US-APWR

HSI Design

Non-Proprietary Version

December 2011

Revision History

Rev.	Date	Page (Section)	Description
0	June 2009	All	Original issued
1	December 2011	General	Revised “Implementation Procedure” to “Implementation Plan”. Revised Figure and Table number. Revised “US Basic” to “US-Basic”. Referred latest revision of the reference documents. Revised “shift supervisor” to “shift manager”. Revised “Reference 0” to “Reference 11.1” for RAI Response No. 797 (Question No. 18-184). Revised “expert panel” to “HFE design team” for RAI Response No. 728 (Question No. 18-114). Revised number of Section, Table, and Figure. “3.8” to “3.9”, “3.9” to “3.10” Revised “NUREG ” to “NUREG-”.
		p. xi (Abstract)	Revised the description.
		p. xviii (List of Acronyms)	Revised “SS Shift Supervisor” to “SM Shift Manager”.
		p. 1 (Part 1 Section 1)	Revised the description.
		p. 1 (Part 1 Section 1.1)	Revised the description.
		p. 2 (Part 1 Section 2.1)	Added the last paragraph.
		pp. 2-3 (Part 1 Section 2.3)	Revised the description for RAI Response No. 728 and 780 (Question No. 18-108 and 18-129).

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		p. 3 (Part 1 Section 3.1)	Revised the description.
		pp. 3-5 (Part 1 Section 3.2)	Revised the description for RAI Response No. 728 (Question No. 18-109). Revised Figure 1 for RAI Response No. 728 (Question No. 18-109). Added the fourth paragraph for RAI Response No. 728 (Question No. 18-111). Added the last paragraph.
		p. 6 (Part 1 Section 3.3.1)	Revised the description for RAI Response No. 728 (Question No. 18-111).
		p. 7 (Part 1 Section 3.3.2)	Revised the description.
		p. 7 (Part 1 Section 3.3.3)	Revised the description.
		p. 8 (Part 1 Section 3.3.4)	Revised the description.
		p. 8 (Part 1 Section 3.4)	Revised the description.
		p. 8 (Part 1 Section 4)	Revised the description.
		p. 8 (Part 1 Section 4.1)	Revised the description.
		pp. 8-9 (Part 1 Section 4.2)	Revised the description.
		p. 9 (Part 1 Section 4.3)	Revised the description.
		p. 10 (Part 1 Section 4.4.2)	Added the last sentence.
		pp. 10-13 (Part 1 Section 5)	Added (1), (2) and (3) for RAI Response No. 728 (Question No. 18-112). Added Figure 5 and 6 for RAI Response No. 728 (Question No. 18-112).

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		p. 13 (Part 1 Section 5.1)	Revised the description.
		p. 13 (Part 1 Section 5.2)	Revised the description.
		p. 13 (Part 1 Section 5.3)	Revised the description.
		p. 14 (Part 1 Section 5.6)	Revised the description.
		p. 15 (Part 1 Section 5.7.1)	Revised the description.
		p. 15 (Part 1 Section 5.7.2)	Revised the description.
		p. 15 (Part 1 Section 5.7.3)	Revised the description.
		pp. 16-17 (Part 1 Section 6.1)	Revised the description for RAI Response No. 728 (Question No. 18-114).
		p. 17 (Part 1 Section 6.3)	Added the last sentence.
		p. 18 (Part 1 Section 6.4)	Added the last sentence.
		p. 18 (Part 1 Section 6.4.1)	Revised the first sentence.
		p. 19 (Part 1 Section 6.4.2)	Revised “describe on” to “described in”.
		pp. 19-20 (Part 1 Section 6.5)	Revised the description.
		p. 20 (Part 1 Section 6.6)	Revised the description.
		p. 21 (Part 1 Section 7.2)	Revised Table 1.
		p. 21 (Part 1 Section 7.2.1)	Revised the description.

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		p. 22 (Part 1 Section 7.2.2)	Revised the section title and Table 3.
		pp. 22-23 (Part 1 Section 7.2.3)	Revised Table 4.
		p. 23 (Part 1 Section 7.2.4)	Revised the description and Table 5.
		pp. 23-25 (Part 1 Section 8)	Revised the description for RAI Response No. 728 and 780 (Question No. 18-108 and 18-129).
		p. 25 (Part 1 Section 8.1)	Revised “MCR” to “HSIS”. Revised “rather it is focused of” to “, but rather it is focused on”.
		p. 26 (Part 1 Section 8.1.1.2 and 8.1.2.1)	Revised “”an implementation procedure” to “a procedure”.
		p. 27 (Part 1 Section 8.1.2.2)	Added the second sentence. Revised last sentence.
		p. 28 (Part 1 Section 8.1.3)	Revised the description.
		p. 28 (Part 1 Section 8.1.4)	Added “in”.
		p. 28 (Part 1 Section 8.1.5)	Revised the last sentence.
		p. 29 (Part 1 Section 8.2)	Added “analyze, ”.
		p. 29 (Part 1 Section 8.2.1)	Revised the description.
		p. 29 (Part 1 Section 8.2.1.1)	Added the last sentence.
		pp. 29-30 (Part 1 Section 8.2.1.2)	Revised the description.

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		pp. 30-31 (Part 1 Section 8.2.2.2)	Revised the description.
		pp. 31-32 (Part 1 Section 8.2.2.3)	Revised the last sentence in the third paragraph for RAI Response No. 728 and 780 (Question No. 18-108 and 18-129). Revised description.
		p. 32 (Part 1 Section 8.2.2.4)	Revised the description.
		p. 32 (Part 1 Section 8.2.2.5)	Revised the description.
		p. 32 (Part 1 Section 8.2.3)	Revised the description.
		p. 32 (Part 1 Section 8.2.4)	Revised the description.
		p. 33 (Part 1 Section 8.3)	Revised the description.
		p. 33 (Part 1 Section 8.3.1)	Revised the description. Revised the last paragraph for RAI Response No. 728 and 780 (Question No. 18-108 and 18-129)
		p. 33 (Part 1 Section 8.3.2)	Revised the description.
		p. 34 (Part 1 Section 8.3.3)	Revised the description.
		p. 34 (Part 1 Section 9.1)	Revised “Process” to “Program”.

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		p. 34 (Part 1 Section 9.3)	Revised “plants” to “plant”.
		p. 34 (Part 1 Section 10)	Revised the description.
		p. 36 (Part 2 Section 1.1)	Revised “will be” to “was” for RAI Response No. 594 (Question No.18-80).
		p. 36 (Part 2 Section 1.2)	Revised “will be” to “was” and deleted “will” for RAI Response No. 594 (Question No. 18-80).
		p. 38 (Part 2 Section 1.4)	Revised Figure 1.4-1.
		pp. 39-40 (Part 2 Section 1.4.1)	Revised “broken” to “faulted”.
			Added the last paragraph for RAI Response No. 793 (Question No. 18-143).
		p. 41 (Part 2 Section 1.4.2)	Revised “broken” to “faulted”.
		pp. 45-46 (Part 2 Section 1.4.3)	Revised the description of the third bullet for RAI Response No. 793 (Question No. 18-149).
			Revised Figure 1.4-2 for RAI Response No. 793 (Question No. 18-141).
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		p. 115 (Part 2 Appendix 1.8.5)	
		p. 116 (Part 2 Section 2.2)	Revised the first paragraph. Added to second paragraph for RAI Response No. 664 (Question No. 18-97).
		p. 118 (Part 2 Section 2.4.2.1)	Revised “such as” to “of” for RAI Response No. 595 (Question No. 18-86).
		p. 120 (Part 2 Section 2.4.2.2.1 B)	Deleted the second sentence for RAI Response No. 797 (Question No. 18-182).
		p. 122 (Part 2 Section 2.5)	Added “Integration” to the first sentence.

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		p. 124 (Part 2 Section 2.9)	Added Reference 2.9-6 and 2.9-7.
		pp. 127-195 (Part 2 Appendix 2.10.2)	
		p. 196 (Part 2 Appendix 2.10.3)	
		p. 197 (Part 2 Section 3.2)	Revised the first paragraph and added the second paragraph for RAI Response No. 781 (Question No. 18-131). HRA Report Part 2 Section 2 refers to that same document for RAI Response No. 664 (Question No. 18-95). Revised the last paragraph for RAI Response No. 595 (Question No. 18-87).
		pp. 198-201 (Part 2 Section 3.4)	Revised the description. Revised Table 3.4-1 for RAI Response No. 781 (Question No. 18-132).
		p. 201 (Part 2 Section 3.6.1)	Revised the first sentence.
		pp. 201-203 (Part 2 Section 3.7)	Revised the description. Added the new description after the last paragraph for RAI Response No. 781 (Question No. 18-137).
		p. 204 (Part 2 Section 3.8)	Added as a new Section 3.8 (from Section 3.8.1 to Section 3.8.3.7) for RAI Response No. 781 (Question No. 18-132).
		pp. 208-245 (Part 2 Section 3.8.3.8)	Added as a new Section 3.8.3.8 for RAI Response No. 781 (Question No. 18-131).

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		pp. 248-255 (Part 2 Appendix 3.10.1)	
		pp. 257-283 (Part 2 Appendix 3.10.2)	Revised the description.
		p. 284 (Part 3 Section 1)	Deleted “The” in the second paragraph.
		p. 289 (Part 3 Section 4.2.2)	Revised “@” to “at”.
		p. 290 (Part 3 Section 4.2.3)	Revised “the” to “The” at the last sentence in the first paragraph.
		p. 292 (Part 3 Section 5.1)	Revised “The” to “the”.

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Abstract

This technical report contains three parts:

Part 1 is the US-APWR Human Factors Engineering (HFE) Overall Implementation Plan, as stated in MUAP DC018 (MHI 2011, Rev.3), Section 18.1. This plan is applicable to the complete US-APWR HFE program, which starts with the development and NRC approval of the US-Basic HSI System, and continues through the implementation of the US-APWR HSI System for a site specific application. The US-APWR HSI System combines the generic control, monitoring, alarm and computerized procedure methods of the US-Basic HSI System with the specific HSI inventory needed for the US-APWR. Similarly, the generic control, monitoring, alarm and computerized procedure methods of the US-Basic HSI System can be applied to the modernization of operating plants with the specific HSI inventory needed for that plant.

Part 2 documents the US-APWR HFE Analysis methodologies and results summary reports for Functional Requirement Analysis and Functional Allocations (FRA/FA), Task Analysis (TA) for Risk Important Human Actions (RIHA) and Human Reliability Analysis (HRA), as stated in MUAP DC018 (MHI 2011, Rev.3), Sections 18.3, 18.4 and 18.6, respectively. The TA section also includes the US-APWR Task Analysis Implementation Plan for additional TA that will be conducted in the future for other functions that are within the scope of the US-APWR HFE program.

Part 3 provides the US-APWR Phase 1b Verification and Validation (V&V) methodology and results report. The Phase 1b V&V program is the second phase of a three phase V&V program for the US-APWR, as described in MUAP DC018 (MHI 2011, Rev.3), Section 18.10. The Phase 1a V&V program was described in MUAP-08014. In Phases 1a and 1b U.S. licensed operators participated and evaluated the Mitsubishi / Japanese Basic HSI system. The HSI tested in Phases 1a and 1b, along with changes resulting from the resolution of key Human Engineering Discrepancies (HED), constitute the US-Basic HSI System, which is documented in MUAP-07007 and for which a Nuclear Regulatory Commission (NRC) Safety Evaluation Report (SER) is expected. The V&V Implementation Plan for Phases 2 and 3 is provided in MUAP-10012.

The complete US-APWR HFE program is defined by the results summary reports described above, the Implementation Plan for future TA activities described above, and the following Implementation Plans for other future HFE activities: Staffing Analysis MUAP-10008, HSI Design MUAP-10009, Training Development MUAP-10010, Procedure Development MUAP-10011, Design Implementation MUAP-10013, and Human Performance Monitoring MUAP-10014.

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List of Acronyms

ALR	Automatic Load Reduction (turbine control)
AO	Auxiliary Operator (Non licensing plant personnel)
AOO	Anticipated Operational Occurrences
AOP	Abnormal operating procedure
APWR	Advanced Pressurized Water Reactor
ARI	All Rods In
ARP	Alarm Response Procedure
ATWS	Anticipated Transient Without Scram
BD	Blow-Down
BHEP	Basic Human Error Probability
BISI	Bypassed or Inoperable Status Indication
BU	Back-Up
CB	Control Bank
C_B	Boron Concentration
CBD	Control Bank D
CBP	Computer-based Operating Procedure
CCF	Common Cause Failure
CCW	Component Cooling Water
C/C	Control Center
CDF	Core Damage Frequency
CET	Core Exit Thermo-couple
CFR	Code of Federal Regulations
Chg	Charging
COL	Combined License
COLA	Combined operating license application
COTS	Commercial-Off-The-Shelf
CPNPP	Comanche Peak Nuclear Power Plant
CPU	Central Processing Unit
CRDM	Control Rod Drive Mechanism
CS	Containment Spray
CSF	Critical Safety Function
C/V	Containment Vessel
CVCS	Chemical and Volume Control System
D3	Defense-in-Depth and Diversity
DAC	Design Acceptance Criteria
DAS	Diverse Actuation System
DBA	Design Basis Accident
DC	Design Certification
DCD	Design Control Document
DF	Dependency Factor
DHP	Diverse HSI Panel
DMC	Data Management Console
DPM	Decades Per Minute

D-RAP	Design Reliability Assurance Program
DRPI	Digital Rod Position Indicator
DTM	Design Team Manager
ECCS	Emergency Core Cooling System
EF	Error Factor
EFC	Error-Forcing Contexts
EFW	Emergency Feed Water
ELM	Engineering Line Manager
EOF	Emergency Operations Facility
EOP	Emergency Operating Procedure
EP	Back Feed Electric Power
ERG	Emergency Response Guidelines
ESF	Engineered Safety Feature
ESFAS	Engineered Safety Features Actuation System
FA	Function Allocation
FMEA	Failure Modes and Effects Analyses
FC	Fail to Close
FC	First Concrete
FCV	Flow Control Valve
FK	Flow Control Valve (Automatically controlled)
FO	Fail to Open
F.O.	First Out
FOP	Full-Out Position
FRA	Functional Requirements Analysis
FSAR	Final Safety Analysis Report
FTA	Fault Tree Analysis
FV	Fussell-Vesely importance measure
FW	Feedwater
GDC	General Design Criteria
GOMS	Goals, Operators, Methods, and Selection rules
GTG	Generic Technical Guidelines
GUI	Graphical User Interfaces
HA	Human Action
HAZOP	Hazards and Operability Analysis
HCV	Hand Control Valve
HDSR	Historical Data Storage and Retrieval
H.E	Human Error
HED	Human Engineering Discrepancy
HEP	Human Error Probability
HEPA	High-Efficiency Particulate Air
HFE	Human Factors Engineering
HFEVTM	HFE V&V Team Manager
HPM	Human Performance Monitoring
HRA	Human Reliability Analysis
HSI	Human System Interface

HSIS	Human System Interface System
HVAC	Heating, Ventilation, and Air Conditioning
I&C	Instrumentation and Control
ID	Identifier
IR	Intermediate Range
ITAAC	Inspections, Tests, Analyses, and Acceptance Criteria
ITV	Industrial Television
LAR	License Amendment Request
LBB	Leak Before Break
LBLOCA	Large Break Loss Of Coolant Accident
LC	Locked to Close
LCO	Limiting Condition for Operation
LCS	Local Control Station
LDP	Large Display Panel
LER	Licensee Event Report
LERF	Large Early Release Frequency
Lo	Low
LO	Locked to Open
LOCA	Loss Of Coolant Accident
LPSD	Low Power and ShutDown
LTOP	Low Temperature Over Pressure
LRF	Large Release Frequency
M	Main Control Room Ventilation System Isolation Signal
MCB	Main Control Board
MCR	Main Control Room
M/C	Metal Clad Gear
MELCO	Mitsubishi Electric Corporation
MELTAC	Mitsubishi Electric Total Advanced Controller
MEPPI	Mitsubishi Electric Power Products, Inc.
MHI	Mitsubishi Heavy Industries
MNES	Mitsubishi Nuclear Energy Systems
MS	Main Steam
MSIV	Main Steam Isolation Valve
MSLB	Main Steam Line Break
MSRV	Main Steam Relief Valve
NIS	Nuclear Instrumentation System.
NPP	Nuclear Power Plant
NR	Narrow Range
NRC	Nuclear Regulatory Commission, U.S.
OER	Operation Experience Review
OPPS	Over Pressure Protection System
OSD	Operational Sequence Diagram
P	Containment Vessel Spray Signal
PA	Postulated Accidents
PAM	Post Accident Monitoring

PB	Push-Button
PCMS	Plant Control and Monitoring System
PCV	Pressure Control Valve
PM	Project Manager
Pmp	Pump
POS	Plant Operational State
PRA	Probabilistic Risk Assessment
PRC	Process Recording Computer
Press	Pressure
Przr	Pressurizer
PSF	Performance Shaping Factor
PSMS	Protection and Safety Monitoring System
QA	Quality Assurance
RC	Reactor Coolant
RCP	Reactor Coolant Pump
RCS	Reactor Coolant System
R.G.	Regulatory Guide
RHR	Residual Heat Removal
RMS	Radiation Monitoring System
RO	Reactor Operator
RPS	Reactor Protection System
RSC	Remote Shutdown Console
RSR	Remote Shutdown Room
RSS	Remote Shutdown Station
RTB	Reactor Trip Breaker
RWSP	Refueling Water Storage Pit
Rx	Reactor
SA	Staffing Analysis
SAR	Safety Analysis Report
SAS	Secondary Alarm Station
SAT	Systematic Approach to Training
SBA	Shutdown Bank A
SDB	Shutdown Bank
SDCV	Spatially Dedicated Continuously Visible
SER	Safety Evaluation Report
SFP	Spent Fuel Pit
SG	Steam Generator
SGTR	Steam Generator Tube Rupture
SI	Safety Injection
SLS	Safety Logic System
SBO	Station Black Out
SOER	Significant Operating Experience Reports
SPDS	Safety Parameter Display System
SR	Source Range
SRO	Senior Reactor Operator

SM	Shift Manager
STA	Shift Technical Advisor
SUR	Start-Up Rate
T	Containment Vessel Isolation Signal
TA	Task Analysis
Tavg	Reactor Coolant Average Temperature
TB	Turbine-Bypass
TBV	Turbine-Bypass Valve
Tcold	Reactor Core Inlet Coolant Temperature
T/C	Thermocouple
Thot	Reactor Core Outlet Coolant Temperature
THERP	Technique for Human Error Rate Prediction method
TMI	Three Mile Island
Tref	Reactor Coolant programmed Tavg Reference Temperature
TSC	Technical Support Center
UMC	Unit Management Computer
UPS	Uninterruptable Power Supply
URS	United Research Services (an architect engineer subcontractor)
US, U.S.	United States
US-APWR	US Advanced Pressurized Water Reactor
UV	Under Voltage
V	Containment Vessel Ventilation Control System Isolation Signal
V&V	Verification and Validation
VDU	Visual Display Unit
Vlv	Valve
VTM	V&V Team Manager
WR	Wide Range

Part 1 Human Factors Engineering (HFE) Overall Implementation Plan

1.0 PURPOSE

This document, the US-APWR Human Factors Engineering (HFE) Overall Implementation Plan, is the implementation plan for the US-APWR HFE Program Plan, which is described in Chapter 18 of the US-APWR DCD. Hereafter herein referred to as the "Implementation Plan."

This Implementation Plan is prepared to achieve a US human system interface (HSI) system (HSIS) with excellent performance for both safe plant operation and plant power production. The Implementation Plan governs the HFE activities needed to:

1. Apply a previously developed and tested Japanese HSIS
2. Define and obtain NRC approval for the US-Basic HSIS that is derived from the Japanese HSIS and is applicable to both the US-APWR and to operating US PWR plants
3. Define and obtain NRC approval for the US-APWR HSIS that may be used for many US-APWR applications
4. Define and obtain NRC approval for site specific US-APWR HSIS applications

The starting point for the US-Basic HSIS is the HSI design that Mitsubishi developed for Japanese PWR nuclear plants, the "Japanese Standard HSI System."

1.1 Background

The Japanese Standard HSIS was developed in the late 1990s. The Japanese Standard HSIS design process was based on NUREG-0711 and almost 200 Japanese nuclear power plant operators participated in the evaluation. The Japanese Standard HSIS is being applied in Japan for new PWR nuclear power plants and for operating PWR nuclear power plant control board replacement projects. The Japanese Standard HSIS is operating at Tomari 3 nuclear plant and at Ikata 1 & 2 nuclear plants. There are also agreements with other Japanese utilities for future new nuclear power plants and replacement of the existing main control boards with the Japanese Standard HSIS.

1.2 US Licensing Approach

This Implementation Plan will require the execution of all the human factors engineering (HFE) program elements defined in the in Chapter 18 of the US-APWR DCD which encompass NUREG-0711, Rev.2. Some HFE work may be brought forward from the Japanese Standard HSI design HFE process. When previous HFE work is used it shall be identified in the implementation plan for that HFE task and the previous HFE work shall be analyzed for applicability to the US-APWR HSI design.

The primary benefits that Mitsubishi foresees in starting with the Japanese Standard HSI design are:

- to efficiently execute the NUREG-0711 program elements for developing the US-APWR HSI system design
- to incorporate US nuclear power plant operators early in the US design evaluation process
- to get pertinent data from the Japanese operating experience (the design will in operation for many years at several nuclear plants prior to operation in the US)

Mitsubishi plans to apply the US-Basic HSI system to operating US nuclear power plants control board replacement programs as well the US-APWR. Therefore, generic NRC approval of the Topical Report is requested so that it can be referenced for the US-APWR and for control board replacements for existing US nuclear power plants. This Implementation Plan, which is a US-APWR plant specific licensing document, is structured to support this request. Additional overall implementation procedures will be created for each project.

2.0 APPLICABILITY

This Implementation Plan shall govern the overall management and execution of all HFE program elements as defined by DCD Chapter 18, except as noted in section 2.3 below, for the Human Performance program element and the design of the Emergency Operations Facility (EOF).

2.1 Implementation Plan

The work aspects of a particular program element are governed by the Implementation Plan that is specific to that element. There shall be an Implementation Plan for each HFE program element required by this Implementation Plan. The Implementation Plan for each HFE program shall describe the HFE facilities, equipment, tools, and techniques used to implement that program element.
All Implementation Plans shall be approved by the NRC. This may be accomplished through a stand-alone Implementation Plan that describes the details of the program element methodology, or through a results summary report which also describes the details of the program element methodology (as in Part 2 of this document).

2.2 Scope

This Implementation Plan covers the development of the HSI for the MCR, RSR, TSC, EOF interface, and Local Control Stations.

In addition to normal plant operation, the HSIS supports:

- On-line testing
- Radiological protection activities
- Required chemical monitoring supporting technical specifications
- Maintenance and manual testing required by technical specifications
- Emergency and abnormal conditions response

The HSIS includes the displays, alarms, and controls for these facilities as well as the procedures and training that support the tasks conducted at these facilities.

2.3 Excluded HFE Elements

This Implementation Plan is applicable to all HFE program elements, as defined in DCD Chapter 18, with the exception of Human Performance Monitoring (HPM). HPM is the responsibility of the license holder and is, therefore, governed by the license holder's own HPM implementation plan, which is written in accordance with the strategy developed in the generic US-APWR HPM Implementation Plan, MUAP-10014. It is noted that most US-APWR COL applicants are expected to reference the US-APWR HPM plan in MUAP-10014, but this is not required.

The license holder shall also create Implementation Plans for any HFE program elements that must be re-evaluated due to facility design changes.

The communications and information requirements of the EOF, are within the scope of the US-APWR HFE program; therefore this Implementation Plan is applicable to those development activities. However, the EOF facility itself is outside the scope of the US-APWR HFE Implementation Plans; therefore this Implementation Plan is not applicable to other activities. The COL applicant is responsible for the complete EOF.

3.0 MULTIDISCIPLINE MULTIPLE ORGANIZATION TEAM

Several companies are working together to execute the US-APWR HFE program. A multidiscipline multiple organization team shall execute the MHI US-APWR HSI Design and V&V Program.

3.1 HFE Team and Organization

The HFE team shall contain HFE experts, I&C experts, and nuclear plant process, systems, and operations experts. Experts shall have at least 10 years of nuclear experience in their expert field and an education background that supports their expert credentials. US licensed reactor operators and senior reactor operators shall be integrated into the HFE team. The organization may comprise team members from:

- Mitsubishi Heavy Industries (MHI) and Mitsubishi Nuclear Energy Systems (MNES), a wholly owned subsidiary of MHI
- Mitsubishi Electric Corporation (MELCO) and Mitsubishi Electric Power Products, Inc (MEPPI), a wholly owned subsidiary of MELCO
- Consultants to MHI/MNES and MELCO/MEPPI
- Subcontractors to MHI/MNES
- US-APWR COLA applicants

An organization chart is included herein. In order to avoid revision to the Implementation Plan to accommodate personnel changes, the names of specific personnel fulfilling each organizational role are not identified in this plan; rather, they shall be identified in results summary reports applicable to each aspect of the HFE program. The personnel identified within a specific results summary reports shall be the key personnel responsible for the HFE activities governed by that report. The contributions from each organization and the responsibilities of each organizational role are described herein.

3.2 Organization Roles and Responsibilities

The HFE Manager shall assure that all HFE program elements are appropriately implemented in accordance with the respective HFE implementation plan. Through matrixed responsibilities, the HFE Manager is also responsible for the oversight of designs and activities from other engineering departments that affect safety significant human performance. The HFE Manager is responsible for organizing the HFE team, oversight of the HFE processes, and controlling HFE resources including those outside of his direct line organization.
MHI shall be the lead technical organization for the complete US-APWR HSIS project, including HFE analysis, HSIS design, V&V and implementation. The HSIS design team shall be separate from the HSIS V&V team. The HFE Manager, the HSIS Design Team Manager (DTM), and the HSIS V&V Team Manager (VTM) shall be from MHI team. Subcontractors shall perform work at the direction of MHI.

The HFE team shall conduct HFE activities in accordance with applicable MHI Engineering Department work procedures which shall comply with MHI's Quality Assurance Program. Figure 1 also shows the matrixed HFE team positions in relationship to the team members from other MHI engineering organizations that are controlled under the MHI QA program. The

HFE Manager assigns HFE activities to the HFE team members according to each subject matter organization's responsibilities. The HFE Manager is the functional manager of the HFE team members. The HFE team members are assigned from each engineering organization according to HFE Manager requests.
The HFE team has a responsibility to identify and oversee the correction of HFE problems in the overall plant design. The HFE team shall coordinate with other plant organization to identify and resolve HFE issues by the following approach:

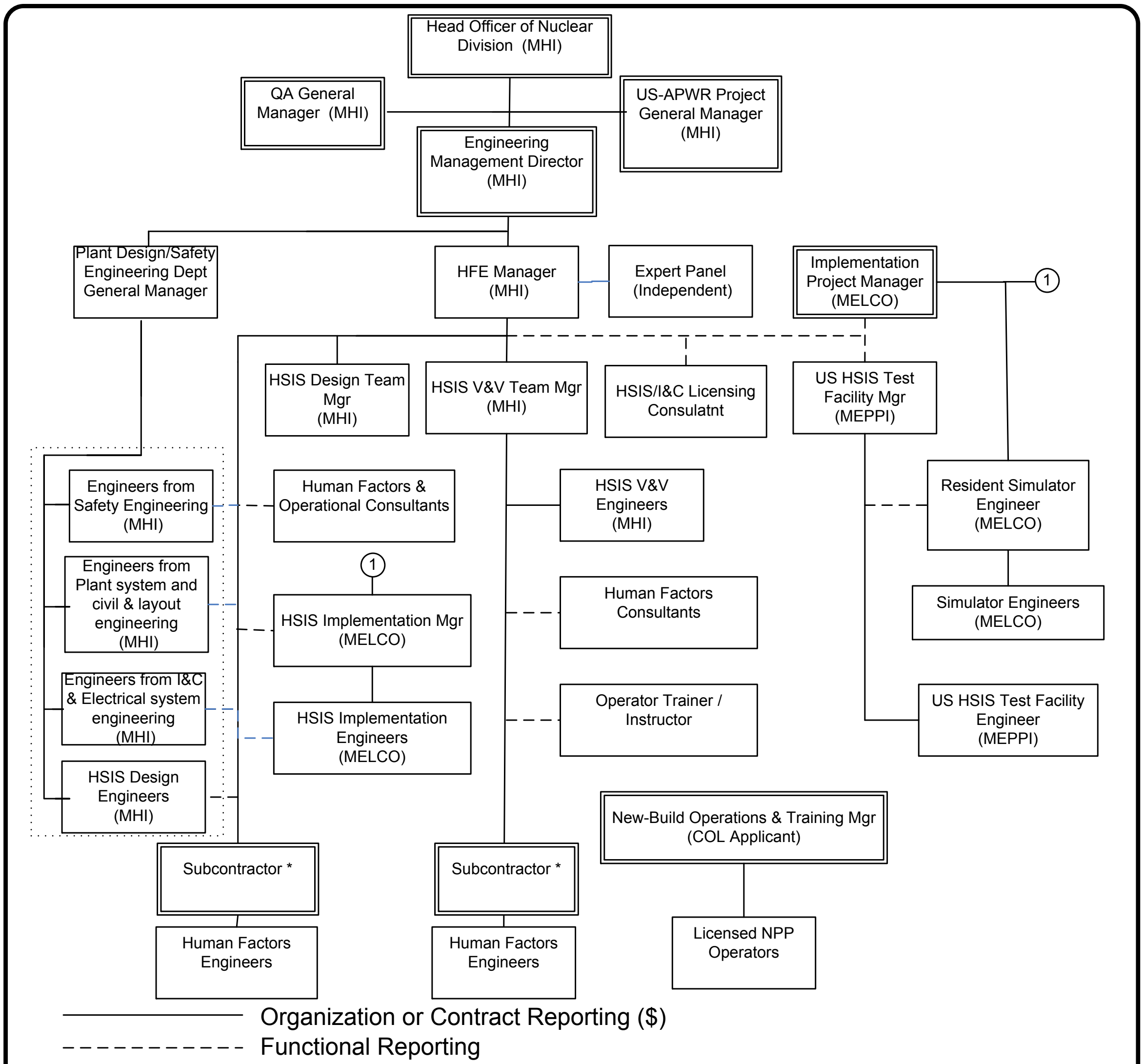
- Organize expert panel meetings with plant design and HFE experts to identify and discuss solution of HFE issues
- Define the responsible design organization to lead issues resolution. Generally, the plant design organizations are responsible for resolving HFE design issues, by improving their plant design specifications.
- Follow up with the assigned design organizations to complete their actions
- Verify the HFE issues are resolved through technical review and/or conducting verifications using prototype models or simulators

The plant design organizations are responsible for resolving design issues which are identified by the HFE program, Resolution typically occurs by improving their plant design specifications. The HFE team is responsible for initiating human engineering discrepancies (HEDs), tracking HEDs, coordinating with experts and plant design organizations to establish HEDs, resolutions verifying HFE resolutions are implemented in the plant design and through pertinent HFE activities.

MELCO shall be the lead organization for the HSIS implementation. Implementation refers to the conversion of the HSI functional design, which is the responsibility of MHI, into software and hardware for the US HSIS test facilities, operator training facilities and the actual plants. The US-APWR Implementation Project Manager and the HSIS Test Facility Manager shall be from MELCO.

There shall be an HSI test facility or test facilities located in the US to support US-APWR HFE program activities. The US HSI test facilities shall include at least one full-scale MCR simulator. The MEPPI location near Pittsburgh is a suitable location for a US HSI test facility. When located at MEPPI, the US HSIS Test Facility Manager shall be from MEPPI. Even though MEPPI is responsible for managing and maintaining the US HSIS Test Facility, the hardware and software design and manufacture for the MEPPI test facilities are the responsibility of MELCO.

The HFE Expert Panel is composed of experts in operations, HFE and I&C. The Expert Panel provides an independent assessment of proposed HED resolutions. As shown in Figure 1, the Expert Panel reports to the HFE Manager, but is independent of the HFE design team and V&V team.



* Responsibilities are delegated to subcontractors at the discretion of MHI's HSIS Design and V&V Managers and by contractual agreement.

Figure 1 HFE Team Organization

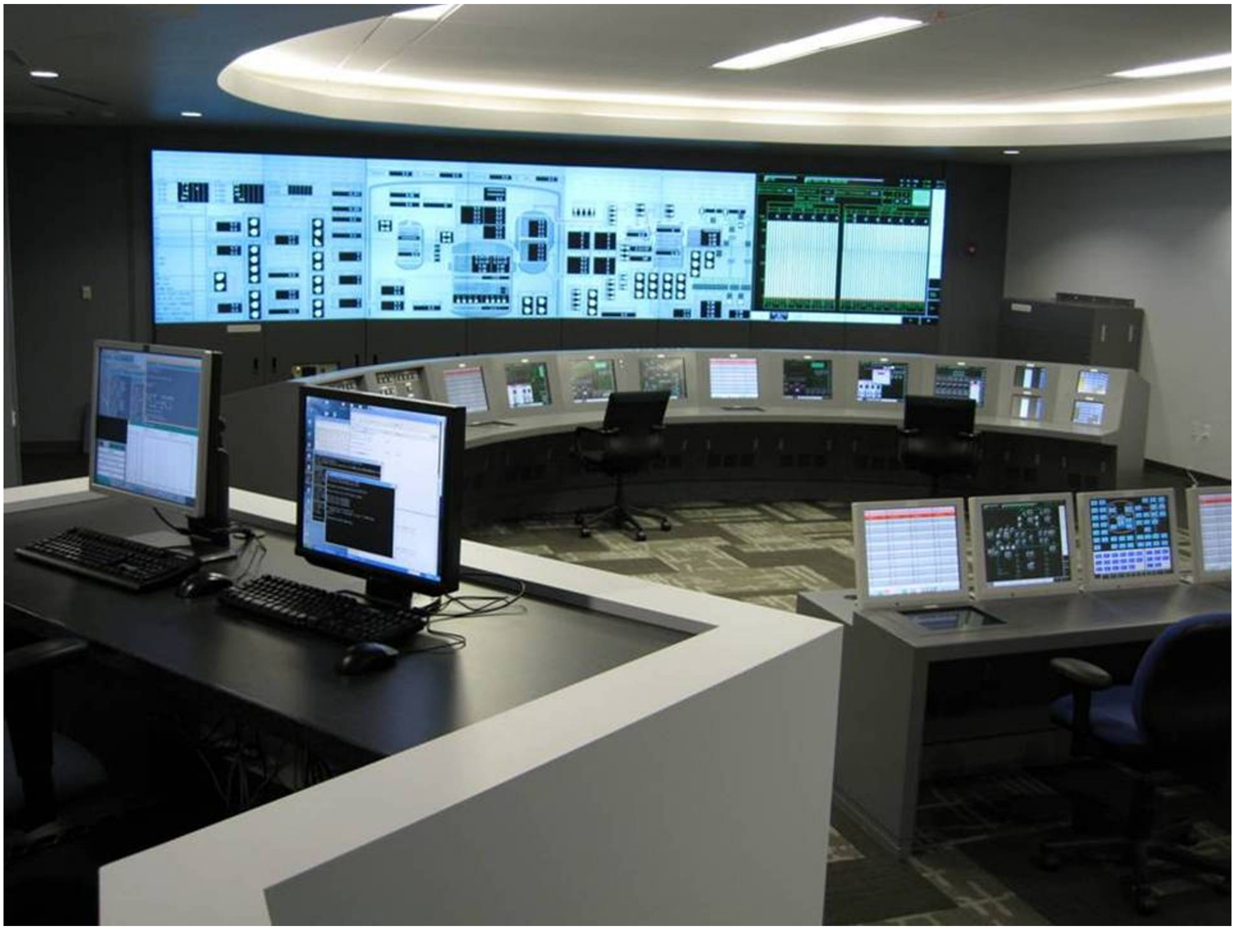


Figure 2 US HSIS Test Facility

3.3 Team Management

3.3.1 HFE Manager (Project Manager)

The HFE Manager (referred to as the Project Manager in DCD Ch.18) shall be responsible for management decisions regarding the HFE program. The HFE Manager shall assign work responsibilities to the technical disciplines within the HFE team and within MHI's engineering organization. The technical managers and their staffs shall implement the assigned work responsibilities.

The HFE Manager shall assure that all HFE program elements are appropriately implemented in accordance with the respective HFE implementation plan. The HFE Manager is responsible for making HFE design decisions and controlling HFE design changes. Plant design authorities (i.e., engineering divisions) are required to change the plant design based on HFE design decisions. HFE members consist of multi-disciplined engineers dispatched from each engineering division. HFE members are responsible for resolving HEDs in accordance with their engineering responsibilities. The HFE manager is responsible for organizing the HFE team, oversight of the HFE processes, and controlling HFE resources including those outside of his direct line organization.

3.3.2 HSIS Design Team Manager

The HSIS Design Team Manager (DTM) shall be responsible for HSI design decisions, including design changes required for resolution of Human Engineering Discrepancies (HEDs). The HSIS DTM shall be responsible for the development of US-APWR HSIS design specifications, either directly or indirectly through other engineering disciplines.

The HSIS DTM shall be responsible for the operating experience review (OER).

The HSIS DTM shall be responsible for the US-APWR HFE analyses:

- functional requirements analysis and function allocation (FRA/FA)
- task analysis (TA)
- human reliability analysis (HRA)
- staffing analysis (SA)

The HSIS DTM is responsible for the HSIS design activities with the exception of HSIS design testing, which is discussed below.

The HSIS DTM shall be responsible for the development of the operating procedures and the operator training material.

3.3.3 HSIS V&V Team Manager

The HSIS V&V Team Manager (VTM) shall be responsible for formal design testing of HFE products during the HSI Design program element, and final V&V testing of the US-APWR HSIS and the plant specific HSIS during the V&V program element. Formal design testing is testing performed by the V&V team to a written procedure with a test results report. In this Implementation Plan "V&V" includes both formal design testing during the HSI Design program element and testing of the final US-APWR and plant specific HSIS, in accordance with NUREG-0711 Rev.2, as defined in the V&V program plan of DCD Chapter 18.10 and the V&V Implementation Plan, MUAP-10012. To distinguish HSI Design program element testing from V&V program element testing, this Implementation Plan will refer to V&V program element testing, as "US-APWR V&V."

The level of design and verification independence is at the discretion of the HFE Manager. Therefore, V&V team members may contribute to the HSI design, and HSI design team members may participate in V&V.

The HSIS VTM shall be responsible for defining HFE V&V processes, generation of V&V procedures, and defining and generating V&V data collection forms.

Licensed nuclear power plant operators (or candidates for an operating license) shall be the test participants for V&V activities. Licensed Operators or previously Licensed Operators shall also participate in the evaluation of HEDs and the approval of HED resolutions.

The HSIS design team shall be responsible for designing and implementing all HSIS changes that may be needed to resolve HEDs. V&V of these HSIS changes shall be by the V&V team. HED resolution shall be reached by consensus between the team members and managers. If consensus cannot be reached, then the HFE Manager has the responsibility to be the final arbiter and shall reach a decision. HED resolution shall also be assessed by the HFE Expert Panel, as described in Section 6.1.

3.3.4 HSIS Implementation Manager

The HSIS Implementation Manager shall be responsible for implementing the hardware and software of the HSI design. The US HSIS Test Facility Manager shall be responsible for any required changes to the MEPPI US test facility. The HSIS Implementation Manager and the US HSIS Test Facility Manager report to the Implementation Project Manager.

3.4 Quality Assurance

Personnel performing HFE activities shall perform the activity according to the HFE Implementation Plan for that activity. These plans are working procedures associated with the MHI DCD Quality Assurance Program (QAP). If the HFE plan does not cover a support activity that may be required to support the HFE process, the person shall follow the nuclear QA program of his or her organization that applies to the support activity. Independent contractors shall work under the MHI/MNES QAP while working on this program.

A subcontractor is considered to be independent and is responsible for their own nuclear QA program (QAP). MHI/MNES shall approve the QA programs of all subcontractors employed in support of this program.

Each HFE program element is conducted by qualified people who have an HFE background or operator experience. Personnel qualification is managed under appropriate QAP.

US-APWR Combined License (COL) applicants shall use their own QAP for the Human Performance Monitoring program and for any other HFE program element deliverables generated directly by the licensee. If the licensee participates in preparing deliverables for which MHI/MNES is directly responsible, the licensee shall adhere to the MHI/MNES QAP as directed by MHI/MNES.

4.0 HUMAN SYSTEM INTERFACE MODEL

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

4.1 Basic HSI System

The Basic HSI System comprises the HSI elements and it performs the HSI operation method or technique. The Basic HSI System is defined by MUAP-07007, which includes a design basis and functional design specification that includes specifications 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, display hardware requirements. The Basic HSIS also encompasses generic alarm prioritization and presentation methods, generic component, process and system controls, and the generic design of computerized procedures.

4.2 HSI Inventory

The HSI Inventory is the set or collection of specific indications, alarms, controls, and procedures implemented using the HSI techniques defined by the Basic HSI System 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 for a nuclear power plant. The HSI inventory is developed from plant

specific HFE analyses. “Plant specific” refers to a specific nuclear unit or a family of units that share the same design. For example, the US-APWR is a plant, as is System 80 and SNUPPS. For the US-APWR, the generic HSI Inventory is referred to as the “US-APWR HSI Inventory”.

When “plant” refers to a family of units that share the same design, there are site specific variations such as interconnection to the grid and to the ultimate heat sink. To ensure completeness, the US-APWR HSI Inventory includes generic assumptions regarding these site specific variations. However, when the actual site specific variations replace these generic assumptions, the result is referred to as the Plant X HSI Inventory (e.g., Comanche Peak Unit 3 HSI Inventory).

4.3 HSI System Application

The two components, Basic HSIS and HSI Inventory are combined to form a plant specific HSI System, as shown in Figure 3. For the US-APWR, the result of combining the Basic HSIS with the US-APWR HSI Inventory is referred to as the US-APWR HSIS. When the actual site specific HSI Inventory replaces the generic site specific assumptions, the result is referred to as the Plant X HSIS (e.g., Comanche Peak Unit 3 HSIS).

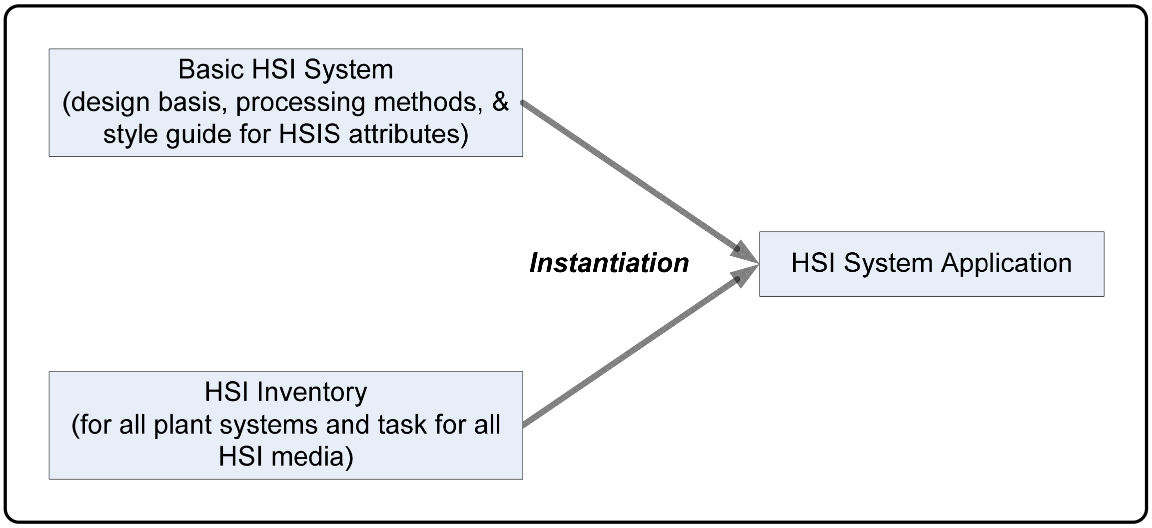


Figure 3 Human System Interface Model

4.4 Relationship of Japanese Standard and US-Basic HSIS

The Basic HSI developed by Mitsubishi for application in the US is referred to as the “US-Basic HSI System.” The HSI System described in Reference 11.1 Section 4 is what MHI refers to as the US-Basic HSI System.

4.4.1 US-Basic HSIS

The starting point for the US-Basic HSIS shall be the Japanese Standard HSIS converted for application in the US. Examples of these conversions include translation to English and American engineering units, and anthropometric changes to the consoles for American body types. Additional changes shall be made only through the US-APWR HFE design and V&V process defined in this Implementation Plan.

4.4.2 US-APWR HSI Inventory

The US-APWR HSI inventory shall be defined and specified by the HSI system designers through an HFE analysis. The US-APWR HSI inventory shall be developed through the HFE analysis defined by the US-APWR DCD Chapter 18 and this Implementation Plan. As described in DCD Chapter 18, to develop the US-APWR HSI Inventory the US-APWR HFE program shall reassess each NUREG-0711, Rev.2 element with emphasis on changes from prior analysis, assessment, and experience. As described above, the US-APWR HSI Inventory includes the portion of the plant that is common to all US-APWR sites and generic assumptions for the portion of the plant that is site specific (e.g., grid connections and ultimate heat sink).

5.0 WORK FLOW

The US-APWR HFE work flow involves activities performed by the HFE team and activities performed by other US-APWR design groups.

The diagram is not depicting a once through process. Like most development processes the US-APWR HSIS development process is an incremental development process with feedback loops. Feedback comes from both HFE analysis and the HSIS V&V. The HSIS V&V is an integrated phased verification and validation testing process that culminates in a V&V of the final US-APWR HSIS. The V&V of the final US-APWR HSIS shall meet the requirements of NUREG-0711, Rev.2, as defined by the V&V program plan of DCD Chapter 18.10.

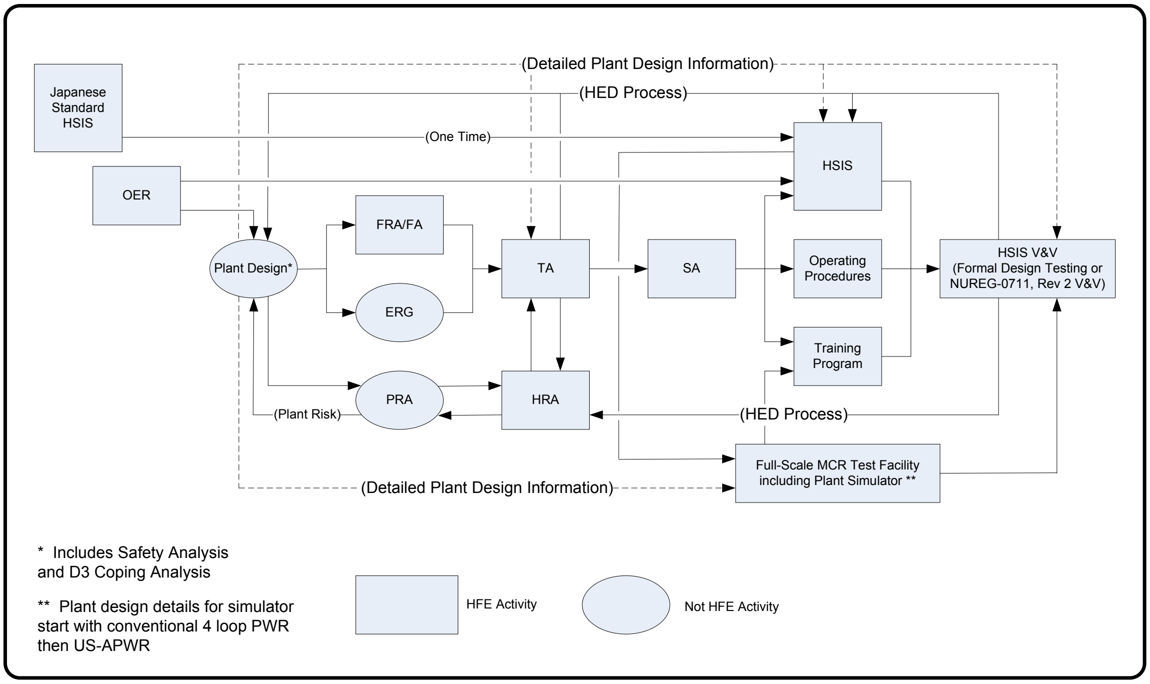


Figure 4 HFE Work Flow

(1) Integration of HFE and Plant Design Activities with Management tool & processes

During HFE activities, if there are any HFE issues identified that may impact plant design engineering, Human Engineering Discrepancies (HED) shall be used to document the item/action and potential solutions. The HED shall be used to track the issue until it is

adequately addressed in the US-APWR plant design. Anyone in the HFE team can initiate an HED for problems identified during the HFE activities. The process of evaluating, tracking, resolving and closing HEDs is described in Section 6.

(2) HFE Program Milestones

Once each HFE program element is completed, the HFE team verifies that activity meets its Implementation Plan and produces a results summary report. During each program element critical check points are performed in conjunction with the plant design and when issues are found, action is taken to resolve the issues. Figure 5 shows the HFE milestone and critical checkpoint embedded in the plant design, procurement, constructions and operation. Figure 6 shows engineering work processes and integration with plant design organizations. Arrows show critical checkpoints which indicate milestones for each activity and the relationship to other HFE elements.

	Licensing			ITAAC			
Phase	Analysis		Design	Procurement		Construction	Operation
HFE	OER	FRA/FA	Task Analysis		V&V	Implementation	Human Performance Monitoring
			HRA	Staffing & Qualification			
				HSI Design			
Plant Design	Safety Analysis		Plant Design	Simulator			
Operating Procedures				Operating Procedure Development			
Training Programs				Training Program Development		Staffing	

Figure 5 HFE Program Milestones Embedded in the Plant Design, Procedure, Construction and Operation

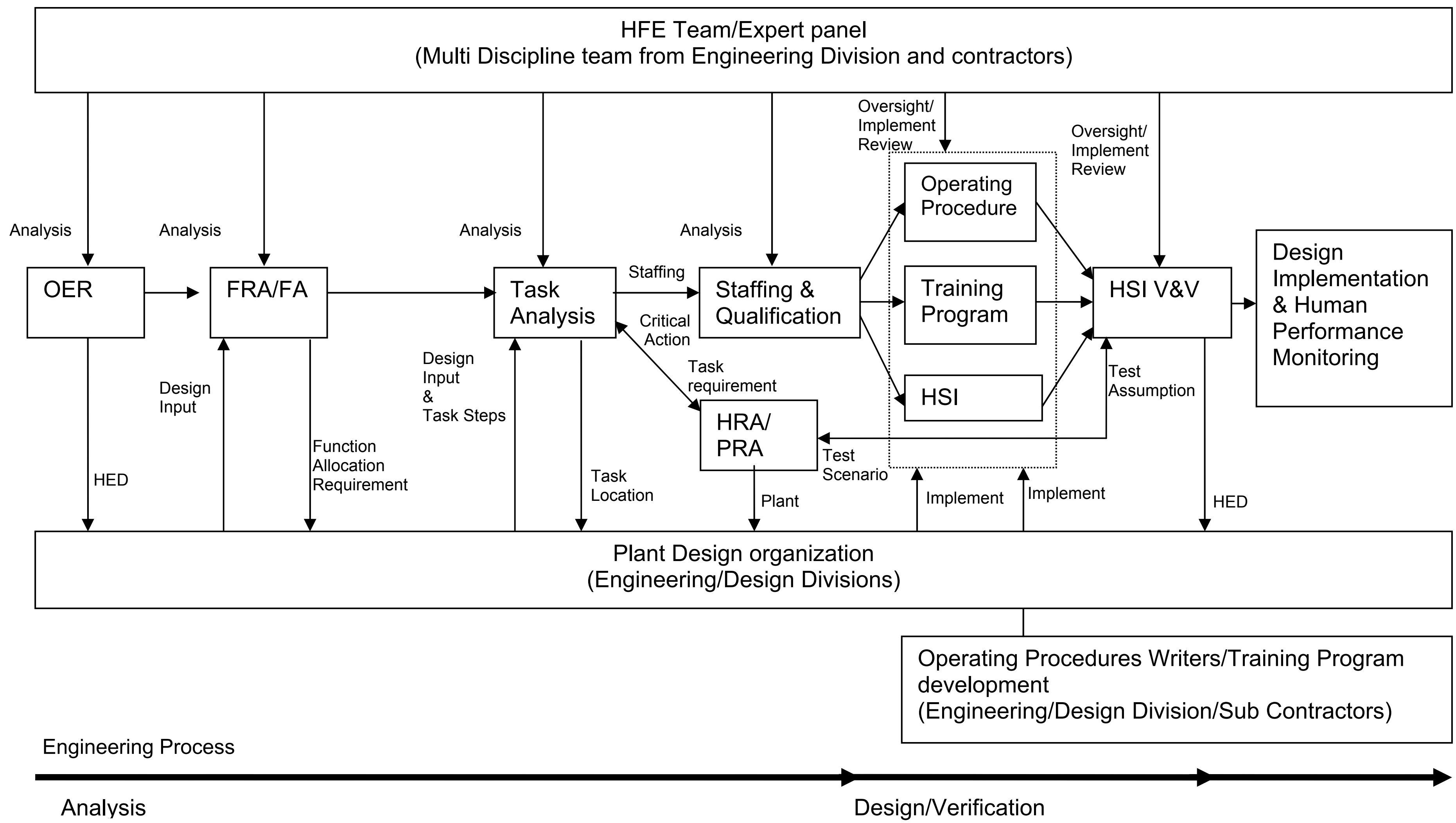


Figure 6 Engineering Work Process and Integrations Low between HFE Team and Plant Design Organizations

(3) Subcontractor HFE Efforts - If a subcontractor is involved in HFE activities, the HFE team verifies the subcontractor complies with the US-APWR HFE Implementation Plans and/or MHI's internal work procedures. The MHI QA organization verifies subcontractors conduct their work in accordance with their QAP, as described in Section 3.4 above.

5.1 Role of the HFE Process in Nuclear Plant Design

The nuclear plant designers design the plant systems including the plant systems that perform the critical safety functions. The plant designers also define the plant components that perform the system functions. HFE analysis shall check the plant design from the HFE perspective and provide discrepancy information to modify the plant design. This checking shall include all stages of plant design from plant analysis to plant implementation to plant operation.
If there are any HFE issues identified that may impact plant design engineering, Human Engineering Discrepancies (HED) shall be used to document the item/action and potential solutions. The HED shall be used to track the issue until it is adequately addressed in the US-APWR plant design. Anyone in the HFE team can initiate an HED for problems identified during the HFE activities. The process of evaluating, tracking, resolving and closing HEDs is described in Section 6.

5.2 OER

The US-APWR HFE analysis shall include an operating experience review (OER). The US-APWR plant design is based on conventional PWR designs. The OER shall identify and analyze HFE related problems in conventional PWR plants in US and Japan. The OER shall also analyze non-nuclear industrial applications of digital technology with screen based HSI. The OER shall identify aspects of the US-APWR HSI system, as documented in Topical Report MUAP-07007, that adequately address historical human factors problems. Where a problem is not adequately resolved by the US-APWR HSI system, a human engineering discrepancy (HED) shall be generated to document the problem and potential solutions. The HED shall be used to track the issue until it is adequately addressed in the US-APWR HSI system or the US-APWR plant as applicable.

5.3 FRA/FA

The functional requirements analysis (FRA) shall determine the plant functions that must be performed to satisfy the plant safety objectives. The FRA shall also identify the plant power production functions since the plant power production is an important aspect of plant performance. The function allocation (FA) shall allocate the identified functions for plant safety and plant power production to human system resources or to automated resources, considering human and machine performance strengths and limitations. The FA forms a basis for the operator task analysis (TA) and staffing analysis (SA).

The FRA/FA shall be updated, if necessary, to reflect any changes in the final nuclear plant design that may have occurred after the FRA/FA was completed.

5.4 TA

The functions assigned to plant personnel define their roles and responsibilities. Human actions are performed to accomplish these functions. Human actions can be divided into groups. A group of related activities that have a common objective or goal is a task. The purpose of the TA is to identify requirements for accomplishing these tasks; which in turn specify requirements for the HSI design including display screens, alarms, controls, data

processing, operating procedures, and training programs that support the accomplishment of the tasks.

The TA shall consider the number of crew members, crew member skills, and allocation of monitoring and control tasks considering the formation of a meaningful job and management of crew members physical and cognitive work load.

Manual allocations for plant functions that are identified by FRA/FA and critical action steps that are identified in the emergency response guidelines (ERG) development shall be available to HFE personnel to perform the TA.

5.5 HRA

The HRA shall identify risk-important human actions (HA) from the PRA/HRA assumptions. Using operator role considerations the HRA shall identify significant controls and parameters needed to conduct these risk-important human actions. The HRA provides critical actions and error assumptions to TA. TA provides detailed task requirements to HRA.

5.5.1 PRA/HRA

The probabilistic risk assessment (PRA) assumes certain safety actions are performed by the operator. The PRA includes a human reliability analysis that assesses and quantifies those operator actions. Within the HRA element of the HFE program, the HFE designers shall confirm the reliability analysis through analyses such as FRA/FA and TA and through the ongoing HSI testing program. As a minimum, this shall include validating the HSI design assumptions, input data, and the analysis related to the identification of the applicable types of human performance errors. Consequently, the HFE design shall give special attention to those plant scenarios, risk-important human actions, and human system interfaces that have been identified in the PRA/HRA as being important to plant safety and reliability.

5.5.2 Integration Role of HRA

It is the role of the PRA/HRA personnel to define the risk-important human actions using appropriate and accepted methods. It is the role of the HFE personnel to assess that the risk-important human actions can be carried out within the time required and to evaluate the assumed PRA success probability. The HRA shall be conducted as an integrating activity to support the HFE process and PRA activities, and to risk inform the overall plant design. The TA is based on the FA/FRA. The TA inputs to the HRA. The HRA provides feedback to the TA. The HRA risk informs the plant design through the PRA.

5.6 SA

Initial staffing level assumptions shall be established based on experience with previous plants, government regulations, and staffing reduction goals as described in Reference 11.1 Section 5.5. SA shall determine the number and background of personnel for the full range of plant conditions and tasks in conjunction with the other HFE analysis.

The initial staffing level assumptions shall be considered constraints for the US-APWR HSI design and plant design. The staffing assumptions impact requirements for the HSI design including the number of physical interfaces, data processing, operating procedures, display screens, alarms, controls, and support aids needed to support the accomplishment of the tasks. The staffing assumptions impact the extent to which monitoring and control can be manually executed or requires automation. The acceptability of the staffing assumptions shall be continuously examined as the design proceeds.

The HFE program shall demonstrate, through V&V activities, that the staffing is sufficient for safe plant operation.

5.7 Role of the US Nuclear Plant License Holders

US nuclear plant license holders operate the nuclear power plants (NPP).

5.7.1 Integration into the MCR Design and Testing Process

US nuclear plant license holders have staffs who are the users of the US-APWR HSIS, the operators. In order to have direct specialist feedback licensed NPP operators shall be integrated into the design and testing of the US-APWR HSIS. This is a core concept of the US-APWR HSIS development program.

5.7.2 Protocols and Procedures

The nuclear plant license holder is responsible for the protocols and procedures for operating the NPP. The US-Basic HSIS shall accommodate US NPP operation protocols and procedures. This does not mean that US NPP operation protocols and procedures are used literally for application to the US-Basic HSIS. It is anticipated that there will be some adjustment necessary to the current US NPP protocols and procedures so as to make them appropriate for application to the US-Basic HSIS. For example, adjustments are expected to accommodate navigational display links, embedded data and screen based place keeping, in computerized procedures. Special procedures are also expected for degraded HSI conditions. US NPP protocols and procedures shall be incorporated into the US-Basic HSIS V&V and the US-APWR HSIS V&V.

5.7.3 Supplementary Activities

US nuclear plant operators perform activities in the main control room (and other locations) related to the operation of the nuclear plant apart from direct monitoring and control of the NPP processes. An example of this type of activity is the generation of plant maintenance work orders and support of those maintenance activities. The nuclear plant license holder shall work closely with the US-APWR HFE team to ensure the US-APWR HSI design shall accommodate these supplementary activities in a manner consistent with US practices. The accommodation of these supplementary activities shall not interfere with the safe operation of the NPP.

6.0 HUMAN ENGINEERING DISCREPANCIES

Human Engineering Discrepancies (HEDs) are the means or mechanism by which deficiencies in the HSIS are identified.

6.1 Human Engineering Discrepancy Process

The human engineering discrepancy (HED) process has four steps:

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

The problem statement is formulated by the person raising the human engineering discrepancy.

The HFE team is responsible for evaluating and resolving HEDs that result from many sources (Items 2 and 3, above). These sources include HFE design reviews, static and dynamic HSI design testing and V&V testing, and all HFE elements contained in the HFE program as described in NUREG-0711. The HFE team shall be comprised of selected HSI design and V&V team members, I&C experts, and nuclear plant process, systems, and operations experts, The HFE team members assigned to resolve HEDs shall have at least 10 years of nuclear experience in their expert field and an education background that supports their expert credentials.

The HFE team shall evaluate the HED and formulate the proposed discrepancy resolution. Some HEDs may be resolved by improved operating training and/or procedures. If the discrepancy requires an HSI design change, the HFE design team shall generate the functional requirements for the HSI design change. The design change shall be developed and implemented by the HFE design team. Some HEDs may require simple changes to the HSI Inventory. Others may require changes to the Basic HSI features. Depending on the extent or significance of the change, HED resolutions may only require documentation of the change; others may also require a documented test plan.

Each HED shall be assessed by an “Expert Panel” that is independent of the HFE team. The Expert Panel shall be comprised of HFE experts, I&C experts, and nuclear operations experts. As stated before, experts shall have at least 10 years of nuclear experience in their expert field and an education background that supports their expert credentials. The Expert Panel shall have available technical consultants from the US-APWR HFE team, including the HSI Implementation Team, as well as US-APWR plant process and systems experts.

For HEDs where a resolution has been proposed by the HFE team, the Expert Panel shall assess that resolution. For HEDs that have no proposed resolution, the Expert Panel shall recommend a resolution. If the recommended resolution requires an HSI design change, the Expert Panel shall generate the functional requirements for the HSI design change to a level of detail that can be understood by the HSIS design team. The HFE team shall assess the resolutions proposed by the Expert Panel, and may propose alternative design solutions.

The HFE team and Expert Panel can work independently or together to evaluate HEDs and define HED resolutions. Ultimately, the Expert Panel and the HFE team must reach agreement on the HED resolution. After resolution agreement is reached, the HFE team will implement the resolution.

HED closure shall occur when the requirements of the HED resolution are considered satisfied by the HFE team and by an independent documented review by the Expert Panel. The Expert Panel shall document their basis for considering the HED closed or for considering the HED closure requirements unsatisfied. The closure requirements establish the Acceptance Criteria for HED closure. It is important to note that some HED resolutions may require retesting. However, HED closure can occur once the test plan is documented. Actual test execution is typically not a prerequisite for HED closure, because if the HED resolution proves to be inadequate, new HEDs will be generated during that testing.

6.2 HED Problem Statement

There can be many sources of HEDs, for example:

- HEDs may be generated during any HFE program activity, such as the OER.
- HEDs may be generated directly by licensed NPP operators during the HSI verification and validation.
- HEDs may be extracted from operator questionnaires and surveys completed by the licensed NPP operators after each test scenario and at the end of the validation test week.
- HEDs may be generated from observer surveys completed during the HSI validation test scenarios and at the end of the validation test week.
- HEDs may be generated from the observers' consensus survey completed at the end of the validation test week.
- HEDs may be generated by HFE and NPP process control experts from operator performance data.
- HEDs may be generated by miscellaneous visitors to the V&V facility (e.g., potential US-APWR customers, visiting HFE and NPP process experts, visiting representatives from the NRC, etc.).

All HEDs shall be evaluated by the HFE team and the Expert Panel.

6.3 HED Evaluation

Outstanding HEDs shall be evaluated periodically and prior to completing any of the HFE phases. At a minimum, HEDs shall be reviewed every six months for what has been closed, design decisions, and progress of design changes.

One consideration in evaluating an HED shall be the number of people who have identified a specific problem. This is referred to as the frequency count.

To support efficient examination, like HEDs may be grouped together. As part of the grouping process one HED may be placed into more than one group because it may have been written with multiple discrepancies. Grouping shall be done by HFE and operations experts using engineering judgment. Grouping is not required if each HED is evaluated and closed individually.

6.3.1 NRC Grouping

To assist HED evaluation, resolution, and explanation it may be constructive to associate HEDs with NRC grouping. NUREG-0711, Rev.2 suggests potential grouping by:

- Scope
- HSI Component
- Plant System

- Personnel Tasks

6.3.2 HFE Classification

To assist HED evaluation, resolution, and explanation it may be constructive to associate HEDs with typical HFE classifications. Typical HFE classifications are HFE basic generic categories used for classifying discrepancies. The HFE Basic Generic Categories are:

- Situation Awareness
  - Ability to maintain the 'big picture' with respect to current plant state and direction of process variables
  - Ability to anticipate / forecast what is going to happen next with respect to the plant's processes, automatic systems and abnormalities
  - Ability to maintain awareness of the critical plant safety functions (e.g., based on the information provided on the wall panel)
  - Ability to monitor trends and detect problems pre-alarm
- Control
  - Ability to take control actions in pace with plant process dynamics
- Following Procedures
  - Ability to access and follow required procedures
  - Ability to monitor effectiveness of the procedures (e.g., is it the right procedure for the event? Are there additional problems that are not being addressed)
- Error-tolerance
  - Ability to catch and correct errors
- Mental workload
  - How much mental and perceptual activity is required to respond to emergency events - e.g., thinking, deciding, calculating, remembering, looking, searching, etc
- Physical workload
  - How much physical activity is required to respond to emergency events -- e.g., pushing, pulling, turning, controlling, activating, etc.)
- Teamwork
  - Ability to maintain awareness of what other crew members are thinking and doing
  - Ability to communicate and coordinate actions
  - Ability to catch and correct misunderstandings or errors
  - Ability to maintain shared situation awareness of the state of the plant and procedures
- Supervising Automated Systems
  - Ability to maintain awareness of the status and actions of automated systems
  - Ability to take-over manual control when needed
- Shift staffing
  - Ability of Basic HSI System to support two-person operation

6.4 HED Significance

There are two types of evaluation categories, Mitsubishi Significance and NRC Priority. At least one evaluation category shall be applied to each HED or to a group of HEDs.

6.4.1 Mitsubishi Significance Category

HEDs may be placed into one or more of the following Mitsubishi Significance categories.

1. The HEDs represent a mean score of less that 3 out of 5, or a weighted score of 3 or lower by 20% of the operators on the V&V Questionnaire.

2. The HEDs have a significant frequency of independent repeat records.
3. The HEDs reflect a violation of regulatory guidance.
4. The HEDs reflect a violation of standard human factors good practice as related to other industries or current NPPs.
5. The HEDs are likely to lead to human error with safety consequences.
6. The HEDs do not necessarily have safety consequences, but are likely to negatively impact efficiency of operations, and the ability to produce power cost effectively.
7. The HEDs do not necessarily have a safety consequence, but are likely to impact minimum staffing requirements.
8. The HEDs do not necessarily have a safety consequence, but are likely to have a Tech-Spec implication.
9. HED represents a potential human performance issue without significant consequences.

6.4.2 NRC Priority

The Mitsubishi set of significance measures results from the Expert Panel review and as such is used for discussions on design change requirements. These can then be converted into NRC measures as described in NUREG-0711, Rev.2 for significance ranking and disposition management. NRC priority risk categories are:

- Priority 1 - direct or indirect consequences to safety
- Priority 2 - consequences to plant or personnel performance
- Priority 3 – other

The Mitsubishi significance category 5 is equivalent to NRC priority 1. Therefore, designating an HED as Mitsubishi significant category 5 is the same a marking it NRC Priority 1.

6.5 HED Resolution

All HEDs shall be processed to closure. Each HED shall be categorized by one of the following typical closure criteria. Other closure criteria may be added as necessary.

1. HED is expected to be resolved by a correction in the simulator or a modification to the simulator to reflect the US-Basic HSI design documented in the HSI Topical Report. HED can be closed when correction/modification is implemented in the simulator and testing is reflected in a V&V program activity (either Phase 1, 2 or 3 as appropriate).
2. HED is expected to be resolved by additional operator training. HED can be closed when training material is updated.
3. HED refers to an HSI design feature which correctly reflects the plant specific design. HED can be closed when the plant specific design is evaluated and resolved.
4. HED is expected to be resolved through a future plant specific HSI design element, or a change to a currently documented plant specific HSI design element. HED can be closed when the plant specific design is documented and reflected in a V&V program activity (either Phase 1, 2 or 3 as appropriate).
5. HED requires updating Basic HSI documentation. HED can be closed when documentation is updated and the subject of the HED is reflected in a V&V program activity (either Phase 1, 2 or 3 as appropriate).
6. HED is expected to be resolved through a Basic HSI design change. The design change must be developed, documented and implemented. HED can be closed when V&V of this design change is reflected in a V&V program activity (either Phase 1, 2 or 3 as appropriate).

7. HED is resolved through an operating procedure change. HED can be closed when the procedure change is documented and reflected in a V&V program activity (either Phase 1, 2 or 3 as appropriate).
8. HED requires no corrective action. The HED can be closed immediately. The HED record shall include the basis for this determination.
9. HED requires further investigation before a resolution can be determined.

Where a resolution is applicable to multiple HEDs, all HEDs may be grouped and closed together. Where HEDs are grouped together for closure, the Expert Panel shall ensure the resolution is sufficient for each HED in the group. Where an HED addresses multiple issues, a resolution may resolve only part of the HED; therefore, that HED shall remain open until all of its parts are resolved.

6.6 HED Closure

Closure does not require demonstration of a successful solution, since if the solution is not successful, additional HEDs will be generated in future design testing or V&V activities. An HED can be closed when the solution is documented and the closure requirements are met, as defined by the HED resolution. HED closure agreement must be reached between the HFE team and the Expert Panel.

7.0 HUMAN ENGINEERING DISCREPANCIES (HED) DATABASE

There shall be a database to manage the HEDs, the HED Database. All HEDs shall be entered into the database.

7.1 HED Database Basic Requirements

In order to manage the HED investigation process, the HED database shall contain fields to track the HED status through the entire investigation process to closure.
The database shall have security measures. The database shall have a system administrator. Only predefined users shall have access to the database. Only the system administrator shall be able to delete an HED from the database. The system administrator shall not delete an HED from the database without agreement of the Expert Panel.

7.2 HED Database Description

The HED are managed and tracked using an issue tracking software application, or issue tracker. The issue tracker is a portal into the HED database. The issue tracker provides the user interface through which data is entered, extracted, or displayed. The issue tracker can be used for simple data analysis or report generation. The issue tracker can also export the data for analysis in other software applications. Since the issue tracker is the only interface into the HED database, the terms issue tracker and database are used synonymously.

The issue tracker allows each HED issue to be captured along with a set of meta-data that further describes or categorizes the HED issue. This meta-data is entered or viewed as a set of data fields that correspond to a workflow step in the HED tracking process. The fields can be used to organize, filter, and search the data. The issues are organized such that they can be grouped to simplify the analysis or resolution of similar issues.

The HED issues progress through the issue tracker in a series of discrete workflow steps. An HED is assigned a ‘Status’ field to indicate its present workflow step. There are five workflow steps that an HED may traverse. The workflow steps and associated issue status are show in the table below. Much of the meta-data associated with each HED is grouped by workflow step.

Many of the data fields are list-type fields that provide a fixed set of values for that field. Others are free-form text fields. In addition to the pre-defined data fields, a ‘Comment’ may be added to an issue by any user to add additional information to an issue.

Table 1 HED Workflow Steps

Workflow Step	Issue Status	Workflow Description
Create	Open	Reporter enters an HED
Evaluate	Evaluated	HFE Expert Panel or HFE team evaluates the issue.
Resolve	Resolved	HFE Expert Panel and HFE team agree on the resolution.
Close	Closed	HFE Expert Panel and HFE team agree that the resolution has been implemented.

7.2.1 HED Creation

The first workflow step is ‘Create’. In this step an HED is entered into the database by the issue ‘Reporter’. A ‘Reporter’ is simply an authorized user of the issue tracking application. Other personnel who are not authorized users of the issue tracking database may create HEDs using paper forms which are then given to an authorized user who will enter the HED into the database. Upon reporting of an issue, the issue tracker automatically assigns a unique issue ‘Key’ (i.e., HED-123). The issue is assigned an initial Status of ‘Open’. The data fields associated with this workflow step are shown in the table below.

Table 2 HED Creation Data Fields

Data Identifier	Description
Summary	A brief one or two sentence interpretive summary of the HED.
Description	An un-interpreted detailed description of the original HED.
Display Number	Screen identifier of HED, if applicable.
Originator	Person who actually identified the HED, either directly through an HED form or HFE survey, or indirectly through an HFE interview.
Originators Company	The Originators company of employment.
Origination Date	The date the HED was originated.
Originators Background	The originators primary area of expertise or training as applicable to the V&V process.
Originators Role	The originators group or organizational affiliation as applicable to the V&V process.
Observer	The observer is an HFE expert who indirectly records an HED that is indirectly identified by an Originator.
Source	The source is the project phase in which the HED was identified.
Source Activity	The source activity is a further decomposition of the project phase. Each project phase has multiple source activities.
Source Activity Number	The source activities are identified by number for the purpose of recording HEDs.
Week Number	The week number identifies which week during the project phase that the HED was identified.

Table 2 HED Creation Data Fields

Data Identifier	Description
HSI Area	The HSI area is a broad description of the location or equipment to which the HED is associated.
Guidance	Guidance is a general description of the basis for identifying an HED.
Design Reference	Design Reference is a specific reference to a document that provides related information to the HED.
Significance	The Significance is the Originator or Observers opinion of the significance of the HED.
Recommended Resolution	The Recommended Resolution is the Originator or Observers opinion of the resolution to this HED.

7.2.2 HED Evaluation

A number of data fields are available to add information to an HED during the evaluation workflow step. The data fields associated with this workflow step are shown in the table below.

Table 3 HED Evaluation Data Fields

Data Identifier	Description
Evaluator	Person(s) or Group(s) performing evaluation.
Due Date	Expected evaluation completion date.
Evaluation Process	Process(es) by which the evaluation was performed.
Evaluation Recommendations	Recommendations from the evaluation.

7.2.3 Issue Resolution

A number of data fields are available to add information to an HED during the evaluation workflow step. The data fields associated with this workflow step are shown in the table below.

Table 4 HED Resolution Data Fields

Data Identifier	Description
Description	Functional description of resolution
Resolution Cost Estimate	Cost estimate to implement the resolution
HED Closure Requirements	Identify the documentation needed to close the HED (e.g., design specification, test plan, training plan, procedures, etc.)
Resolver	Person(s) or Group(s) responsible for implementing the closure requirements
Closure Schedule	Milestones for meeting the HED closure requirements.
HFE Team Approval	Person representing HFE team who approved the HED closure requirements
Expert Panel Approval	Person representing Expert Panel who approved the HED closure requirements
Other Considerations	Other items that are required to fully implement the resolution, but these are not required for HED closure (e.g., considerations for

Table 4 HED Resolution Data Fields

Data Identifier	Description
	detailed design implementation)

7.2.4 Issue Closure

When the HED closure requirements are documented, the HED may be closed. Otherwise an issue may remain with 'Resolved' status and closed when the required closure activities are complete. Additional information can be added to the issue using the issue 'Comment' field.

Table 5 HED Closure Data Fields

Data Identifier	Description
Closure Documentation	Identify the documents reviewed to facilitate HED closure. Include configuration control identifiers (e.g., document and revision numbers).
HFE Team Approval	Person representing HFE team who approved the HED closure
Expert Panel Approval	Person representing Expert Panel who approved the HED closure

8.0 US-APWR MAIN CONTROL ROOM DEVELOPMENT

The US-APWR HSIS encompasses the Main Control Room (MCR) the Remote Shutdown Room (RSR) and the Technical Support Center (TSC). All three of these facilities are developed using the same HFE process because they are all derivatives of the MCR. This HFE process is tailored to address the unique aspects of the communications and information requirements of the Emergency Operations facilities (EOF) and local stations.

The US-APWR HSIS development is divided into three phases.

1. Phase 1 yields the generic US-Basic HSIS.
2. Phase 2 develops the US-APWR Inventory and combines that with the US-Basic HSIS to yield the US-APWR HSIS.
3. Phase 3 makes minor site specific changes to the US-APWR HSIS to yield a site specific HSIS (e.g., Comanche Peak 3&4 HSIS).

Major development activities and products for each phase are shown below. The phases are divided into two steps, a) and b). The activities associated with each step for each phase are different. The phases and steps are activities performed at overlapping times. The development schedule shows the overlap.

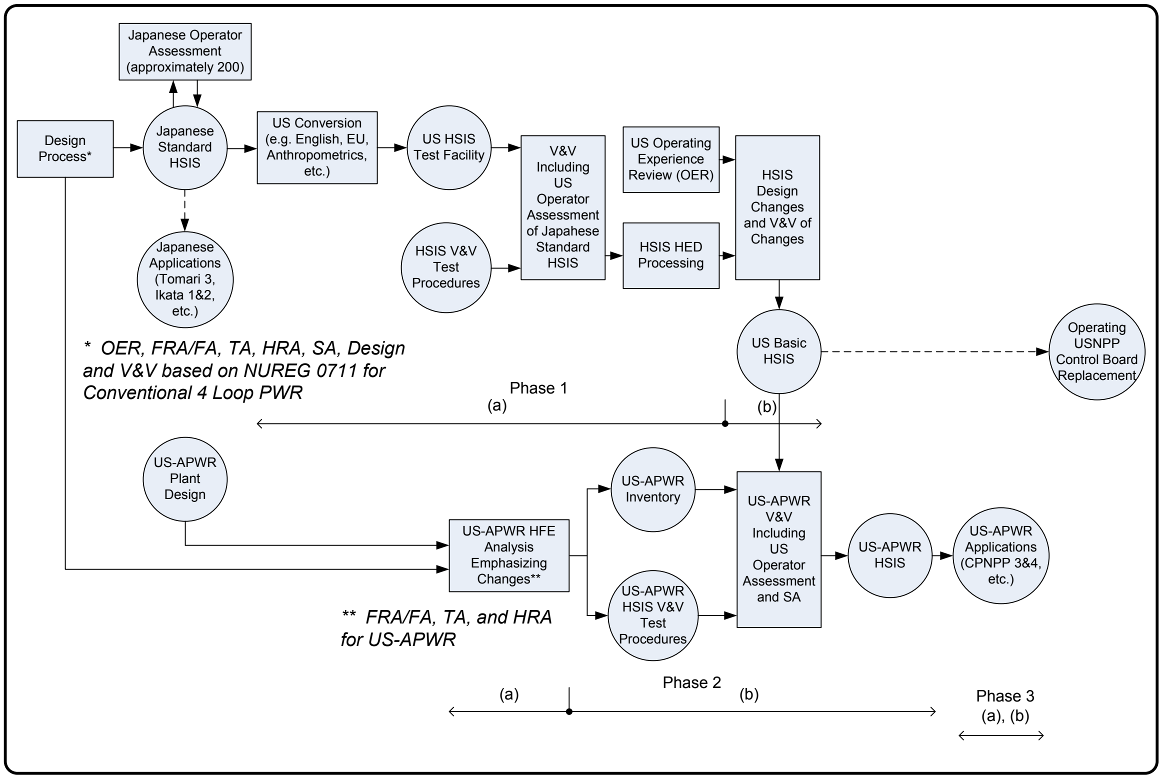


Figure 7 US-APWR MCR Development High Level Logic

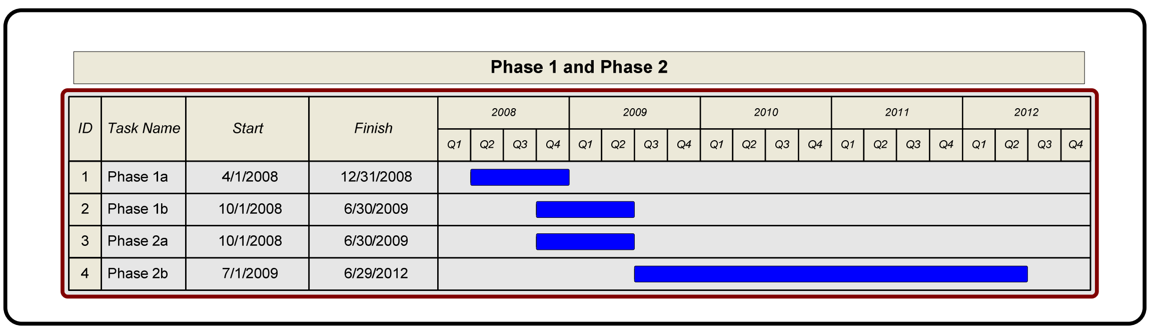


Figure 8 US-APWR MCR Development High Level Schedule

The development phases can be correlated to the US-APWR licensing steps of the DCD, the DCD ITAAC, and the COLA ITAAC. Note that while Phase 1 is correlated in time to the US-APWR DCD review process, this phase generates the US-Basic HSI System. Therefore, Phase 1 is applicable to the US-APWR and to operating nuclear power plant control board replacements.

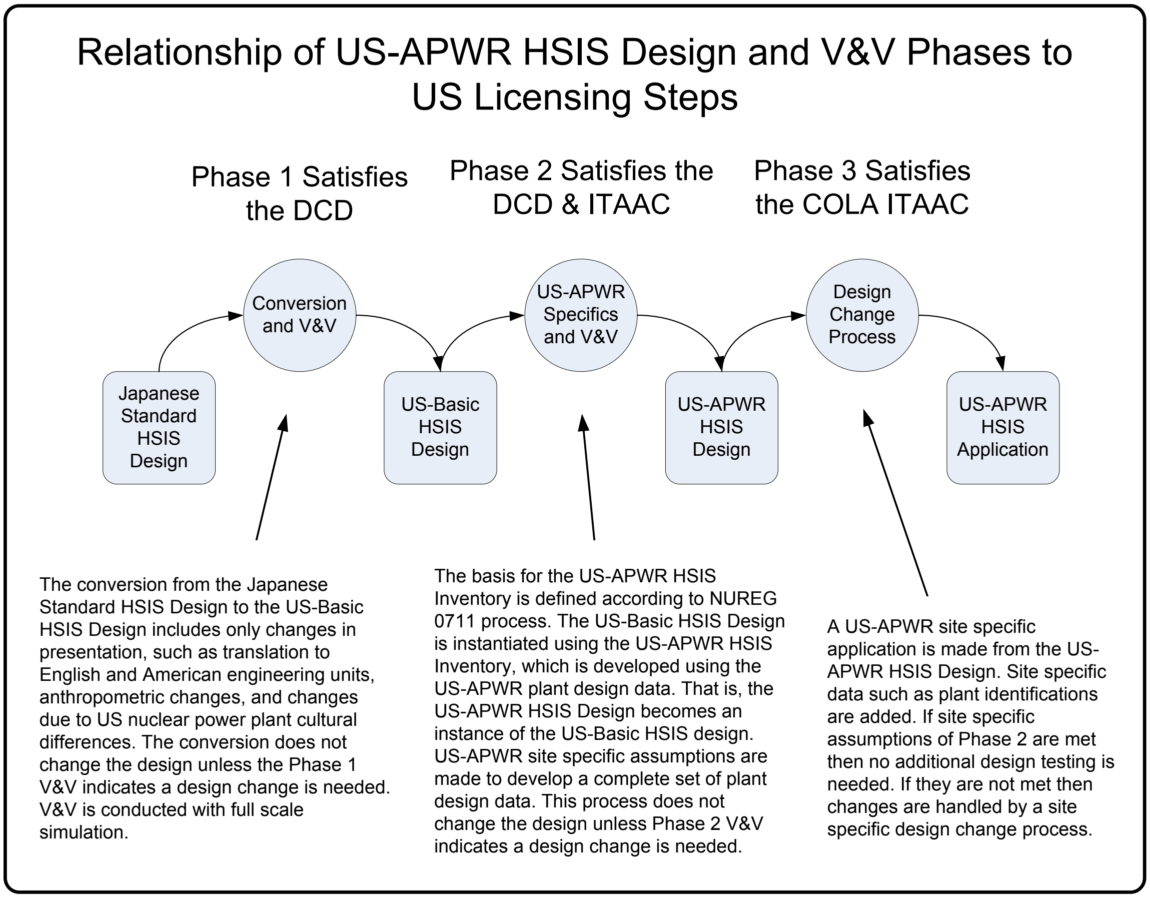


Figure 9 Design and V&V Phases and Licensing Correlation

8.1 Phase 1

The objective of the US-APWR HSIS development Phase1 is to define the US-Basic HSI System. The Phase 1 design and V&V activities shall be conducted by licensed nuclear plant operators, HFE experts, nuclear plant process operation experts, and I&C experts. Phase 1 is divided into two parts, Phase 1a and Phase 1b. The objective of Phase 1a is to assess the Japanese Standard HSI System and identify any changes needed. The assessment is based on analysis of human engineering discrepancies (HEDs) generated from various sources. The objective of Phase 1b is to design and V&V any changes to the Japanese Standard HSIS needed from the Phase 1a HED analysis. The result of Phase 1b is the US-Basic HSI System.

It should be noted that the Phase 1 formal design testing is part of an integrated V&V program that will include follow on V&V activities. That is, Phase 1 formal design testing is not a V&V of a specific application whether that application is a US-APWR application or an operating plant application. The formal design testing performed for Phase 1 is not focused on HSI Inventory details, but rather it is focused on the suitability of the design concepts for application to US nuclear power plants. The HSI Inventory used in Phase 1 is a vehicle for evaluating the US-Basic HSI design. An application specific HSI Inventory must be developed for all MCR applications. As defined in US-APWR DCD Section 18.10, all MCR applications shall have an application specific V&V that meets the requirements specified in NUREG-0711, Rev.2.

8.1.1 Phase 1a

The first step of Phase 1a is the conversion of the Japanese Standard HSIS to an HSIS that is useable by US nuclear power plant operators. This is referred to as the initial US-Basic HSI System. The displays are converted to English and to American engineering units. US step-by-step operating procedures are adopted in lieu of Japanese guidance style procedures. Changes are made to the Standard Japanese HSI System for US ergonomic and cultural differences. This conversion does not change the design. That is, the conversion does not change the HSIS functionality. For example, it does not change the layout of the LDP and the LDP data processing; it does not change the alarm prioritization, presentation, and management; it does not change the mimic display structure and display navigation; it does not change the soft control operation.

The Phase 1a V&V shall consist of both static verification analysis using a portable HSIS analysis tool and dynamic validation tests using a full-scale control room driven by a nuclear plant simulator computer. The Style Guide for the US-Basic HSI and changes to the Style Guide shall be verified against NUREG-0700.

Detailed US-APWR plant design data is neither available nor required for Phase 1 since Phase 1 is intended to develop the US-Basic HSI System. Therefore, in Phase 1 the HSI Inventory and the plant simulator model can use a conventional four-loop two-train PWR. The V&V activities shall be conducted with licensed nuclear plant operators and HFE experts. For validation at least eight operating crews of licensed nuclear power plant operators (six crews of one RO and one SRO and two crews of two ROs and one SRO) shall execute dynamic validation test scenarios that cover normal plant operation, anticipated operational occurrences (AOO), and postulated accidents (PA) under both normal HSI and degraded HSI conditions. At minimum, observations shall be made by operations and HFE experts. Operators and observers shall have the opportunity to generate HEDs for any aspects of the HSI design that they believe should be evaluated for improvement.

Phase 1a HEDs shall be evaluated by an Expert Panel. The Expert Panel shall document their evaluation. The evaluation documentation shall include the HED significance defined in this Implementation Plan.

HSI design solutions for HEDs requiring HSI design assessments and possible changes shall be produced in Phase 1b.

8.1.1.1 Operating Experience Review (OER)

Phase 1a activities shall include updating the HSIS design operating experience review (OER) which was originally conducted to generate the Japanese Standard HSIS. The updated OER shall include US nuclear power plant operating experiences and recent technology related operational experiences from other industries. The OER shall justify the adequacy of the US-Basic HSI System or identify HEDs that must be resolved, either within the US-Basic HSI System or through future US-APWR HSI Inventory design activities. For completeness, significant issues from the original Japanese OER that impact the Japanese Standard HSIS and are, therefore, carried into the US-Basic HSI shall be included in the OER report.

8.1.1.2 Phase 1a Procedures

There shall be a procedure for each major HFE program activity, including test procedures for each validation activity. Each V&V procedure shall contain configuration control information to define what HSI design version is under analysis and/or test. There shall be a procedure for:

- Phase 1a verification
- Phase 1a validation testing
- Phase 1a OER

8.1.1.3 Phase 1a Report

A report of the Phase 1a V&V activities and the updated OER shall be submitted to the NRC. The report shall summarize the results of Phase 1a. The Phase 1a completion date is 12/31/08.

8.1.2 Phase 1b

Phase 1b shall develop and test the HSIS changes required by Phase 1a. These changes shall be made on the test facility before the start of the Phase 1b testing program.

Phase 1b shall also include features of the basic HSIS that were not available for testing in Phase 1a. For example, as a minimum, Phase 1b shall include testing of the Diverse Actuation System Human Systems Interface Panel (DHP).

Modifications made to the interface as a result of the resolution of Phase 1a HEDs shall be evaluated through dynamic testing in Phase 1b.

Phase 1a HEDs not addressed and new HEDs from Phase 1b will be tested at a later time using the test facility. The test facility need only be modified to the extent necessary to design, verify, and validate the changes. For example, the change may be only partially implemented within the plant systems, but the implementation shall be sufficient to allow a thorough HFE evaluation.

The scope of the Phase 1b dynamic testing shall be based on the extent of changes from Phase 1a. Additional tests may be added to Phase 1b for other reasons, if this testing is determined to be necessary based on the evaluation of the Phase 1a results. Phase 1b validation shall be conducted using the same full-scale simulator as in Phase 1a with a sampling of test scenarios that cover normal plant operation, AOOs, and PAs under both normal HSI and degraded HSI conditions including common cause failures. Phase 1b shall include a preliminary assessment of computer based procedures.

Operators, HFE experts, and operations experts shall have the opportunity to generate HEDs for any aspects of the HSI design that they believe should be further evaluated for improvement.

8.1.2.1 Phase 1b Procedures

There shall be a procedure for each major HFE program activity, including test procedures for each validation activity. Each V&V procedure shall contain configuration control information to define what HSI design version is under analysis and/or test. There shall be a procedure for:

- Phase 1b validation testing

8.1.2.2 Phase 1b Report

A report that summarizes the results of Phase 1b shall be submitted to the NRC. An updated topical report, Reference 11.1, which reflects the updated US-Basic HSIS, shall also be submitted to the NRC. The updated US-Basic HSIS shall include the resolution of key HEDs identified in Phase 1b validation testing. The Phase 1b completion date is 06/30/09.

8.1.3 Incremental HSI Improvement Process

After the report submittal the Expert Panel shall evaluate the remaining HEDs from Phase 1b validation testing. The Expert Panel shall perform and document the HED evaluation. The evaluation documentation shall include the HED significances defined in this plan. HEDs shall be tracked to closure.

The Expert Panel shall also review the Phase 1a HEDs to either close the HED or decide that additional HSI design and testing is required.

Open HEDs shall be addressed in Phase 2, including additional V&V testing in Phase 2b. Any adjustments to the US-Basic HSI design during Phase 2 shall be handled by regression analysis and testing of the design change.

8.1.4 US-Basic HSI Design Documents

Reference 11.1 Section 4 “Design Description” defines:

- US-Basic HSI design basis
- US-Basic HSI functional specification that includes specifications for data processing

The following design documents complete the US-Basic HSI design specification:

- The US-Basic HSI Style Guide defining the HSI features and operation in sufficient detail to assure consistency throughout the entire HSI.
- The US-Basic HSI Nomenclature defining the standard acronyms and abbreviations and equipment description guidelines used in the HSI design.
- The US-Basic Component Control Design Guide that reflects generic control logic and information processing logic to support the US-Basic HSI. This document is required because the operation of the controlled component must be reflected in the HSI operator control face plate operation including associated indications and alarms.

The US-Basic HSIS description provided in Reference 11.1 provides the design basis for the details documented in the three documents above. All US-Basic HSI design documents shall be updated as required by Phase 1 V&V activities.

8.1.5 Generic Approval

Mitsubishi has requested generic approval by the NRC of the US-Basic HSIS design as defined by Reference 11.1. Reference 11.1 is referenced by the US-APWR DCD and will be referenced by any License Amendment Requests (LAR) from operating plants. It is expected that when the US-Basic HSI system is approved, future licensing submittals will only need to address the plant/site specific HSI Inventory, the HFE process that generates that HSI Inventory and the V&V of the fully integrated plant specific HSIS.

8.1.5.1 US Operating Environment

The goal of Phase 1 is to develop the US-Basic HSIS based on the Japanese Standard HSIS. A significant portion of Phase 1 is devoted to testing the converted Japanese Standard HSIS design in a simulated US operating environment. The most significant part of the simulated US environment is the use of licensed US NPP operators. They are used primarily for validation testing.

8.1.5.2 Application to an Operating NPP

For application to another plant, such as an operating US NPP, a suitable branch point will be selected from the US-APWR design and test regime to proceed to an application specific V&V for that plant. The branch point selected will depend on the commonality between that

application and the US-APWR application. For example, will the entire control room be replaced at one time or will it be phased replacement over many years. The justification for the selected branch point and the HFE Program Plan for the plant specific HSI Inventory development and HSIS V&V for the operating plant shall be presented in the license amendment request (LAR) for the plant. The V&V of the final operating plant HSIS shall meet the requirements specified in NUREG-0711, Rev.2, as documented in Section 18.10 of the LAR.

8.2 Phase 2

The objective of Phase 2 is to analyze, design and V&V the HSI inventory and, therefore, the HSIS for US-APWR. Phase 2 is divided into two parts, Phase 2a and Phase 2b.

8.2.1 Phase 2a

The objective of Phase 2a shall be to generate the HFE analysis results necessary to produce the HSI Inventory.

Phase 2a satisfies the commitments of the US-APWR DCD, which includes performing the analysis according to NUREG-0711, Rev.2, as defined in DCD Sections 18.3, 18.4, and 18.6. These activities include the US-APWR HSIS functional requirements analysis and function allocation (FRA/FA), the task analysis (TA) for risk important human actions (RIHA), and the human reliability analysis (HRA).

As described in the DCD, the US-APWR HFE analysis shall be an extension of the FRA/FA, the TA, and the HRA performed for the Japanese Standard HSI System where that predecessor information is relevant to the US-APWR. Therefore, the reports for each of these program elements shall describe the pertinent information derived from the corresponding Japanese program elements. If, for example, the FRA/FA report describes all automatic controls that have been historically automated in Japanese conventional plants and will continue to be automated for the US-APWR, the report shall explain the basis for retaining this automation and keeping it unchanged. The basis shall demonstrate conformance to the FRA/FA criteria of NUREG-0711.

8.2.1.1 Phase 2a Implementation Plans

There shall be an implementation plan for each major HFE program activity. There shall be an implementation plan for:

- Phase 2a functional requirements analysis and functional allocation (FRA/FA)
- Phase 2a human reliability assessment (HRA)
- Phase 2a task analysis (TA)

For submittal to the NRC, the Implementation Plan may be integrated with the report described below.

8.2.1.2 Phase 2a Report

An HFE analysis report, which explains the results of Phase 2a, shall be submitted to the NRC. The Phase 2a completion date is 06/30/09. The June HFE report shall include:

- FRA/FA plan and FRA/FA analysis results summary report.
- TA plan and TA analysis results summary report to confirm the time response for risk important operator actions. TA for the full range of operating tasks will be conducted in conjunction with operating procedure development in Phase 2b and will be documented.

- HRA plan and HRA analysis results summary report that identifies the risk significant operator actions, reasonability of the error probability used in the PRA, and future activities to minimize error probability.

8.2.2 Phase 2b

The objective of Phase 2b is the generation of the generic US-APWR HSI Inventory, to combine that with the US-Basic HSIS to form the US-APWR HSIS, and V&V of the US-APWR HSIS.

8.2.2.1 US-APWR HSI Inventory

The Phase 2a HFE analysis results, the Phase 2b analysis results and the US-APWR plant design data shall be used to generate the US-APWR HSI Inventory for the alarms, displays, procedures, and controls. The 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 shall be included in the US-APWR HSI Inventory, as necessary, to complete the total plant design data set. Intermediate states of the constituents shall be checked against each other for consistency.

8.2.2.2 Development of Operating Procedures

Operating procedures are a key component of the US-APWR Inventory. Computer based procedures shall be developed for normal HSI conditions. Backup paper procedures shall be developed for degraded HSI conditions.

The US-APWR Emergency Response Guidelines (ERGs), which establish the basis of the US-APWR Emergency Operating Procedures (EOPs), are being developed by MHI in two phases. These phases should not be confused with the HSI development phases; they are different. ERG/EOP Phase 1 will develop a draft ERG that reflects the US-APWR design, and will include US industry input. Phase 1 draft ERG will be completed by the end of 2009. During ERG/EOP Phase 2 (January 2010 to December 2012) MHI will add detailed design specific bases and add equipment details such as MHI component IDs to complete the ERGs. During ERG/EOP Phase 2 MHI will also develop US-APWR EOPs for use by US-APWR COL applicants when creating plant specific EOPs.

A similar process will be used to develop other US-APWR operating procedures which will be used by the US-APWR COL applicants when creating plant specific operating procedures. The process of verification and validation of EOPs and operating procedures shall be conducted as follows:

1. Plant designers provide operating procedure guidelines.
2. Operation procedure writers (who have to have conventional PWR operation experience and knowledge of the differences between US-APWR and conventional PWR) complete operation procedures with above operating procedure guidelines and US-APWR design information
3. Plant designers including plant safety analysis engineers verify those procedures from a US-APWR design point of view and plant safety
4. Paper procedures are converted to computer based procedures by the HSIS Design Team.
5. The Phase 2b HSI verification and validation will be conducted by the HFE V&V team using US-APWR computer based procedures and backup paper procedures. Static task support verification will confirm the procedures and displays have the necessary information and controls. Dynamic validation

confirms the procedures and displays using the full scale plant simulator test facility. Through these V&V activities, procedure problems will be extracted as human engineering discrepancies (HEDs) and will be tracked to closure using the HFE issues tracking system.

6. In Phase 3, plant specific procedures are developed, verified and validated, and then used for operator training (see Section 8.3).

8.2.2.3 US-APWR HSIS

The US-APWR Inventory is combined with the US-Basic HSI System to produce the US-APWR HSIS. The Phase 2b V&V shall consist of both static verification analysis and dynamic validation tests.

Phase 2b static verification shall be completed prior to dynamic validation testing. Phase 2b static verification shall verify:

- the display details against the Style Guide which was previously verified against NUREG-0700
- the operating procedures technical content and execution order by the plant design and safety engineers
- the operating procedures details against the Writer's Guide
- the operating procedures against the TA
- the displays contents information and controls necessary to execute the procedures

A test facility consisting of a full-scale US-APWR MCR and US-APWR plant and I&C simulator models shall be developed to support the US-APWR HSIS dynamic validation testing. Failure modes of the plant components and I&C equipment shall be included in the simulator models. The simulator shall be adaptable to encompass V&V for the Remote Shutdown Console and the information displays used at the Technical Support Center. It is noted that the HFE design team defines the information displays requirements and communication requirements for the EOF, in accordance with the US-APWR HFE Implementation Plans, but the design and V&V of the EOF is outside the scope of the US-APWR HFE Implementation Plans.

The Phase 2b V&V activities shall be conducted by licensed nuclear plant operators, HFE experts, and operations experts. The Phase 2b V&V of the final US-APWR HSIS shall meet the requirements specified in NUREG-0711, Rev.2, as defined in DCD Section 18.10. There shall be a sampling of dynamic validation test scenarios that cover normal plant operation, anticipated operational occurrences (AOO), and postulated accidents (PA) under both normal HSI and degraded HSI conditions. There shall be validation tests for detection of failed plant components and I&C equipment and taking corrective action. Phase 2b shall include validation of time critical manual actions credited in the US-APWR DCD Chapter 15 safety analysis and the US-APWR Defense-in-Depth and Coping Analysis, MUAP-07014. Phase 2b shall include complete validation of the use of computer based procedures (CBP) and the transition between CBP and backup paper procedures. The verification analysis shall be most rigorous for HSI that supports tasks shown by the HRA to be risk significant. This shall include operating procedures and training material. In addition, the validation scenarios shall encompass all human actions shown by the HRA to be risk significant.

At a minimum, observations shall be made by operations and HFE experts. Operators and observers shall have the opportunity to generate HEDs for any aspects of the HSI design that they believe should be further evaluated for improvement.

As for all HEDs, Phase 2b HEDs shall be evaluated by the HFE team and the Expert Panel, as described in Section 6. The evaluation, resolution and HED closure requirements shall be documented in the HED database. The evaluation documentation shall include the HED significances defined in this plan. The Expert Panel shall approve the HED closure requirements and shall approve closure of the HED when they are satisfied the closure requirements have been met.

HEDs shall be tracked to closure. HEDs that cannot be completely closed in Phase 2b shall be closed in Phase 3.

8.2.2.4 Phase 2b Implementation Plans

There shall be an Implementation Plan for each major HFE program element, as defined in DCD Chapter 18. There shall be an Implementation Plan for:

- Phase 2b task analysis
- Phase 2b HSI design
- Phase 2b procedure development (the procedure development program shall include a Writer's Guide)
- Phase 2b training program development (the training development program shall include a Training Developer's Guide)
- Phase 2b staffing and qualification analysis (SA)
- Phase 2b verification and validation

These implementation plans shall be submitted to the NRC as part of the US-APWR licensing process.

8.2.2.5 Phase 2b Results Summary Reports

Phase 2b shall satisfy the requirements of the US-APWR DCD ITAAC.

Results summary reports (RSR) shall be generated which document the results of each Phase 2b program element, including a summary of key HEDs and their resolution. The V&V RSR shall contain configuration control information to define what HSI design version has been analyzed and tested. The results summary reports for each of these activities shall be made available for NRC inspection as part of US-APWR ITAAC closure.

8.2.3 US-APWR Documents

In addition to the update to the US-APWR DCD and the design documents listed for Phase 1, the following documents shall be generated during Phase 2b:

- The US-APWR operating procedures shall be generated and used during the Phase 2b validation testing.
- US-APWR training material sufficient to train the operators for validation testing shall be generated and used during the Phase 2b validation testing. Other generic US-APWR training material is also expected to be developed during Phase 2b, but this additional training material is not required to support Phase 2b validation testing.

8.2.4 Phase 2 Relation to Operator Training

The simulator used for Phase 2b validation testing need not have, but may have, sufficient functionality to perform partial or full operator training required for operator licensing.

8.3 Phase 3

The objective of Phase 3 is to design, verify, and validate the HSI System for a US-APWR site specific application (e.g., CPNPP 3&4) and to train the operators for that site. Phase 3 satisfies the commitments of the COLA ITAAC. Phase 3 is divided into two parts, Phase 3a and Phase 3b.

8.3.1 Phase 3a

The objective of Phase 3a shall be to design, verify, and validate the site specific HSIS. If the site specific assumptions of the US-APWR HSIS, which is verified and validated in Phase 2b are applicable to the actual site specific application, then no additional design or V&V is needed. If the site specific assumptions of the US-APWR HSIS are not applicable to the actual site specific application, then a design change process shall be conducted. The scope of rework for the FRA/FA, HRA, TA, SA, HSI design and V&V, training and operating procedures shall be based on the extent of changes for the site specific application. For most US-APWR applications, very few changes are expected.

If additional HSI validation testing is required in Phase 3a, that testing is conducted using the site specific Operator Training Simulator. Even if additional HSI validation testing is not required, the Operator Training Simulator itself will be validated in Phase 3a.

As for Phase 2b, the scope of required training material is limited to that needed for Phase 3a validation testing. However, all site specific training material is expected to be developed during Phase 3a.

When Phase 3a is complete, the Operator Training Simulator is turned over to the site's training department for "Phase 3b - Site Specific Operator Training"

The scope of the Phase 3a site-specific activities includes all facilities addressed in Phase 2, including the information and communication requirements for the EOF. The site specific design and V&V of the EOF is outside the scope of the US-APWR HFE Implementation Plans.

8.3.2 Phase 3b

The objective of Phase 3b is operator training, using the plant specific Operator Training Simulator. The operator training material and simulator shall be sufficient for the US-APWR operators to receive NRC certification.

Since Phase 3b includes additional operating crews and additional plant scenarios, which may not have been conducted during Phase 1 or 2, it is anticipated that additional HEDs may be identified by operators participating in the training program. HEDs shall be evaluated as part of the Phase 3b training program. HEDs shall be tracked to closure using the same process as described in Section 6. Any required HSI design changes after Phase 3a shall be managed in accordance with the design change process defined in Reference 11.1 Section 5.11, and MUAP-10013 US-APWR Design Implementation Plan. All HEDs from all phases shall be closed in Phase 3b.

8.3.3 Phase 3 Implementation Plans

Any rework conducted during Phase 3a for the FRA/FA, HRA, TA, SA, HSI design and V&V, training or operating procedures shall be conducted in accordance with the Implementation Plans used for the corresponding activities in Phase 2. In addition, there shall be an implementation procedure for the Phase 3b site specific operator training program.

9.0 US-APWR LOCAL CONTROLS

Other departments and groups provide plant design outputs with HSI, such as local controls on motor control centers and skid mounted equipment.

9.1 Inclusion in HFE Program

Design outputs that have HSI safety significance shall be included in the US-APWR HFE Program. In order to assure HSI across the nuclear plant systems and components conform to industry accepted HFE practices and do not represent conflicts with the US-APWR HSI System or with one another, the HFE team shall interact with the rest of the plant design teams to review and control design products that contain information related to safety significant HSI. This HFE review and control of the HSI shall apply to both internal and external suppliers of unique systems or systems with local controls. For example, HFE review and control shall apply to local skid mounted HSI and local controls that may be supplied as part of a pump or valve, if those components are safety related and the local HSI will be used to support safety significant testing or maintenance activities, as follows:

- On-line testing, radiological protection activities, and required chemical monitoring supporting technical specifications
- Maintenance required by technical specifications
- Emergency and abnormal conditions response

9.2 HFE Guidance and Review

For HFE control the HSI V&V Team shall review the HSI designs from other departments to assure conformance to the guidance in NUREG-0700 and to ensure there are no conflicts with US-APWR HSIS. The review shall ensure local controls conform to industry accepted HFE practice. The review shall also ensure that local controls do not have inconsistencies that are likely to lead to human performance error. However, since local equipment may be procured from numerous suppliers, the review shall not try to define HSI standards to the same level as would be expected within an HSI design style guide.

9.3 QA Supervision

This process of interaction between the HFE Design/V&V Teams and other plant design organizations shall be included in the QA procedures governing plant design activities that involve the specification of safety significant human system interfaces. HFE comments that cannot be resolved through mutual agreement between the HFE organization and the plant design organization shall be brought to management attention for resolution.

10.0 US-APWR AS-BUILT HSIS

Any aspects of the US-APWR plant design that would affect the final HSIS V&V program results, but that could not be V&V’ed as part of the V&V using test facilities (e.g., lighting and noise), shall be evaluated for consistency with the assumptions of the V&V program. Any HSIS design modifications that may occur after completion of the Phase 3a V&V program shall be evaluated and managed in accordance with the design change process described in Reference 11.1 Section 5.11, and MUAP-10013 US-APWR Design Implementation Plan. As

described, this process includes a reassessment of some or all of the previous HFE program elements, depending on the risk significance of the change.

11.0 REFERENCES

11.1 HSI System Description and HFE Process, MUAP-07007, Revision 5, November 2011.

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

11.3 U.S. Nuclear Regulatory Commission, Human Factor Engineering Program Review Model, NUREG-0711, Revision 2.

Part 2 HFE Analysis (Phase 2a)

1.0 FUNCTIONAL REQUIREMENT ANALYSIS AND FUNCTIONAL ALLOCATION

1.1 Purpose

The goal of the US - Advanced Pressurized Water Reactor (US-APWR) human factors engineering (HFE) functional requirements analysis (FRA) / function allocation (FA) is to ensure that the safety functions of the US-APWR are assigned properly as human actions (HAs) or to automated systems.
The purpose of this document is to describe the procedure for how the FRA/FA was conducted and the results for the US-APWR, using the structured and documented methodology contained herein, that reflects human factors principles to meet the final goal.

1.2 Scope

The scope of the FRA/FA includes the identification of functions that must be performed to satisfy plant safety objectives; that is to prevent the occurrence or to mitigate the consequences of postulated accidents that could damage the plant or cause undue risk to the health and safety of the public. Also, the scope includes the analysis of the requirements for plant control and assignment of control functions to either personnel, system elements (automatic control or passive self-controlling phenomena) or combinations of personnel and system elements.

A FRA/FA process was conducted previously for the development of the standard Japanese Human System Interface (HSI) System. The FRA/FA for the US-APWR was based on that performed for the Japanese APWR design, and include analyses to address differences in the US-APWR design from the predecessor plant. The details of the technical basis for modifications to high-level functions in the new design (compared to the predecessor design) as stated in Reference 1.7.1-1 Subsection 18.3.3, are documented.

The functions and allocations may be modified where necessary to accommodate issues identified in the operating experience review (OER), issues with reduced staffing, new functions for the US-APWR that were not in predecessor plants, or functions that are changed significantly by the introduction of the use of digital instrumentation and control technology.

All aspects of the FRA/FA shall be conducted as described in Reference 1.7.1-1, Section 18.3. The FRA/FA shall be documented.

1.3 Definitions

Component - An individual piece of equipment such as a pump, valve, or vessel; usually part of a plant system or instrumentation loop.

Function – A process or activity that is required to achieve a desired goal.

Primary tasks - Those tasks performed by the operator to supervise the plant, specifically, monitoring, detection, situation assessment, response planning, and response implementation.

Secondary tasks - Those tasks that the operator must perform when interfacing with the plant, but are not directed to the primary task. Secondary tasks may include: navigating through and paging displays, searching for data, choosing between multiple ways of accomplishing the same task, and making decisions regarding how to configure the interface.

System - An integrated collection of plant components and control elements that operate alone or with other plant systems to perform a function.

Task - A group of activities that have a common purpose, often occurring in temporal proximity and that utilize the same displays and controls.

1.4 Methodology

The methodology for performing the FRA/FA and documentation to support the HFE analyses are described in this section. This methodology is based on that provided in References 1.7.1-2. The scope of the US-APWR FRA/FA includes function allocation changes between the current Japanese APWR design and the US-APWR design. Since the Japanese HSI System forms the basis of the US-APWR HSI System, the US-APWR FRA/FA documentation shall include a summary description of the Japanese FRA/FA process, and the significant findings from the Japanese FRA/FA that influenced the design of the Japanese HSI System. Figure 1.4-1 shows the analytical data flow for the FRA/FA process described in this plan, including the differences from the conventional PWR FRA/FA results.

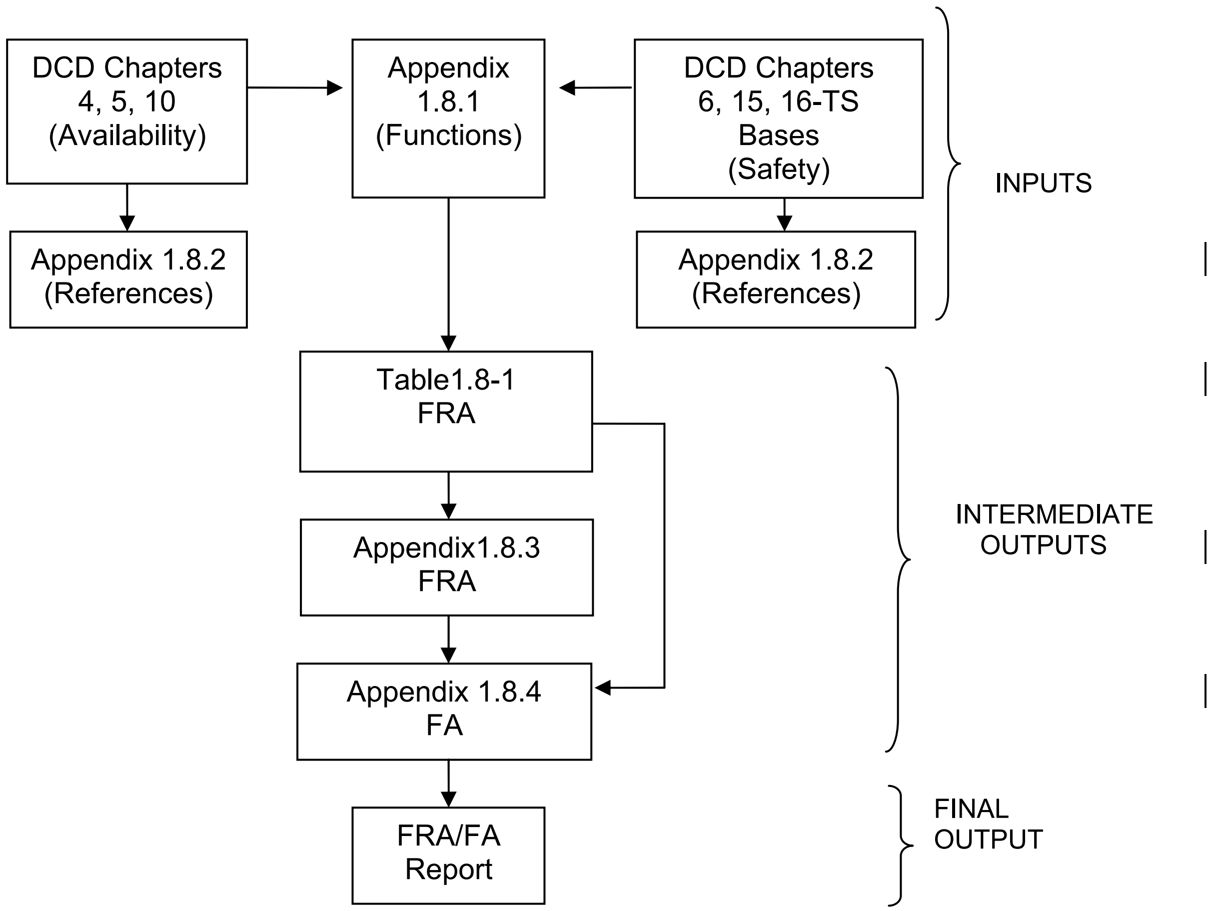


Figure 1.4-1 FRA/FA Analytical Data Flow

1.4.1 Functional Requirements Analysis

A functional requirements analysis is conducted to:

- Determine the objectives (top hierarchical goals), performance requirements (i.e., facility availability and safety), and constraints of the design
- Define the high-level functions that have to be accomplished to meet the design's objectives and desired performance (essential design considerations) for efficient electrical generations and critical safety functions
- Define the relationships between high-level functions and plant systems (e.g., plant configurations or success paths) responsible for performing the function
- Provide a framework for understanding the role of controllers (whether personnel or system elements) that control the plant

The objectives (goals), goal statements, and functions of US-APWR are the same as the previous FRA for conventional PWR that are depicted in Figure 1.4-2 and listed in Appendix 1.8.1.
The only changes from the convention PWR plant's functions are;

- An automatic Emergency Feedwater isolation of the faulted SG.
- Elimination of recirculation of ECCS and Spray

Although the following major system configuration changes exist, they do not affect plant function change;

- Four train system configuration (Contribute for high reliability, redundancy)
- Advanced steam generators and accumulators, other improved design equipment, gas turbine generator for backup system

(Improved design but the function to support higher-level is the same.)

The functional requirements analysis determines the following:

- The high-level functions (Plant Goals) necessary for the achievement of safe and efficient operation are identified
- Purpose of the high-level function
- Function characteristics for operational availability and safety:
  - Function Parameters – Parameters to be controlled/protected (Functional Level)
  - Systems required (System Level) – Overall system performance (operation/time)
  - Individual actions (Component level) – Number, Sequence, time

Requirements of each high-level function are identified including:

- Conditions that indicate that the high-level function is needed
- Parameters that indicate that the high-level function is available

- Parameters that indicate the high-level function is operating (e.g., flow indication)
- Parameters that indicate the high-level function is achieving its purpose (e.g., reactor vessel level returning to normal)
- Parameters that indicate that operation of the high-level function can or should be terminated (parameters may be described qualitatively (e.g., high or low) since specific data values setpoints are not necessary at this stage)

The Mitsubishi Heavy Industries (MHI) functional requirements hierarchical structure is shown in Figure 1.4-2. The hierarchy shows the functions essential to plant safety, and specific emergency and accident events that may affect each plant safety function, and the components that affect each emergency and accident event. Functional requirements associated with plant availability are not extended beyond the functional level in Figure 1.4-2. Plant availability functions are extended to the system and component level to fully address proper function allocation between automation and humans.

For each of the availability and safety functions identified in Appendix 1.8.1, the associated systems are identified. The parameter(s), action(s), time, and component(s) involved in maintaining the function are determined. The US-APWR Design Control Document (DCD) Chapter 4, Reactor, (Reference 1.7.2-1), DCD Chapter 5, Reactor Coolant and Connecting Systems, (Reference 1.7.2-2), DCD Chapter 10, Steam and Power Conversion System, (Reference 1.7.2-3), and Topical and Technical Reports referenced in those DCD chapters provide the primary source of data to determine plant availability goal's functional requirements. The DCD Chapter 6, Engineered Safety Features, (Reference 1.7.2-4), DCD Chapter 15, Transient and Accident Analyses, (Reference 1.7.2-5), DCD Chapter 16 Technical Specifications (and Bases), (Reference1.7.2-6), and Topical and Technical Reports referenced in those chapters provide the primary source of data to determine plant safety goal's functional requirements. The analyses contained in the DCD chapters address normal operating (availability) and safety issues during full power, low power, and shutdown facility configurations. If new functions are identified then they are incorporated into the tables of the Appendices.

Appendix 1.8.2 is used to record functional requirements so that they can be documented and introduced in the function allocation process. Each function listed in Appendix 1.8.1 is assigned its own table. The systems, parameters, actions, response times, and components (as determined from the source documents) are entered. The source document (DCD section or DCD section reference document) number is entered. Clarifying comments on any of the data entries are provided if required. Source document citations are entered in Table 1.8-3 and the citation numbers are assigned.

Each function listed in Appendix 1.8.1 is evaluated to determine which ones may be in progress at the same time or closely in time. This information is determined from the DCD or supporting references. Appendix 1.8.2 is generated for both normal operating conditions and abnormal/ emergency operating conditions. Appendix 1.8.4 is used to record functions occurring in temporal proximity. This information requires subjective evaluation that should be determined in consultation with operating and system subject matter experts. Appendix 1.8.4 also assists in determining function loading and complexity during the allocation process in Section 1.4.2 (using Table1.8-4).

Since there are no OER-related HEDs regarding FRA/FA in the OER which was evaluated and documented in the "Human System Interface Verification and Validation (Phase 1a)", (MUAP-08014) part 2, no specific methodologies are established.

1.4.2 Function Allocation

The function allocation (FA) analysis verifies that the historical allocations of functions (based on previous designs) result in a coherent role for plant personnel and that any new functions specific to US-APWR are properly allocated.
Again, the US-APWR plant functions are the same as those of the conventional PWR. The conventional PWR plant functions are proven as a historical precedence.

The only changes from the convention PWR plant's functions are;

- An automatic Emergency Feedwater isolation of the faulted SG.
- Elimination of recirculation of ECCS and Spray

Those changes are also included as FA but do not impact functional allocation. Therefore, US-APWR Function Allocation does not any conflicts with this historical allocation.

The function allocation analysis considers not only the primary allocations to personnel, but also their responsibilities to monitor automatic functions and to assume manual control in the event of an automatic system failure. The FA includes credited manual operator actions identified in the plant accident analysis, using Appendix 1.8.4 "Function Allocation Determination".

The technical basis for FA can be any one or a combination of evaluation factors. For example, the performance demands to successfully achieve the function, such as the degree of sensitivity needed, precision, time, or frequency of response, may be so stringent that it would be difficult or error prone for personnel to accomplish. This establishes the basis for automation (assuming acceptability of other factors, such as technical feasibility or cost). Qualitative criteria for function assignment to man or machine (automation) are given in Table 1.4-1(see Reference 1.7.1-2).

Table 1.4-1: Criteria for Function Assignment to Man or Machine

Characteristics	Assignment	
	Man	**Machine**
Load	Moderate	High or Very Low
Time margins	Large	Small or Very Large
Rate	Moderate	High or Very Low
Complexity of action logic	Simple	Complicated
Types and complexities of decision-making	Ill-structured	Well-structured

Load – The function load is the number of functions in progress simultaneously or in close temporal proximity. Typically humans can perform one control function (composed of sequential primary tasks and associated secondary tasks that are well learned or considered skill-of-the-craft) and monitor (supervisory control) an additional number of additional functions determined by the design of the human system interface (HSI). A greater number of supervisory control functions can be performed if that function is performed by monitoring compelling high level alarms (large screen display). When multiple simultaneous (or close in time - high load) control functions are required or long time period control actions with imbedded monitoring is required (very low load), then automation is preferred. In addition, separation in time between functions is important because of issues with workload transitions. Workload transitions refer to the transition from low to high workload experienced by human operators in the wake of unexpected failures or other anomalies. A slowly evolving transition is more readily handled by humans and a quickly changing situation should be handled by automation.

Time margins – The function time margin is the elapsed time from when a parameter deviates from its preferred value to when an action must be performed to protect the availability or safety function. Time intervals for crediting diagnosis or a combination of diagnosis and operator action are also provided. The following time interval guidelines (general and specific identified scenarios requiring diagnosis) can be used when assigning functions to man or machine and the operator's location:

Table 1.4-2 Criteria for Function Assignment to Man or Machine Based on Time

Man/Machine/Location Determination		
If Action Time Available is:	≤ 10 minutes[1]	> 10 minutes
Then Function Assignment is:	Automation	Human
If Human Action Time is:	≤ 30 minutes[2]	> 30 minutes
Then Action Location should be:	MCR	Outside MCR

Table 1.4-3 Examples of Scenario Complexity Based on Operator Response Time, for Comparison Purposes

Isolation of Small Coolant Leak Outside Containment	
Operator Actions to Perform Isolation	≥ 45 minutes[3]
Moderator Dilution Operator Response	
During Refueling Operation	≥ 30 minutes[4]
During Startup, Shutdown, Hot Standby and Power Operation	≥ 15 minutes[4]

Note: Isolation of Small Coolant Leak Outside Containment and Moderator Dilution Operator Response are specific scenarios but may be used to evaluate scenarios of comparable complexity, as determined by subject mater experts.

Key:

[1] MUAP-07006 rev 1 (pages 20, 43), (Reference1.7.1-3), MUAP-07007r1 (page 100), (Reference 1.7.1-4)
[2] MUAP-07006 rev 1 (page 20, 43), (Reference 1.7.1-3)
[3] DCD Section 15.0.0.8, Table 15.0-7, (Reference 1.7.1-5)
[4] NUREG-0800, Section 15.4.6-4, (Reference 1.7.1-6), DCD 15.4-50, (Reference 1.7.1-5)

Rate - The function rate involves the time allotted to complete the primary tasks and associated secondary tasks that compose each function. The greater the number of tasks and the shorter the allotted time to complete the tasks the greater the requirement for automation. If the tasks composing the function are few and spread over a long time interval, then automation or automated management may be required to assist operators.

Complexity of action logic - Functions that are simple, primarily sequential with a minimum number of decisions points, can readily be handled by humans. Functions that incorporate numerous decision points based on numerical or binary (yes/no) decisions should be handled by automation. For example, for large procedures (or sets of procedures) with complex navigation based on logical “if/then” type statements, automation is preferred where practical.

Types and complexities of decision-making - Functions that require complex decision making based on qualitative assessments (ill-structured) and with potentially unrelated or conflicting

goals (e.g., where the Safety and Availability goals may compete or current state of the plant may be different from the expected state) are better performed by humans than by automation. (An example is an external event that does not produce any immediately discernable impact on operation, but human judgment based on experience and/or training may determine there will be a negative impact to the facility, therefore protective actions should be taken.)

Appendix 1.8.4 is used to document the evaluation of function allocation. Information developed in Tables 1.8-3 and 1.8-4 are evaluated with respect to the parameters in Table1.4-1. This evaluation is conducted in conjunction with operating and systems subject matter experts. The “assignment” evaluation criteria from Table 1.4-1 are entered in the column location on Appendix 1.8.4 and a description of the parameters that resulted in the assignment is given in the associated comment space.

The OER (Reference 1.7.1-1, Section 18.2) is used to identify modifications to function allocations, if necessary. If problematic OER issues are identified, then an analysis should be performed to:

- Justify the original analysis of the function
- Justify the original human-machine allocation
- Identify solutions such as training, personnel selection, and procedure design that will be implemented to address the OER issues

Disposition of HFE issues identified from the OER is discussed in Section 4.3.

1.4.3 Data Documentation

The results of the functional requirements analysis and function allocation is documented in 1.8 Appendices. The FRA/FA report includes the following descriptions:

- The plant goals (availability and safety), functions and systems, along with a comparison to the reference plants/systems (i.e., the previous plants or plant systems on which the US-APWR systems are based). This description identifies differences that exist between the US-APWR and reference plants/systems. (Obtained from the DCD facility description and Appendix 1.8.2)
- The safety function provided (e.g., reactivity control). The safety functions include functions needed to prevent or mitigate the consequences of postulated accidents that could cause undue risk to the health and safety of the public. For each safety function, the set of plant system configurations or success paths that are responsible for or capable of carrying out the function is clearly defined. Function decomposition starts at “top-level” functions where a general description of major functions is provided, and continues to lower levels until a specific critical end-item requirement emerges (e.g., a piece of equipment, software, or HA). (Obtained from Appendix 1.8.2) The functional decomposition addresses the following levels:

  – High-level functions (e.g., maintain Reactor Coolant System integrity) and critical safety functions (e.g., maintain Reactor Coolant System pressure control)
  – Specific plant systems and components

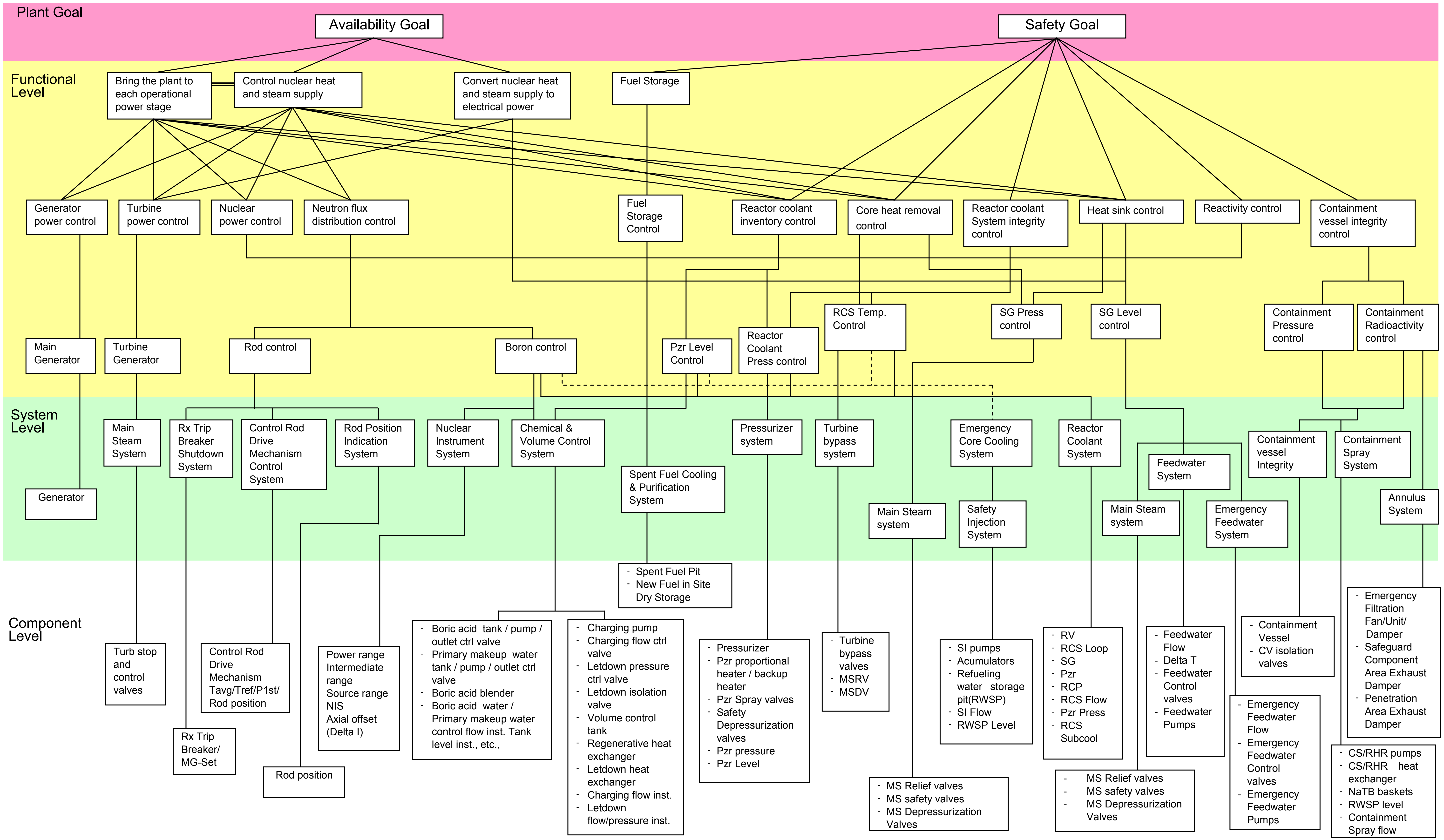


Figure 1.4-2 Functional Requirements Hierarchical Structure

- The integrated personnel role across functions and systems is provided in terms of personnel responsibility and level of automation. (Obtained from Table 1.8-3)
- The technical basis for each function allocation is documented, including the allocation criteria, rationale, and analyses method. (Obtained from Appendix 1.8.4)

The FRA/FA evaluation data is recorded on forms contained in the Appendices. Each FRA/FA item determined to be appropriate for HFE consideration is entered in the form (typically in an associated comment section). Those items that are considered to be included already in the US-APWR HSI System are dispositioned and closed out within the form (within the comment section). Those items not already addressed in the US-APWR HSI System are noted on the form and further documented by entering a human engineering deficiency (HED) in the HFE issues tracking system.

The FRA/FA identifies potential HEDs that could exist in the US-APWR HSI. HEDs that are currently addressed in the US-APWR HSI System are dispositioned with an explanation of the design elements that resolve the issue. HEDs that are not currently addressed in the US-APWR HSI System are entered into the issues tracking system to ensure evaluation and resolution during the FRA/FA HED evaluation process, described below.

Issues identified during the review are classified for their applicability. The review determines if the issue is generically applicable to the US-Basic HSI System or applicable on a plant specific basis and whether it is already addressed in the current design. Some identified issues may include a combination of both generic basic HSI features and plant specific HSI features.

1.5 Records

The results from the HFE FRA/FA analysis are documented. Issues identified during the FRA/FA are entered into the HFE issues tracking system. All documentation activities are conducted as described in Reference1.7.1-8.

1.6 Responsibilities

1.6.1 FRA/FA Team

The FRA/FA Team has the following functions and responsibilities:

- Perform FRA/FA
- Develop the initial draft of the Tables (forms in the Appendices)
- Conduct evaluation of the tables
- Writes the FRA/FA report Disposition technical reviewer’s comments.

1.6.2 HSI System Design Team Manager

The HSI system design team manager (DTM) organizes the FRA/FA team. The DTM is responsible for issuing the FRA/FA results.

Additionally, the DTM:

- Ensures that the FRA/FA is kept current over the life cycle of design development (for use as a design basis when modifications are considered)
- Ensures that the FRA/FA is kept within the QA program until decommissioning

- Determines if control functions should be re-allocated in response to developing design specifics, operating experience, and outcomes of ongoing analyses and trade studies

1.6.3 Additional Guidance

Reference 1.7.1-1, Section 18.1 provides additional guidance on organizational requirements in the area of people, roles, responsibilities, and qualifications for work performed under this procedure.

1.7 References

1.7.1 Developmental References

1.7.1-1 Design Control Document for the US-APWR, Chapter 18, Human Factors Engineering, MUAP-DC018 , Revision 3, MHI, March 2011.

1.7.1-2 Pulliam, et al., A Methodology for Allocation if Nuclear Power Plant Control Functions to Human and Automated Control, NUREG/CR-3331, June, 1983.

1.7.1-3 IEC 60964, Design for Control Rooms of Nuclear Power Plants, International Electrochemical Commission, 2009.

1.7.1-4 Defense in Depth and Diversity, MUAP-07006, Revision 2, June 2008.

1.7.1-5 HSI System Description and HFE Process, MUAP-07007, Revision 5, November 2011.

1.7.1-6 Design Control Document for the US-APWR, Chapter 15, Transient and Accident Analysis, MUAP-DC015, Revision 3, March 2011.

1.7.1-7 U.S. Nuclear Regulatory Commission, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, NUREG-0800, Subsection 15.4.6, Revision 2, “Inadvertent Decrease in Boron Concentration in the Reactor Coolant System (PWR),” March 2007.

1.7.1-8 Quality Assurance Program (QAP) Description for Design Certification of the US−APWR, PQD-HD-19005, Revision 4, Part II, Document Control, Section VI, April 2011.

1.7.2 Analytical References

1.7.2-1 Design Control Document for the US-APWR, Chapter 4, Reactor, MUAP-DC004, Revision 3, March 2011.

1.7.2-2 Design Control Document for the US-APWR, Chapter 5, Reactor Coolant and Connecting Systems, MUAP-DC005, Revision 3, March 2011.

1.7.2-3 Design Control Document for the US-APWR, Chapter 10, Steam and Power Conversion System, MUAP-DC010, Revision 3, March 2011.

1.7.2-4 Design Control Document for the US-APWR, Chapter 6, Engineered Safety Features, MUAP-DC006, Revision 3, March 2011.

1.7.2-5 Design Control Document for the US-APWR, Chapter 15, Transient and Accident Analysis, MUAP-DC015, Revision 3, March 2011.

1.7.2-6 Design Control Document for the US-APWR, Chapter 16, Technical Specifications, MUAP-DC016, Revision 3, March 2011.

1.8 Appendices

Appendix 1.8.1 Functional Requirements Analysis - Identification of Functions

Table 1.8-1 US-APWR High Level Essential Functions Descriptions

Appendix 1.8.2 FRA Information Sources

Table 1.8-2 FRA Information Sources

Appendix 1.8.3 Function Load Evaluation

Appendix 1.8.4 Function Allocation Determination

Table 1.8-4 US-APWR System/Component Level Function Allocation

Appendix 1.8.5 Verification of Functional Requirements Analysis and Function Allocation

2.0 HUMAN RELIABILITY ANALYSIS

2.1 Purpose

The purpose of the US-APWR human reliability analysis/probabilistic risk assessment (HRA/PRA) integration evaluation is to identify, analyze, and document that HRA/PRA results are thoroughly incorporated into the human factors engineering (HFE) design analysis and that the human factors engineering (HFE) design process interacts iteratively with the HRA/PRA. The proper interaction of HFE design and HRA/PRA most effectively contributes to minimizing personnel errors, allowing human error detection, and providing human error recovery capability.

2.2 Scope

The scope of the HRA/PRA integration evaluation incorporates into the HFE design effort risk-important human actions (HAs). The iterative nature of the interaction of HFE design and the HRA/PRA continues as the design progresses. Although this process continues throughout the design, and as such is not considered to be complete as reported in this section of MUAP-09019, it is complete enough to consider this section in place of a separate implementation plan or result summary report. Any revisions, based on this process, to the HRA will be made available to the NRC for review. The influence of the HRA/PRA on the HFE design manifests itself in changes to the task analysis primarily by developing more accurate estimates of workload and task completion times. The human performance assumptions, based on the HFE design influence on the HRA/PRA, are confirmed as part of the task analysis and the control room HSI test and evaluation program that will lead to the final verification and validation (V&V).
MHI will validate, as described in the US-APWR V&V Implementation Plan (MUAP-10012), all HRA assumptions for dominant sequences identified and validated using the process as described in MUAP-09019 Part 2.5. In the early design stage they are verified using a static display navigation system with walk through and display selection analysis. In the final design stage, they will be validated through operability testing using a US-APWR simulator with licensed plant operations personnel. These reviews will be conducted before the final quantification stage of the PRA and HRA as part of the V&V process.
All aspects of the HRA/PRA integration evaluation shall be conducted as described in Reference 2.9-1, Section 18.6.

2.3 Definitions and Abbreviations

2.3.1 Definitions

<u>Initiating Event</u> - An initiating event is a disturbance which causes an upset condition of the reactor plant, challenging reactor systems and requiring operator performance of safety functions that are necessary and sufficient to prevent core damage. Initiating events result in challenges to plant safety functions, and postulated failures in these systems, equipment, and operator response could lead to an end state involving core damage and/or radionuclide release.

<u>Performance Shaping Factors (PSF)</u> - Factors that influence human reliability through their effects on performance. PSFs include factors such as environmental conditions, human-system interface design, procedures, training, and supervision.

<u>Risk-Important Human Actions</u> - Actions that must be performed successfully by operators to ensure plant safety. There are both absolute and relative criteria for defining risk important

human actions. From an absolute standpoint, a risk-important human action is one whose successful performance is needed to ensure that predefined risk criteria are met. From a relative standpoint, the risk-important human actions constitute the most risk-significant human activities identified in the HRA/PRA.

2.4 Methodology

The methodology for evaluating the HRA/PRA influence on the HFE design is described in this section. Incorporating HRA/PRA results into the HFE design process involves identifying risk-important HAs, analyzing the HAs to characterize the components (human action types and performance shaping factors (PSFs)) and documenting the analysis results.

HRA/PRA results, including the risk important human actions (HA), will be reviewed by each organization involved in the design of the US-APWR HSI. This includes the HFE organizations responsible for the functional requirements analysis /function allocation (FRA/FA), task analysis (TA), staffing and qualifications analysis, HFE test and evaluation, procedure design, training design, and HSI design, and V&V. Each organization assures these results are considered in their respective design, analysis or testing programs such that the HSI design minimizes the likelihood of human error and provides opportunity for error and fault detection and error recovery.

The HRA provides human error probabilities (HEPs) and the analysis for Type A (pre-initiating event) and Type C (post-initiating event) human interactions is based on the NUREG/CR-4772 “Accident Sequence Evaluation Program HRA Procedure” (ASEP), and the HEP analysis for Type B (Errors that cause an initiating event) human interactions is based on NUREG/CR-1278 “Technique for Human Error Rate Prediction” (THERP).

The HEP analysis of type C at the design certification stage is conservatively assessed by ASEP approach because the plant specific information is not fully available. Also the time available to complete actions is not estimated at the design certification stage in detail, but an evaluation is performed to assure that identified operator actions are possible to perform in the time available. If it is difficult to judge whether the actions can be completed in the time available, those actions were not modeled in the PRA. The evaluations of the identified operator actions and human error probabilities can be updated as more specific US-APWR design and updated thermal-hydraulic analyses become available.

2.4.1 HRA/PRA Data Acquisition

Risk-important HAs are identified from the HRA/PRA (Reference 2.9-2, Chapter 19) and used as input to the HFE design effort. These actions are extracted from the Level 1 (core damage) PRA and Level 2 (release from containment) PRA and include both internal and external events. The HRA methodology is described in Subsection 19.1.4.1.1, “Description of the Level 1 PRA for Operations at Power” and Subsection 19.1.6.1, “Description of Low-Power and Shutdown Operations PRA.” The categorization of the risk-importance of HAs is described in Subsections 19.1.4.1.1 and 19.1.6.1. The US-APWR Design Control Document (DCD), Chapter 19 and, if required, Chapter 19 references provide the sole source of input data for this analysis.

2.4.2 HRA/PRA Data Evaluation

A structured evaluation is conducted to identify the risk-important HAs and their associated tasks, scenarios, interactions, PSFs, and assumptions. The primary focus of the HFE analyses are the 1) general HSI, 2) operating staff, and 3) procedures associated with the HAs. These parameters may be explicitly stated or inferred in the HRA/PRA, Reference 2.9-2. This information can be obtained from the text, tables, or figures in Reference 2.9-2, Subsections 19.1.4.1.1 or 19.1.6.1 or may be obtained from another Chapter 19 Subsection or Chapter 19 reference (technical document or another DCD chapter) if there is a formal reference provided.

2.4.2.1 Identification of Initiating Event Scenario Model

The HRA/PRA integration evaluation identifies the initiating event scenario model from the Chapter 19 description. The model should include the operator actions that either respond to the initiating events or mitigate failure of other systems. The HRA modeling addresses three types of human interactions, including actions before and after an initiating event, and actions that may cause or lead to an initiating event:

- Type A: Pre initiating event human interactions -
  These actions take place before an initiating event and are usually routine activities (e.g., test, maintenance, or calibration). If these actions are not completed correctly, the error may impact the availability of equipment necessary to perform a system function modeled in the PRA. Typically Type A HAs are composed of component misalignment or miscalibration. Misalignments of components can in many cases be easily detected by the plant personnel in the control room during plant operation. In the HRA, these kinds of Type A human failure events are screened out, and not explicitly modeled in the PRA.
- Type B: Initiating event related human interaction -
  These actions take place before an initiating event (including type A) and if not completed correctly may cause an initiating event. In many cases these contributors to initiating event frequency are included in the data base and are therefore included in the quantification of the PRA.
- Type C: Post initiating event human interaction -
  These actions take place after an initiating event and are evaluated to determine the likelihood of error or conversely task completion. The operator responses required for each of the accident sequences are modeled when they are risk significant and evaluated probabilistically in the HRA. Type C human interactions are categorized into type Cp and type Cr. Type Cp are the actions required to operate the mitigation system, and type Cr represents the recovery actions for failed equipment, or realignment of systems.

The methodology to identify risk important HAs based on the Level 1 and Level 2 PRA (probabilistic risk assessment) for the US-APWR DCD is as follows:
Risk importance measures of the Risk achievement worth (RAW) and Fussell-Vesely (FV) importance measures, which can be derived from the PRA, were used to measure risk importance of HAs. RAW represents the factor of increment in core damage frequency (CDF) or large release frequency (LRF) when the probability of an event (e.g., failure of function, human error or structural failure) is set to 1. Generally, events with RAW values greater than or equal to 2 are considered as risk important events. FV importance measure value indicates the contribution of an event to plant CDF or LRF. Events with FV values greater than or equal

to 0.005 are also considered as risk important events. Risk important HAs are identified by the risk importance measures and the criteria for risk important events discussed above.

Additionally, HAs that will cause an initiating event are considered to be risk important from the perspective of impact on initiating events. Such human actions are also candidates of risk important HAs. The criteria applied to identify risk important human actions are summarized below.

- Risk important HAs to mitigate initiating events:
  - Human actions that meet the importance criteria shown below are risk important: FV ≥ 0.005 or RAW ≥2.
  - HAs failures that are considered to have large contribution to CDF or LRF, based on engineering judgment, are risk important.

- Risk important HAs that are potentially incipient of an initiating event:
  - During at power operation, HAs that can result in reactor trip by a single human error are risk important.
  - During low-power and shutdown operation, HAs that can result in re-criticality or loss of decay heat removal are risk important.

In the low-power and shutdown (LPSD) PRA for the US-APWR DCD, detailed PRA has been carried out only for the mid-loop operation state. For plant operational states (POS), a simplified risk assessment method has been applied to evaluate the bounding value of CDF and LRF. Since the simplified risk assessment method does not calculate the risk importance of HAs, for POSs other than mid-loop, risk important HAs were identified based on engineering judgment. Risk important HAs for LPSD are identified based on the criteria shown below.

- Risk important HAs during mid-loop state
  - Human actions that meet the importance criteria shown below are risk important: FV ≥ 0.005 or RAW ≥2.

- Risk important human action during POSs other than mid-loop state
  - HAs that are risk important during mid-loop are also risk important during other POSs.
  - HAs that are not credited in the PRA for the mid-loop state are all risk important.

2.4.2.2 HFE Characteristics Evaluation

The HFE characteristics (US-APWR general HSI, operating staff, and procedures) that influence the HRA/PRA and their integrated relationship are evaluated. The following detailed HFE parameters are identified from the HRA/PRA and are recorded on the form presented in Attachment 2.10.1.

2.4.2.2.1 General HSI

The general HSI parameters of interest include the ergonomics parameters (facility location and workstation details), environmental influences, communications considerations, and HSI description.

A. Ergonomics Parameters

The ergonomics parameters include the location and physical layout of the facility and the workstation.

- Facility Location - The facility location determination involves identifying the location where the human action described in the HRA/PRA is performed. This is normally interpreted as a room within the facility or an outside area. However, if the HA specifies or implies movement between locations involving more than one room or outside area, then the travel path is determined. The start and end locations and length of travel should be specified (as a minimum level of detail) along with significant associated actions (e.g., don protective clothing, put on a respirator, or obtain equipment), if known.

- Control Panel/Console/Workstation - This HFE parameter involves identifying the specific location within a facility room or outside area where the HA is performed. This usually involves a clearly specified control panel, console, or workstation (e.g., operator console, supervisor console, remote shutdown panel or specific field location/equipment panel).

B. Environmental Influences

Environmental influences typically refer to ambient conditions that could have a negative influence on successful performance of the HA. (e.g., contribute to performance shaping factors that reduce the probability of success). The range of situational factors that are known to challenge human performance are specified, including adverse or inhospitable environmental conditions such as poor lighting, extreme temperatures, high noise, and radiological issues (dose rate or contamination). When evaluating performance associated with the use of HSI components located remotely from the main control room, the specific effects on crew performance due to potentially harsh environments (i.e., high radiation) are considered (i.e., additional time to don protective clothing and access radiologically controlled areas).

C. Communications

When communication between personnel is required to perform the task, the specifics of the communication is identified. 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).

D. HSI Description

The HSI description includes specifying the alarms, displays, and controls used by the operators. This description is presented at a high level of detail. For example, the information provided by the alarm should include: visual characteristics (color, text), audible characteristics (buzzer, bell, generated voice), data characteristics (single parameter, table, graph), and/or control characteristics (touch screen, mouse, control switch, other). More detailed information and control interface design details, such as graphic display formats, symbols, dialog design, and input methods are not required. Systematic strategies for organization such as arrangement by importance, frequency of use, and sequence of use are not required for this analysis. These details are addressed during the Task Analysis. Failure events, such as instrumentation and control failures, miscalibration and component restoration errors, or recovery action(s) in response to feedback are defined within the PRA structure and do not need to be specified as part of this parameter.

- Alarm or Display Monitoring - The general purpose of the alarm or display data for determining parameter status or overall automated system performance is provided. Examples are:

    - Parameters that indicate that the high-level function is available
    - Parameters that indicate the high-level function is operating (e.g., flow indication)
    - Parameters that indicate the high-level function is achieving its purpose (e.g., reactor vessel level returning to normal)
    - Parameters that indicate that operation of the high-level function can or should be terminated

- Control Actions - Controls used to conduct manual actions are the primary focus of this analysis. The control action (i.e., open valve, shutdown/trip pump, throttle flow, etc.) should be specified with the following additional information as appropriate:

    - Primary or backup to an automated action or another operator
    - Concern for errors of omission and/or commission
    - Operating precision (specify governing parameter – flow, pressure, temperature) if more complex than on/off activation

2.4.2.2.2 Operating Staff

The facility operating staff (crew) specifications addresses personnel requirements stated or implied in the HRA/PRA. This primarily includes the number of personnel and their skill level. Detailed analysis of staffing levels is conducted in the TA and staffing analyses and addresses minimal (and potentially less than minimum), nominal, and high-level staffing. This level of detail is not provided in the PRA and is beyond the scope of this evaluation.

A. Number of personnel
The number of personnel required to perform actions as specified in the HRA/PRA is determined. Stated or implied assumptions used in the HRA/PRA are identified and potential issues listed. These may include:

- Conflicts between tasks and personnel (simultaneous/parallel tasks or operators using the same controls)
- Workload issues addressing whether tasks can be accomplished within time and performance criteria
- Personnel interactions involving decision making, coordination and feedback within the control room and between the control room and local control stations and support centers.

The HRA/PRA evaluation extracts the number of personnel required to perform the required actions for the task requiring the maximum manpower from the PRA scenario(s). However, for purposes of this integration evaluation, the individual tasks must be evaluated to determine if manpower is available for parallel activities.

B. Personnel Skill Level
Information is extracted from the HRA/PRA relative to stated or implied operator capabilities. This parameter usually is reflected in operator designation/qualifications (i.e.,

SRO, RO, Auxiliary Operator, fire brigade, Emergency Medical) and is used to support an HA being classified as Skill-of-the-craft or justifying the designation of an HA as a memorized action. Training requirements are implicitly reflected in personnel job titles.

All results of the staffing level analysis will be documented and reviewed to assure that staffing level assumptions are assessed in the HRA. Results from the HRA that apply to staffing that are considered to be discrepancies with staffing assumptions will result in an HED being generated and entered into the HED data base for resolution.

2.4.2.2.3 Procedures

Based on the description, stated or implied in the HRA/PRA, the type of the plant procedures are determined. The procedures that provide guidance to personnel for the affected actions such as failure/error recovery include the following types:

- Emergency operating procedures (EOPs)
- Severe Accident Management Guideline (SAMGs)
- Plant and system normal operating procedures (including startup, power, and shutdown operations)
- Abnormal and emergency operations procedures (AOPs)
- Alarm response procedures (ARPs)

2.4.2.2.4 Comments

The HRA/PRA evaluation should consider the HFE topic areas described in Subsection 4.2.2 during the review. Comments should be provided where it is deemed necessary to clarify data or where information is obtained from a supporting reference of (the primary reference) Reference 2.9-2.

2.5 Data Documentation

The HRA/PRA integration evaluation data is recorded in a summary table as depicted in Appendix 2.10.2 “US-APWR HRA/PRA Integration Evaluation Table”. Each HRA/PRA evaluation item analyzed in section 4.2 is entered in the form. HFE design issues or concerns that should be addressed to minimize human error probabilities are identified in the “comment” section of Appendix 2.10.2. Issues or concerns are resolved through the HFE design process, primarily in the Task Analysis and HSI design activities. The issues or concerns are formally dispositioned as Human Engineering Deficiencies and transmitted to the HRA/PRA analysts for inclusion in that process as required in the HFE Program.

HRA assumptions identified during the evaluation for Appendix 2.10.2 such as decision-making, diagnosis strategies, and staffing are validated by walkthrough reviews with personnel with operational experience and the HSI test and evaluation program. These reviews are conducted before the final quantification stage of the PRA as part of the final V&V process.

The HRA/PRA evaluation information obtained from supporting source documents referenced in US-APWR DCD Chapter 19, Reference 2.9-2 are listed and summarized on a form contained in Appendix 2.10.3. The source document is listed, its unique source document identifier is recorded (for use in the comment section in Appendix 2.10.2), and a brief summary of HFE information from the source document are recorded.

2.6 Records

The results from the HRA/PRA integration evaluation are documented in the 2.10.2 Appendices. Issues identified during the HRA/PRA integration evaluation are entered into the HFE issues tracking system. All documentation activities are conducted as described in Reference 2.9-5.

2.7 Responsibilities

2.7.1 HRA/PRA Evaluation Team

The HRA/PRA Evaluation Team has the following functions and responsibilities:

- Perform a detailed review of Reference 2.9-2, focusing on HRA and related topics
- Identify risk important human actions and evaluate HFE components
- Develop the initial draft of the risk important human actions table (form in Appendix 2.10.2) for each identified top event
- Conduct evaluation of the tables
- Writes the HRA/PRA evaluation report
- Disposition technical reviewer's comments
- Develop and enter HEDs into the HED database (HFE issues tracking system).

2.7.2 HSI System Design Team Manager

The HSI Design Team Manager has the following functions and responsibilities:

- organizing the HRA/PRA evaluation team
- issuing the HRA/PRA evaluation in the HSI Design Technical Report
- dispositioning HEDs resulting from the HRA/PRA integration process, and tracking the HEDs to closure
- assigning each of the HFE organizations issues related to their area of assignment to assure that the risk important HAs are considered.

2.7.3 Additional Guidance

Reference 2.9-1, Section 18.1 provides additional guidance on organizational requirements in the area of people, roles, responsibilities, and qualifications for work performed under this procedure.

2.8 Results

Assessment results are shown in Appendix 2.10.2. With these operation step assumption (i.e. Basic HSI assessment (Indications/Controls allocation, etc.), operating procedure step reflection on corresponding operation procedures and staffing estimation), any risk significant human action steps are mitigated from Human Factor Engineering aspect. HSI basic design,

operating procedure and operator training program including staffing assumption shall use those assumption as their input information.

2.9 References

2.9-1 Design Control Document for the US-APWR, Chapter 18, Human Factors Engineering, MUAP-DC018 , Revision 3, March 2011.
2.9-2 Design Control Document for the US-APWR, Chapter 19, Probabilistic Risk Assessment and Severe Accident Evaluation, MUAP-DC019, Revision 3, March 2011.
2.9-3 IEEE Guide for Incorporating Human Action Reliability Analysis for Nuclear Power Generating Stations, IEEE Std 1082-1997, Institute of Electrical and Electronics Engineers, NY, September 1997.
2.9-4 Higgins, J.C and O'Hara, J.M., Proposed Approach for Reviewing Changes to Risk-Important Human Actions, NUREG/CR-6689, October 2000.
2.9-5 Quality Assurance Program (QAP) Description for Design Certification of the US-APWR, PQD-HD-19005, Revision 4, Part II, Document Control, Section VI, April 2011.
2.9-6 Probabilistic Risk Assessment, MUAP-07030, Revision 3, June 2011.
2.9-7 US-APWR Risk Significant Human Errors, N0-EB40026, Revision 0, December 2011.

2.10 Appendices

Appendix 2.10.1 Methodology Applied to Identify Risk-Important Human Actions

This attachment describes the methodology applied to identify risk important human actions based on the Level 1 and Level 2 PRA (probabilistic risk assessment) for the US-APWR DCD. Risk importance measures such as the Risk achievement worth (RAW) and Fussell-Vesely (FV) importance, which can be derived from the PRA , was used to measure risk importance of human actions. RAW represents the factor of increment in core damage frequency (CDF) or large release frequency (LRF) when the probability of an event (e.g., failure of function, human error or structural failure) is set to 1. Generally, events with RAW values greater than or equal to 2 are considered as risk important events. FV indicates the contribution of an event to plant CDF or LRF. Events with FV values greater than or equal to 0.005 is also considered as risk important events. Risk important human actions have been identified by the risk importance measures and the criteria for risk important events discussed above.

Additionally, human actions that will cause an initiating event are considered to be risk important from the perspective of impact on initiating events. Such human actions are also candidates of risk important human actions. The criteria applied to identify risk important human actions are summarized below.

- Risk important human actions to mitigate initiating events
  - Human actions that meet the importance criteria shown below are risk important: FV≥ 0.005 or RAW ≥2.
  - Human action failures that are considered to have large contribution to CDF or LRF base on engineering judgment are risk important.

- Risk important human actions that are potentially incipient of an initiating event
  - During at power operation, human actions that can result in reactor trip by a single human error are risk important.
  - During low-power and shutdown operation, human actions that can result in re-criticality or loss of decay heat removal are risk important.

In the low-power and shutdown (LPSD) PRA for the US-APWR DCD, detailed PRA has been carried out only for mid-loop operation state. For POSs, a simplified risk assessment method has been applied to evaluate the bounding value of CDF and LRF. Since the simplified risk assessment method does not calculate the risk importance of human actions, for POSs other than mid-loop, risk important human actions were identified based on engineering judgment. Risk important human actions for LPSD are identified based on the criteria shown below.

- Risk important human action during mid-loop state
  Human actions that meet the importance criteria shown below are risk important: FV≥ 0.005 or RAW ≥2.

- Risk important human action during POSs other than mid-loop state
  - Human actions that are risk important during mid-loop are also risk important during other POSs.
  - Human actions that are not credited in the PRA for mid-loop state are all risk important.

Appendix 2.10.2 US-APWR HRA/PRA Integration Evaluation Table

Appendix 2.10.3 HRA/PRA Information Sources*

3.0 TASK ANALYSIS

3.1 Purpose

The purpose of the US - Advanced Pressurized Water Reactor (US-APWR) human factors engineering (HFE) task analysis (TA) is to identify the specific tasks that are needed for function accomplishment and their information, control and task-support requirement.
TA is used to inform:

- PRA and HRA
- HSI design
- HSI task support verification as part of the HFE verification and validation
- Procedure development
- Staffing and training program development

3.2 Scope

The Task Analysis performed in Phase 2a included US-APWR risk important human actions (HAs) from the PRA results which cover full range of plant operations. These HAs are documented in HRA report (MUAP-09019 Part2 Section 2). In Phase 2b, the task analysis scope will be expanded to include human actions which are not risk important, including:
The Task Analysis performed in Phase 1 included US-APWR risk important human actions (HAs) from the PRA results which covered the full range of plant operations. These HAs are documented in HRA report (MUAP-09019, Part 2 Section 2). In Phase 2b, the task analysis scope will be expanded to include human actions which are not risk important, including

- Selected representative and important tasks from operations, maintenance, test, inspection, and surveillance performed
- Full range of plant operating modes, including startup, normal operations, abnormal and emergency operations, transient conditions, and low-power and shutdown conditions
- All human tasks where critical functions are automated and monitoring of the automated system and execution of backup actions if the system fails.

Phase 2b task analysis will be performed in conjunction with operating procedure development and HSI design development utilizing the methodology described in MUAP 09019 (R1) Part 2, Section 3. A results summary report will be submitted upon completion of the Phase 2b task analysis.

The purpose of the TA includes confirming the time response assumptions for the risk important HAs. The list of HA that have been analyzed are presented in Appendix 3.10.1. The results of the TA are presented in Table 3.7-1.
Detail level of the operating task analysis will be conducted in conjunction with ERG and General Operating Procedures (GOP) development. The results will be documented in the Phase 2 Task Analysis report.

3.3 Definitions and Abbreviations

3.3.1 Definitions

Component - An individual piece of equipment such as a pump, valve, or vessel; usually part of a plant system or instrumentation loop.

Function – A process or activity that is required to achieve a desired goal.
Task - A group of activities that have a common purpose, often occurring in temporal proximity and that utilize the same displays and controls.

3.4 Methodology

Each HA is broken down into substeps that are either cognitive tasks (e.g., detection, confirming a parameter value) or action steps (e.g., opening or closing a valve).

These substeps are then evaluated with respect to a number of characteristics that can influence the quality or timeliness of performance. Table 3.4-1 presents the list of required functions for human task accomplishment. These are drawn from Table 5 in NUREG-CR 0711, Rev.2. These items correlated to the columns shown in Table 3.7-1 for each risk important HA.

For each subtask answers to these items are determined based on analysis of the APWR plant design and general PWR NPP operational knowledge, and documented in summary table form. (See Table 3.7-1).

One of the items in Table 3.4-2 relates to Response time requirements when the OSD response time is compared to the time required assumptions from Appendix 3.10.1. This item examines whether a task can be accomplished in the time available specified by PRA and Safety Analyses. The time available within which a HA needs to be completed as well as the time required to complete the actions are presented in Appendix 3.10.1.

A second, table-top, method is used as an independent check that the HA can be accomplished within the time available specified by the PRA and safety analyses.

A table-top technical review of the Phase 1 Task Analysis for risk important human actions for the US-APWR was performed with the objective of ensuring the following for each task:

- Accuracy of the English translation
- Accuracy of the task substeps
- Time required to complete each task
- Other evaluation aspects of Table3.4-1 criterion

Technical documents referenced for the review, where available, consisted of P&ID drawings of the applicable nuclear plant systems found in the Tiers 1 and 2 DCD for the US-APWR and PRA/HRA results in DCD Chapter 19.

This table top analysis was performed by two operations experts (both SRO Instructors with plant experience) who are familiar with U. S. NPP operations and the MHI US-Basic HSI as implemented in the MEPPI simulator.

They evaluated whether the tasks could be completed within the required time available, assuming one RO and one SRO in the control room, and a local operator (in cases where local operation is required).

All discrepancies from the stated objectives which were identified by the reviewers were annotated and forwarded to MHI engineers for incorporation into the task analysis results table.

Table 3.4-1 Required Functions for Human Task Accomplishment (1 of 2)

No.	Evaluation Items	Acceptance Criteria	Remarks
1	Information Requirement	The plant information needed to accomplish the subset (e.g., flow and pressure indication)	
2	Decision-making	The type of decision required. Ab (Absolute information): Prompting information in the MCR (such as an alarm) that notifies the operators of the plant situation. R (Relative information): Plant symptom information (such as changes in plant parameters and/or component status indications caused by plant malfunctions) is presented in the MCR that enables the operators to gain awareness of the plant situation. P (Probabilistic): Information is available at the local area but is not directly indicated in the MCR, so that operators would only become aware of the plant situation from the local area (e.g., during periodic inspections). "Ab", "P", and "R" appear in this column of Table 3.7-1 to indicate the type of decision required for the action.	Decision making requirements are specified for the first substep of a task sequence. This defines how the decision to initiate the task is determined.
3	Communication Requirements	Type of communication required V: Verbal communication between RO and SRO in the control room R: Remote communication between RO (AO) and SRO can be performed. "V" and "R" are listed in this column of Table 3.7-1 to indicate the type of communication required for the action.	
4	Time Required (OSD time)	The time in this column of Table 3.7-1 is the time required to complete the HA based only on the summation of the individual times for each OSD pattern (See Table 3.10-3 in Appendix 3.10.2). The total Time Required, which includes additional considerations for qualitative factors (Columns 6-8), is shown in Note 1 of the table. An 'A' in this column of Table 3.7-1 indicates that the total Time Required to complete the HA is acceptable.	

Table 3.4-1 Required Functions for Human Task Accomplishment (2 of 2)

No.	Evaluation Items	Acceptance Criteria	Remarks
5	OSD Pattern	The HA is composed of subtasks which are represented by the standard OSD Patterns. The numbers in this column of Table 3.7-1 indicate the specific OSD Pattern from Appendix 3.10.2.	
6	Task Support Requirements	Specific job aids, tools, or protective clothing needed. D: Support material such as some reference document or calculation sheet for dedicated action. T: Some support apparatus such as valve handling tool if required in the action. "D" or "T" appear in this column of Table 3.7-1 if either is required to support the action.	
7	Situational and Performance Shaping Factors	Whether there are any situational factors such as high stress, or reduced staffing that may affect the required action. An 'A' in this column of Table 3.7-1 indicates that no factors exist that influence performance of the action; otherwise the factors are listed.	These factors are considered for the difficult action and high workload action.
8	Workplace Factors & Hazard	Whether there are any significant workplaces factors that may affect actions required in the local area. These factors are considered only for local actions. Most actions are taken in the control room. The control room is good environment and no consideration for this issue is required. Any hazards that may affect required actions. These factors are considered only for local actions. The control room is good environment and no consideration for this issue is required. An 'A' in this column of Table 3.7-1 indicates that no workplace factors or hazards exist that influence performance of the action; otherwise the factors and/or hazards are listed.	Examples of significant workplace factors considered are high or low temperature, radiant heat by high energy piping, noise, radiation, lighting, roaring sound by turbine rotation etc. Examples of potential hazards considered are falling materials, actions on the ladder, actions at height etc.

The TA method described in this section was used to analyze the risk important HA identified from the PRA. Additional task analyses intended to support HSI design, HSI task support verification and procedure development will be conducted in conjunction with operating procedure development in Phase 2.

Phase 2 task analyses is described in Section 3.8 and will cover a broader range of representative and important tasks from the areas of operations, maintenance, test, inspection and surveillance and a broader range of operating modes. Phase 2 task analyses will also specifically address the supervisory role of MCR operators with respect to critical functions that are automated. This includes monitoring of the automated systems and execution of backup actions if the system fails. TA is necessarily an iterative process, with each cycle requiring more detailed inputs and providing more specific results.

3.5 Records

Issues identified during the TA are entered into the HFE issues tracking system. All documentation activities are conducted as described in DCD Chapter 18.1.4 (Reference 3.9.2).

3.6 Responsibilities

3.6.1 TA Team

The TA is performed by MHI HFE engineers or qualified subcontractors, and is based on input from safety analysis, HRA, plant fluid systems engineering and I&C.
The results are reviewed by operations experts familiar with U. S. plant operations, the APWR plant design, and the MHI US-Basic HSI as implemented in the MEPPI simulator.

3.6.2 HSI System Design Team Manager

The HSI system design team manager (DTM) organizes the TA team. The DTM is responsible for issuing the TA results within the HSI Design Technical Report

3.7 Results

The results of the TA for risk-important HA are presented in Table3.7-1. There is a separate sheet for each of the risk-important HA identified in the HRA:

- Column 1 numbers the HA substeps.
- Column 2 describes the HA substeps

Required functions for human task accomplishment

- Column 3 provides the information requirements for the substep and whether the information is available in the main control room (MCR) or locally
- Columns 4 and 5 specify the decision making and communication requirements as defined in Table 3.4-1.
- Column 6 indicates the Time Required to complete the HA based on the summation of times for each OSD pattern.
- Column 7 indicates which operational sequence diagram (OSD) pattern this substep corresponds to. (See Appendix 3.10.2 and Table 3.10-1 for an explanation of OSD patterns and the OSD pattern corresponding to each number.)
- Columns 8, 9, and 10 are used to document any task support requirements, situational and performance shaping factors, and workplace factors and hazards associated with the substep.

Results

- Columns 11 and 12 specify whether the substep is a monitoring or control task and provides additional descriptive details.
- Column 13 specifies the number of operators involved in performing that substep
- Column 14 indicates the type of operator that is required to perform that substep.

As shown in Task Analysis and Evaluation Tables, the results of the TA indicated that the risk-important HA can be completed within the time available specified by the PRA and safety analyses. This analysis assumes one SRO and one RO in the MCR and one local operator (if applicable)

The time required for human actions for events in Appendix 3.10.1 are based on both engineering judgment and GOMS evaluations. Column 7 of each Task Analysis and Evaluation Table (Table 3.7-1) specifies an Operational Sequence Diagram (OSD) for each sub-step of a risk important human action. As specified in Appendix 3.10.2, OSD patterns clearly identify operator decision and action functions required to perform that sub-step. GOMS is then used to assess the workload and evaluate time requirements for each OSD pattern specified for each sub-step of the risk important human actions performed in the main control room. For example, OSD pattern 1 in Table 3.10-1 of Appendix 3.10.2 would be appropriate to analyze a sub-step of a task that requires the operator to verify a single plant parameter in the main control room as illustrated below.
GOMS applies the Model of Human Information Processor by Card, et al. as specified in Figure 3.10-2 of Appendix 3.10.2 to determine time requirements for OSD patterns. Basic human actions specified in Table 3.10-2 of Appendix 3.10.2 are assigned to each sub-step of each OSD pattern and evaluated for response time requirements using the Card et al. approach in the “Internal Processing” and “Workload” columns in Table 3.10-3 of Appendix 3.10.2. The OSD pattern sub-step response times are then summed and the total time required to perform each OSD pattern is specified in the applicable Table 3.10-3 of Appendix 3.10.2.
For example, the total time required to verify a plant parameter (OSD pattern 1) is approximately 2.31 seconds; the total time required to start a pump (OSD pattern 4) from the main control room is approximately 3.48 seconds. Response times for some OSD patterns are based on engineering judgment. For example, OSD pattern 2, “Energize a valve”, OSD pattern 8 (open or close the valve- local action) and OSD pattern 9 (unlock the valve- local action) response times are estimated to require approximately 10 minutes, the basis of which is given in Table 3.10-3 for that OSD pattern. As indicated in Section 3.4, “Methodology”, the engineering judgment applied in the Phase 1 Task Analysis was verified through a table-top analysis performed by two operations experts (both SRO Instructors with plant experience) who are familiar with U. S. NPP operations and the MHI US-Basic HSI as implemented in the MEPPI simulator.
It can now be shown how engineering judgment and GOMS evaluation are both used in determining the response time for risk important human actions specified in Table 3.7-1.

Example 1: In Table 3.7-1 (36/44), “RCS water level recovery and Charging Injection System Establish Operation Failure (LOCA, OVDR, LORH, LOOP, FLML)” is decomposed into seven sub-steps with each sub-step assigned an OSD pattern, the time response requirements which have been analyzed by the GOMS approach (for OSD patterns 1, 3, and 4) and engineering judgment (for OSD pattern 8) in Table 3.10-3. The time required to perform each sub-step of this risk important human action would be:

Sub-step 1: 2.31 sec (OSD 1; response time based on GOMS)
Sub-step 2: 3.48 sec (OSD 4; response time based on GOMS)
Sub-step 3: 2.31 sec (OSD 1; response time based on GOMS)
Sub-step 4: 3.48 sec (OSD 3; response time based on GOMS)
Sub-step 5: 10 min(OSD 8; response time based on engineering judgment)
Sub-step 6: 10 min(OSD 8; response time based on engineering judgment)
Sub-step 7: 3.48 sec (OSD 4; response time based on GOMS)
Total time: 20 min.,15.06 sec.

Based on the time summary above, it is shown that the time required to perform this risk important human action is "About 30 minutes" as indicated in column 6 of Table 3.7-1 (36/44), "Time required (OSD time)". This time is also specified in Appendix 3.10.1 table "Response Time Criteria for Risk significant human actions" in the "Time Required" column, which is less than the time of one hour specified in the "Time Available" column, indicating that there is sufficient margin between the Time Available (as defined in the safety analysis or PRA) and the Time Required (as determined by the HFE task analysis).

Example 2: In Table 3.7-1, (3/44), "Failure to Start the Standby Charging Injection Pump B (PLOCW, ATWS)" is decomposed into two sub-steps with each sub-step assigned an OSD pattern, the time response requirements which have been analyzed by the GOMS approach only (for OSD patterns 1 and 4). The time required to perform each sub-step of this risk important human action is:

Sub-step 1: 2.31 sec (OSD 1; response time based on GOMS)
Sub-step 2: 3.48 sec (OSD 4; response time based on GOMS)
Total time: 5.79 sec

Again, it is shown that the time required to perform this risk important human action is "Within a few minutes" as indicated in column 6 of Table 3.7-1 (3/44), "Time required (OSD time)". This time is also specified in Appendix 3.10.1 table "Response Time Criteria for Risk significant human actions" in the "Time Required" column, which is less than the time of one hour specified in the "Time Available" column, indicating that there is sufficient margin between the Time Available (as defined in the safety analysis or PRA) and the Time Required (as determined by the HFE task analysis). The methodologies are based on the Japanese HFE program.

The "Time Required to complete actions" in Examples 1 and 2 above are merely a summation of the times required to perform each OSD as specified in Table 3.10-3 because the substeps for these risk important human actions are not influenced by any other qualitative factors, such as Task Support Requirements, Situational and performance shaping factors, or Workplace Factors & Hazards.

3.8 Future Phase 2b Task Analysis Implementation Plan

3.8.1 Introduction

For the remaining tasks that are outside the risk important actions described above the Implementation Plan for Phase 2b task analysis uses the same methodology as that used in Phase 2a described above, however there may be some variations to that methodology as described below.

3.8.2 Background

The operational sequence diagram (OSD) is utilized to indentify simplified operator action patterns and break down complicated or integrated operator's actions to those OSD patterns in order to evaluate operator's physical and cognitive work load. The OSD patterns are also utilized for breaking down operator's task to sub tasks which can be evaluated by the OSD pattern template.

The OSD provides operator's task sequence and patterns with illustrated pictures and flows. The OSD also provides interactions between operators and human system interface systems. The OSDs are assigned to several general tasks such as alarm acknowledgement and component actuations, and then categorized as specific patterns. Operator actions in these general tasks are broken down into sub-tasks utilizing the OSD patterns to evaluate operator's physical/cognitive work load. The resulting sub-tasks are evaluated from other task evaluation point of view which is explained in Table 3.4-1 utilizing table top evaluation method.
Goals, operators, methods, and selection rules (GOMS) which is described in Appendix 3.10.2 Section 2 or engineering judgment will be utilized supporting operator's action time and cognitive work load to evaluate how long (what time order- second, tens of seconds, or minutes) operator take for performing the dedicated OSD patterns.
The actual scope and input for task analysis will be identified in a plant licensing document.

The OSD represents operator and computer tasks (HSIS interactions) in graphical scheme sequentially. The symbols which shall be utilized for the OSD, are shown in Figure 3.10-1. In Figure 3.10-1, task symbols are defined for human (operator's) actions and machine (HSIS's) interactions using shape codes. Supplemental task information to represent each task will be added inside the shape code using letter code (i.e. S, V, W, and T).
Operator's actions shall be presented using the task symbols (shape and letter codes) connecting each task in chronological order. Table 3.10-1, OSD Pattern Sheet, shows an example of an operator's task flow diagram. In Table 3.10-1, task descriptions to explain the task code, person or HSIS who shall take actions shall also be identified within the sequence of steps.

3.8.3 Methodology

3.8.3.1 Introduction

Operator tasks are broken down into sub-tasks which can be evaluated by the OSD patterns. In Phase 2b task analysis, if a new task pattern needs to be developed during the identification of subtasks, a new task pattern shall be developed and defined as described in Subsection 3.8.3.3 below. Subtasks are listed in a task analysis and evaluation table (Table 3.7-1) and evaluated from other HFE task analysis aspect as listed in Table 3.4-1.

After developing the task flow diagram, a task analysis summary sheet shall be developed for each typical task in order to evaluate action time and cognitive workload. Table 3.10-4 shows an example of the OSD Task Analysis Summary Sheet. In the OSD Task Analysis Summary Sheet, task symbols which are used in the task flow diagram are counted. If the task activities are categorized as a primary role, then they shall be categorized as “Primary Loop”. If the task activities are categorized as a secondary role (i.e. supervisory role as SRO or monitoring automation), they shall be categorized as “Secondary Loop”. GOMS and/or experienced operator knowledge are used to evaluate action times.

In summary, the general steps for task analysis are as follows:

- Step 1: Identify typical operator’s actions (i.e. substeps of the task, such as acknowledgment of alarms, start/stop pumps, etc)
- Step 2: Assign a pre-developed task flow diagram or develop a new one as shown in the Table 3.10-1 and described in Subsection 3.8.3.2 below for each typical operator’s action using task symbols.
- Step 3: Develop OSD Task Analysis Summary Sheet Table 3.10-4, for evaluating action time and cognitive workload.
- Step 4: Categorize above typical tasks as the OSD pattern (i.e. Acknowledge/reset the alarm, Start or stop the pumps as a template utilized for evaluating sub-task’s workload
- Step 5: Break down tasks into sub-tasks which can be evaluated by the OSD pattern.

The following subsection provides each step process in detail.

3.8.3.2 Typical Operator’s Actions Identification

A sub set of operator actions are identified based on operating experiences and existing operating procedure review. An existing sub set of operator actions include:

- Verify parameters
- Energize the valves
- Open or close valves
- Start or stop the pumps
- Set or reset the designated signals
- Connect or disconnect the load to the bus
- Unlock the valves
- Acknowledge/reset the alarm, etc.

Additional OSDs may need to be developed during task analysis implementation for Phase 2 task analysis as described in Subsection 3.8.3.3 below.

3.8.3.3 Task Flow Diagram Development

The task symbols which present operator’s and HSIS’s actions in the OSD shall be pre-determined and listed in the Figure 3.10-1. If new symbols have to be developed to represent specific tasks, the new symbols shall be added in the Figure 3.10.1.
Human action’s (operator’s action’s) symbols are represented using single a single line layer and machine reaction’s (HSIS reaction’s) are represented using a double line layer.

Both of actions are represented with shape codes, which consist of geometric configurations. Supplemental task information which represent actions, such as visual, touch etc., will be added inside the shape code using letter code (i.e. S, V, W, and T).

Then, operator's actions shall be presented using the task symbols (shape and letter codes, as described above), making a flow diagram by connecting each task symbol in chronological order as in Table 3.10-1.

The task flow diagrams shall be allocated in the OSD Description column. Who (or which HSIS) takes each action shall be identified and allocated in each human's role or HSIS role column in OSD Description column.
Action steps which correspond to the task symbols, shall be provided in the Operating Procedure column and each task's explanation shall be filled out in the Task Description column to complete Table 3.10-1.

In summary, for each typical sub set of tasks which are identified, the following steps are executed:

Step 1:
List all specific sub-tasks by sequential order in the operating procedure column as listed in Table 3.10-1.

Step 2:
Indicate graphical task flows with interactions of humans (i.e. RO, SRO and other personnel) and systems/component (i.e. Displays/Controls) in the OSD Description column as listed in Table 3.10-1. The OSD Description symbols represent operator and computer tasks. The symbols for OSD Description are shown in Figure 3.10-1.

Supplemental task information which represent actions, such as visual, touch etc., shall be added inside the shape code using letter code (i.e. S, V, W, and T) if task can be represented by that supplemental information.

Step 3:
Describe each sub task represented by OSD symbols accordingly in the Task Description column as listed in Table 3.10-1.

Step 4:
Complete the OSD pattern sheet Table 3.10-1 for each typical sub set of tasks. If new tasks are identified during task analysis, a new OSD task pattern has to be developed using this methodology.

3.8.3.4 Development of OSD Task Analysis Summary Sheet

After completing OSD pattern sheet for each sub set of tasks, the OSD Task Analysis Summary Sheet, Table 3.10-4 shall be developed for each sub set of tasks in order to evaluate action time and cognitive workload as follows:

Step 1:

Fill out each action step in the “Activity” column in the Table OSD Task Analysis Summary Sheet, Table 3.10-4. If the task activities are categorized as a primary role, then they shall be categorized as “Primary Loop.” If the task activities are categorized as a secondary role (i.e. supervisory role as SRO or monitoring automation), they shall be categorized as “Secondary Loop.” The categorization is used to evaluate if that task has interaction with others. If secondary role is identified, count number of interaction with the primary role, then fill out the number in either and/or both of “Parallel Monitoring” and “Parallel Operation.”

Step 2:

Count task symbol’s numbers which are used in the task flow diagram and fill them in the summary table as listed in OSD Task Analysis Summary Sheet, Table 3.10-4.

The OSD Description symbols are categorized for communication, monitoring, decision making and operation (manipulation) so that total number of task symbols shall be filled out for each categorized symbol’s column.

The greater the number in each category is, the more complicated the task is regarded. If parallel activities between personnel are required for each subsequent task, the number shall also be tracked in that table. That also impacts on the complexity of that task.

Step 3:

“Necessary Time” shall be determined by evaluating total number of OSD symbols including “Parallel Monitoring and Operations” which represents interaction with other tasks and the other complexities which the task originally has. (For example, adjusting the present setpoint value during the task stressful? conditions shall be regarded as “more complex task.” If specific reasons exist, they have to be described as a remark in that column of OSD Task Analysis Summary Sheet Table 3.10-4.

In general, if the number is less than 10 without any specific remarks, that task could be conducted within a few minutes.

Goals, operators, methods, and selection rules (GOMS) which will be described in Appendix 3.10.2, or engineering judgment will support those time evaluations. Experienced operator feedback and simulator V&V shall also be considered for that evaluation.

3.8.3.5 Categorization above Typical Tasks as the OSD Pattern

Specific task patterns are identified based on the development of task flow diagrams as described in Section 3.8.3.3.
Those patterns are utilized for evaluating a task’s workload as a template.
If no other factors from Table 3.4-1, influence the subtask performance, then the response time to complete the substep is the OSD time only.

3.8.3.6 Task Decomposition

As in Phase 2a task analysis, tasks shall be broken up into several sub tasks which can be evaluated by the OSD pattern.
If a new task pattern needs to be developed during decomposition of the tasks, a new task pattern shall be developed and defined using above approach.

The sub tasks are listed in a task analysis and evaluation table as shown in Table 3.7-1, and then evaluated not only from workload and time as described in Section 3.8.3.5 but also from other HFE task analysis aspects as listed in Table 3.4-1.

As in Phase 2a task analysis, for each sub task, required functions for human task accomplishment (i.e. "Information Requirement" column through "Workplace Factors & Hazard" column) are evaluated and filled out. Evaluation items and criteria for each item are described in Table 3.4-1.

In the OSD Pattern column, pre-defined OSD patterns from Section 3.8.3.2 or new patterns that were developed in Subsection 3.8.3.3 above shall be entered. In the "Response Time (OSD Time)" column, an "A" indicates performance is within specified time requirements and shall be filled out with rational reasoning. The OSD task analysis summary sheet in Section 3.8.3.4 and its GOMS evaluation and/or engineering judgment can support that evaluation.

As in Phase 2a task analysis, after evaluating required functions (Table 3.4-1 Evaluation Items) for human task accomplishment, Result columns, i.e. "Allocation of Monitoring", "Allocation of Control Tasks", "Number of Crew members" and "Personal Skill level" shall be filled out based on its required function evaluation results.

For example, in the "Allocation of Monitoring" and "Allocation of Control Tasks" column, indicate specific plant parameters and control actions which shall be used for accomplishing that sub task accordingly. In the "Number of Crew members" and "Personal Skill Level" column, specific number of plant personnel and their qualification (i.e. RO, SRO, or AO (Non-licensed operator) shall be filled out.

3.8.3.7 Results

As in Phase 2a task analysis, table top based task analysis and evaluation results shall be recorded and documented as per Table 3.7-1.
"Results" column in Table 3.7-1 identifies necessary information, actions/controls, number of crew and their skill level.
That information shall be utilized as input information of operating procedure development, HSI design and training program development.
The actual implementation results will be developed and documented in the plant licensing document.

3.8.3.8 Results Summary Report

The Phase 2b US-APWR task analysis Results Summary Report will include:

- The Task Analysis team members and backgrounds
- The scope of the Task Analysis
- A description of the implementation methodology
- Task descriptions and implementation results

Table 3.7-1 Task Analysis and Evaluation Table

3.9 References

3.9.1. U.S. Nuclear Regulatory Commission, Human Factor Engineering Program Review Model, NUREG-0711, Revision 2.

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

3.9.3. Defense in Depth and Diversity, MUAP-07006, Revision 2, June 2008.

3.9.4. HSI System Description and HFE Process, MUAP-07007, Revision 5, November 2011.

3.9.5. U.S. Nuclear Regulatory Commission, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, NUREG-0800.

3.9.6. Quality Assurance Program (QAP) Description for Design Certification of the US-APWR, PQD-HD-19005, Revision 4, Part II, Document Control, Section VI, April 2011.

3.9.7 The Psychology of Human-Computer Interaction, Stuart K. Card, Thomas P. Moran, and Allen Newell, Lawrence Erlbaum Associates, 1983.

3.10 Appendices

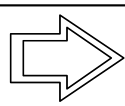
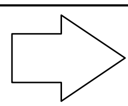
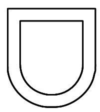
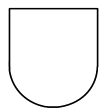
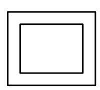
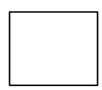
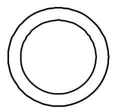
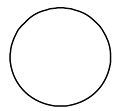
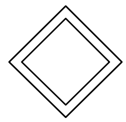
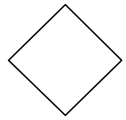
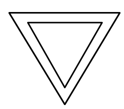
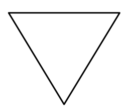
Appendix 3.10.1 Response Time Criteria for Risk Significant Human Actions

Appendix 3.10.2 Cognitive Workload Analysis

1. OSD Pattern

The OSD represents operator and computer tasks (Automated tasks) in graphical scheme sequentially. The symbols for OSD are shown in Figure 3.10-1. Through the use of symbols to indicate actions, data transmitted or received, inspections, operations, decisions and data storage, the OSD shows the flow of information through a task. The information flow is shown in relation to both time and space. If detailed information on a given action is needed, code letters (S, V, W, T) may be used to indicate the mode of actions. The OSD is used to develop and present the system reaction to specified inputs.

In the OSD, the interrelationships between operators and equipment (including computers for human-machine interfaces) are easily displayed. Operator activities are sequentially categorized. Decision and action functions are clearly identified, and task frequency and load become obvious.

SHAPE			CODE	
MACHINE	HUMAN	ACTION	LETTER	MEANING
		Transmit	S	Sound
		Receipt	V	Visual
		Inspect	W	Walking
		Operate	T	Touch
		Decision		
		Storage		

* A code letter may indicate Mode of shapes

Figure 3.10-1 Symbols Used in Operational Sequence Diagram (OSD)

The OSD corresponding to each task is constructed by the following steps:

Step 1 : Description of task scenario
- Represent elements of task in simple linguistic form
- Select appropriate detail level in design phase

Step 2 : Breaking down job task into individual activities

Step 3 : Activity assignment to human and machine
- Use the result of Function Allocation
- Assign each activity to operator or machine

Step 4 : Description of activity sequence for functions assigned to operator

Table 3.10-1 shows an OSD table which is used to record the analysis results. Fields in this table are described below:

- Operating Procedure Field: Full task contents are described in task sequence.
- OSD Description Field: Human and machine (Automation) actions are represented using OSD symbols. The contents of task are described as activities in simple form. Activity description is broken down into individual actions (OSD symbols) such as ‘Transmit’, ‘Receipt’, ‘Inspect’ as shown in Figure 3.10-1. Each action is located in appropriate column (Human: senior reactor operator or reactor operator, Machine: displays and controls) according to the output of the Function Allocation process. Finally all actions are connected to each other to represent the temporal sequence of the elements of the task
- Task Description Field: Key information of task execution such as reading plant parameters and identification of plant status.
- Note Field: Remark for task execution.

Each task is categorized into following representative patterns;

1. Verify Parameter
2. Energize/de-energize the valves (Local action)Power on the valves at local
3. Open or close the valves
4. Start or stop the pump

4A. Jumper on/off motor control center terminal block. (local action)

5. Set or reset the plant demand signal

5A Place component control switch or controller in Pull-lock/Auto/Manual mode

6. Connect or disconnect the load to the electrical bus
7. Connect or disconnect the load to the bus (local action)
8. Open or close the valve (local action)

8A. Start or stop the pump(s) (local action)

9. Lock/Unlock the valve/component (local action)

10. GO TO or REFER TO action
11. Adjust the controller/control

In task analysis evaluation, response time for each task is evaluated using above template.

Table 3.10-1 OSD Pattern Sheet

Table 3.10-2 Extended Human Information Processing Model

Table 3.10-3 Time Required to Perform OSD Pattern Tasks

Table 3.10-4 Example of OSD Task Analysis Summary Sheet

Part 3 HSI System Verification and Validation (Phase 1b)

1.0 INTRODUCTION

This report discusses the second set, Phase 1b, of HSI tests in support of the HSI design process of the US-APWR and the Mitsubishi US operating plant modernization program, as described in section 1 of this report, US-APWR Overall Implementation Procedure. As such it represents the continuation of the test and evaluation program which has the goal of determining the changes needed to safely introduce the Japanese Basic HSI into US operation as reported in December 2008, as Phase 1a Technical Report, MUAP-08014-P (R0).

In general, the tests described here in follow the same methodology as Phase 1a and continued the assessment of the full main control room HSI, with the two exceptions. First, the Phase 1b tests used the dynamic simulator with human in the loop scenarios focusing on the evaluation of HSI design changes that were proposed in response to the Human Engineering Discrepancies, HEDs. Second, they began the process of integrating HFE analysis and HSI testing by reviewing the risk important human actions and including a sub set of these actions into the test scenarios. Results of this program are captured and transferred to other elements of the overall HFE program through the HED process, Part1 of this report, and through this and a follow up the detailed-level documents. Where this report is only a summary of methodology and results, the detailed-level documents, will be a complete document including data, analysis and robust conclusions and recommendations for use by the HSI designers, and analysis's and developers of the other HFE elements, such as function and task analysis, HRA/PRA/ procedures and training. The detailed-level documents will be an internal Mitsubishi document meant to be used within the design process and auditable, upon request, by the NRC. This summary report finds its bases primarily on the subjective data collect, the detailed analysis and analysis of the objective performance data was not completed at the time of publication and will be reported on in the detailed-level documents.

The iterative process of analysis, design and test will continue over the next 2 years as the HSI for the US-APWR is refined, leading up the full Verification and Validation as recommended by NUREG-0711 Rev.2, in Phase 2 as described earlier in this report

The test results as reported here, fully support the above process. Changes made to the HSI, as assessed in Phase 1a, have been convincingly demonstrated to not only have better acceptance by US operators, but also measurably enhanced their performance. This, however, did not result in absolute, a number of HFE issues were identified through the test data and or new HEDs that will now be evaluated for next round HSI design changes.

2.0 HUMAN ENGINEERING DISCREPANCIES (HED)

2.1 Description of the HED Process

As a result of the Phase 1a testing, over 700 HEDs were documented in the formal project HED data base. These represent un reviewed, raw HEDs from all the operating crews that supported the 1a testing, the V&V team and all qualified observers to the test facility, including representatives of the industry and the NRC, The test facility, located at MEPPI head quarters, is made up of a full scope dynamic main control room simulator representative of the, at that time, current HSI design. These Phase 1a HED were then binned by the V&V team, using results from the test data analysis, into higher level HFE issues termed "Parents." The Parents as well as the raw HEDs were then evaluated one by one by the designers and independently

by the HFE Expert Panel in committee session, resulting in a set of design changes that were considered to give reasonable assurance of HED and parent resolution. The expert panel alone represented a senior manpower intensive exercise using the equivalent of approximately 2000 person hours.

The design changes that reasonable could be made in the simulator HSI, were then considered for inclusion in the Phase 1b tests, as described in this report. As design changes were completed, the test scenarios were developed to include multiple independent failures which would stress the new designs along with the full HSI.

A procedure that used a two step process, described later in the report, to document the HEDs resulting from this series of tests was developed and applied which resulted in a comprehensive binning of the new and old HEDs for evaluation as before. At the time of writing this report, this evaluation is in the planning stage.

2.2 Summary of HEDs Resulting from Phase 1a Testing

As a result of the HED process from Phase 1a verification and validation testing during 2008, a set of HSI design changes were arrived at. Those that could be implemented on the MEPPI simulator prior to the start of the Phase 1b were and became part of the test scenarios to allow their testing in a dynamic human in the loop setting. Appendix 8.1 presents these HEDs, their parents and how they were incorporated into the scenarios. Appendix 8.2 presents the order in which the scenarios containing the HEDs were run and Appendix 8.3 shows the 8 scenarios along with which HED s were included and how. It is the intent of the detailed-level documents, which will be available to the NRC for audit, to address each HED tested in a level of detail that is suitable for HED resolution by the HSI Expert Panel or feed back to the HSI designers.

2.3 Description of Changes to the MEPPI Simulator

In order to incorporate many of the Phase 1a proposed HSI design change, that were agreed to by the designers and the Expert Panel, into the tests for Phase 1b, the MEPPI simulator underwent changes to the Basic Japanese HSI. In some cases the change was implemented in full and in some cases, due to schedule constraints, it was partially implemented and in still others only static demonstrations were used to complete the testing. These changes, along with several additional new automation functions are described in Appendix 8.5.

2.4 Description of Scenario Selection

Dynamic simulator scenarios were developed to exercise human system interface design changes that were implemented as a result of HEDs that were generated in Phase 1a testing and evaluation activities. The specific identification of HED-to-scenario assignments are described in Appendix 8.1 and 8.3. A total of eight scenarios were developed by the V&V team nuclear plant systems engineer and nuclear training instructor, and reviewed by the teams HFE and HRA/PRA experts, to encompass all HED design changes made for Phase 1b.

In addition, the US-APWR Risk Significant Human Errors, defined in Part 2 Chapter 2 HRA, was reviewed to select a subset of risk important human actions that could be incorporated into the test scenarios. This was not intended to be an exhaustive test of these human actions but instead the beginning of the needed assessment of the Phase 1b HSIs ability to limit these important human errors. As the testing program continues this subset of risk important human actions will be expanded to eventually include all risk important human actions in the final

Phase 1b full V&V tests for the US-APWR HSI. Results of the Phase 1b tests and all future tests will be shared, through the HED data base, reports and face to face meetings as needed, with the HRA/PRA team so that the insights gained will be incorporated into future analyses updates.

Static part task tests were integrated in Phase 1b testing to solicit operator feedback from the test crews on human system interface design features that could not be incorporated into the simulator for dynamic testing in a timely manner, reference section 4.2.2 of this report.

3.0 NEW HSI FEATURES TESTED

3.1 Diverse Actuation System (DAS) Diverse HSI Panel (DHP)

The installation of the DHP for Phase 1b testing allowed for the evaluation of operator response in coping with a beyond design basis common cause failure in the main control room digital human system interface. Detailed descriptions of DAS and the DHP are located in MUAP-07006 Defense in Depth and Diversity, Section 6, MUAP-07007 HSI System Description and HFE Process, Section 4.11.4, and the DCD Section 7.8 Instrumentation and Controls.

3.2 Computer Based Procedures

Operating crew response to scenario events with the normal full complement of human system interface was in accordance with scenario related procedures that were developed and installed in the computer based procedure visual display units (paperless procedures). Some examples of the types of procedures in the available compliment include normal station operating procedures, alarm response, abnormal, and emergency procedures. A more detailed description of computer based procedures, as tested, is found in MUAP-07007 HSI System Description and HFE Process, Section 4.8.

4.0 METHODOLOGY

4.1 Overview of Approach for Achieving Test Objectives

Phase 1b utilized a similar test methodology as was used in Phase 1a testing. The methodology was slightly modified to address the specific goals of Phase 1b:

- test Phase 1a HED resolutions implemented on the MEPPI simulator,
- test new HSI features not tested in Phase 1a,
- continue to test the full HSI.

Among the major HSI changes that were implemented in response to Phase 1a HED and tested in Phase 1b, a number were found to be notable due to their direct measurable effect on human performance and are listed below :

- An additional VDU screen at the SRO's desk that allowed the SRO to monitor the ROs detailed control actions;
- Modifications to the LDP including:
  - Use of up/down arrows to indicate trend information
  - Areas devoted to critical safety function
- Automated auxiliary feedwater control

Among the specific new HSI features tested in Phase 1b included:

- OK and BISI panel added to the LDP
- computer based procedures
- Diverse Actuation System/Diverse HSI Panel (DAS/DHP)
- Mode-dependent LDP
- Ability to create user-defined trend displays and to display them on the variable area LDP
- Ability to enter and display Tag-outs on the LDP

In addition to testing specific new HSI elements, Phase 1b attempted to expand the scope and complexity of the test scenarios to include:

- Inclusion of scenarios that sampled risk significant human actions
- Inclusion of scenarios where more than one critical safety function was challenged requiring the crews to utilize function restoration guidelines
- Inclusion of instances where automated systems failed enabling testing the ability of the crews to detect automation failures and manually take-over automated functions.
- Inclusion of scenarios that included multiple independent failures.

A summary of the test methods used is provided below. Supportive details can be found in the detailed-level documents.

4.2 Test Methods

As in the case of Phase 1a, Phase 1b testing employed:

- experienced plant crews as test participants (5 two-person crews)
- realistic normal and emergency scenarios (8 scenarios, plus crews 3 and 5 performed an additional SGTR)
- Collection of objective data of operator performance as well as subjective operator feedback collected via questionnaires and verbal debrief sessions.

As in Phase 1a crews were tested over a four day period. They arrived on Monday afternoon. They were provided approximately 6.5 - 8 hours of training (4 hours on Monday afternoon, and 2.5 - 4 hours on Tuesday morning). As most of the operators in the Phase 1b test had also participated in Phase 1a, training primarily focused on HSI changes from Phase 1a.
All two person crews then participated in 8 test scenarios (5 with the non-safety VDU referred to as the O-VDU; 1 with the DAS, and 2 with the S-VDUs), reference Appendix 8.4 and Appendix 8.5, scenarios and test success criteria, respectively:

- Manual load run-back with failed instrument channel, controller mode malfunction, etc. (O−VDUs)
- Large Break LOCA with failed Aux. feedwater automation and circ water pump trip (O−VDUs)
- Small break LOCA with violation of two critical safety functions (O-VDUs)
- SGTR with operation from O-VDUs and with Aux. F/W automation (O-VDUs)
- DAS/DHP operation due to common cause failure (DAS/DHP)
- SGTR with operation from the S-VDUs and with Aux. F/W automation (S-VDUs)
- Small break LOCA from S-VDUs with Violation of two critical safety functions (S-VDUs)

- High pressure feedwater heater tube leak (O-VDUs)

As noted above, if time permitted they also were presented the SGTR scenario a second time, as the last scenario of the week, in order to assess the impact of training on the speed and facility with which they could perform the SGTR. Two of the five crews tested were able to run in a second SGTR. In this scenario the crews were given the additional guidance to gain control of the event as quickly as possible without having the effected steam generator going solid.

Following each scenario operators filled out a short questionnaire followed by a short (15 minute to 30 minute) verbal debrief where the operators were given the opportunity to mention any HEDs of particular concern.

After the DAS scenario operators filled out a final DAS questionnaire. It included likert- ratings questions of the primary features of the DAS as well as space to write in HEDs. This final written questionnaire served as the primary source for operator input on HEDs for the DAS HSI. Since only one scenario was conducted with the DAS, a post-scenario form was not filled out after the DAS scenario.

After the two safety VDU scenarios operators filled out a final safety VDU questionnaire. It included likert- ratings questions of the primary features of the safety VDUs as well as space to write in HEDs. This final written questionnaire served as the primary source for operator input on HEDs for the safety VDU HSI.

At the completion of the week, participants were given a final written feedback questionnaire on the non-safety VDU HSI to fill out. This questionnaire included questions on all features of the non-safety VDU HSI and provided the operators the opportunity to list HEDs of particular concern. This final written questionnaire served as the primary source for operator input on HEDs for the non-safety VDU HSI. Operators took approximately an hour to an hour and a half to fill out this questionnaire.

Following the written final feedback questionnaire, a final verbal debrief session was conducted where operators were provided the opportunity to explain and discuss the HEDs they listed. This final verbal debrief took approximately one hour.

All sessions were videotaped and the video tapes reviewed as in the Phase 1a tests..

4.2.1 Major Changes from Phase 1a to Accommodate Phase 1b Objectives

While Phase 1b primarily followed the test logic and procedure used in Phase 1a, a number of changes were made to address specific Phase 1b objectives as well as to streamline the data collection and analysis process based on Phase 1a lessons-learned.
Primary changes included:

- The scenarios were developed to include specific events/malfunctions intended to exercise HSI modifications that resulted from Phase 1a HEDs.
- The test questionnaires were modified to include questions that addressed the HSI modifications as well as the new HSI features that were not tested in Phase 1a
- A section was added to the final non-safety VDU HSI feedback questionnaire and safety VDU HSI feedback questionnaire asking operators to indicate whether the HSI changes provided in Phase 1b were an improvement over the HSI in Phase 1a.

- Part-task and static demonstrations were conducted to address HSI features that were not fully implemented in the simulator but could be demonstrated for purposes of eliciting operator feedback
- The final feedback questionnaires (one for DAS, one for safety VDU, one for Non-safety VDUs) were used as the primary means of collecting HEDs from the operators participating in the test.

4.2.2 Use of Part-Task and Static Demonstrations

Several static and part-task demonstrations were conducted to obtain operator feedback on aspects of the HSI that were not fully implemented in the simulator to allow dynamic scenario testing. These static and part-task demonstrations were conducted in an interspersed fashion around the scenarios, to take advantage of available time that arose.
Part-task and static demonstrations included:

1. Main Control Room, MCR, Ergonomics- show with tape on the floor, the possible limits if positioning the shift managers control consol with respect to the operators control console. Discuss with the RO and SRO the noise level in the CPNPP MCR Ask the crew if the two consoles should be moved closer. Also document any other console relationship layout changes that are recommended, i.e. elevation of the shift manager console.

2. Computer Based Procedures, CBP, Display Screen Ergonomics- after the crew has had a chance to use the CBPs in several scenarios, discuss the mock up of the raised display on the STA console. Discuss readability, glare and loss of table top lay down surface area.

3. Mode Dependent LDP- after several scenarios change the LDP to the prototype of the Mode #6 DISPLAY. Discuss the plan to have the ability to switch the LDP display for different plant modes. Solicit crew input on the general concept and the specific content for Mode #6

5. Task Displays- demonstrate the prototypes of task specific displays on the VDUs. This should include task displays for Rx trip and SI. Also discuss with the crew specific content and navigation to displays GD 6.1, 2, 3 and EM 4, 5.

6. Pull to Lock- demonstrates the pull to lock permissive requirement on the SVDUs to lock out automatic activation of safety components on the O-VDUs for activities such as maintenance activities. Discuss the design requirement, specific actions and specific control displays on the VDUs and the LDP.

7. Tag Out- allow the RO to exercise, during and outside of the scenarios, the tag out system from the maintenance PC, tag out request, and the O-VDUs, tag out acceptance and implementation. Record their debrief comments.

8. Custom Trends- allow the RO to set up and the RO and SRO to use trends they set up using the prototype of the Customized Trend System. This should be during a scenario and independent from the scenario tests. The latter will take at 15 minutes. Show them how to select the parameters and scales, the fact that they can put up to 5 parameters on each trend plot and up to 4 plots on the VDU or LDP. Demonstrate the zoom feature on the VDU. Ask about usability, scales and dynamic scaling, specific custom trends that they would save.

4.2.3 Test Crews

Five two-person crews made up of experienced Comanche Peak plant operators (one SRO and one RO) participated in the evaluation. In the case of three of the crews, both crew

members had participated in Phase1a testing. In the case of the remaining two crews, one of the crew members had participated before and one had not (in one case the RO was new, in the other case the SRO was new). Training of the test crews was based on the assumption that most had participated in the Phase 1a tests and were therefore familiar with the HSI and the test process. The 2 crew members that did not were treated as the exception and given remedial training. The training is briefly described in Appendix 8.3.

Operating crew training for Phase 1b validation activities was supplemental to previously administered initial training during Phase 1a V&V activities for repeat crew members. The initial training description is explained in the Phase 1a Final Report. Two crew members (one RO and one SRO) did not participate in Phase 1a activities and thus were given accelerated initial control room HSI training prior to commencing testing activities. Phase 1b training was then administered to all crew members and consisted exclusively of a training handout which concatenated descriptions of the HEDs that were chosen to be implemented as a result of being generated in Phase 1a. This training was approximately 4 hours in duration and discussed major HSI changes including:

1. Operational VDU custom trending
2. Audio alarm reduction
3. Computer based procedures
4. OK monitor
5. Bypass and Inoperable Systems Indication
6. System auto status monitor
7. Critical Safety Function monitor
8. Trending on the LDP
9. Diverse HSI Panel
10. Safety VDU HSI changes

HSI changes that were implemented on the MEPPI simulator were demonstrated by a dynamic means where practical. Minor verification type HSI changes such as labeling enhancements were also listed in the training.

4.2.4 Observers

The test procedure was developed, administered and analyzed by a team made up of three HFE experts, one of which also had HRA/PRA experience, and one plant operations/ training expert. The same team developed and conducted the Phase1a evaluation.

The four team members served as test observers during the test scenarios, and were responsible for documenting any problems in operator performance that they observed during the scenarios on post-scenario observer forms. The plant operations expert and one of the three HFE experts were present during all eight weeks of testing. The other two HFE experts switched off so that on any given test week there were at least three expert observers – two HFE observers and one plant operations expert. The observer team for the Phase 1b testing were responsible for test procedure design, scenario developement, modification of the data collection tools from Phase 1a, and data analysis. They are members of the 8 person Expert Panel involved in the evaluation of the HEDs and performed the same roles for the Phase 1a testing. The joint experience of the observors includes; HFE,HF test design and assessment, nuclear power plant operations, HSI control room design, and HRA/PRA.

In addition to the primary observer team, other observers were routinely present during the test scenarios and debrief sessions. Additional observers included MHI and MELCO

designers, simulator experts, instrumentation and control engineers and a manager from Luminant power. All individules were encouraged to document HSI concerns through the HED process and take part in the verbal debriefing sessions described.

4.2.5 Data Collection Instruments

A number of objective and subjective data collection instruments were used. The objective was to obtain multiple converging measures to assess the impact of the HSI on individual and crew team performance.

Formal questionnaire instruments included:

- Post-scenario operator forms – This form included 5-point likert rating questions (where 1 was poor; 3 was acceptable; and 5 was very good) that asked operators to rate their technical performance, teamwork, situation awareness, and mental and physical workload. It also asked them to indicate whether they felt the crew size was sufficient for the scenario. The form also included space for the operators to list HEDs that they felt contributed to performance problems.
- Post-scenario observer form – This form was used by the primary test observers (the operations expert and the two or three HFE experts) to document any technical performance problems they observed during the scenario (e.g., errors of omission; errors of commission; delays in taking appropriate action) as well as any problems in monitoring/detection; situation awareness, teamwork, or work-load. Observers were also asked to rate crew technical and team performance on a 5 point scale. A consensus post-scenario observer form was then filled out jointly by all the expert observers that documented observer consensus on each item on the post-scenario observer form.
- Final operator feedback forms. Specific final operator feedback forms were developed for the non-safety VDU HSI; the safety VDU HSI; and the DAS respectively. These forms included summary 5-point likert-rating questions (1 = very poor; 3 = acceptable, and 5 = very good) that asked for operator self-ratings of the impact of that HSI on their situation awareness, ability to take control actions in pace with plant process dynamics; ability to follow procedures; ability to catch and correct own errors, mental workload and physical workload; teamwork and ability of the SRO to supervise the operator activities and control actions of the RO. It also asked about the ability of the HSI to support two-person operation. The final questionnaires also included 5-point likert rating questions intended to evaluate different aspects of the primary features of the HSI. Space was provided for operators to write in HEDs.
- Unlike the Phase 1a tests, where all HEDs from all sources were directly entered, unaltered or reviewed, into the HED data base, the Phase 1b tests applied a two step procedure. All potential HEDs generated by the test crews were reviewed by at least two of the expert observers at the end of each week's testing and a consensus based evaluation made to determine if:
    1. the HED represented a repeat of an HED already in the HED data base,
    2. the HED represented a new HED,
    3. the HED represented an HED based on the HSI design changes made for 1b,
    4. the HED was not an HED.

The results of the evaluation were then documented and entered into the HED data base for formal tracking and resolution.

In addition to these formal questionnaires a number of data collection guidance forms were developed to support the expert observers in following the scenarios and recording operator actions and timing. Check-lists were also developed to support structured verbal debrief sessions.

Time-stamped plant parameter data were also collected directly off of the simulator to provide objective operator performance data with respect to their ability to maintain plant parameters within required tolerance bands, ref Appendix 8.4 for the acceptance criteria used in each scenario, and to take timely action to avoid excessive plant process perturbations/excursions.

5.0 SUMMARY OF RESULTS AND OPEN ITEMS

5.1 Conclusions from Final Operator Feedback Data

As noted in section 4, above, the basic approach to analyzing the Phase 1b test used the same ‘converging methods’ approach that was used in the Phase 1a test. Both objective crew performance measures and subjective operator feedback measures were collected and analyzed.

Due to scheduling constraints on the part of the utility, the last crew had to be rescheduled several weeks later than originally planned. As a consequence the results summarized in this report are based on the first four crews. The final results based on all five crews will be fully documented in the detailed-level documents.

A summary of major results is provided below. A more complete description of results is provided in the detailed-level documents.

The results reported in this section include operator ratings provided on the final feedback questionnaires as well as ratings and observations provided by the expert observer team.

5.2 Open Items

6.0 CONCLUSIONS

7.0 REFERENCES

7.1. U.S. Nuclear Regulatory Commission, Human Factor Engineering Program Review Model, NUREG-0711, Revision 2.

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

7.3. Design Control Document for the US-APWR, Chapter 19, Probabilistic Risk Assessment and Severe Accident Evaluation, MUAP DC019, Revision 3, March 2011.

7.4. Defense in Depth and Diversity, MUAP-07006, Revision 2, June 2008.

7.5. HSI System Description and HFE Process, MUAP-07007, Revision 5, November 2011.

7.6. U.S. Nuclear Regulatory Commission, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, NUREG-0800.

8.0 APPENDICES

Appendix 8.1 Phase 1a Generated and Expert Panel Reviewed HEDs Included in Phase 1b Testing

Appendix 8.2 Weekly Test Schedule

Appendix 8.3 Scenarios

Appendix 8.4 Scenario Acceptance Criteria

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Appendix 8.5 Simulator HSI Modifications Made from Phase 1a to Phase 1b as a Result of Phase 1a HEDs