new TCS system simulation.

3.4.7 Participants

Section 11.4.3.4, "Plant Personnel," of NUREG-0711 states that validation participants should be licensed operators. Validation should use a sample representative of the characteristics of the utility's control room personnel to account for variability among operators. One should avoid using participants that are members of the design organization or have participated in prior evaluations.

One team consisting of a Shift Technical Advisor (STA), Shift Manager, Shift Supervisor (SS), and two Reactor Operators (ROs) participated in this validation. All team members had participated in the utility's TCS training program prior to participation in the TCS validation. Only having one crew was a limited sample. To account for variability among TCS users, the validation divided the team into two TCS teams and repeated two selected scenarios for both teams. Taking the limited scope and the non-safety status of the TCS system into account, one team of four participants was not ideal, but this was considered a minimum sufficient number of participants.

3.4.8 Test Facility – Simulator

The data collection was conducted in the utility's glass-top simulator (see Figure 5). The simulator has been and will continue to be used for the operator's training on the new TCS. The simulator is compliant with Nuclear Power Plant Simulators for Use in Operator Training (ANS, 2009).

During these scenarios, minor issues with the simulator were experienced, but they were pointed out and clarified by the instructor for the crew and therefore did not affect the validation.

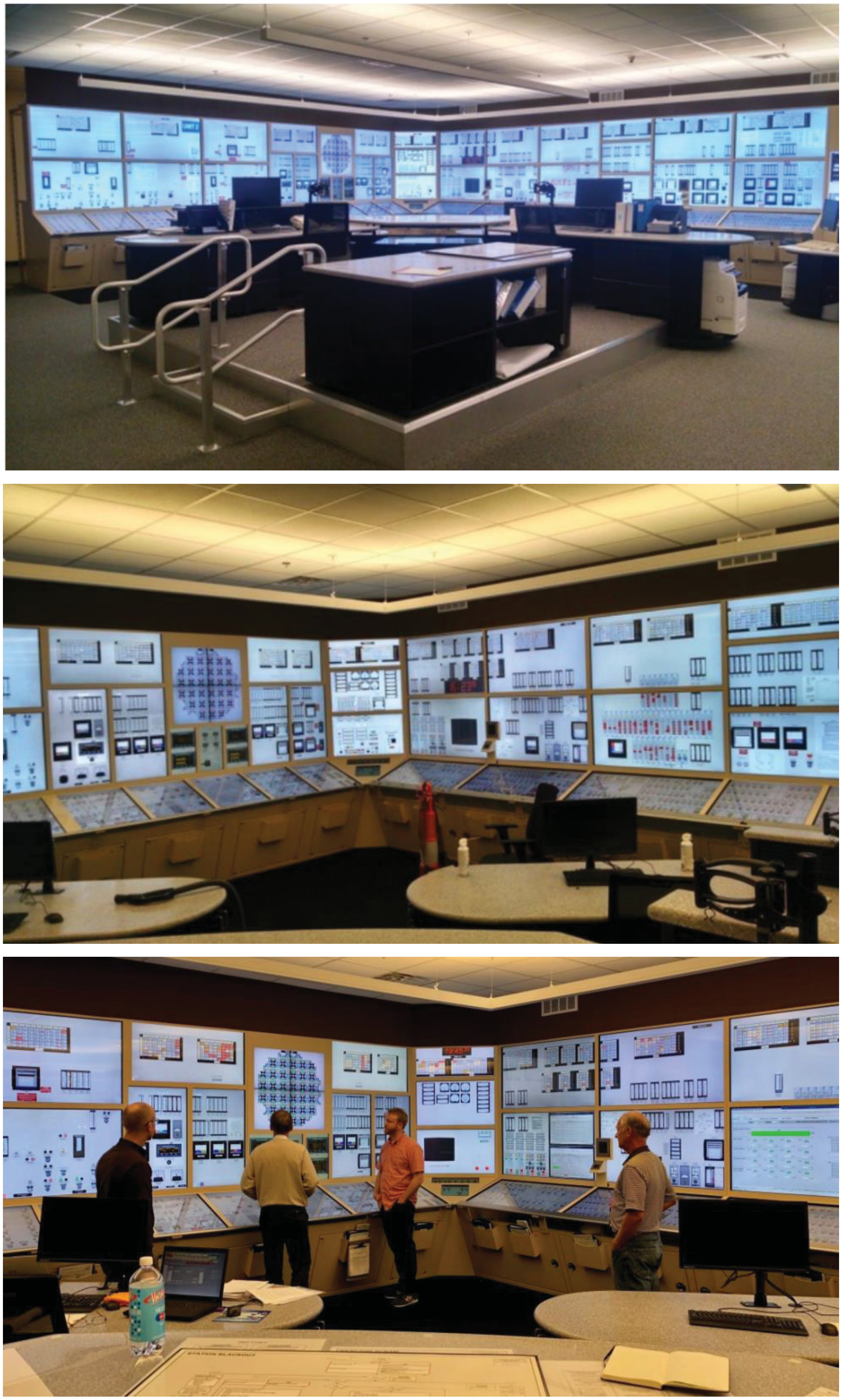

Figure 5. Glass-Top Simulator Used in TCS Validation.

3.5 Test Design and Test Procedure

3.5.1 Participants' Introduction, Data Collection, Interview, and Debriefing

The control room crew participated in the simulator for about two full days.

Before participating in the scenarios, the operators were introduced to the test situation and a plan for data collection was outlined. The introduction included information about the purpose of the validation, the confidentiality of individual operators and the operation of the individual teams, use of the collected data, and secure storing of data where persons can be recognized. The introduction also included an explanation of the operator measures and questionnaires, and how to interpret and respond to them.

The validation staff described informed consent for participation in the validation and the participants signed a consent form.

At the end of each scenario, the operators responded to a questionnaire about workload and situation awareness. Following the questionnaire, the participants participated in an interview led by HFE Observers about their experiences working with the new TCS.

The operators participated in 11 planned test scenarios.

Following completion of the final test scenario, the control room crew participated in a debriefing session where they could express any concerns or comments about their participation as well as provide feedback regarding their overall experience working with the TCS system.

3.5.2 Observer Data Collection and Recording of Audio/Video

Expert observers applied the Supervisory Control Rating and Evaluation (SCORE) measure, while an observation template for classifying and describing HSI design issues related to any performance problems was observed. The expert observers were stationed in the simulator control room to be able to closely follow the work of the control room teams and use of the TCS system.

Audio/visual (A/V) recordings were made by a number of portable video cameras. The purpose of the A/V was backup in case any clarification regarding what happened during a scenario was deemed necessary. Once the validation report has been formally acknowledged and accepted the A/V recordings will be deleted.

Observers were asked to note any operation or use of the TCS system that went beyond the prepared observation sheets (with pre-planned content) to capture any non-anticipated topics.

3.5.3 Validation Personnel Procedures

The validation project developed a checklist of validation personnel tasks. The purpose of the checklist was to assure that participants were informed, scenarios were run properly, and that all data were collected as planned.

3.5.4 Pre-Validation Scenario Testing and Dry-Runs

The project performed scenario testing and scenario demonstration in the simulator as part of the scenario development and as the basis for performance measures. This was considered a pre-ISV and was performed about a month before the ISV described in this report. Prior to this data collection, the project performed dry runs in the simulator to test the AV and data collection setup and to familiarize the validation staff with each person's tasks during the validation.

3.6 Performance Dimensions and Measures

3.6.1 NUREG-0711 Guidance

The validation used NUREG-0711 (NRC, 2012) as the general guidance document for performance measures, which describes a set of performance dimensions that should be measured in ISV, as follows:

- Plant performance (performance of functions, systems, or components).
- Task performance (i.e., being able to perform the required actions to handle a given event). The guide distinguishes between primary and secondary tasks:
  - The guide points to primary tasks needed for goal completion. Task performance should reflect the importance of system performance and can address time, accuracy, degree of completion, etc. The observation of omission and commission errors should also be included.
  - Secondary tasks are those that personnel must perform when interfacing with the HSI, such as navigating through computer screens to find a needed display and configure HSIs.
- Situation awareness (SA). The guide focuses on "objective" SA measurement in the sense that SA is defined by the perception of personnel on plant status as compared to its actual condition (Salmon et al., 2009). Further, the guide distinguishes between the perception of plant parameters and the understanding of the condition of a plant.
- Cognitive workload. The guide mentions physical, cognitive, and other demands.
- Anthropometric and physiological factors, such as the visibility of displays, the accessibility of control devices, and the ease of manipulating control devices, etc.
- Teamwork. The guide does not specifically list teamwork as a performance dimension for ISV; however, it does describe teamwork as a consideration for task analysis, the specification of staffing and qualifications, and the training program.
- Errors of omission and commission are also mentioned by the guide.

Other anthropometric and physiological factors, such as sightlines, are best covered by V&V activities other than ISV because their observation and measurement can influence the realism of the tests and can thereby influence other performance measures. Experiences from previous validation projects suggest that in addition to the performance dimensions, it is useful to measure the perceived usability of the control room by the operators for diagnostic purposes. Also, even if the NUREG does not list any specific measure of usability, its objectives include evaluating that interface management tasks, such as display configuration and navigation, are not a distraction or an undue burden.

NUREG-0711 also points to a need to identify measurement characteristics, such as the following:

- Construct Validity
- Reliability
- Sensitivity
- Unobtrusiveness
- Objectivity.

NUREG-0711 further suggests that a validation project should specify whether each measure is either a "pass/fail" or "diagnostic" one. Pass/fail measures are those used to determine whether the design is acceptable or not. Diagnostic measures are used to understand personnel performance and to facilitate the analyses of errors and HEDs.

NUREG-0711 also describes a measurement approach for new builds and states that the TCS validation needs to develop a suitable, compatible approach for the upgrade's scope. The approach must take into account that the TCS system is classified as non-safety and, as described above, is a relatively limited upgrade of the control room.

3.6.2 Plant Performance and Task Performance

Plant performance and task performance are obviously related. Operator actions directly influence plant performance. Task performance captures operation from the point of view of the control room task and can be seen as direct indication of control room quality. Plant performance provides indications of the consequences of operator actions and can be especially useful in the case of no or wrong actions performed.

For the TCS upgrade, operator tasks did not (directly) influence safety parameters, safety systems, or safety functions. Since the TCS upgrade was relatively limited, it was anticipated that by observing task performance it would be possible to understand its impact on plant performance. Therefore, for the TCS validation, the validation focused on observing task performance. The validation did not include a specific measure on plant performance.

The TCS validation observed both primary and secondary tasks.

3.6.3 Situation Awareness (SA)

SA is a widely used but highly debated concept. The validity of various SA measures is questioned (e.g., Salmon et al., 2006). Looking at the literature, one finds that few or no SA measures have been substantially validated for control room evaluation (Reinerman-Jones et al., 2015). Utilizing scenario breaks for operator response, potential replacement candidate measures include situation awareness control room inventory (SACRI) (Hogg et al., 1995), the process overview measure (Lau et al., 2015), and the process awareness and situation understanding (PASU) measure (Braarud & Svengren, 2017). These measures require substantial resources to setup, specify, and successfully apply to an actual project. While reasonable to apply for new builds and large modifications, applying these types of measures to the TCS upgrade seems to be unjustified priority of evaluation resources.

A simple, subjective, generic SA technique, such as the situation awareness rating technique (SART) (Taylor, 1990), is among the most commonly applied SA measure. However, one needs to be aware that the validity and diagnostics of these techniques are limited. As such, this validation chose to use a simple subjective rating scale. However, the project considered that this measure alone could not inform the acceptability of the TCS upgrade. The measures provided supplemental information to the observer-based measures and the interview.

Observer rating is one technique used for SA assessment (Salmon et al., 2008). This is an efficient technique and seems suitable for the TCS upgrade. To support content validity and diagnostics, the validation planned to develop task-specific SA items for observer assessment (as opposed to generic rating scales). Regarding SA, the SCORE method included both monitoring and understanding items, which covers the NUREG-0711 distinction between the perception of plant parameters and understanding of the condition of a plant. However, the limited scope of the TCS upgrade limited the possibilities for observing meaningful monitoring and understanding items.

3.6.4 Workload

Generally, there are four classes of techniques for workload assessment: 1) subjective ratings provided by subjects or observers; 2) measures of primary task performance; 3) subsidiary task methodologies, where secondary tasks are introduced for the purpose of measuring residual capacity; and 4) physiological measures like heart rate, pupil size, etc. (e.g., Lysaght et al., 1989).

Subjective techniques are popular due to their ease of use, general non-intrusiveness, low cost, high face validity, and known sensitivity to workload variations (Reid and Nygren, 1988). The U.S. National Aeronautics and Space Administration (NASA) task load index (TLX) is one of the most frequently applied subjective techniques. As such, the NASA TLX was chosen to be implemented as well.

The validation also included workload assessment by primary task performance—at least indirectly. Observation protocol was considered and, in the interview, the team was asked for explanations on any performance deviation of primary tasks. It also contained an open question about perceived workload during the scenario.

3.6.5 Teamwork

The primary focus regarding teamwork was determining to what extent the TCS upgrades influenced established communication protocols of the team while conducting their control room work. The evaluation attempted to measure this influence by including relevant teamwork items in the SCORE measurement. The follow-up interview included asking the participating operators about their experience of the TCS upgrade and its influence on their teamwork.

3.6.6 Errors of Commission

During the evaluation, the validation staff made notes regarding unexpected team performance, while the interview included questions to help clarify and ask for possible causes for such observations.

3.7 Selected Performance Measures and Observations

3.7.1 Overview of Measures

The validation applied:

- SCORE – observer evaluation of task performance, SA, and teamwork
- NASA TLX – cognitive workload
- SART (Situation Awareness Rating Technique) and an additional SA rating
- Expert observer protocol
- Control room team interview.

3.7.2 SCORE – Observer Evaluation of Task Performance, SA and Teamwork

SCORE is an observer assessment measurement of crew performance. The measurement has been applied in the validation of modernized control rooms and in simulator experiments (Halden Work Report 1125; Halden Work Report 1175). SCORE is developed from a task analysis of a given scenario. The measurement is structured according to the main events in a scenario, while the task analysis outlines the overall and detailed goals for each event. Concrete observable markers can be specified to aid the assessment of the detailed goals. During the run of the scenario, an observer assesses the acceptability of performance regarding the overall and detail goals.

So far, the measurement has been used in the evaluation of fully modernized control rooms and the focus of the assessment has been on the crew rather than on the individual control room positions; however, goals are evaluated at a detailed level where it is usually easy to relate one operator position to the goals.

Figure 6 illustrates the elements of the measurement.

Events	Overall Goal(s)	Detailed Goals	Markers
Main process (scenario) events for testing the relevant parts of the control room function	The crew's overall goal(s) of controlling and/or diagnosing the plant process for the event	Detailed goals of verifying status, overviewing the situation, chosing strategy, and performing control actions. Categories = (Monitoring, Interpretation, Strategy, Action and Teamwork)	Observable markers supporting an observer's assessment of the detailed goals
1 Turbine trip with steam line faulted open	1,01 Verify Turbine Trip	1,1 Monitoring: Detect Trip actuated (Acceptable: within 15 sec)	
	1,02 Control reactor pressure (isolate steam line)	1,2 Monitoring: Detect valve X1 and X2 (isolation valves in series) open	
		1,3 Action: Manual Trip (Acceptable: performed without delay)	1.3.1 Manual Trip performed
		1,4 Strategy: Apply Turbine Trip procedure	1.4.1 TO starts applying or Supervisor order procedure use
2 Event 2			
... Event...			

Figure 6. Overview of SCORE elements.

The SCORE specification is based on a scenario analysis. Typically, experts for the actual plant and control room specify the content with the support of the operating procedures, the conduct of operation, and other plant materials. Often, scenario testing in a simulator is very useful for the development of detailed goals and markers, as well as discussions with experts. It is also a clear advantage if the evaluating experts are involved in the measurement specifications, because they can become more familiar with the content and the scenario progression to be observed and assessed.

The development of SCORE includes the following (steps can be iterative):

- Identified events based on main process events the control room team needs to understand and handle during the scenario.
- For each event, one or more overall goals are specified that concentrate on the crew's overall goal(s) of controlling and/or diagnosing the plant process.
- Detailed goals outline what the crew needs to achieve to fulfill the overall goals and how those overall goals should be achieved by robust and safe work. The detailed goals should be categorized according to the performance dimensions to aid in the aggregation of performance results. Past experience with the measurement shows that it is often easy and efficient to specify the content of detailed goals without considering the classification. Classification can be done at a late stage.
- Markers are concrete observable crew actions or crew behavior that can support an observer's assessment of the goals. These should be so concrete that they can be determined as performed or not (binary yes / no type of markers).
- Each detailed goal should have a brief guide on what is considered acceptable performance. The expert observer will use this as a guide when evaluating performance in a scenario.

The detailed goals can be classified according to performance dimensions commonly used in human factors guides and standards and in the literature. Based on the review of guides, standards, and recent human factors research on safety, the measure includes six performance dimensions for the assessment of safe control room operation:

- *Monitoring* refers to how the control room operators gather plant process information. The monitoring evaluation includes what process information the operators attend to, redundancy issues, and diversification of the information obtained.
- *Interpretation* refers to how the control room operators interpret plant status and its progression. The interpretation assessment includes understanding specific events, performance episodes, and the "big picture."
- *Strategy* refers to how the control room operators establish main goals and a plan to reach these goals. The strategy assessment looks at how control room operators understand the strategies provided by the standard operating procedures, and to what extent the operators are capable of adjusting and adapting these strategies when needed.
- *Actions* concern the manipulation of systems and components. The focus is on key actions for controlling the plant process.
- *Teamwork* concerns the interaction between team members. The evaluation focuses on leadership initiatives to perform consultations, distribute the work, team member involvement, communication, backup behavior, and team climate.
- *Control and Verification* refers to the team's critical thinking about their own work—the correspondence between the situation and the strategy chosen, the need to adapt plans to the situation, verification of plant process responses, and supervision of the progress towards established goals. It should be noted that this category may be difficult to distinguish from other categories and therefore difficult to observe during scenarios.

Each overall and detailed goal is evaluated in terms of acceptability on a rating scale. The scale ranges from 1 to 6 where 1-2 define levels of unacceptability, 5-6 define levels of acceptability, and the middle values of 3 and 4 represent borderline acceptability. In the case of evaluating performance as borderline acceptable, the observer has to choose if the judgment tends towards acceptability or unacceptability by rating 4 or 3, respectively. Over the full range of the scale, 1 represents the poorest score, while 6 represents the best score. This scale is simply defined as shown in Figure 7.

Rating					
Not Acceptable			Acceptable		
1	2	3	4	5	6
Strongly not acceptable	Not acceptable	Acceptability disputable, but probably not acceptable	Acceptability disputable, but probably acceptable	Acceptable	Strongly acceptable

Figure 7. SCORE Rating Scale.

As part of SCORE content development, the experts developed a brief guiding statement of what is considered acceptable performance.

The SCORE measurement was developed and has been applied to larger plant modifications. The observation performance dimensions usually require malfunctions and/or scenario events that are specifically designed to trigger control room team behavior representative for the dimension to be evaluated. Due to the limited scope of the TCS system, it was not possible to develop scenarios that clearly targeted all performance dimensions. As such, the TCS validation used a simplified SCORE design.

3.7.3 HSI Design Issues Form

One observer developed a form to identify HSI design issues and used it to note issues needing to be discussed with the crew following completion of a scenario. Issues contained on this form are shown below. Each issue was defined briefly on the form to facilitate understanding. The issues are:

- Procedures
- Display Navigation
- HSI Display
- HSI Controls
- HSI Alarms
- Alarm Windows
- Situation Awareness
- Workload
- Personal Awareness

3.7.4 NASA TLX – Cognitive Workload

The project used the original NASA TLX rating sheet (Hart and Staveland, 1988). The project used the so called "raw score" from the operators rating and not the original sorting procedure. Studies have found that the "raw score" correlates highly with the score resulting from the sorting procedure.

3.7.5 Operator Self-Assessment of Situation Awareness

The validation planned to use the 3-item version of the SART (Situation Awareness Rating Technique) (Taylor, 1990) with an operator rating of the Endsley's (1995) SAGAT dimensions of perception of plant information, comprehension of meaning, and projection of near future plant development.

3.7.6 Control Room Team Interview

The project developed an interview guide that covered the participants' experience of working with the new TCS system. The guide included items on sufficient support to perform work and/or if participants experienced any obstacles/hindrances during the scenario. The interview was planned as a discussion of the main stages of the scenario.

4. RESULTS

4.1 Method for Identification and Analysis of HEDs

In line with NUREG-0711, an HED is identified if the performance criteria are not met (p. 73). Figure 8 provides more information on how this worked.

An HED could be identified in two ways:

1. Certain negative results of the individual measures act as a pass/fail measure (NUREG-0711), giving a HED directly (see Section 4.1.1).
2. Further, a combination of results from the same or different measurements can determine a HED. For example, a trend observed for several measurements or a trend observed across several scenario events.

All measures provided diagnostic information, while some measures provided diagnostic information only. Diagnostic results and observations were applied to the analyses of performance impacts and human engineering discrepancies (HEDs).

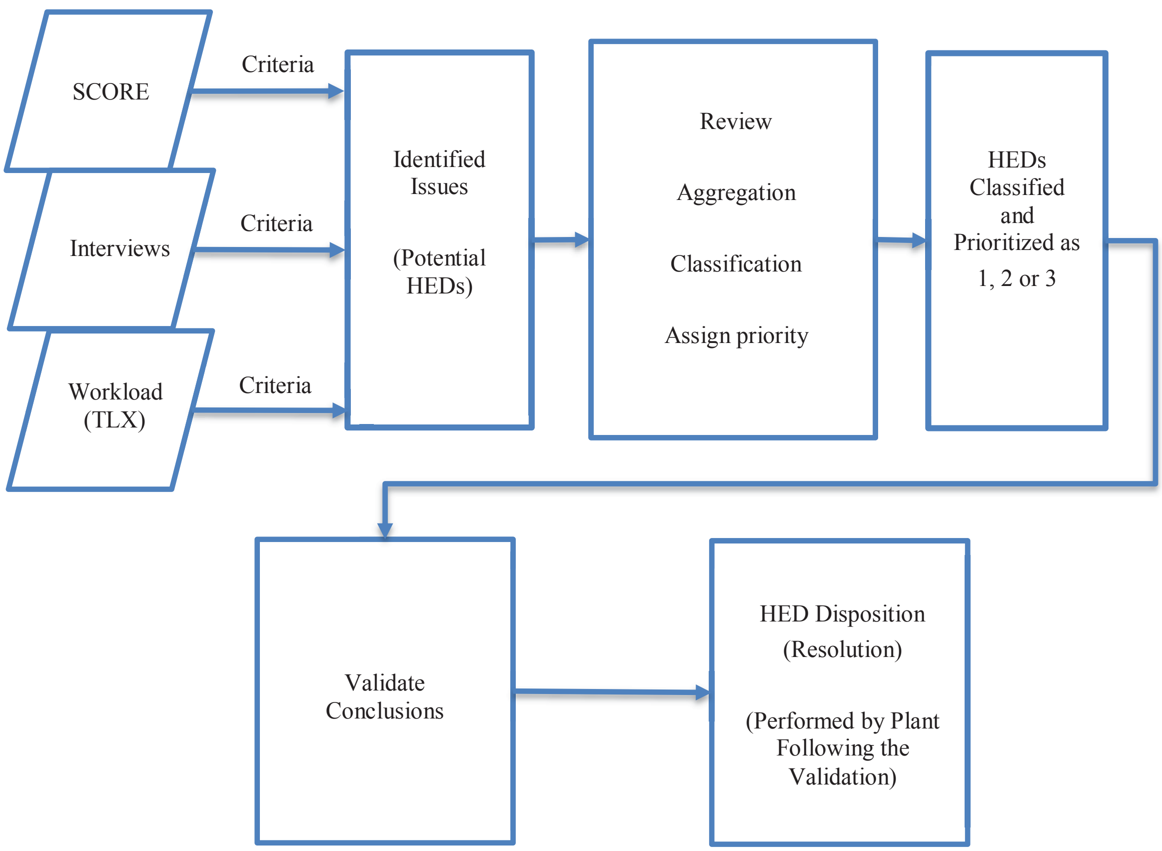

Figure 8. Overview of HED Identification and HED Process.

4.1.1 Identification of Potential HEDs

Issues identified during testing were evaluated by expert observers against the criteria for the three Priority Levels (see below). The method applied was to obtain agreement among expert observers based on:

- Observing and assessment of detailed task performance
- Discussion and assessment by the validation team
- Interview with participating operators
- Applying the guidance shown in following paragraphs.

Five expert observers covering human factors, subject matter expertise, training, and engineering participated—agreement among all participants provides confidence in the results.

The following criteria provided guidance for HED identification:

- SCORE:
    - A SCORE priority 1 item with a score of 2 or lower determined a potential HED
    - Average SCORE priority 1 items with a score of 3 or lower determined a potential HED.
- Workload (NASA TLX) and SA Rating:
    - A TLX item or SA rating item with a rating poorer than ¼ of the scale (i.e., the scale's lowest quartile) determined a potential HED.
- Control Room Team Interview and Observer Protocol:
    - The interviews had an open format and did not have predefined criteria for the identification of potential HEDs. The same was the case for the Expert Observer protocol. For the issues identified during the interview or the observation protocol, observer agreement or majority opinion determined a potential HED.

4.1.2 Review of Potential HEDs – Aggregation, Classification, and Prioritization

The validation team reviewed potential and determined actual HEDs. The validation team's assessment, for example, took into account coherence between the results (i.e., convergent indications). The HEDs identified were evaluated by the Validation Lead Team with the assistance of the Validation Support Team. The results of the set of measurements, as well as operational expertise, were used to interpret the HEDs and assign Priority according to the levels described below.

NUREG-0711 (NRC, 2012) suggests that individual HEDs should be classified as HEDs that should be corrected for acceptable control room functionality and HEDs acceptable as is. The project expanded this classification and applied HED priority levels as follows:

- **Priority 1:** Have direct, indirect, or potential safety or plant availability consequences and requires resolution.
- **Priority 2:** Potential consequences to plant performance/operability or personnel performance and resolution shall be considered.
- **Priority 3:** Other (not meeting priority 1 and 2 criteria).

Further, the HEDs were classified as pertaining to one of the following main elements:

- Interfaces
- Procedures
- Operator Proficiency.

Note that procedures still under development would be assumed to be remedied as part of procedure development plans already underway. Also note that deficiencies in operator proficiency are generally attributable to training. Not all training had been completed for the new TCS at the time of the validation.

4.1.3 Disposition of HEDs

The total set of HEDs and their analysis will make the basis for an overall judgment of the control room function. The number and their priorities indicate whether, from a human factors perspective:

- Overall, the TCS upgrade is acceptable as is, and there are no noteworthy issues (no Priority 1 or 2 HEDs).
- Overall, the TCS upgrade is acceptable if the Priority 2 HEDs are resolved and dispositioned in a satisfactory way (no Priority 1, but one or more Priority 2 HEDs).
- Overall, the TCS upgrade is not acceptable. The results point to either fundamental underlying problems that pervade a number of tasks and a number of human performance dimensions or one/few HEDs assessed as having serious safety implications. Priority 1 and 2 HEDs need to be corrected before the control room function can be judged as acceptable. If Priority 1 or 2 issues cannot be resolved at a satisfactory level, then the TCS HSI design upgrade is not acceptable.

4.2 Results: HED Identification, Analysis, and Prioritization

4.2.1 Interviews and Observer Debriefs

The test scenarios consisted of a broad and relevant set of tasks for the TCS validation, but there were some malfunctions that were currently not available in the new simulation of the TCS system. Therefore, the analysis of potential HEDs and their prioritization emphasize results from the interviews and observations.

4.2.2 Priority 1 HEDs

The validation identified no Priority Level 1 HEDs.

4.2.3 Priority 2 HEDs

Several Priority 2 HEDs were observed. These are numbered to facilitate dispositioning by the plant, but are also categorized as to whether they pertain to the interface (see section 3.10.3.1), procedures (see section 3.10.3.2), operator proficiency (see section 3.10.3.3), or the simulator (see section 3.10.3.4). Comments are added to the HEDs for consideration by the plant as it determines actions to resolve and disposition them.

4.2.3.1 Interface

There were various interface issues:

1. It was too easy to unintentionally double click the track pad and provide a command where none was intended.
   - Comment: An operator reported that peer checking is much easier without touch. The screen on the panel XU-3 is too high to be able to use the touch screen effectively, and thereby, it cannot be consistently used on all screens. A proposed suggestion was to disable the double tap capability of the trackpad and eventually consider replacing it with a larger trackpad.
2. It is not possible to navigate by entering the display number (e.g., a long string of the screen name must be entered instead) (e.g., see scenario 5 interview).
   - Comment: A possible solution is a drop-down menu for choosing screens. This solution means that using the keyboard would not be necessary.

3. Inconsistencies regarding acknowledgement for controls and confirmations (e.g., no confirmation for “Go” after selecting “Auto” warming control).
4. The terminology for the BPV bar graph on display 105, 110, and 113 was somewhat confusing.
    - Comment: The BPV bar graph on display 105,110 and 113 could be renamed from “Bypass Valve Position” to “Bypass Valve Demand” since the graph actually shows the sum demand of all valves and not the valve position (see scenario 5).
5. The all valves closed button, which allows operators to stop the turbine, was greyed-out and inactive. This button is particularly important and should be available at all times (see scenario 6).
6. Turbine roll up graph provided no useful information.
7. Discrepancy with the Steam Chest differential temperature (e.g., setpoint presented on one screen, but different process values on another).

4.2.3.2 Procedures

There were various procedural inaccuracies, including:

1. The alarm response procedures are not yet complete (e.g., they will guide the operators in handling and diagnosing alarms).
2. Operators skipped step 1 of OP26 because they did not know where to find the trip status light:
    - Comment: The procedure should define where this information is displayed.
3. The warming time (clock) is re-calculated each time the clock is checked. This was not obvious to the operators and was discussed:
    - Comment: For clarification, there should be a note in the procedure stating that the clock is re-calculated when exiting the screen.
4. The procedures do not adequately address criteria for using the bypass analog jack controls or allowing the digital TCS HSI controls to move the bypass valve jacks:
    - Comment: It seemed the functionality of the analog jack controls has not been communicated effectively to the operators via training or procedure updates (see scenario 9 interview).
5. An issue was identified with procedure step 31a of OP26 in that operators are instructed to determine if the system is working as designed, which is quite vague.
6. The all valves closed button, which allows operators to stop the turbine, was greyed-out and inactive. This button is particularly important and should be available at all times (see scenario 6):
    - Comment: Screenshot of the current TCS would be an efficient and less error-prone alternative. In general, a digital system should have the ability to support digitally snapshotting these values for recall later – or via a separate screen. Another solution would be to have the critical parameters collocated in one page (or appendix) of the procedure.

Procedure inconsistencies included:

1. Missing guidance – missing note on cleared “test complete status” for valve test (see scenario 2 notes).
2. Some unnecessary verification steps – to observe a valve’s last few percentages travelled during testing (see scenario 3):
    - Comment: Not needed and impossible to perform.
3. Inconsistent terminology for status checks – “active,” “on,” and “true.”

4. For some acknowledgement of actions required by the TCS, there was no procedure step for performing "acknowledge."
5. Knowing that alarms cleared after trip was confusing in the overspeed test scenario:
   - Comment: A note should be added to the procedure to convey the alarms for the overspeed trip automatically being reset so that the operators are aware of this new feature of the TCS.

4.2.3.3 Operator Proficiency

Limited familiarity with the TCS system and its operation, including:

1. Understanding of alarm system functionality (e.g., "Test failed" indication disappeared unexpectedly when the alarm was acknowledged) (see scenario 1B). Is this is an interface issue?
2. Knowing that alarms cleared after a turbine trip was also confusing in the overspeed test scenario:
   - Comment: A note should be added to the procedure to convey the alarms for the overspeed trip automatically being reset so operators are aware of this new TCS feature.
3. How to acknowledge alarms (e.g., what screens are for "acknowledge" and "overview").
4. Inefficient display navigation:
   - Comment: Operators initially did not always know what screen to use to support various activities. Screens are referenced by number in the procedure, but by name on the TCS. This did not help navigation. However, operators greatly improved throughout the ISV, indicating that familiarity facilitates navigation fluency.
5. Behavior of icon indications (e.g., SV 2% open and icon indicating closed [symbol changes at 3% and 97%]).
6. Operators noted a training gap on the importance of the maintenance screen. It is used extensively (i.e., the procedure does not contain any guidance on accessing this screen):
   - Comment: In addition, one could consider a "hot-button" to navigate directly to the maintenance screen.
7. The operators pointed to the importance of hands-on training and experience and expressed that all control room team members could need training similar to the validation scenarios to achieve sufficient familiarity with the new TCS (see closing interview):
   - Comment: Operators requested laptops to be made available in the main control room (MCR), so they can use to familiarize themselves with the system and walk-through evolutions (e.g., closing interview). This would be helpful for training and would be helpful prior to an evolution to let an operator who is less familiar with an evolution to walk through the interface before completing it.

4.2.3.4 Simulator HEDs

Some simulator issues were also encountered during the validation. These could have implications for the quality of the simulator training. Operators expressed concerns about these issues could carry through to the actual system in their closing interviews:

1. TCS priority alarms were not presented in the annunciators. Red and yellow alarms within the HSI should cause an audible alarm within the simulator.
2. Turbines rolls to 30 RPM when the setpoint was selected, but before "Go" ordered.
3. Stop valves opens much faster than at the plant when the turbine rolls to 100 RPM.
4. The expected alarm for the BPV open is clear (step 12, Display 118).

5. Bearing number 7 y-axis alarm was encountered, but this is due to a simulator issue, since it was not part of the scenario (see scenario 7).

4.2.4 Priority 3 HEDs

4.2.4.1 Interface

1. Pop up menu for setting the RPMs and the ramp rate was occluding information and did not pop up to the right in a faceplate area as expected (see scenario 6 interview):
   - Comment. In general, this issue should be checked throughout the new interface.
2. IV valve status on the HSI shows "1%," but those values are actually set at "0%." However, alternative information sources are no longer available, so it is not possible to verify.
3. There is another popup that shows the servers connected to each of the thin client HSI displays (DCS alarms). This popup does occlude a small portion of the lower left section of the interface similar to the ramp rate selection dropdown popup. This information blocked the turning gear status:
   - Comment: Removing the popup was classified as a training issue during the observer debrief, but it remains a concern whether this is proper interface behavior.
4. The operators reported that unlike many plants they use pounds of pressure instead of the degrees of Fahrenheit when setting the depressurization rate to mitigate the leak:
   - Comment: One solution would be to implement a function that converts pressure to temperature so the operators can use temperature instead of pressure. Needs much more margin to maximum cool down rate if the operator needs to calculate the temperature (added by IFE).
5. One additional screen on XU3 to minimize display navigation:
   - Comment: For some tasks it would be an advantage to have four TCS screens. Some tasks of the turbine roll procedure require using four screens (simultaneous controls and monitoring). It was mentioned that the forthcoming TCS/DISCP will provide additional screens in the control room for monitoring of TCS parameters.

4.2.4.2 Interface

1. Combine procedure steps (put DOME pressure back in service) (see scenario 10 and 11 interview).

4.2.5 Advantages of the New TCS

This section summarizes some of the main advantages with the new TCS from the crew interviews and observer debriefs:

- Operator proficiency notably increased during the two days of testing.
- Performing shell warming and chest warming was perceived as much better than the current TCS system.
- The TCS system provided flexibility as we observed several configurations of the three TCS screens that all seemed to work well for the given tasks at hand.
- The crew experienced automated valve testing as a clear improvement.
- The Turbine Overspeed test was seen to be much better than the previous system. All needed information was laid out on the TCS screens as compared to spread out in the control room.

5. VALIDATION CONCLUSION

The observers' rating (e.g., SCORE measurement), expert observations, and operators' rating showed that the crew using the new TCS clearly could achieve their overall objectives in the test scenarios with sufficient situation awareness. The validation observed no critical issues of the new TCS hindering the crew in their work. Therefore, no priority 1 HEDs were identified. There were no issues with direct, indirect, or potential safety or plant availability consequences.

However, the validation resulted in a number of priority 2 and priority 3 HEDs. The results pointed to undue operator efforts in finding and interpreting information, as well as distractions due to incomplete interfaces and procedures. Operator proficiency with the new TCS was not fully sufficient due to limited familiarity with the new TCS system and its operation.

The new TCS compared to the old system provided clear improvements of the control room work regarding shell and chest warming and regarding testing.

On this basis, the overall conclusions are that:

- Since no priority 1 HEDs were identified there is no HFE reason not to continue implementation of the TCS.
- TCS upgrade is acceptable if the Priority 2 HEDs are resolved and dispositioned in a satisfactory way. That is, HED resolution concerns disposition of the HEDs identified by the validation. The plant dispositions the HEDs identified and should promptly resolve and disposition priority 2 HEDs.
- Priority 3 HEDs should be noted and considered for future modifications.

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