US-APWR

HSI Design Implementation Plan

October 2012

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Revision History

Revision	Date	Page (Section)	Description
0	April 2010	All	Original issued
1	November 2011	General	Revised capitalization of section and figure titles. Revised "US Basic" to "US-Basic"
		p.vi (Abstract)	Revised "describe" to "describes". Revised "HEDs" to "Human Engineering Discrepancies (HEDs)".
		p.1 (Section 1.0)	Revised description.
		p.2 (Section 2.0)	Added description to the end of third sentence in subsection 1. Added description to the end of sixth sentence in subsection 2. Added "or" in subsection 3. Added description to the last sentence in subsection 3.
		p.4 (Section 4.1)	Deleted "the". Revised "the" to "to". Revised "Stuffing" to "Staffing". Added "(TA for risk significant human actions, only)".
		pp.4-5 (Section 4.1, 1))	Added "HSI Design defines the HSI environment to meet the assumption …" for RAI Response No. 664 (Question No. 18-88).
		pp.5-6 (Section 4.1, 2))	Revised "function," to "functions and".

Revision	Date	Page (Section)	Description
			Revised description of first bullet in subsection 2) 2) a. HSI.
			Added “HSI”.
			Revised description about regulatory requirements.
			Revised description about other requirements.
		pp.8-9 (Section 4.2)	Revised “Shift supervisor” to “Shift manager” for RAI Response No. 792 (Question No. 18-140).
			Revised description about overriding automatic systems.
			Revised description about tagging.
		p.11 (Section 4.4, 1))	Revised description of second paragraph.
		pp.11-12 (Section 4.4, 2))	Added a sentence to last paragraph for RAI Response No. 797 (Question No. 18-180).
			Revised “will be” to “are” for RAI Response No. 797 (Question No. 18-180).
			Added “2 and 3” for RAI Response No. 797 (Question No. 18-180).
		p.12 (Section 4.4, 3))	Revised “will be” to “are” for RAI Response No. 797 (Question No. 18-180).
			Added “2 and 3” for RAI Response No. 797 (Question No. 18-180).
		p.12 (Section 4.4, 4))	Revised “will be” to “are” for RAI Response No. 797 (Question No. 18-180).
			Added “2 and 3” for RAI Response No. 797 (Question No. 18-180).
		pp.12-13 (Section 4.4, 5))	Revised “concept” to “design” for RAI Response No. 797 (Question No. 18-180).
			Added “as documented in Topical Report MUAP-07007,”.

Revision	Date	Page (Section)	Description
			Revised “will be updated to reflect” to “reflects” for RAI Response No. 797 (Question No. 18-180). Revised “Phase 1 design related HEDs” to “the significant HEDs from Phase 1” for RAI Response No. 797 (Question No. 18-180). Added two sentences to last paragraph for RAI Response No. 797 (Question No. 18-180).
		p.14 (Section 4.5)	Revised “… size etc).” to “… size, etc.).”.
		p.15 (Section 4.5, 2))	Revised “we conduct an … using…” to “an … is conducted using …”.
		p.15 (Section 4.5, 3))	Revised “stuffing” to “staffing”.
		pp.15-18 (Section 4.5, 8))	Added a sentence to the end of first paragraph. Revised “in” to “for the”. Added “operators”. Added “the”. Revised “is” to “are”.
		p.19 (Section 4.5, 9))	Revised “was” to “is”. Revised “were” to “are”. Revised “conducted” to “conduct”. Revised “allowed” to “allows”.
		p.22 (Section 4.6)	Revised “design plan” to “designs”. Revised “described” to “describe”. Added “(Phase 3)”.
		pp.22-23 (Section 4.7)	Added “and Monitoring Circuit Basic”. Revised “(e.g. “ to “(e.g., “.

Revision	Date	Page (Section)	Description
		p.23 (Section 4.8) p.24 (Section 5.0)	Added new section 4.8 about results summary report. Added reference 5-20. Revised description of references.
2	October 2012	All pages	Revised to incorporate comments by the NRC in March 2012 to keep consistency in technical description with DCD Chapter 18, MUAP-09019, MUAP-10008, MUAP-10012, MUAP-10013 and MUAP-10014.

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Abstract

This document describes the Human System Interface (HSI) design implementation plan of the US-APWR Human Factors Engineering (HFE) process. The methodology for the function design used for the HSI System design such as alarms, displays, controls, and other aspects of the HSI are described in this document. This document describes two activities: (1) Design activities to create the US-APWR HSI inventory (2) Design activities to resolve Human Engineering Discrepancies (HEDs) from Phase 1 that impact the US-Basic HSI System design. Item 1 includes resolution of the HEDs from Phase 1 that impact the US-APWR HSI inventory. The topical report “HSI System Description and HFE Process” MUAP-07007 (reference 5-8) addresses the functional design of the HSI System and the HFE process used to create this system. In addition to the topical report and Design Control Document (DCD) Chapter 18, this document supplements the methodology and the process of how HSI designs are created.

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List of Acronyms

BISI	bypassed and inoperable status indication
CAS	central alarm station
CBP	computer-based procedure
CCF	common cause failure
CSF	critical safety function
D3	defense-in-depth and diversity
DAS	diverse actuation system
DCD	Design Control Document
DHP	diverse HSI panel
DMC	data management console
EOF	Emergency operations facility
EOP	Emergency operating procedure
FA	function allocation
FRA	functional requirements analysis
HA	human action
HED	human engineering discrepancy
HFE	human factors engineering
HRA	human reliability analysis
HSI	human system interface
HSIS	human system interface system
I&C	instrumentation and control
LCS	local control station
LDP	large display panel
MCR	main control room
MELCO	Mitsubishi Electric Corporation
MHI	Mitsubishi Heavy Industries
NRC	Nuclear Regulatory Commission, U.S.
OER	operation experience review
PRA	probabilistic risk assessment
QAPD	quality assurance program description
RSR	remote shutdown room
SA	staffing and qualifications analysis
SAS	secondary alarm station
SDCV	spatially dedicated continuously visible
STA	shift technical advisor

TA	task analysis
TSC	technical support center
US, U.S.	United States
US-APWR	US Advanced Pressurized Water Reactor
V&V	verification and validation
VDU	visual display unit

1.0 PURPOSE

The purpose of this implementation plan is to describe the approach being applied to translate functional and task requirements in defining the US-APWR human system interface (HSI) inventory and the detailed HSI design of alarms, displays, controls, layout and other aspects of the HSI that have been defined for the US-APWR. The human engineering discrepancies (HEDs) from Phase 1 verification and validation (V&V) that pertain to the US-Basic HSI System are incorporated to complete the design of the US-APWR Basic HSI System. The HEDs from Phase 1 V&V that pertain to the HSI inventory of the simulator reference plant are incorporated, as applicable to the US-APWR, to complete the US-APWR HSI Inventory. The subsequent US-APWR V&V program is applied to the completely integrated design of the US-APWR HSI System, as described in US-APWR V&V Implementation Plan MUAP-10012 (Reference 5-12).

2.0 SCOPE

The US-APWR HSI development is divided into three phases. The functional requirement specification serves as the initial input source to the HSI design effort. The US-APWR design is a direct evolution from a predecessor and the criteria is considered relative to operating experience of the predecessor and the design features (e.g., aspects of the process, equipment, or operations) of the new design that is different from the predecessor. Human performance issues identified from operating experience with the predecessor design are resolved. The initial source of input to the US-APWR HSI design is addressed in Reference 5-8, 5-9 and 5-10.

1. Phase 1 yields the US-Basic HSI System (HSIS). The conversion from the Japanese Basic HSIS to the US-Basic HSIS includes only changes in presentation, such as translation to English and American engineering units, anthropometric changes, and changes due to US nuclear power plant cultural differences. The conversion does not change the design unless the Phase 1 V&V indicates a design change is needed by the creation of HEDs. HEDs are resolved and any needed design changes are implemented and verified in Phase 2. The Phase 1 V&V is conducted with full scale simulation using a typical 4-loop PWR plant model. (Reference 5-8, 5-9 and 5-10)
2. Phase 2 is when the US-APWR Inventory is developed and then combined with the US-Basic HSI Design to yield the US-APWR HSIS. The basis for the US-APWR HSIS Inventory is defined according to the NUREG-0711 process. The US-Basic HSI System is instantiated using the US-APWR HSIS Inventory, which is developed using the US-APWR plant design data. Thus, the US-APWR HSIS becomes one specific application of the US-Basic HSIS. The US-APWR site-specific assumptions are used to develop a complete set of plant design data. This process does not change the US-Basic HSIS design unless Phase 2 V&V indicates a design change is needed by the creation of HEDs. HEDs are evaluated and resolved. HEDs that pertain to the V&V Acceptance Criteria are resolved, including any needed design changes and retesting, to complete the V&V program element. Other HEDs are resolved in Phase 3. The Phase 2 V&V is conducted with full scale simulation using a US-APWR plant model, including site-specific assumptions.
3. Phase 3 confirms the applicability of the site-specific assumptions from Phase 2 for a specific US-APWR plant application (e.g., Comanche Peak 3 and 4) or makes minor site-specific changes to the US-APWR HSIS to yield a site-specific HSIS (e.g. Comanche Peak 3 and 4 HSIS). Phase 3 ensures all outstanding HEDs from previous phases are resolved.

Since Phase 1 was completed in mid 2009, the scope of this document includes the US-APWR HSI Design Implementation Plan in Phase 2 and 3. The design input for the HSI Design Implementation Plan is the US-Basic HSIS design (Phase 1), which is addressed in HSI System Description and HFE Process (Reference 5-8). Other design inputs include the outputs of the following US-APWR HFE Program Elements, as described in Section 4 below:

- Operation experience review (OER)
- Functional requirements analysis and function allocation (FRA/FA)
- Human reliability analysis (HRA)
- Staffing and qualification analysis (SA)
- Task analysis (TA)

The scope of the HSI Design program element encompasses the main control room (MCR), remote shutdown room (RSR) and technical support center (TSC). This program element will also generate HSI designs for safety-significant local controls, and detailed communications and information requirements for the emergency operations facility (EOF). The HSI Design program element will also be used to generate the design of the HSI used by the operators in the MCR to communicate with the EOF, and with the central alarm station (CAS) and secondary alarm station (SAS).

3.0 APPLICABLE CODES, STANDARDS AND REGULATORY GUIDANCE

Compliance to the applicable codes and standards for the US-APWR HSIS design is the same as Section 3.0 of HSI System Description and HFE Process (Reference 5-8). Reference 5-8 includes the following standards and guidelines:

- Code of Federal Regulations
- Staff Requirements Memoranda
- NRC Regulatory Guides
- NRC Branch Technical Positions
- NUREGs
- IEEE standards
- Other Industry Guidelines

4.0 IMPLEMENTATION PLAN

4.1 HSI Design Input

The US-Basic HSI design described in Reference 5-8 is the initial design input for the US-APWR. The following sources of the US-APWR information, developed as part of design control document (DCD) Sections 18.2 through 18.6 (Reference 5-4), provide input to the US-APWR HSI design process:

a. Analysis of Personnel Task Requirements

The analyses performed in earlier stages (including the design of the Japanese Basic HSI, the OER, FA, TA and HRA) of the design process are used to identify requirements for the HSIs. Section 18.7.2.1 of DCD (Reference 5-4) addresses the HSI design inputs. Sections 18.2 through 18.6 of DCD (Reference 5-4) provide an overview of the processes for OER, FRA/FA, TA, HRA and SA. The detailed descriptions of the processes and the results for OER, FRA/FA, HRA and TA (for risk important human actions only) are provided in Part 2 of Human System Interface Verification and Validation (Reference 5-9) and Part 2 of US-APWR HSI Design (Reference 5-10). Implementation plans for TA (for other actions that are not risk important) and SA, provide the detailed description of the processes for these remaining analyses, see References 5-10 and 5-11.

These analyses include the following:

– OER (Reference 5-4 Section 18.2)

  Issues identified during the OER include human performance issues, problems, and sources of human error as well as design elements that support and enhance human performance. The OER identified potential HEDs that impact either the US-Basic HSIS or the US-APWR. Those HEDs that impact the US-Basic HSIS design or the US-APWR HSI inventory, rather than procedures or training, are inputs to the HSI design process. The design-related HEDs that were not closed in Phase 1 are inputs to the HSI Design Implementation Plan.

– FA/FRA (Reference 5-4 Section 18.3)

  The output of the FA/FRA for the US-APWR is used for functional elements of the HSI development such as key parameters and components that are used to control critical systems and functions. The key input of FA is operator’s role in the plant (e.g., appropriate levels of automation and manual control).

– TA (Reference 5-4 Section 18.4)

  The TA is the key input to developing the HSI inventory. It ensures the inventory directly supports the operating procedures and the risk-important human actions (HAs) by identifying the specific inventory needed and the characteristics of that inventory, including HFE and other design aspects.

– HRA (Reference 5-4 Section 18.6)

  All risk-important HAs, other actions performed by MCR operators, and safety significant actions of other non-licensed personnel are reviewed in light of the US-APWR HSI design to ensure that the interface design: (1) supports timely and accurate identification that a risk significant action is needed; (2) limits the probability of errors occurring when taking the action; and (3) increases the probability of timely error identification and recovery if an error does occur. HSI Design defines the HSI environment to meet the assumption of the HFE integrated HRA for all RI HAs. For example, HSI Design ensures necessary plant information and control functions are available on the same operational visual display unit (VDU) display, or are easily accessible through efficient display navigation. To aid in HSI design implementation, TA is used to determine what HSI environment should be used.

– SA (Reference 5-4 Section 18.5)

The minimum and maximum licensed operator staffing and qualifications are design constrains for the US-Basic HSIS. Therefore, staffing was a key input to the US-Basic HSIS design. During Phase 1, it was confirmed that the US-Basic HSIS adequately supports the minimum and maximum staffing. This same minimum and maximum licensed operator staffing is also a design constraint for the US-APWR HSIS. During Phase 2 analyses, HSI design and V&V, it will be reconfirmed that the US-APWR HSI System adequately supports the minimum and maximum licensed operator staffing.

The details for the US-APWR staffing and qualification implementation plan are described in technical report (Reference 5-11). The staffing and qualifications program element will confirm the minimum and maximum operator staffing and qualifications for non-licensed personnel that perform operations or maintenance tasks directly related to plant safety. The staffing numbers and qualifications and TA are an input to the design of the HSI used for the safety significant tasks performed by these personnel. The HSI is confirmed through the V&V program element or the Design Implementation program element.

The development of the above key implementation plans, analysis, evaluations and correlation between the elements is identified and described in Figure 4.1-1.

b. System Requirements

Constraints imposed by the overall instrumentation and control (I&C) system, such as redundancy, equipment qualification, and coping with common cause failures (CCF) are significant inputs for the HSI design and are considered throughout the HSI design process. The HSI design constraints and criteria from the overall I&C configuration are identified based on References 5-2 and 5-5. The Diverse Actuation System (DAS) provides diverse automatic actuation for time critical functions and diverse HSI to allow the operator to monitor critical safety functions (CSF) and manually actuate safety process systems. The design features and design processes for the Defense in Depth and Diversity (D3) for I&C systems described in Reference 5-7. The D3 coping analysis (Reference 5-19) establishes the design basis for the minimum HSI inventory needed to cope with accidents and concurrent CCF in the digital I&C and HSI systems.

The system requirements as mentioned above are applied to the following functions and Operation and Monitoring equipment for HSIS.

(1) Functions

-Operation Function: Non-safety operation function, safety operation function

-Plant Monitoring: Non-safety monitoring functions, safety monitoring function and alarm monitoring function

-Operation data management function: Recording, logging, performance calculation, tag management and printing

(2) Operation and Monitoring equipment (including communication system)

a) HSI

-Operator console (including hard-wired switches, Operational VDUs, alarm VDUs, Computer-Based Procedure (CBP) VDUs, safety VDUs, and Data Management Console (DMC))

-Supervisor console

-Shift technical advisor (STA) console

-Large Display Panel (LDP)

-Maintenance console

b) Plant computer system

c) Data communication

d) DAS HSI panel

c. Regulatory Requirements

Applicable regulatory requirements and industry standards, including those identified in Reference 5-8, are inputs to the HSI design process. (Refer to Section 3 of this document.)

US-APWR plant design specifications, which include Piping and Instrumentation Diagram (P&ID), functional diagrams for plant safety, component control logics, electrical diagrams, and alarm requirements, are used to develop the US-APWR HSI inventory. Those plant design input documents are used for HFE analysis such as FRA/FA, TA and HRA. The outputs from FRA/FA, TA and HRA may also provide feedback for changes in the plant design. The OER is used as input to the plant design and HSI design.

d. Other Requirements

The HSI design style guide which is in conformance with NUREG-0700 and other human ergonomic criteria is used for HSIS display design:

Other HSI design inputs include:

- HEDs from US-APWR Phase 1 V&V, or from any other phases as the design progresses
- Component Control Circuit Basic Design Guide (Reference 5-18)
- Expert Panel recommendations (Reference 5-10)

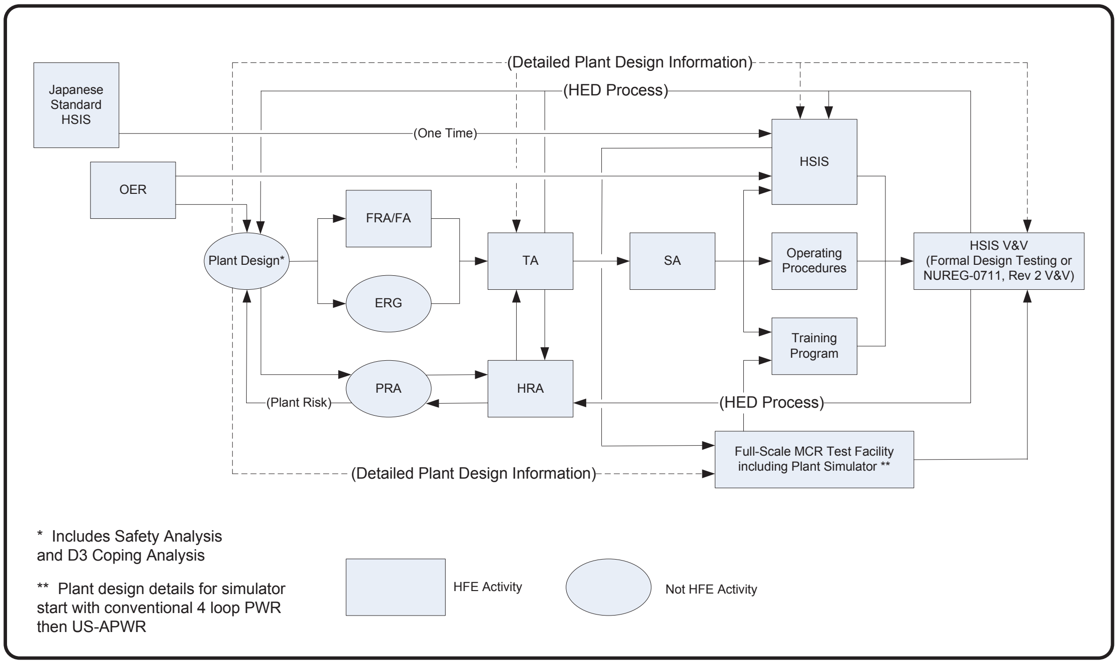

Figure 4.1-1 Overall Design Process

4.2 Concept of Operation

The concept of operations for the US-APWR is described in Reference 5-8, and includes:

- Crew composition (Reference 5-4 Section 18.1.1.1)
- Roles and responsibilities of individual crewmembers (Reference 5-4, Section 18.1.1.1)

Plant personnel addressed by the HFE program include licensed control room operators as defined in 10 CFR Part 55 and the following categories of personnel defined by 10 CFR 50.120:

- Non-licensed operators,
- Shift manager,
- Shift technical advisor,
- Instrument and control technician,
- Electrical maintenance personnel,
- Mechanical maintenance personnel,
- Radiological protection technician,
- Chemistry technician,
- Engineering support personnel.

The roles and responsibilities are described in the Staffing and Qualifications Implementation Plan (Reference 5-11).

In addition, any other plant personnel who perform tasks that are directly related to plant safety are addressed in the HFE program.

There is no computerized operator support system other than the HSIS which is described in Reference 5-8.

Other concepts of operations include:

- Personnel interaction with plant automation (Reference 5-8, Subsections 4.1.a, 4.1.b, 4.1.e, 4.1.h)
  - Overriding automatic systems

    Automatic interlocks and actuation signals are distinguished from automatic control signals. Automatic interlocks and actuation signals are provided for plant, system or equipment protection. Automatic control signals are provided to reduce operator task burden for functions that meet HFE automation criteria, such as frequent or complex operations.

    All automatic interlocks and actuation signals are always enabled and initially prioritized over opposite manual actuation signals and automatic control signals. After actuation, automatic safety actuation signals can be overridden by manually resetting the actuation signal at the train level. Where the plant designer has predetermined a specific need, automatic interlocks or actuation signals can be overridden at the component level.

To allow periodic testing or maintenance, interlocks and actuation signals can be manually inhibited at the component level by the “Lock” button. To ensure situational awareness of bypass conditions, and to avoid potential human error of unintentionally leaving a component in the “Lock” mode after testing or maintenance, bypass alarms for each train of each safety function are continuously displayed on the LDP.

Automatic control signals can be manually enabled or disabled by the plant operator. For situational awareness, the LDP displays the status of automated systems that are critical to power production critical functions.

- Use of control room resources by crewmembers (Reference 5-8, Sections 4.1.c, 4.1.d and 4.2)
- Methods used to ensure good coordination of crewmember activities, including non-licensed operators, technicians, and maintenance personnel. These coordination tools/methods include:
  - LDP (Reference 5-8, Section 4.9)

    LDP in MCR is designed to support crew situational awareness, coordination and communications;

    1) Providing continuously visible information to the crew members in order to ensure that the RO and SRO have all relevant plant information.

    2) Making plant information simultaneously available to all plant operating staff on duty and to support operator team activities.
  - Local Control Station (LCS) (Reference 5-8, Subsection 4.2.5), CAS and SAS

    In order to facilitate the communication between the MCR and LCSs and between the MCR and CAS/SAS, the communication systems provide for effective intra-plant and plant-to-offsite communications during normal, transient, fire, accidents, abnormal operational occurrences (e.g., LOOP), and security-related events. The various plant communication systems provide independent, alternate, redundant communication paths that ensure the ability to communicate with station and offsite agencies during all operating conditions. The design interface requirement between the MCR and LCS, and between the MCR and CAS/SAS, is confirmed through V&V activities. (Reference 5-12) Those HSI/HFE interfaces such as local panel design and communications system design are performed in accordance with US-APWR Quality Assurance Program Description (QAPD) (Reference 5-15) When communication between personnel is required to perform a task, the specifics of the communication is identified in the TA documentation. This includes the type of communication (e.g., verbal, written, hand signal), purpose (e.g., coordination, feedback) and equipment used (i.e., telephone, radio, public address, text pager).
  - The distance between each console and between the consoles and the LDP is set considering the vertical and horizontal viewing field of the operator, and the visibility of information displayed on the LDP.
  - Tagging (Reference 5-8, Section 4.5)

    To support maintenance and testing, plant components are tagged to bring attention to operability restrictions. The tagging feature of the HSIS is used to display tags for components controlled by Operational VDUs.

In addition, distribution of plant data via the unit bus and the plant station bus is described in Reference 5-2, Section 7.9, and voice communication systems for the US-APWR are described in Reference 5-3, Subsection 9.5.2.

The key design goals of the US-APWR HSIS are:

- Ensure the ability to continue to monitor the ‘big picture’ status of the plant while taking control actions;
- Minimize task burden related to display management (ensure there is no excessive need to switch between displays to collect needed information, make comparisons or execute a control sequence);
- Ensure the ability to take control actions in pace with plant dynamics;
- Ensure the ability to maintain broad situational awareness and stay ‘mentally’ ahead;
- Ensure the ability to maintain awareness of the status of the CSF;
- Ensure the ability to take control actions in pace with plant dynamics;
- Ensure the ability to follow procedures in pace with plant dynamics;
- Ensure the ability to catch and correct errors;
- Ensure mental workload is not excessive;
- Ensure physical workload is not excessive;
- Ensure ability to maintain awareness of what other crew members are doing; ensure ability to communicate and coordinate actions; ensure ability to catch and correct misunderstandings or errors, and ensure ability to maintain shared situational awareness; and
- Ensure ability to supervise automated systems and take manual control when necessary.

Personnel interactions involving decision making, coordination and feedback within the control room, between the MCR and LCSs, and between the MCR and support centers (including CAS and SAS) are evaluated in the V&V program element. (Details for V&V are described in Reference 5-12.)

Since the Concept of Operations is already described in Reference 5-8, it is not an output of the HSI Design Implementation Plan.

4.3 Functional Requirement Specification

Functional requirements for the HSIs address:

- The concept of operations
- Personnel functions and tasks that support their role in the plant as derived from function, task, and staffing/qualifications analyses
- Personnel requirements for a safe, comfortable working environment

The functional design requirements specify the control room systems and equipment that perform the assigned monitoring and control functions. It also specifies the interface between the human and the control room equipment. The design is based on an integrated HSIS engineering approach which includes consideration for:

-Human capabilities and characteristics

-Location, environment and personnel protection

-Space and configuration

-Panel layout

-Information and control systems

-Control-display integration

-Communication systems

-Other requirements

- Power supplies
- Qualification
- Maintainability
- Testability

The basic functional requirements for all HSI resources for the Functional Requirement Specification are reflected in the HSI design as described in Reference 5-8. During the detailed design process, the HSI inventory is added reflecting the output from the TA, including alarms, information and control content for specific displays.

4.4 HSI Concept Design

1) The US-Basic HSIS described in Reference 5-8 serves as the initial source of input to the HSI design. The HSI design development, from basic design phase through final design, is also described in Reference 5-8.

The Phase 1 V&V design testing of the US-Basic HSI design resulted in HEDs identified, with the majority being resolved. Outstanding HEDs from Phase 1 will be resolved in Phase 2.

The HED process is used to resolve HFE issues identified during any phase of the HFE program. The HED process has four steps:

1. Discrepancy Problem Statement
2. Discrepancy Evaluation
3. Discrepancy Resolution
4. Discrepancy Closure

The details for each step are identified in Reference 5-10. The HEDs evaluation process shall be executed according to Part1, Section 6 of Reference 5-10.

2) Additional approaches may also be used for addressing HSI functional requirements. As part of developing the US-Basic HSIS, a survey of the state-of-the-art HSI technologies was conducted to:

- Support the development of concept designs that incorporate advanced HSI technologies;
- Provide assurance that proposed designs are technically feasible; and
- Support the identification of human performance concerns and tradeoffs associated with various HSI technologies

During the conceptual design, the digital I&C/ HSI technology, such as touch-panel display, communication network, basic/application software for HSI, and communication equipment in the MCR was surveyed and introduced to develop the HSIS. Additionally, the R&D-based activities regarding HSI technology, I&C and IT technology were conducted separately from the development of the HSI design.

The US-Basic HSI design (Topical Report MUAP-07007) addressed “alternative approaches for addressing HSI functional requirements”. Additional approaches for addressing HSI functional requirements are considered in resolving Phase 1, 2 and 3 design-related HEDs.

3) Alternative approaches utilized for addressing HSI functional requirements include:

- Operating experience as an input to develop the HSI design described in Section 4.1 design input.

- Literature analyses (desk-check), tradeoff studies and engineering evaluations conducted from the view point of HSI functional requirement, such as safety, including regulatory requirements, maintainability, testability, operability and crew coordination/performance, etc. (e.g. new concept of HSIS, new alarm system concept, virtual reality, new technology of displays, etc.)

Alternate approaches for addressing HSI functional requirements are considered in resolving Phase 1, 2 and 3 design-related HEDs.

4) Alternative concept designs were provided through the HSI design review. The evaluations and the design review were performed in accordance with the US-APWR QAPD and design standard/procedure (e.g., document/drawing review, check list, etc). Review criteria include:

- Situation Awareness,
- Operability,
- Following Procedures,
- Error-tolerance,
- Mental workload,
- Physical workload,
- Teamwork,
- Supervising Automated Systems,
- Shift staffing, etc.

The same process evaluation and design review processes are applied to any design changes resulting from the resolution of Phase 1, 2 and 3 design-related HEDs.

5) HSI design performance requirements result from the design evaluation where the selected HSI conceptual design is defined with the functional requirement specification, and includes the result of the HSI technology considerations described above.

The US-Basic HSIS design documented in Topical Report MUAP-07007, reflects the resolution of the significant HEDs from Phase 1. Other Phase 1 HEDs will be addressed in either the generic US-APWR HSIS design developed in Phase 2, or the site-specific US-APWR HSIS design developed in Phase 3. The US-Basic HSIS design, documented in Topical Report MUAP-07007, will not be revised unless this simplifies the licensing application for a future project which references that specific Topical Report.

4.5 HSI Detailed Design and Integration

1) Style Guide Development

US-APWR design-specific HFE design guidance is the HSI Design Style Guide (Reference 5-17) utilized in the design of the HSI features, layout, and environment. The Style Guide will also be applied in the HSIS verification process of Phase 2b V&V implementation Plan (Reference 5-12).

The HSI design style guide is derived from NUREG-0700 as a generic HFE guidance and Mitsubishi's own guidelines. This style guide is updated to incorporate the resolution of HEDs of Phase 1 testing. The Style Guide and its updates undergo verification review to ensure compliance with the requirements of NUREG-0700. The HSI design style guide will be made available for NRC audit.

The style guide addresses: (1) general guidelines for display development; (2) guidelines for each display element, including the functional description of the elements; (3) display system description; and (4) display formats of the HSIS scope.

General guidelines for display include:

- Display design consistency
- Understandability of information
- Information grouping
- Information readability
- Distinctive coding
- Uncluttered displays
- Status display indication
- Display update rate requirements

Guidelines for display elements include:

- Character
- Labels
- Color
- Tables and Lists
- Graphs
- Mimics
- Icons and Symbols
- Alarms
- Controllers

Display format includes:

- Monitoring and Control displays (operational VDU screens)
- LDP
- Alarm VDU
- Operating procedure VDU
- Monitoring and Control display for safety systems

The individual guidelines are expressed in concrete, easily observable terms (e.g., VDU character size, etc.).

The style guide supports the interpretation and comprehension of design guidance by supplementing text with graphical examples, figures, and tables. For example, the guideline of the trend graph using a graphical example is shown below.

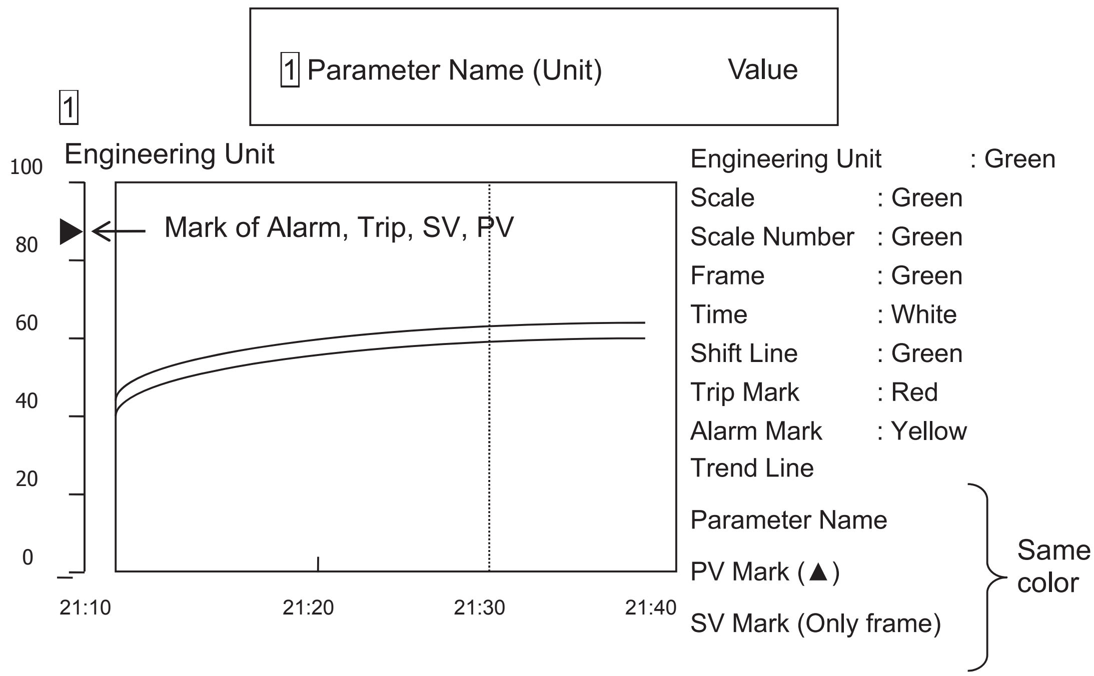

Figure 4.5-1 Trend Graph Using the Graphical Example

The style guide is maintained in a form that is readily accessible and usable by designers and facilitates modification when the contents require updating as the design matures. Each guideline included in the style guide documentation includes a reference to the source upon which it is based (as applied in NUREG-0700). The style guide ensures the screen elements (e.g., graphic symbols, tables, graphs, etc.) and their coding are consistent across all displays (e.g., Monitoring and Operational display, alarm display, LDP, etc). The style guide ensures plant conditions are consistent across information screens to allow operators to quickly and accurately assess the status of the plant. The V&V Team verifies all displays against the style guide.

Section 18.7.2.5, Reference 5-4 addresses the style guide. The basic design of the display and the style guide is provided in Section 5.7.3.2, Reference 5-8. Sections 4.4 through 4.9, Reference 5-8, contain the basic display design.

In the HSI design, especially in the screen design for HSIS, the style guide is applied to develop the screens for each HSI element, such as monitoring and control display and LDP. Detailed rules of the elements for the screen design such as font size, color coding and symbols are followed when the screen is developed. The HSI details, such as window manipulation, display selection, display system navigation, are designed to support personnel in their role for monitoring and controlling the plant while minimizing personnel demands associated with use of the HSIs. These principles from NUREG-0700 are reflected during the HSI development. Additionally, the style guide is applied in combination with the other design guidelines and specifications (e.g., controller, alarm), and the results of the screen are documented as a display specification.

2) Risk Important HAs

Section 18.7.2.5, Reference 5-4 addresses how the design both minimizes the probability of error in the performance of risk-important HAs and provides the opportunity to detect errors. A minimum of two actions is required for all controls to reduce the potential for erroneous operator actions that may cause a transient. In addition, operational VDU displays are designed to support credited manual operator actions for event-based mitigation.

In accordance with the overall HFE process shown in Figure 4.1-1, after the HSI design for the alarms, graphics and controls in the VDU screen are developed based on input from the plant design and the TA, an independent table top walk-through is conducted using operations and HFE experts to assess those designs against the HRA.

3) Functional Requirements to MCR and LCS

When developing functional requirements for monitoring and control capabilities that are provided either in the control room or locally in the plant, the following factors are considered:

- Communication, coordination, and workload
- Feedback
- Local environment
- Inspection, test, and maintenance
- Importance to safety

All control functions are accessible in the MCR and RSR and no LCS controls are credited for normal operation or accident condition operator response under normal HSI conditions. The basis for the MCR layout, and the organization of HSIs within consoles, panels, and workstations assures the MCR is designed to support the range of crew tasks and staffing and operational VDUs that are used during all normal and emergency modes of operation are centrally located. MCR layout is discussed in Section 4.3.1, Reference 5-8, and staffing and qualification is addressed in Reference 5-11.

4) Analyses of Operator Roles

Section 18.7.2.5, Reference 5-4 addresses how the control room supports a range of anticipated staffing situations. The design accommodates minimum and maximum staffing, as described in Section 18.5, of Reference 5-4. Sufficient space is available to accommodate shift/turnover transitions.

5) Performance Due to Fatigue

Reference 5-8, Section 4.3 and Reference 5-3, Subsection 9.5.3 describe how the HSI characteristics mitigate excessive fatigue, including lighting, ergonomics and layout design.

6) Environmental Conditions

Reference 5-2 and Reference 5-3 Subsection Section 9.4 and 9.5.3 describe how the HSI characteristics support human performance under a full range of environmental conditions. The MCR is a highly controlled environment without a significant fluctuation of environmental conditions, including emergency lighting, ventilation and control room habitability for plant accident conditions.

7) Inspection, Maintenance, Tests and Repair of HSIs

Inspection, maintenance, tests, and repair of HSIs is accomplished without interfering with other control room tasks described in Reference 5-8, Section 4.11 “Response to HSI Equipment Failures” that discusses response to HSI equipment failures without impacting plant control functions.

8) HSI Inventories

The US-APWR MCR development work sequence is based on modeling the HSIS as two components, a generic constituent and a plant-specific constituent. The generic constituent is referred to as the “US-Basic HSIS” and the plant-specific constituent is referred to as the “US-APWR HSI Inventory.” The US-Basic HSIS is common to all US nuclear power plants (e.g. the US-APWR and US operating plant control board replacements). The US-APWR HSI Inventory is unique to the US-APWR.

The US-Basic HSIS comprises the HSI elements and it is where the HSI operation methods and techniques are used. The US-Basic HSIS is defined by Reference 5-8, which includes a design basis and functional design specification for data processing, access, and presentation, and a style guide defining the HSI attributes. Examples of HSI attributes are general display guidelines, display element design, display screen format, and display hardware requirements.

The HSI Inventory is the set or collection of specific indications, alarms, controls, and procedures implemented using the HSI techniques defined by the US-Basic HSIS for all plant systems and tasks for all HSI media for a specific nuclear power plant. For example, the HSI inventory includes, but is not limited to, the mimic screens, alarm messages, control stations, and procedures. The HSI inventory is developed from an HFE analyses.

The US-APWR HSI inventory is defined and specified by the HSIS designers through an HFE analysis. The US-APWR HSI inventory shall be developed through the HFE analysis defined by Reference 5-4 and this Implementation Plan. As described in Reference 5-4, to develop the US-APWR HSI Inventory, the US-APWR HFE program reassesses each NUREG-0711 element with emphasis on changes from prior analysis, assessment, and experience. The US-APWR Phase 2a HFE analysis results (Reference 5-10) and the US-APWR plant design data are used to generate the US-APWR HSI Inventory for the alarms, displays, procedures, and controls. The US-APWR HSI Inventory constituent generation activities are interrelated and can be iterative with the HFE products being refined as more detailed plant design data becomes available. Site-specific assumptions are included in the generic US-APWR HSI Inventory, as necessary, to complete the total plant design data set. Intermediate states of the constituents are checked against each other for consistency.

- Functions and Roles in MCR

In developing the US-APWR MCR HSI inventory, the work performed by operators is classified based on the TAs, and the roles and role sharing of MCR operators are clarified. Subsequently, the function classification required for MCR development is performed.

a. Classification of Operation Tasks

Operation tasks are analyzed in the TA. The work categories, outlined frequencies and the systems required along the work flow were investigated so that the operator work might be classified. Table 4.5-1 shows the operation work performed in the MCR.

b. Function Classification Required for MCR Development

Basic functions

Requirements related to the operating functions are shown below. The roles of MCR are put in order as shown in Figure 4.5-2.

c. Requirements related to operation include:

1. Central power supply (load dispatch communication function)
2. Paging / broadcast function
3. Clock function
4. On-site communication function
5. Operating function
6. Display function
7. Function to communicate with local areas in the plant
8. Test function
9. Operating function by shift supervisor
10. Data recording function
11. System isolation control function (outage)
12. Test function (outage)

d. Requirements related to spaces in MCR:

The basic function and the requirements related to the spaces are shown below:

1. Space for shift turnover
2. Space to prepare operating records and forms
3. Space for operations
4. Space for operations in coordination with maintenance personnel
5. Space for operation monitoring

6. Space for reporting the result of patrol checks
7. Space for accident management or other failure
8. Space for shift manager on-duty
9. Space for general meeting
10. Space capability for storing various documents and forms

e. HSI inventory requirement

As a result of the HSI inventory development process described above, the following inventories are derived (the HSI inventory is broadly classified into the following categories):

Plant management

Supervisor Console

DMC

Monitoring and Control (Operation)

LDP

Operation Console

Diversity HSI panel (DHP)

Maintenance and Testing

Maintenance Console

Communications

Desk for meetings

Paging, communication systems

f. Minimum HSI Inventory

The LDP fixed area presents spatially dedicated continuously visible (SDCV) information to the operating staff. The parameters and alarms on the LDP are described in Reference 5-8, Section 4.9, including SDCV indications for bypassed and inoperable status indication (BISI) for RPS, ESFAS and plant safety systems.

Means are provided in the MCR for manual initiation of protective functions at the system level. These functions are realized by conventional hard-wired Class 1E switches that enable easy and prompt access by the operator. Means for manual control of safety systems at the component level are realized by the safety VDUs described in Reference 5-8, Section 4.6.

The minimum SDCV inventory and the minimum inventory for degraded HSI conditions are established to monitor and control six CSF:

- Reactivity Control
- RCS Inventory
- Core Cooling
- Secondary Heat Sink
- RCS Integrity
- Containment Integrity

This applies to all normal and emergency plant modes. The specific functions, tasks and the key required HSI resources, including alarms, controls, displays and procedures, are extracted from Normal Operating Procedures (NOP), Emergency Operating Procedure (EOP) and Plant Probabilistic Risk Assessment (PRA) described in plant licensing documents. The minimum inventory is based on monitoring key performance parameters for each critical function and controlling the preferred non-safety and safety success paths. The minimum inventory HSI design is developed and evaluated through the HFE design process described in Reference 5-8, Section 5.

The design of the minimum inventory HSI (SDCV and Class 1E) is developed and evaluated through the HFE design process described in Reference 5-8, Section 5.

9) Qualification of HSI Designers

The HFE team includes a technical reviewer and is made up of personnel that are experienced in HFE. The personnel have experience:

- Related to the human factors aspects of HSI
- Design, development, test, and evaluation of HSI
- Related to the human factors aspects of workplace design

The HFE Team personnel who conduct the HFE are trained in the purpose, scope and methodology of the HFE in accordance with US-APWR QAPD (Reference 5-15). HSI personnel are trained in the Basic HSI Design and HFE Design Process, and the plant systems of the US-APWR. This training allows HFE personnel to evaluate the applicability of an HFE issue to the US-APWR, to assess those items that are considered to be already included in the US-APWR HSIS and those items not already addressed in the US-APWR HSIS. Personnel are trained in identifying HEDs and entering those HEDs in the HFE issues tracking system.

Table 4.5-1 Classification of Operation Tasks

No.	Task	Description
1	Shift turnover	Relay work of operation in shift.
2	Receiving power supply command (central load dispatcher requests)	Perform operations requested by the central load dispatcher.
3	Operation report	Report to prevent plant accident and insufficient communication.
4	Operation records	Record and review operating logs to maintain efficient operation and prevent accidents.
5	Operating work by on-duty personnel	On-duty personnel shall work under the direction/supervision of on-duty shift manager or supervisor.
6	Operation standard values and operation limit values	Ensure compliance with the operation standard values/limit values in all operations.
7	Component control (daily operation)	Effectively monitor plant operation and control the component.
8	Component control (associated with maintenance & testing)	Perform work with maintenance personnel and ensure all work instruction steps are complete.
9	Operation monitoring	By monitoring the equipment and controllers, maintain the best condition at all times.
10	Routine system checks	Carry out patrol checks of the specified systems.
11	Periodic testing	Carry out periodic tests of equipment, controllers, and security systems in operation.
12	Provisional testing	Carry out infrequently performed or provisional tests and special tests.
13	Recovery during accident	Perform necessary task to mitigate accidents in accordance with the operating procedure
14	Accident prevention	Monitor equipment to prevent malfunction
15	Safety control	Take every measure to prevent accidents when there are indications of such dangers in plant facilities and/or working environment.
16	Operation maintenance	Carry out daily checks, routine maintenance work.
17	Radiation control	Ensure early detection of faults/malfunctions by observing radiation monitor trends.

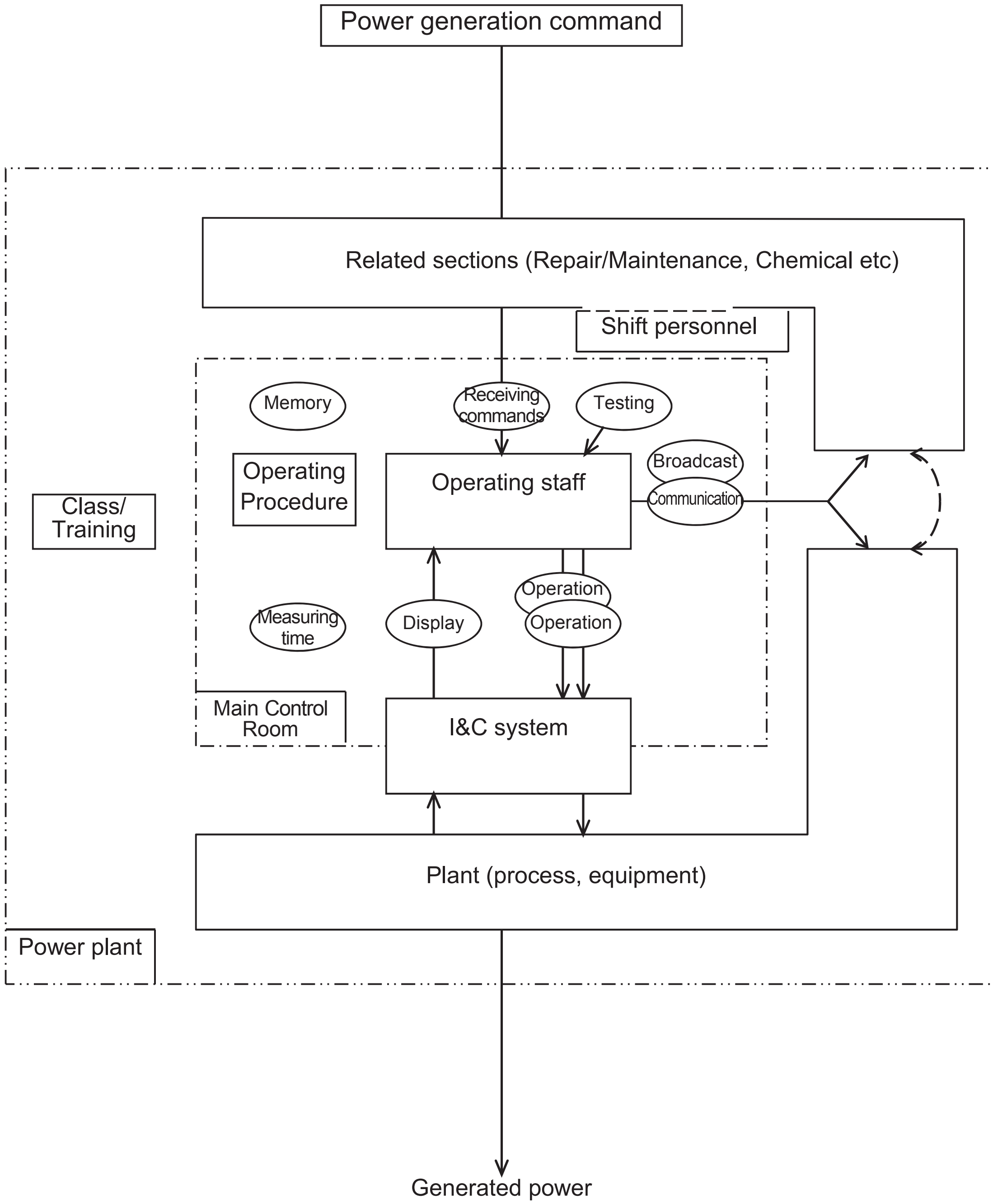

Figure 4.5-2 Roles and Interfaces in MCR

4.6 HSI Tests and Evaluations

The design process applied to the resolution of Phase 1 design-related HEDs for the US-Basic HSIS is an iterative design and test process. These tests are focused on specific interface elements and conducted as a human in the loop scenarios on a dynamic part task simulator, applying similar data collection and analysis used in the final validation of the US-APWR HSI. As the final design matures, additional testing will be used, to evaluate important design resolution choices prior to entering the validation Phase, 2b.

Testing and evaluation of US-Basic HSI design changes to resolve Phase 1 HEDs are conducted throughout the HSI development process, and evaluations are performed iteratively. Trade-off evaluations are executed for selecting alternative HSI designs from the viewpoint of reliability and usability. Some prototypes of HSI design (part-task), such as CBP mock-up, are made for performance-based tests.

Reference 5-8, Appendices A and B describe the tests and evaluations conducted for the Japanese Basic HSIS, which is the basis of the US-Basic HSIS described in Reference 5-8, Section 4.0. Appendix C describes the additional tests and evaluations conducted for the development of the US-Basic HSIS (Phase 1), and the additional tests and evaluations that will be conducted for the plant-specific application of that system (Phase 2), and the site-specific application of that system (Phase 3). The V&V activities conducted during Phase 2b and Phase 3a of the HFE program are conducted on the ‘final’, integrated design. Phases 2 and 3 are applicable to new plants and operating plant modernization programs. The testing and evaluation of the HSI designs are addressed in Reference 5-4, Section 18.7.2.6. These methodologies are provided in Section 18.10 of Reference 5-4. The details for V&V and how to incorporate HEDs are described in Reference 5-9 and 5-10.

4.7 HSI Design Documentation

The detailed HSI design description includes: form, function and performance characteristics; basis for the HSI requirements; design characteristics with respect to operating experience and literature analyses; tradeoff studies; engineering evaluations; experiments; and benchmark evaluation records, which is the basis for design changes.

The following documentation is provided to define the US-Basic HSIS described in Reference 5-8:

- The HSI Design Style Guide.
- The US-Basic HSI Nomenclature Guide defining the standard acronyms, abbreviations, and equipment description guidelines used in the HSI design.
- The US-Basic HSI Component Control Circuit Basic Design Guide describing the generic control logic and information processing logic to support operator control face plate operation, including associated indications and alarms.
- The US-Basic HSIS Detailed Design Description
- Key design documents that complete the integrated US-APWR HSI design include:
- Graphic display and panel layout drawings
- HSI database, defining characteristics (e.g., instrumentation ranges and alarm prioritization) and links to the VDU display icons, parameters, trends, alarms, soft controls, and panel hardware devices to the database of the control and protection systems
- Logic and algorithm diagrams for HSI function processing, such as OK status monitoring, BISI and critical safety function monitoring.
- Detailed room and console configuration diagrams (layout drawings).
- All documents defined in the two sections above are developed and maintained in accordance with QAPD (Reference 5-15) for important to safety functions. Graphics and panel layout drawings for the Safety-VDU and console sections that are safety-related are developed and maintained in accordance with QAPD for safety related functions.
- The following apply to both the US-Basic HSI System and US-APWR HSIS:
- HED data base
- All QAP required configuration control documentation

The design documentation for the US-APWR HSI is developed based on the US-Basic HSI design documentation. The design changes records are incorporated in the design documentation.

The tests and evaluations outcomes, such as V&V activity and part task design evaluations, are documented as Quality Records.

4.8 Results Summary Report

The HSI design results which are based on the processes described in Sections 4.1 through 4.7 are summarized in a HSI Design Implementation Plan Results Summary Report. This report is intended to fulfill the requirements of the Inspections, Tests, Analyses, and Acceptance Criteria defined in Tier 1 of the DCD .

5.0 REFERENCES

5-1 Design Control Document for the US-APWR, Chapter 6, Engineered Safety Features, MUAP-DC006, Revision 3, MHI, March 2011

5-2 Design Control Document for the US-APWR, Chapter 7, Instrumentation and Controls, MUAP-DC007, Revision 3, MHI, March 2011

5-3 Design Control Document for the US-APWR, Chapter 9, Auxiliary Systems, MUAP-DC009, Revision 3, MHI, March 2011

5-4 Design Control Document for the US-APWR, Chapter 18, Human Factors Engineering, MUAP-DC018, Revision 3, MHI, March 2011

5-5 Safety I&C System Description and Design Process, MUAP-07004, Revision 7, MHI, May 2011

5-6 Safety System Digital Platform -MELTAC- , MUAP-07005, Revision 8, MHI, July 2011

5-7 Defense-in-Depth and Diversity, MUAP-07006, Revision 2, MHI, September 2009

5-8 HSI System Description and HFE Process, MUAP-07007, Revision 5, MHI, November 2011

5-9 US-APWR Human System Interface Verification and Validation (Phase 1a), MUAP-08014, Revision 1, MHI, May 2011

5-10 US-APWR HSI Design, MUAP-09019, Revision 2, MHI, October 2012

5-11 US-APWR Staffing and Qualifications Implementation Plan, MUAP-10008, Revision 2, MHI, October 2012

5-12 US-APWR Verification and Validation Implementation Plan, MUAP-10012, Revision 2, MHI, October 2012

5-13 US-APWR Design Implementation Plan, MUAP-10013, Revision 2, MHI, October 2012

5-14 US-APWR Human Performance Monitoring Implementation Plan, MUAP-10014, Revision 2, MHI, October 2012

5-15 Quality Assurance Program (QAP) Description For Design Certification of the US-APWR, PQD-HD-19005, Revision 4, MHI, April 2011

5-16 Nuclear power plants – Control rooms – Design, IEC 60964

5-17 HSI Design Style Guide, JEJC-1763-1001, Mitsubishi Electric Corporation (MELCO)

5-18 Component Control Circuit Basic Design Guide, N0-EJ30102, MHI

5-19 Defense-In-Depth And Diversity Coping Analysis, MUAP-07014, Revision 5, MHI, September 2011