US-APWR

Verification and Validation Implementation Plan

Non-Proprietary Version

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Signature History

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Revision History

Revision	Date	Page (Section)	Description
0	April 2010	All	Original issued
1	November 2011	General	Revised capitalization of section titles.
		p.1 (Section 2.0)	Added the paragraph to end of this section for response to RAI 755 (Question No. 18-117).
		p.3 (Section 4.1)	Added two sentences as second paragraph for response to RAI 664 (Question No. 18-88).
		p.21 (Section 5.0)	Revised document title and revision number of references.
2	October 2012	All pages	Revised to incorporate comments by the NRC in March 2012 and to keep consistency in technical description with DCD Chapter 18 and MUAP-09019.

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Abstract

This document presents the Implementation Plan for the US-APWR human factors Verification and Validation program (V&V). The US-APWR Verification and Validation Implementation Plan complies with NUREG-0711 (Reference 6-7) and follows the methodology developed for and applied to the design testing program conducted under the Mitsubishi Heavy Industry's Phase 1a and Phase 1b program, described in MUAP-DC018 and MUAP-07007 (Reference 6-1, 2). The V&V program utilizes the output from the task analysis (TA), human reliability analysis (HRA), operating experience review (OER) and HSI design, as well as the procedure development effort.

The V&V is conducted under a test procedure utilizing U.S. licensed, or previously licensed plant personnel for subject test crews and independent, qualified and trained test personnel for test management, administration and observation and post-test data analysis. The Verification will utilize an NRC approved HSI Design Style Guide (Reference 6-5) early in the V&V process so as to allow for Human System Interface System (HSIS) modifications based on Human Engineering Discrepancies (HEDs) resulting from the Verification. The Verification will rely on the use of interface photographs and drawings, a PC part task representation of the displays designed specifically for the Verification, mock-ups, and a full scope simulator.

The Integrated System Validation (ISV) will apply a set of 20 selected test scenarios with clearly defined evaluation criteria on a full scope dynamic simulator. These scenarios will be selected to include a robust set of operating conditions that will include all risk-important human actions identified in the HRA that are pertinent to plant operations and the results from the OER study that are pertinent to operations. The ISV program will specifically use the full scope dynamic simulator developed for operator training and in compliance with ANS/ANSI 3.5 (Reference 6-6) requirements, for all activities conducted in the main control room (MCR). All validation tests will rely on a set of US-APWR operating procedures and will include the incorporation of minimum staffing design assumptions. The Validation of the MCR will include activities outside of the MCR when they are supporting or in communication with the MCR during Validation scenarios. These outside activities include local control stations (LCS) that fall into the categories identified in DCD section 18.1.1.2 and 18.10.1 (Reference 6-1), the Technical Support Center (TSC), and the Central Alarm Station/Secondary Alarm Station (CAS/SAS). To simulate real world conditions, as they impact the performance of the MCR personnel under times of high personnel loading, personnel engaged in startup, maintenance, instrument calibration, surveillance test and inspection activities will be included in the validation of the HSI through insertion of additional personnel loading selected scenarios. Communications with offsite facilities and other outside organizations will be simulated during the ISV. The actions of the personnel outside the MCR who actually conduct these activities will be simulated to confirm the MCR communications.

Validation of the HSI for supportive activities outside of the MCR (local control stations, TSC and test and maintenance panels) will use mock-ups and part task approaches. In cases where analysis shows that the supportive activities have no impact on plant safety, analytical approaches will be used to validate the HSI design.

As in the previous design tests, subjective data will be collected through test personnel and subject crew questionnaires, structured interviews, and real time video and audio recording. Objective plant data will automatically be collected via the simulator computer for each

scenario. A converging perspectives analysis approach will be applied to the data analysis and conclusions regarding the HSI interface performance, including use of the existing Human Engineering Discrepancies (HED) identification, resolution, closure and tracking process as described in Appendix 2.

In the philosophy of continuous improvement, data collection for evaluation of further improvements to the HSI design will be clearly distinguished from acceptance data.

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List of Acronyms

AOO	Anticipated Operational Occurrences
ARP	Alarm Response Procedure
ATWS	Anticipated Transient Without Scram
BHEP	Basic Human Error Probability
BISI	Bypassed or Inoperable Status Indication
CCF	Common Cause Failure
CCW	Component Cooling Water
C/C	Control Center
COL	Combined License
CBP	Computer-based Operating Procedure
CHP	Charging Pump
COTS	Commercial-Off-The-Shelf
CPU	Central Processing Unit
CV	Containment Vessel
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	Date Management Console
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
EP	Back Feed Electric Power
EPM	Engineering Project Manager
ESF	Engineered Safety Feature
ESFAS	Engineered Safety Feature Actuation System
FMEA	Failure Modes and Effects Analyses
FC	Fail to Close
FO	Fail to Open
F.O.	First Out
FTA	Fault Tree Analysis
GOMS	Goals, Operators, Methods, and Selection rules
GUI	Graphical User Interfaces

HA	Human Action
HAZOP	Hazards and Operability Analysis
HDSR	Historical Data Storage and Retrieval
HE	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
HRA	Human Reliability Analysis
HSI	Human System Interface
HSIS	Human System Interface System
HVAC	Heating, Ventilation, and Air Conditioning
I&C	Instrumentation and Control
ISV	Integrated System Validation
ITAAC	Inspections, Tests, Analyses, and Acceptance Criteria
ITV	Industrial Television
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	Locked to Open
LOCA	Loss Of Coolant Accident
MCB	Main Control Board
MCR	Main Control Room
M/C	Metal Clad Geer
MELCO	Mitsubishi Electric Corporation
MELTAC	Mitsubishi Electric Total Advanced Controller
MHI	Mitsubishi Heavy Industries
MSLB	Main Steam Line Break
NIS	Nuclear Instrumentation System
NPP	Nuclear Power Plant
OCS	Operational Conditions Sampling
OER	Operation Experience Review
OSD	Operational Sequence Diagram
PA	Postulated Accident
PAM	Post-Accident Monitor
PC	Personal Computer
PCMS	Plant Control and Monitoring System
PM	Project Manager
PRA	Probabilistic Risk Assessment
PRC	Process Recording Computer

PSF	Performance Shaping Factor
PSMS	Protection and Safety Monitoring System
QA	Quality Assurance
RCS	Reactor Coolant System
R.G.	Regulatory Guide
RHR	Residual Heat Removal
RIHA	Risk Important Human Actions
RMS	Radiation Monitoring System
RO	Reactor Operator
RPS	Reactor Protection System
RSC	Remote Shutdown Console
RSR	Remote Shutdown Room
RSS	Remote Shutdown Station
RT	Reactor Trip
RTB	Reactor Trip Breaker
RWSP	Refueling Water Storage Pit
SAR	Safety Analysis Report
SAT	Systematic Approach to Training
SDCV	Spatially Dedicated Continuously Visible
SER	Safety Evaluation Report
SG	Steam Generator
SGTR	Steam Generator Tube Rupture
SBO	Station Black Out
SPDS	Safety Parameter Display System
SRO	Senior Reactor Operator
SS	Shift Supervisor
STA	Shift Technical Advisor
Tcold	Reactor Coolant Inlet Temperature
T/C	Thermocouple
Thot	Reactor Coolant Outlet Temperature
THERP	Technique for Human Error Rate Prediction method
TMI	Three Mile Island
TR	Topical Report
TSC	Technical Support Center
UMC	Unit Management Computer
UPS	Uninterruptible Power Supply
UV	Under Voltage
V&V	Verification and Validation
VDU	Visual Display Unit
VTM	V&V Team Manager

1.0 PURPOSE

This document describes the Verification and Validation (V&V) Implementation Plan for the US-APWR.

The Mitsubishi Heavy Industry (MHI) V&V program will provide logical and comprehensive evidence that the integrated Human System Interface (HSI) of the US-APWR conforms to good human factors principles and that it adequately supports plant personnel in the safe and efficient operation of the plant. The V&V program will assure that the integrated design meets MHI specified design guidance and remains within acceptable performance limits under a broad set of operating modes and conditions.

2.0 SCOPE

The MHI V&V Implementation Plan is intended to fully meet the review criteria as outlined in NUREG-0711 (Reference 6-7). The V&V program makes use of the other HFE elements in the design process as shown in the Overall Work Flow, Figure 2.1-1, and as described in the HFE Overall Implementation Plan (Reference 6-4, Part 1).

The US-APWR V&V implementation program will verify that the HSI provides all the alarms, information and controls needed to support the personnel tasks as identified in the Phase 2a and Phase 2b task analysis (TA) and that the HSI characteristics and environment meet the HSI Design Style Guide (Reference 6-5). The V&V implementation program will also validate the integrated HSI system through performance based tests applying, using as additional guidance, NUREG/CR-6393 (Reference 6-8), to all risk-important Human sctions (RIHAs), selected beyond design bases events and the full range of plant operating conditions including the following:

- Startup/ Shutdown
- Normal Operations
- Abnormal and Emergency operations
- Transient conditions

The Implementation Plan addresses the Main Control Room (MCR) and selected remote locations (local control stations (LCS), Technical Support Center (TSC), and Central Alarm Station/ Secondary Alarm Station (CAS/SAS)) that can influence the main control room crew's performance. Communications between the MCR and the Emergency Operations facility (EOF) and between the MCR and other off-site entities (e.g., emergency officials) are included in the Integrated System Validation (ISV) for the MCR (Reference 6-1 section 18.10.1). HSI outside of the MCR (local control stations, TSC and test and maintenance panels) will also be evaluated by implementation of this V&V Implementation Plan through the application of the same tool set with the exception of not utilizing dynamic simulation since the simulator is limited to the MCR. V&V facilities, outside of the MCR, will rely on mock-ups and part task simulations for all facilities that, through analysis, have been determined to have an impact on plant safety. The same V&V methods as applied to the MCR will be adapted to thoroughly evaluate the HSI facilities outside of the MCR. Analytical approaches will be applied to those facilities that have been determined by analysis not to impact plant safety. The V&V program will include personnel beyond the minimum MCR crew of senior reactor operator (SRO), and reactor operator (RO). This will exercise the integrated system, including the HSI, personnel and procedures for situations in which communications and coordination with personnel outside of the control room is required, and when additional personnel are performing work in the control room. The goal of the V&V program is to test the HSI in real world conditions resulting in confidence that all possible situations have been enveloped by the V&V and therefore provide high confidence that the integrated HSI of the US-APWR meets safety and performance objectives.

All the HSI that is in the scope of the US-APWR HFE program, as described in the .DCD subsection 18.1.1.2 (Reference 6-1) is within the scope of the V&V program. The V&V for the MCR will utilize full scope dynamic simulation, including lighting conditions and simulation of noise and environment. The process of identification, resolution, closure and tracking HEDs as discussed in Appendix 2, and Reference 6-4 Part 1, will be applied to the HSI V&V results and reported in the Results Summary Report.

2.1 Background

MHI has incorporated into its HSI design process, a set of HSI tests and assessments which include verification of a sample of the HSI to the NUREG-0700 standards (Reference 6-9), and as recommended by ISO 11064 (Reference 6-10), scenario driven dynamic, human in the loop, MCR design simulation tests. The methodology and results of this effort are used as a basis throughout this V&V Implementation Plan. This methodology is described in the Implementation Plan as needed to clarify the V&V program, including test data collection instruments and the HED process (Reference 6-3 and 4). For clarity, the HED process is also described in Appendix 2 of this Implementation Plan and the data collection instruments are presented in Appendix 3 of this Implementation Plan. MHI will employ these earlier methods which were reported, and reviewed by NRC staff, under Human System Interface Design Element 8 of NUREG-0711 (Reference 6-7). These methods will be applied to the US-APWR V&V program through this Implementation Plan and subsequent supporting V&V Test Procedures. The V&V program will utilize US licensed or previously licensed operators, for the makeup of the MCR test crews throughout the implementation of the ISV program. The V&V will utilize the final HSI design, including operating procedures, with the exception of changes that result from the V&V itself. When design changes result from the V&V, an analysis will be performed to determine if additional V&V is required to assess the effect of the specific V&V originated design changes. If it is determined that design changes which occur as a result of the V&V that have a significant impact on the final HSI as reported in the DCD, the DCD will be revised and resubmitted to the NRC.

The V&V results will be documented in a Results Summary Report that supports the conclusion that the HSI design of the US-APWR has met the criteria. The Results Summary Report will also summarize the open HEDs and include a description of the V&V program as described in section 4.8.

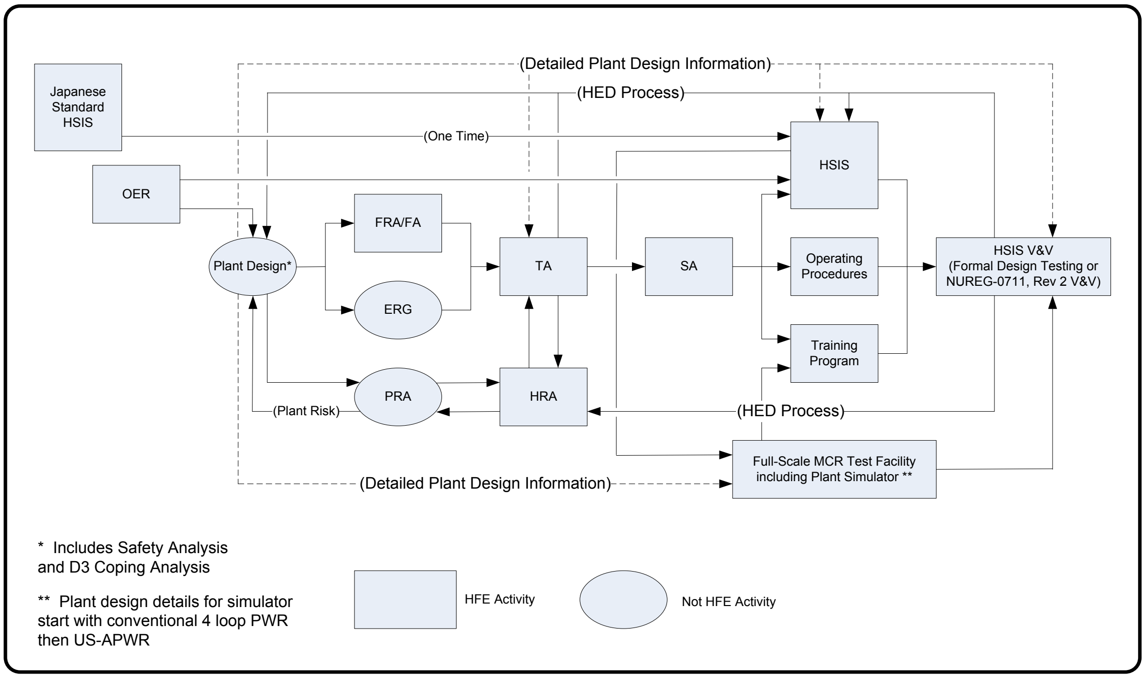

Figure 2.1-1 HFE Overall Work Flow, Ref MUAP-09019 Rev. 2, Part 1

3.0 APPLICABLE CODES, STANDARDS AND REGULATORY GUIDANCE

Applicable codes and standards are referenced in MUAP-DC018 and MUAP-07007.

4.0 IMPLEMTATION PLAN

4.1 Operational Conditions Sampling

MHI will select a combination of HSI features, test scenarios, plant process equipment degradations and failures, number and qualifications of operating staff members, operating procedures which are to be employed, exercised and stressed with each HSI Validation Test scenario. What follows is a description of the process that MHI follows, as part of executing the V&V Implementation Plan, to select test scenario variables for each Validation Test. The Operational Conditions Sampling (OCS) process will only be applied to the Validation tests. The Verification will not make use of the OCS process in that it will sample one hundred percent of the HSI. OCS is presented at this point in the Implementation Plan to facilitate review to the order of NUREG-0711 criteria (Reference 6-7).

The OCS will define difficult tasks resulting from the OER as those that initiated an HED and are reported in Reference 6-3.The Validation will specifically evaluate the design changes resulting from these OER originated HEDs. In addition, the OER report will form one input to the OSC as important operational experience for consideration in scenario development.

The OCS will identify, as one aspect of difficult tasks, knowledge based tasks by:

First: analyzing the operating procedures. For this purpose tasks in the operating procedure will be assigned two categories, 1) the operator simply controls or monitors plant conditions following clear and routine procedures and prompts, and 2) the operator must diagnose plant conditions and appropriate actions with incomplete or conflicting procedures and/or prompts. For the OCS, the HSI design and V&V team will review the operating procedures. If the text in the Action/Expected Response column contains activities in the second category the task will be identified as knowledge based task.

Second: reviewing the Phase 2a and Phase 2b task analysis to identify tasks that the analysts have identified as complex, requiring knowledge based decision making or under high work load. The results from this analysis will be then compared to the procedure based analysis and differences reconciled.

Third: identifying and adding complicating factors to well understood tasks by the addition of secondary and tertiary events or failures, such as;

1. Failures of needed and expected instrumentation that result in incomplete or misleading information.
2. Failures of manual controls that are needed to manage the task.
3. Failures of automated systems that require the operator to in part, or in full, take over the control of plant response.
4. Failures of the CBP system
5. Failure of non-safety systems
6. Failures of all digital systems, including HSI

Fourth: including knowledge based tasks from existing operator licensing examinations.

Fifth: introducing Risk-Important HAs that require cognitive judgment, planning and analytical decision making.

Sixth: encompassing beyond design bases events through evaluation of functional recovery procedures to identify knowledge based tasks.

The OCS will define additional difficult tasks, in addition to those identified by the OER, by those actions that historically have given operators of existing PWRs difficulty in qualification and requalification examinations or have been identified by the industry and NRC through operational events.

Lastly, tasks that were identified as high workload in the function allocation and Phase 2a and Phase 2b task analysis, and did not result in a design change to reduce the workload, will be included.

The OCS will have a goal to drive the operator into causing errors that must be identified and recovered from. Knowledge of the weaknesses of the human will be used to test the robustness of the HSI to tolerate error and offer the capability of the operator to identify and recover from those errors. These error forcing contexts will be accomplished by introducing:

1. Routine and repetitive tasks
2. Multiple related and independent events
3. Masked failures of automated systems

4. Train versus Loop recognition (e.g., a component is located in SG loop A, but the component is assigned to Train D)

The OCS will define high workload as tasks where significant multitasking is required, such that performance degradation that is attributable to the workload can be observed or measured. This situation includes both physical as well as cognitive conditions, such as number of tasks for screen navigation and searching for information in different VDU screens. High workload tasks are identified in the TA and will be augmented by the subject matter experts on the scenario development team.

Varying workload will be also considered by including scenarios that have significant increase or decrease in alarms, procedural tasks, and external communications demands. This will include varying workload when transitioning between the CBP and paper procedures, between the operational video display units and the safety video display unites, and between the operational video display unites and the Diverse Actuation System.

The effects of fatigue will be evaluated by running selected tests for 10 hour days and through test schedule variations.

Environmental factors such as normal expected variation in the MCR lighting, noise and temperature during high personnel loading will be included in the OCS considerations.

The Validation will encompass all Risk-Important human actions (HAs) that are pertinent to plant operations to ensure the HSI design supports human performance as defined in the HRA/PRA.

The Validation will include, as per NUREG-0711 (Reference 6-7), the interface, operating procedures, staffing and qualifications results.

MHI's V&V Team (Reference 6.4 Part 1) includes persons who are knowledgeable in designing HFE evaluations and V&V programs and have experience in designing and managing tests that assess human performance. These persons will prepare a Test Procedure that includes a set of test goals and objectives for the Verification and Validation that is used as the starting point by the scenario developers in developing each detailed scenario that is used to support the Validation.

In addition, the V&V Team assures that a maximum range of situational factors that are known to challenge human performance (e.g., situational awareness, workload, error forcing contexts, recovery, ergonomics, environmental stressors and fatigue) will be addressed and assessed in the set of test goals and objectives that are used in the validation test scenario development.

The scenario developers are responsible for assuring that a satisfactory set of plant conditions and ‘personnel tasks’ (procedure guided tasks, knowledge based tasks, risk-important human actions, OER supported human interactions, and degraded HSI) are covered in the set of scenarios that comprise the Integrated HSI Validation testing.

The scenario developers and the scenario development process are augmented with additional personnel when the focus of the Validation testing is on HSI outside of the MCR (safety significant local control stations, TSC) and when MCR HSI Validation requires interfacing with facilities outside the MCR (Emergency Operations facility and CAS/SAS). The additional experts bring an understanding of the scope of plant operations that are defined by the system and HSI being evaluated and can determine which human performance issues that are to be supported by the specific HSI.

4.2 Design Verification

The HSI Design Verification and design changes resulting from HEDs that have been identified from the verification will be completed prior to beginning the integrated system validation. The Design Verification is composed of HSI Inventory and Characterization (section 4.2.1), HSI Task Support Verification (4.2.2), and HFE Design Verification (4.2.3), as described in Reference 6-7.

4.2.1 HSI Inventory and Characterization

The US-APWR HSI employs the US Basic HSI system as derived from the completed Phase 1a and Phase 1b design testing program. The US-APWR HSI inventory is developed from the US-APWR TA. As the final US-APWR HSI design is completed, the inventory will be entered into the MHI quality assurance configuration control program, including a complete description of its characteristics.

The inventory of HSI components forms the basis for the design verification. The characterization of this inventory represents the detailed descriptive information relating to each of the HSI components. The inventory, design characterizations, graphical and physical representations are verified against the US-APWR HSI design documents: JEJC-1763-1001 (Reference 6-5), HSI Design Style Guide, NUREG-0700 (Reference 6-9), and other documents to be defined at a later point as the HSI design is completed. These will include nomenclature, acronym and component control guides.

4.2.2 HSI Task Support Verification

As part of the Design Verification, an HSI Task Support Verification will be performed to assess the HSI design as it supports the tasks identified in the Phase 2a and Phase 2b task analysis. A multidisciplinary team composed of at least three members having the combined expertise of HFE, plant operations and task analysis, and independent from the design team, will be formed. Each member will have at least five years of experience in his or her field (HFE, plant operations, or TA). This team will, applying the Verification Procedure, conduct a detailed assessment of the personnel tasks identified by the task analysis as compared to the available alarms, displays and information sources, and control capabilities provided by the HSI. The HSI Task Support Verification will also include an assessment of the Computer Based Procedure (CBP) system design (e.g. display design, display content, navigation links, and record keeping) and the procedures completeness. A paper and pencil check list method will be used in this assessment. This will include the use of a Static Portable PC Based Analysis tool that includes graphical presentation of all operational and safety VDU display screens and the LDP display design contents. This PC Based Analysis tool is specifically designed to support the Verification. When it is determined by any one member of the team that the HSI design does not adequately supply the needed interface, an HED will be written and entered into the HED data base for resolution. Similarly, when any one member of the team determines that part of the interface is unnecessary, an HED will be written and entered into the HED data base for resolution. As with all HEDs, the process will follow the HFE-HED process as described in Appendix 2 of this V&V Implementation Plan and in MUAP-09019 (Reference 6-4) Part 1.

The Team will base its assessment on;

- The most recently completed task analysis
- Detailed descriptions of the final HSI design

The Static Portable PC Based Analysis tool containing Plant Control and Monitoring System (PCMS) provided, safety and non-safety display screens (alarms, indications and controls) for all systems, and simplified navigation capabilities, as described and applied in past Phase 1 design tests. This tool is designed to support

- The analyst's verification of display screen content.

The HSI Task Support Verification will verify that the HSI inventory of components/ displays/ alarms/ controls meets those identified by the task analysis. The inventory includes all HSI components associated with the personnel tasks based on the identified operational conditions. The inventory describes the characteristics of each HSI component. The following is the minimum set of information required for the characterization of each component in the inventory:

- A unique identification code number or name
- Associated plant system and subsystem
- Associated personnel functions/sub functions
- Type of HSI component
    - computer-based controls
    - conventional (hard-wired) controls
    - computer-based displays
    - conventional (hard-wired) indicators
- Display characteristics and functionality
- Control characteristics and functionality
- User-system interaction and dialogue types
- Location in data management system
- Physical location in the HSI

In addition to the HEDs generated by the Task Support Verification, the Results Summary Report documenting the assessment will be written, reference section 4.8.

4.2.3 HFE Design Verification

For the HFE Design Verification, as a second part of the Design Verification, one hundred percent of the final HSI screen design, content, and ergonomic design will be assessed per Reference 6-5. A three member team, composed of experts with the same background as described for the HSI Task Support Verification, described in Section 4.2.2, will be assembled to perform the Design Verification. The HFE Design Verification will follow a procedure that guides the team members through the process to assure analyst variation bias is controlled through consistent application of this Implementation Plan. All discrepancies identified during the HFE Design Verification will be documented in the HED data base. The Results Summary Report, reference Section 4.8, will be generated upon completion of the V&V program.

The objectives of the HFE Design Verification are:

- confirm that the characteristics of the HSI, its ergonomic layout and the environment in which it is used, conform to HFE guidelines, as defined in the HSI Design Style Guide (Reference 6-5), and
- identify any inventory or characterization non-conformance.

The HFE Design Verification will be based on the HSI Design Style Guide, JEJC-1763-1001 (Reference 6-5) and additional design documents to be identified through the HSI design process.

One hundred percent of the MCR HSI will be included in the HFE Design Verification to assure a consistent application across the entire HSI of the design principles. In order to have an efficient process, and to assure that the Verification covers the full one hundred percent of the MCR HSI with at least one team member reviewing each part, the HSI will be divided into logical parts that will be assigned to different team members to allow the team members to conduct the assessment independently and in parallel. Upon completion of the independent assessment the combined results will be reviewed by the full team to reach a consensus conclusion. The robust approach of verifying one hundred percent of the MCR HSI will not rely on the results of the OCS process as described in section 4.1. The results of the OCS will be applied only to the Validation and will not be applied as a sampling process to the Design Verification.

The HFE Design Verification will use both of both the most recent US-APWR HSI Design Style Guide (Reference 6-5) and the Static Portable PC Based Analysis tool used in the HSI Task Support Verification. Reference 6-5 has been successfully audited by the NRC during the Topical Report SER process. The PC Based Analysis tool, containing all the displays in the MCR will be used to evaluate screen design and consistency of the application. The dynamic simulator, the same as will be used in the Validation, will be used to evaluate display presentation sizes, colors and the MCR ergonomic design.

In compliance with NUREG-0711, the US-APWR HSI Design Style Guide (Reference 6-5) includes the following guidance:

- Display screen format organization
- Font size for each display screen
- Touch size for touch screen operation
- Color coding
- Display labeling coding
- Ergonomic requirement for display
- Standards for controllers and switches
- Guidelines for display design (guidelines and coding rules for display screen implementation)

4.3 Integrated System Validation

The Integrated System Validation (ISV) will include a minimum of three crews, each performing all twenty scenarios. To assure that the plant simulator that will be used as the Validation Test Bed represents the final HSI design for the US-APWR, the ISV will be undertaken only after HEDs that were identified in the upstream process have been resolved, and resulting design changes completed and implemented on the simulator. The ISV will be considered complete when all three crews have achieved the criteria for the specific scenario. In cases where consistent results are not reached, a fourth crew will be added to the validation. If at that point, the scenario criteria have not been achieved by at least three of the four crews, the HSI will be considered unacceptable for that scenario. The HSI must be acceptable for all scenarios to complete the V&V program element. As with the Verification, the ISV will result in the identification of HEDs and their inclusion into the HED process, as described in Appendix 2. The results of the Validation will be reported in the Results Summary Report as described in Section 4.8.

The ISV will be performed on the final US-APWR design, however, when design changes result from the ISV, they will be addressed through the HED process and the Design Implementation element (Reference 6-17).

4.3.1 Objectives

The objectives of the ISV are presented below:

- Validate the role of plant personnel
- Validate the minimum MCR staffing levels
- Validate maximum shift levels
- Validate that personnel tasks can be successfully performed in the required time within performance limits, under normal and degraded HSI conditions
- Validate that the HSI contains adequate alarms, information, control and feedback during all modes of plant operation and conditions
- Validate that the HSI supports all identified risk-important HAs
- Validate that the HSI supports human error reduction and recovery activities
- Validate the crews situation awareness and workload, including secondary tasks
- Validate the efficiency of the interface management system and the crews ability to navigate between the HSI and procedures
- Validate that the crew can identify and recover from failures of individual HSI features
- Validate continued operation, accident management, and safe shutdown with a complete loss of all non-safety HSI
- Validate accident management and safe shutdown with common cause failure of digital systems
- Validate that the MCR crew can coordinate and communicate within the MCR and with personnel outside of the MCR
- Validate that the crew can effectively transition between the computer based procedures and paper procedures

- Validate the transition from the MRC to the RSR to achieve safe shut down
- Validate that there are no elements of the HSI that can negatively affect performance, such as unneeded or confusing alarms
- Validate that the operating crew can adequately support plant maintenance and test activities
- Validate that the ergonomic and environmental design and conditions support safe and efficient operations

4.3.2 Test Beds

The principal Validation Test Bed will be a dynamic plant simulator. The simulator used for the Validation will have been demonstrated to be consistent with the Validation Test Bed criteria specified in NUREG-0711 (Reference 6-7), Section 11.4.3.2.2, using ANSI/ANS 3.5-1999 (Reference 6-6) as a reference, and the fidelity of the simulator's model and HSI will be verified to represent the current, as designed, US-APWR prior to use as the test bed for the Validation. The Validation Test Bed will accurately simulate the expected MCR environment. Where this is not achievable an exception will be taken and notation will be made in the test procedure and in the V&V Results Summary Report. In these limited cases additional testing will be confirmed in the as built plants MCR through the Design Implementation Plan.

The simulator test bed evaluation will assure:

- Interface Completeness – The test facility completely represents the integrated system. This includes HSI and procedures not specifically required in the test scenarios. For example, adjacent controls and displays may affect the ways in which personnel use those that are addressed by a particular validation scenario.
- Interface Physical Fidelity –A high degree of physical fidelity in the HSI and procedures is represented, including accurate presentation of alarms, displays, controls, job aids, procedures, communications, interface management tools, layout and spatial relationships.
- Interface Functional Fidelity –A high degree of functional fidelity in the HSI and procedures is represented. All HSI functions are available. High functional fidelity includes HSI component modes of operation, i.e., the changes in functionality that can be invoked on the basis of personnel selection and/or plant states.
- Environment Fidelity –A high degree of environment fidelity is represented. The lighting, noise, temperature, and humidity characteristics reasonably reflect those expected. Thus, noise contributed by equipment, such as air handling units and computers is represented in validation tests.
- Data Completeness Fidelity –Information and data provided to personnel completely represent the plant systems monitored and controlled from that facility.
- Data Content Fidelity – A high degree of data content fidelity is represented. The information and controls presented are based on an underlying model that accurately reflects the US-APWR. The model provides input to the HSI in a manner such that information accurately matches that which is actually presented in the US-APWR.

- Data Dynamic Fidelity – A high degree of data dynamic fidelity is represented. The process model is capable of providing input to the HSI in a manner such that information flow and control responses occur accurately and in a correct response time; (e.g., information is provided to personnel with the same delays as would occur in the plant.)
- The test facility is verified for conformance to the test facility characteristics identified above before validations are conducted.

4.3.3 Plant Personnel

Test crew personnel will be selected from a pool of experienced U.S. plant staff. All test crew personnel will have the same qualifications and licenses as those required by the USNRC for currently operating plants. Plant personnel will have at least one year of experience in the position that will be filled on the test crew. The test crew selection process will be based on the requirement to have an unbiased representative sample of plant personnel that will be interfacing with the HSI. This will include three crews for each scenario. When consistent results are not reached between the three crews, an additional fourth crew will be tested on the scenario. Crew makeup will remain consistent throughout the Validation (i.e. crew members will not rotate between crews). To control crew bias a sampling will be employed in crew selection that assures the plant personnel represent the population of U.S. operating crews. This process will include the dimensions of:

- Random selection from a pool of operators
- Industry age distribution
- Industry gender distribution
- Industry education level distribution
- Industry experience distribution

Personnel that have supported the Validation Test development and the Validation Pilot Test will not take part as plant personnel test participants.

Crew size for the Validation Test will include a range of expected sizes to assure that the HSI supports operations and event management. The crew size for each scenario will be identified in the Validation Test procedure. The minimum number will be the design assumption of one RO and one SRO. The upper range will be determined during the scenario development process, and the Validation will include one scenario with an increased manpower level. This will simulate test conditions during times of high control room traffic and distractions and high environmental loading, related to larger numbers of secondary personnel, such as technicians or accident response teams in the control room. These staffing levels will be determined by the scenario developers based on meeting all the test objectives/ goals.

The Expert Panel will have an independent review role in selected areas of the V&V program, as described in this Implementation Plan, and will be governed by an approved charter that is auditable by the NRC. Members of the Expert Panel will represent only senior experts with at least 10 years of related experience in HFE, engineering, design or operations, and will hold a college degree in a related field (HFE, psychology, engineering).Reference section 4.4.3 D.

4.3.4 Scenario Definition

The ISV scenarios will meet the Operational Conditions Sampling (OCS), criteria of NUREG-0711 (Reference 6-7) Section 11.4.1.2.1, 11.4.1.2.2 and 11.4.3.2.4. Individual sampling dimensions will be combined through expert judgment by the scenario developers of the US-APWR V&V Team into the scenarios, as part of their responsibilities as described in Section 4.1 above. Resulting scenarios will combine into realistic events; the multiple characteristics identified from the OCS process. The scenario developers will assure that the scenarios are not biased by representing only positive outcomes or scenarios that are easy to conduct or well-structured and practiced. As described under the OCS, scenarios will stress the crew through both normal and challenging events containing multiple and unanticipated failures. As guidance, the scenario developers will use References 6-3, 6-4, 6-6 and 6-16. The resulting scenarios will be documented by the Scenario Developers and be independently reviewed by the Expert Panel.

The ISV scenarios will fully meet the criteria of NUREG-0711 (Reference 6-7) Section 11.4.1.2.1 and will include:

- Full range of plant operating modes, including startup, shut down, significant power changes, refueling and normal operations
- Abnormal and emergency operations, transient conditions, and low-power and shutdown conditions which include credited operator's action in the DCD Chapter 15
- Specific initial conditions (precise definition provided for plant functions, processes, systems, component conditions, and performance parameters. (e.g., similar to plant shift-turnover)
- Events (e.g., failures) to occur and their initiating conditions. (e.g., time, parameter values, or events)
- Precise definition of workplace factors, such as environmental conditions
- Task support needs. (e.g., procedures and technical specifications)
- Staffing objectives
- Communication requirements with remote personnel. (e.g., load dispatcher via telephone)
- RIHAs
- Internal and external initiating events and actions affecting the PRA Level I and II analyses of Chapter 19.
- HAs for which the HSI is credited in the OER, including OER originated HEDs
- Failure of digitalized I&C systems with above scenarios
- HAs with computer based systems, such as alarms and CBP system
- HAs in monitoring automated systems and in assuming control when automation fails.
- Failure of all non-safety HSI
- Operation from the remote shutdown console to safe shutdown

- System interconnections as they relate to failures
- Full range of procedures, knowledge based and cognitive tasks, and tasks including personnel interactions within and external to the main control room.
- Situations that stress navigational requirements
- Full range of situational factors such as operationally difficult tasks, error forcing events, high physical and mental workload, and environmental factors as applicable for the specific operating location
- Factors and HEDs that were found during the Phase 1a/1b V&V testing program

Qualifications of Personnel Performing Scenario Development:

The focus of the integrated Validation Test is the MCR HSI. Therefore, the Validation will utilize a scenario development team of three experts that have collective experience in HSI design, who are familiar with the US-APWR HSI design and accepted HSI design practices, and human factors experts familiar with human error initiators and causes in conjunction with personnel that are experienced in PWR reactor operations. This team is not required to be composed of the same three experts that are discussed in section 4.2.2, HSI Task Support Verification or section 4.2.3, HFE Design Verification. The team is responsible for developing and applying the OCS process, section 4.1, selecting the specific test objectives to be applied to the specific scenario, section 4.3.1, and selection, definition, description and documenting the test scenarios, section 4.3.4. Each expert involved in the OCS and the scenario development will have at least five years of experience in HSI design, HFE or PWR plant operations.

For validation of a remote location (e.g., the TSC, Remote Shutdown Stations (RSS) and local panels) the Validation will use additional experts (in addition to the base 3 noted in the above paragraph) that are familiar with the operation of the remote location that is included in the scenario. These additional experts will have a minimum of 5 years of experience and are expected to specifically understand the tasks and task needs of personnel that are working in the remote location in question.

Scenario Definition:

The development of HSI Validation test scenarios is dependent upon the:

1. Experience training of the scenario developers
2. Results of the OCS process
3. Stated test objectives as described in Section 4.3.1
4. OER
5. Function Allocation
6. Phase 2a and Phase 2b task analysis
7. RIHAs
8. Phase 1 HEDs and their resolutions
9. ISV Procedure
10. Independent review by the Expert Panel

The details of developing the scenarios are described in the ISV Procedure which will be completed prior to beginning the V&V program and will be used as a detailed implementation procedure the V&V program. To assure consistency, the ISV Procedure and this Implementation Plan will be applied as a requirement by the scenario development team.

Depending on the test objectives in Section 4.3.1 that are identified and required to be met in the scenario, the scenario developers use a variety of plant process events and contexts as the bases upon which a scenario is built. As a minimum these include:

1. Major design basis and beyond-design basis accidents
2. Major normal plant evolutions
3. Evolutions and scenarios that are included in current operating plant reactor operator re-qualification exams

Due to the operational application of the Safety VDU system, scenarios that assess the Safety VDU system will test the HSI within the design basis for the Safety VDU system. As such, the Safety VDUs provide the following limited operational capabilities and design will be tested accordingly:

1. Maintain continued stable plant operation without exceeding the licensed thermal power limit, while maintaining all critical safety functions. Stable plant operation shall be maintained for a reasonable duration that permits non-safety HSI to be restored.
2. Manage AOOs and PAs identified in the safety analysis (Chapter15) with the defined malfunctions and within the defined criteria.
3. Achieve safe shutdown (i.e. cold shutdown) from the stable or abnormal plant conditions defined above.

In the course of assembling the underlying ‘major’ event or plant evolution that is to be involved in the scenario and adding additional malfunctions to it, the developers will also document the relevant information that will be employed as the equivalent of the ‘shift turnover briefing’ that will ‘set the current operational stage’ for the incoming MCR crew/test subjects. No one scenario is expected to address all the test objectives as discussed in Section 4.3.1. However, in the aggregate, all test objectives will be included in the extent of the sum of all the scenarios. Each scenario will include a number of human actions to be tested, including both primary and secondary actions. The scenarios will include real world communications and other MCR activities that would be expected to be occurring at the same time as the primary and secondary actions.

The definition for each scenario included in the V&V will include:

(1) The operational conditions selected for inclusion in the Validation Tests shall be developed in detail so they can be performed on a simulator. The following information should be defined to provide reasonable assurance that important performance dimensions are addressed and to allow scenarios to be accurately and consistently presented for repeated trials:

- Description of the scenario and any pertinent "prior history" necessary for personnel to
- Understand the state of the plant upon scenario start-up

- Specific initial conditions. (precise definition provided for plant functions, processes, systems, component conditions and performance parameters, e.g., similar to plant shift turnover)
- Malfunctions to occur, point in the scenario they occur and their initiating conditions. (e.g., parameter values, or events)
- Precise definition of workplace factors, such as environmental conditions
- Task support needs (e.g., procedures and technical specifications)
- Staffing objectives
- Communication requirements with remote personnel (e.g., load dispatcher via telephone)
- Precise specification of what, when and how data are to be collected and stored (including videotaping requirements, questionnaires and rating scale administrations)
- Specific criteria for terminating the scenario

(2) Scenarios will have task fidelity so that realistic task performance will be observed in the tests and test results can be generalized for the HSI design.

(3) When evaluating performance associated with operations remote from the main control room, the effects on crew performance due to potentially harsh environments should be realistically simulated.

The resulting twenty scenarios will be reviewed and approved by the independent Expert Panel (section 4.3.3 and Reference 6-4 Part 1).

Scenario Human Performance Evaluation Criteria Development:
As with the development of the scenario, MHI will utilize operational experts to develop and review proposed ‘evaluation criteria’ for the scenario, including human performance, plant equipment operation, and outcomes from the scenario. The operational experts have backgrounds as reactor operator training instructors, systems engineers, plant and I&C designers, and HSI design with at least 5 years of experience.

In addition, consideration is given to good practices and evaluation criteria that are stated in current industry standards and guidelines, including those used for operator license examinations by the U.S. NRC (Reference 6-16).

The evaluation criteria that are developed for a given scenario are dependent upon the test objectives of the scenario, Section 4.3.1, as well as on the details of the event(s) that the test subjects / operators are being asked to cope with during the scenario. The types of evaluation criteria that will be developed by this group of experts:

- Global plant process parameter criteria (e.g., process parameters maintained below safety system actuation, or within design limits)

- Timeliness of operator actions. Time can also take on the dimension of ‘number of touches’ in the navigation between displays to access desired data, alarms or controls, in particular, controller face-plates, time to take action, time to control a plant parameter or set of plant parameters

- Operator performance with respect to teamwork, communications, execution of procedures, thoroughness of annotations of procedures, check-off of procedure steps and sign-off of completion in defined blocks of paper based procedure steps, are evaluated against current U.S. industry standards of good practices

- Risk-based criteria derived from the PRA, the associated fault trees, and cited risk-important human actions

- Operator awareness of plant or process circumstance, status of automation and alarm status. The operator's understanding of the current plant state or the state of a particular component or variable will be acquired and compared against the actual predetermined state or value

- Lessons learned from the OER

- Secondary tasks associated with a digital control room such as screen navigation, the drill down process and transition between HSI features

Evaluation criteria related to human performance are defined and included in the description of each scenario. In the case of plant performance measures, the evaluation criteria are shown, include a clear definition of the process parameter of interest as part of the test plan and included in the analysis of the test.

Appendix 1 describes four examples of complete validation scenarios to demonstrate the level of detail contained in each scenario. Each scenario will contain:

- Scenario name
- Summary of the scenario selection criteria and test objectives satisfied
- Plant initial condition
- Simulator initial conditions and set up instructions
- Scenario details (timing of events, expected displays, alarms, automation actions, and details of expected crew actions for observers/ administrators to look for)
- List of primary and secondary tasks
- Description of supplemental failures and MCR activities
- Failure modes and detailed acceptance criterion, including Pass/Fail criterion. Measures and measurement tools to be used
- Special instructions for the MCR environment and monitoring equipment
- Test observer instructions, timing, scripted input, intervention for collection of data

4.3.5 Performance Measures

Performance measures for each scenario are identified in the test procedures. ISV observers will add additional measures to be collected prior to the start of a scenario; however, no measures can be deleted from the Test Procedure. Performance measures will be collected for both primary and secondary tasks. In addition, results of all communications outside of the MCR, including observer/administrator verbal probes on workload and situation awareness, will be included in the identified performance measures.

- The following sources of measurements are used:
  - Alarm history
  - Operator control log
  - Plant variable control log

- Event log
- HSI use history (display screen request history, operational history)
- Plant performance resulting from operator action, or in-action that includes plant process data (i.e., pressures, temperatures, flows, levels, radiation level), component states (i.e., off / on; open / closed, as a function of time, at various vital locations in the plant simulation as is possible). This data is taken from the entire energy flow path of the plant from reactor to electrical grid switch-yard.

• Personal task measurement

For each specific scenario, the tasks that personnel are required to perform are identified and assessed. Two types of personnel tasks are measured: primary (e.g., start a pump), and secondary (e.g., navigate to the pump controller display). Following measurements are used:

- Time
- Operation and monitoring log
- Errors (omission and commission)
- Amount achieved or accomplished
- Subjective report of participants
- Behavior categorization by observers

For knowledge based tasks more detailed data will be collected in order to assess the complexity of the crew actions. In addition the "Time" to identify, decide and take action, data will be collected for both primary and secondary tasks:

- Number of attempts or navigational steps
- Accuracy of actions
- Frequency that a specific action had to be taken
- Number and severity of errors of omission and commission
- Range of plant parameter to their limit before actions take
- Subjective feelings and observations of test crews/observers and
- Plant performance

Multiple converging measures of performance are used to analyze the results of the Validation and to identify HEDs that have the potential to negatively impact operator individual and team performance. HEDs can also be directly identified by the test crew participants and the test observers.

The integrated validation will include two, explicitly defined, types of performance measures:

1. *Performance Measures used as 'Pass/Fail' Indicators*: These are a subset of performance measures that will be considered as critical indications of a successful HSI design and are designated as Pass/Fail that are used for decisions as to whether the design is validated or not. Pass/Fail indicators are defined as any violation of Technical Specifications, impacts on the conclusions of the PRA/HRA and the RIHAs, or impacts on the Chapter 15 transient and accident analysis (Reference 6-1). All Pass/Fail indicators result in an HED as described in Appendix 2 and will require design/procedure/operator training changes.

2. *Other Performance Measures:* These are additional performance measures that enable detailed understanding of the impact of the HSI on individual operator and crew performance. They are used to evaluate the success of the HSI to support safe and efficient human performance and can identify HEDs that will then be evaluated using the HED evaluation process as described in Appendix 2.

Specifically, the Performance Measures include collecting:

(a) *Objective measures*, designed to be direct physical measures of plant behavior based on data capture of plant process data, operator actions on the HSI, and response time of the operator;

(b) *Objective measures* of crew performance that are collected during the Validation scenario and are used for historical repeatable evaluation include video and audio recordings of operator performance. The four capture schemes will be:

- Camera Recording
- Display Recording
- Operator Control Data Log
- Plant Variable Data Log

A display recording system that is synchronized with the video and audio recordings will capture video images of computer display screens from the Main Control Room HSI to a multi-channel security type digital video recorder. The monitored computer screens are:

- Four large display panel screens
- Three operational VDU screens
- One operator alarm VDU screen
- One operator procedure VDU screen
- Six safety VDU screens

(c) *Objective measures* of operator performance including responses to situation awareness probes (both verbal probes that require interruption of the scenario and non-intrusive measures).

(d) *Subjective assessments* of individual and team performance made by the interdisciplinary team of expert observers/ test administrators that includes human factors and plant operations experts with a minimum of 5 years of HFE or operations experience. Data collection tools are contained in Appendix 3.

(e) *Subjective assessments* of the HSI and its impact on performance, including self-ratings of workload, situational awareness, and teamwork, are provided by the experienced NPP operators who participate in the study. Operator questionnaire feedback on the HSI will be collected via post-scenario and final questionnaires. This includes both Likert rating-scale questions and open-ended questions soliciting operator self-assessment and HEDs. The questionnaires that will be used to collect subjective information from the test crews and test observers are contained in Appendix 3.

(f) Specific HEDs and number of related HEDs documented by individuals involved in the V&V, including test observers/administrators and test crew participants.

(a. & b. above) Objective measures of crew performance - Objective Performance Analysis

The ‘objective’ data collected during each test scenario is analyzed by a team of operational experts and HFEs, with at least five years of experience in PWR MCR operations and human performance testing respectively, to assess the impacts of operator actions on the plant’s processes and equipment states. The analysis compares the performance derived from parameters and times collected by the simulator to the evaluation criteria for operator actions and for overall plant process behavior, developed for each scenario.

The results of these analyses form one of the ‘perspectives’, or performance measures of the tests, which is converged with the others in the final conclusions from the Validation tests.

(c. above) Objective measures of operator performance – Situation Awareness

Results from explicit verbal probes are captured by the expert observers. Non-intrusive measures of situation awareness are reflected in the operator actions and verbalizations during the scenario, identified through a review of the video and audio records of the scenarios as well as the simulator’s computer capture of control actions.

(d. above) Subjective assessments of individual and team performance – Expert Observer Assessment of Operator Performance

Each scenario will be observed by a plant operations expert and a minimum of one HFE expert. The observers document their individual assessments of crew performance on a post-scenario observer form (Appendix 3) that is filled out during and immediately after the scenario.

The first portion of the form asks the expert observer to document performance problems that they observed during the scenario. The form explicitly asked observers to document the following nine categories of performance problems:

- Monitoring/detection problems
- Errors of omission
- Critical action delays
- Errors of commission
- Procedure deviations
- Teamwork problems
- Situation awareness problems
- Workload problems
- Other problems

Observers indicate whether they observed problems in each of these performance problem categories and describe the nature of the problem, if any, that arise. These form entries amount to ‘measures’ of inadequate performance as judged by the expert observers.

A consensus process is used to merge the inputs of the different observers into a single consensus summary description of the performance of each crew on each scenario.

The next section of the post-scenario observer form asks the observers to rate technical and teamwork performance on a five-point Likert rating-scale.

The Post-Scenario Observer Form also asks expert observers whether they felt that the crew size was sufficient for that scenario.

The final portion of the post-scenario observer form includes blank spaces for observers to write down HEDs they identified.

(e. above) Subjective assessments of the HSI – Operator Questionnaire and Operator Comments during the Debriefs

There are two questionnaire forms that operators fill out (Appendix 3):

(1) A post-scenario operator form that is filled out at the end of each scenario

(2) A final operator feedback form that is filled out at the end of the non-safety HSI scenarios

The operator questionnaire forms consist of two types of items:

(1) Rating questions that use a five-point Likert–scale

(2) Questions that solicit HEDs in free-form text

(f. above) HEDs generated during the scenario

(1) HEDs and the HED evaluation process, including the data base, assessment and resolution is discussed in Appendix 2 and Reference 6-4 Part 1

Measures of Situation Awareness:

Situation awareness is a complex, multi-dimensional construct that represents one important factor in crew performance (Reference 6-12, 6-13). MHI intends to establish that the US-APWR HSI effectively supports operator situational awareness by explicitly evaluating it through the use of multiple different measures, including both objective measures and subjective operator self-assessment measures of situation awareness that produce converging results.

Objective measures of situation awareness will be obtained using two methods:

(1) *Non-intrusive human performance measures*. Specific events will be inserted into the simulator scenarios (e.g., equipment malfunctions, systems placed in manual that should be in automatic) to determine whether operators are able to quickly detect resulting plant symptoms and identify the source of the problem. This provides an objective indication of operator situation awareness. This measurement technique has the advantage that it can be collected while the scenario is dynamically running without interfering with the natural ongoing cognitive and collaborative operator crew processes.

(2) Non-intrusive *Verbal probes.* While operators are engaged in scenario task performance, simulated phone calls will come in at predefined points in the scenario. The simulated call will be from higher-level plant management personnel asking for a status update. The operators are asked to respond to a single spoken

question to assess their current situation awareness. They will be asked to provide a brief oral response summarizing current plant status (including any ongoing plant disturbances and/or equipment malfunctions they are aware of), and how they are currently addressing those problems. This enables an objective assessment of operator situation awareness, without requiring the simulation to be interrupted.

(3) Intrusive *Verbal questioning.* During a scenario the Validation Test Procedure scenario description will call for the test administrators to stop the scenario and ask scripted questions of the crew to measure their awareness and understand of the plant condition, alarm status, and actions they have taken. When the questioning is complete the scenario will be restarted at the point of interruption.

The ISV will apply a combination of all three of the methods to measure situation awareness. In addition, subjective operator self-assessment of situation awareness will be obtained via Likert-rating scale questions that are included in questionnaires (See Appendix 3) that operators are asked to fill out following each simulator scenario as well as after the completion of all test scenarios. This provides a complementary measure of situation awareness that taps operator confidence that the HSI is providing adequate information to support situation awareness. Likert-rating scale questions have been successfully used to measure operator self-assessment of the effectiveness of support of an HSI on different aspects of situation awareness in a number of previous studies (Reference 6-14 and 6-15) and were successfully applied during the Phase 1 HSI design tests.

Measures of Workload

Another important factor in crew performance is workload, both physical and mental. This will be explicitly evaluated during the Validation. After each Validation Test scenario, plant operations personnel / operators will be asked to fill out an assessment of their own mental and physical workload with respect to the effort required for this scenario as compared to what would be required for equivalent scenarios at their home plant. The workload questions are included as part of a short post-scenario questionnaire that includes Likert rating scale questions eliciting operators' subjective self-assessment of mental workload, physical workload, situation awareness and teamwork. Post-scenario questionnaire forms are provided in Appendix 3.

In addition, cognitive workload will be assessed by evaluating the operator's excess mental capacity (Reference 6-8). During each scenario, scripted queries will be introduced that ask the operator to gather specific plant information. The operator verbal response, and the time it takes to gather the information and feed it correctly back while managing the scenario will be collected and evaluated as an indirect measure the level of cognitive workload and how much reserve capacity the operator has at a given time.

In addition, the qualitative information from observation of crew performance during the scenarios and verbal debriefs that are conducted at the conclusion of the scenarios provide important background information for interpreting the results of the data analysis and specific HEDs that operators document on the HED forms. This facilitates later analyses by the HED Expert Panel and HSI Designers review that requires interpreting, connecting, and generalizing across often cryptically written individual HEDs.

These multiple sources of data are analyzed and the results are used to provide converging indications of human factors issues of primary concern, as well as to identify specific 'HEDs' that are entered into an HED database. If multiple measures or indications point to the same problem, it reinforces the need to address it. If none of the measures reveal a problem, it increases confidence that there is not a problem.

) Objective measures of operator performance – Situation Awareness

Results from explicit verbal probes are captured by the expert observers. The first portion of the form asks the expert observer to document performance problems that they observed during the scenario. Monitoring/detection problems**Converging the Perspectives**

The multiple types of objective and subjective data that are collected and analyzed provide converging evidence with respect to the adequacy of the HSI design. The operator performance data provides objective indication of instances of human performance problems. The Likert-scale rating questions on the operator post-scenario and final operator feedback form provide numeric scores provide objective evidence of the design adequacy. The HED input forms and open-ended HED entries in the operator feedback forms provide indication of specific HEDs that need to be addressed. The verbal debrief sessions provide rich contextual information that are used to interpret any HEDs that have been initiated, understand their extent, and how they are linked to human performance difficulties that the operator crews experienced. Multiple measures are expected to point to the same conclusion with respect to the HSI design adequacy. In cases where none of the measures reveal a problem the fact that multiple measures were used to probe for a problem, increases confidence that there is no problem and improvements to the HSI design do not need to be considered and the HSI design is acceptable.

4.4 Test Design

Recent human factors research makes clear that changes in control room technology can impact operator monitoring, situation awareness, teamwork, cognitive workload and technical performance. The ISV approach includes measures that are intended to assess the impact of the US-APWR HSI on the ability of individuals and teams to maintain situation awareness of plant state; to take control action in pace with plant dynamics, and to maintain supervisory control of automated systems, including assuming control of automated systems when they malfunction. Special emphasis is placed on the ability of the US-APWR HSI to support two-person operation, an RO responsible for controlling the plant and a supervisor; this is the design basis of the US-APWR plant design.

When designing the ISV, consideration will be given to anthropometric and physiological factors that may affect performance. The control room will include miscellaneous equipment that may add clutter. Only when areas outside of the control room are considered special environmental stressors such as temperature and radiation will also be included in the tests.

Test bias will be controlled by evaluating the contributions from:

- Test procedure under specification through the Pilot Testing
- Overall test bias, by controlled by use of a test procedure which includes standardized instructions and through training of crews and observers/administrators
- Observer/administrator expectancy, by using 3 independent observers/administrators and by evaluating inter observer/ administrators variation
- Test crew response, by reviewing test crew member’s change in performance over the course of the set of 20 scenarios
- Test environment, by having an environment that is what is expected to bound the

MCR of the US-APWR

- Inter test crew variation, by reviewing differences in performance between test crews for each scenario and across the set of 20 scenarios
- Scenario sequence effects, by varying the order of scenarios between crews
- US-APWR knowledge, by applying a structured training program to all crew members
- Test pre-knowledge by instructing crews not to discuss the test or their feeling about the HSI
- Small sample size, by adding an additional crew when convergence is not achieved and by analyzing by scenario, by crew, by crew member and by each of the 3 observers/administrators and applying a converging measures philosophy

4.4.1 Coupling Crews and Scenarios

All test crews will perform all scenarios. If consistent results are not achieved between the three crews, a fourth crew will be given the scenario to manage. Results between crews for each scenario and across scenarios will be analyzed.

Scenario sequencing has the possibility of a training bias. Based on past testing experience and good HFE practice, MHI will vary the scenario sequences used in the US-APWR validation testing. This sequencing will be reviewed by an experienced human factors test designer and human factors engineer to assure that such bias is minimized and documented. All crews will undergo the same training program. The training program will be generalized to assure the test crews have a basic knowledge of the plant and the operations of the HSI. The training program will be based on learning objectives and will be developed and conducted by a training instructor with at least ten years of US nuclear plant experience.

In order to control crew expectation bias the test scenarios will be neutral, random, and in different order for each test crew and scenario sequences will not follow “give away" sequencing. Scenario sequences will be varied between test crews to control sequence bias. Scenarios will also contain reasonable normal operation time to assure crews are not pre-tuned to immediate events and actions at each onset of a scenario.

4.4.2 Test Procedures

Basic conditions and limitations

Prior to the ISV, a detailed test procedure will be prepared to manage the test, assure consistence, control test bias, support repeatable results and focus the test on the specific scenario test objectives. The V&V Team (Reference 6-4 Part 1) will develop the Test procedure. The test observers/administrators will apply these procedures to set up each scenario, manage the scenario and analyze the test results, and the scenario developers will use the test procedure to build the scenario set. The test procedures are not the US-APWR operating procedures that will be used by the test crew to manage the scenario and run the simulated plant. The test procedures will include:

- Identification of which crews receive which scenarios and the scenario order
- Detailed and standardized instructions for briefing test crews

- Specific criteria for conduct of specific scenarios
- Scripted responses for test observers who will act as plant personnel during the test scenarios
- Guidance on when and how to interact with test crews when simulator or testing difficulties occur.
- Instructions regarding when and how to collect and store data
- Procedures for documentation of the Validation Tests

The test observers will have been trained, as outlined in Section 4.4.3, and will have agreed to policies on how to interact with test subjects when unexpected behavior or unplanned events in the test scenario occur.

Test crew personnel returning to their normal plant duties shall be instructed to refrain from discussing operational details of the test scenarios and their sequences with all operating plant operations personnel (i.e., possible future test subjects). Discussion regarding the US-APWR HSI features shall also be avoided. This helps to distinguish HEDs that are limited to individual operator opinions vs. HEDs that reflect a broader spectrum of operator opinions, and therefore are likely to indicate more serious design flaws. Regardless, all HEDs and their extent across the HSI will be evaluated (Appendix 2).

Prior to start of the ISV, all test subjects will have had sufficient training, as outlined in Section 4.4.4. As a result, any difficulties, errors, and problems encountered or exhibited by plant operations personnel will be attributed to deficiencies in the support provided by the HSI or an indication of a problematic V&V training program or test procedure. To reduce unwanted bias from the training program or test procedure, a Pilot Testing (Section 4.4.5) will be performed, and crews retrained or test procedure rewritten based on the Pilot Testing results.

Video and audio recording are used to support the analysis and to serve as an historical record of the execution of the scenarios and debriefings. Recordings will be reviewed to resolve inconsistent results between test observers/ administrators and to independently confirm validation results after the test is completed. They will also help to evaluate and compare performance between test crews in support of evaluating the breath of performance findings across the HSI. Five cameras will be positioned to capture information about crew performance during each scenario.

Test crews shall be informed during the training program that they are expected to ‘verbalize all actions’ during the execution of the scenarios.

4.4.3 Test Personnel Training

To control inter administrator/observer bias a minimum of three experts in the areas of HFE, plant operations, and operator training shall serve as test observers/administrators on any given test series for each crew. In order to control the consistency of results, the team same of three specific will be maintained for each set of scenarios given to a test crew. The observer/administrator team will include two HFE experts. These individuals will be responsible for running the test, observing and documenting the crew actions, running the debriefings, performing the data analysis and collecting HEDs. The third member will have either a plant operations or training background. In addition there will be one simulator engineer that will be responsible for running the simulator and assuring the scenarios are managed.

Training of test observers/administrators involves:

1. Prior to the start of the ISV, training and coordination meeting will be held to review the test procedure, practice using the data collection instruments, walk through all the scenarios, and participate in a formal training on the HSI. All test personnel will also be involved in the Pilot Testing prior to the start of the validation. This provides an opportunity for the test observers to gain a shared understanding of the purpose of the data collection instruments, and how they are to be used.
2. All observers/administrators will be in attendance during the first week of the Validation. This enables all of the observers to gain a shared understanding of the test procedure, how the observer forms are to be filled out, and how the debriefings are to be conducted.
3. On the first day of each test group, consisting of one crew with the set of 20 scenarios, the three test observers/administrators will be given a minimum of one hour of re-training by human factors and operational experts familiar with the origin of the data collection forms with regard to the data collection forms, their usage, and the test scenarios scheduled for the testing period.
4. The three observers/administrators in attendance at a crew test shall meet jointly at the end of each week to review their observations made during the week, and fill out a consensus expert observation form. This serves to further calibrate the observers and insures a shared understanding and interpretation of observations.

The test observers/administrators will be instructed not to address the test crews in any way during the scenario, other that as instructed and predefined in the scenario description for probing for situation awareness or to manage simulator and test unexpected difficulties. They will be expected not to discuss the scenario between themselves during the scenario. They will be instructed how to conduct the post scenario debriefings and the final debriefing. They will be instructed to at no time discuss any other crew performance and not give leading questions or comments. At no time will the observers be allowed to give any information that may predefine an upcoming scenario

The simulator system engineer receives the same training as the test observers/ administrators.

Qualifications of personnel supporting the V&V program

A. The multidisciplinary V&V Team, responsible for the overall V&V program (Reference 6-4 Part 1), will be composed of members, including members from the HSI Design Team, holding a degree in engineering human factors or psychology, with at least 5 years of experience in operations, HSI design, and HFE testing. The V&V team will function independently from the Design Team and be the pool from which the test observers/ administrators for both the Verification and Validation are supplied. The V&V team responsibilities included:

1. Developing the test procedures for the V&V,
2. Establishing the data collection and analysis protocols,
3. Performing the verification,
4. Conducting the introduction to the operating crews and all crew training,
5. Managing the simulations and observers/administrators debriefs of the crews,
6. Writing post scenario individual observer notes and consensus notes,

7. Developing or collecting individual HEDs based on observations,
8. Conducting the final V&V data analysis,
9. Briefing Mitsubishi and client management,
10. Participating in the Expert Panel HED review.
11. Managing all aspects of the V&V and all personnel involved.

B. The test observer/administrators will hold degrees in engineering, human factors or psychology and have at least 5 years of experience, including plant operations, HSI design and HFE testing. In addition observers/administrators will undergo Validation Test training as discussed above.

C. The scenario developers (See Section 4.3.4 for a description).

D. The Expert Panel, an independent group of senior experts, holding a degree in engineering, human factors or psychology, each with at least ten years of experience in the combined areas of plant operations, I&C system design, HSI design and HFE. The independence assures no influence from the Design Team or from the V&V Team.

The V&V Results Summary report will include the names and qualifications of all personnel supporting the V&V Program, including the V&V Team, test observers/administrators, scenario developers and test crews.

4.4.4 Test Crew Training

Each test crew participant will be selected randomly from a pool and will have completed an accredited operator license (at either the RO or SRO license level) training program and hold or have held the appropriate US license for the position in the scenario. Additionally, the participants will have completed a hands on familiarization program via the US-APWR dynamic V&V simulator, and in addition, a formal training program, taught by training experts that include classroom and simulator training. The training goal will be to have the participants at a level of proficiency that approximates licensing on the US-APWR plant. Classroom training will include US-APWR plant systems, operating procedures and HSI design. Participants will be trained on numerous plant events that encompass the knowledge needed to perform the validation scenarios, but will not be trained on the specific validation scenarios nor will participants be made up of the crew that supported the Pilot testing, see Section 4.4.5. To assure a consistent level of proficiency between operators a written and practical test on the US-APWR simulator being applied to the Validation will be administered. Only crews attaining a satisfactory outcome of 75% on the written and as judged by the Validation training instructor on the practical will be considered as qualified for test crew assignment.

4.4.5 Pilot Testing

Pilot Testing, ISV dry run, is conducted to validate the accuracy of the simulator, evaluate the training program for the observers/administrators and the test crew participants (using 1 crew that will not be part of the Validation tests), evaluate the test design and test procedure, gain experience for the test observers/administrators and simulator system engineer in running the test and assure that the validation runs smoothly and correctly. The Pilot Testing will be used to identify any remaining controllable bias in the test. The Pilot Testing will be performed on the final US-PWR HSI and apply the ISV procedure, scenarios, success criteria, and data collect methods prior to the actual validation.

4.5 Data Analysis

The ISV will include explicitly defined types of performance measures and data analysis as described in Section 4.3.5. Subjective data collection tools are contained in Appendix 3.

The multiple types of objective and subjective data that will be collected and analyzed provide converging evidence that the HSI meets plant safety goals, or identifies areas of the US-APWR HSI that need to be improved. The operator performance data and success criteria provide objective indication of instances of human performance success or problems. The Likert-scale rating questions on the operator post-scenario and final operator feedback forms, as well as the test personnel forms, provide numeric scores that could be used to objectively identify aspects of the US-APWR HSI that operators perceive are positive and aid the success of the crew, or deficient and lead to human performance difficulties. The HED input forms and open-ended HED entries in the operator feedback forms provide indication of specific HEDs that need to be addressed. The verbal debrief sessions provide rich contextual information that will be used to identify successful performance, as well as interpret the HEDs, understand their extent, and the broad cumulative effects and interrelationships that cross HEDs. Finally, the video and audio records offer a historical temporal link between the plant data (i.e., plant parameters, component positions, alarms, and displays) and the crew actions for each scenario. Multiple measures are expected to point to the same problem, reinforcing the need to address the issue. In cases where none of the measures reveal a problem the fact that multiple measures were used to probe for a problem increases confidence that there is no problem.

The results are entered into a spreadsheet and frequency counts are computed indicating how many crews (out of the total number included in the test) exhibited (one or more) performance problems in each of the nine performance problem categories:

1. Situation awareness
2. Control
3. Following procedures
4. Error tolerance
5. Mental workload
6. Physical workload
7. Team work
8. Supervision of automated systems
9. Staffing

<u>Acceptance Score:</u> Categories where two or more crews exhibited the same problem are highlighted as requiring additional assessment.

Such categories point to human performance areas of potential concern and indicate a need to examine the extent to which HEDs may have contributed to this human performance problem. Using the converging measures logic, HEDs that may have contributed to the human performance difficulties are identified based on review of validation team observations made during the scenarios as well as operator feedback obtained during the post-scenario debrief sessions, final debrief sessions, and HEDs that are submitted by the operators.

The post-scenario observer form asks the observers to rate technical and teamwork performance on a 5-point Likert-rating scale.

Acceptance Score: A score of 3 is labeled “acceptable”, a score of 1 is labeled “very poor” and a score of 5 is labeled “very good”.

Mean scores for each scenario across crews is computed separately for the plant operations expert and the 2 HFE experts that make up the observer/ administrator team since they represent different types of expertise. Mean scores are also computed across all the observers for each scenario. The results are presented in a table. Mean scores across observers of 1 or 2 will be highlighted to flag performance problems. Scores of 1 or 2 point to human performance areas of concern and indicate a need to examine the extent to which HSI may have contributed to this unsatisfactory human performance problem.

The final portion of the post-scenario observer form includes blank spaces for observers to write down HEDs they identified. Each validation team member reviews their own forms across the weeks they participate in crew observations and enters their HEDs into the HED tracking database.

The two questionnaire forms that operators fill out can be found in Appendix 3:

(1) A post-scenario operator form that is filled out at the end of each scenario

(2) A final operator feedback form that is filled out at the end of the non-safety HSI scenarios

The operator questionnaire forms consist of two types of items:

(1) Rating questions that use a five point Likert–scale

(2) Questions that solicit HEDs in free-form text

Responses to the Likert-scale rating questions will be entered into a spreadsheet from which simple descriptive statistics are computed (number of responders, mean score, range, and frequency of responses with a score of 1 or 2 representing unsatisfactory.).

Acceptance Score: Since “3” or above on the 5-point Likert-scale is labeled ‘acceptable’, any questions that receive a mean rating score of 1 or 2 are flagged for further examination.

The HEDs that operators enter in the questionnaires will be entered into the HED tracking database.

In addition, as part of the detailed data analysis, one of the HFE experts will review the final debrief videotapes and generate notes summarizing the recurring themes that arise across crews. These notes will be used as a basis for evaluating the results of the Likert scale analysis where scores of 1 or 2 have resulted, and for entering HEDs into the HED database. The HEDs resulting from the review of the video tapes will be used as a basis for identifying the extent, or links between human performance issues.

The data analysis and interpretation process will combine quantitative and qualitative methods to evaluate performance on these performance measures, identify and resolve HEDs, and establish that the HSI design has been validated. HEDs and data analysis results showing a rating of 1 or 2 will move into a corrective action and design change process and will be evaluated by the Expert Panel and the Design team to determine if HSI design changes are required. Immediate priority is given to Pass/Fail indicators which, when identified, enter the corrective action and design change process for immediate evaluation and resolution (reference the next section titled “Analysis of Pass/Fail Indicators”).

This corrective action and design change process is the same as been applied to the Phase 1a and Phase 1b HSI design test results, including HED resolution and closure. The Expert Panel will perform its review and assessment of results under the Expert Panel Charter. This review will be documented and will be auditable by the NRC. The data analysis, HEDs and design change conclusions will be documented in the Results Summary Report, section 4.8.

Analysis of Pass/Fail Indicators

If three crews cannot meet the Pass/Fail Indicators it will be considered as a failure. This will be defined as an HED that must be resolved, including retesting, prior to completion of the V&V program element and closure of the associated ITAAC.

All changes in the HSI design, plant operating procedures or plant training program as a result of a failure to comply with the Pass/Fail indicators will be.
If evaluated to determine the extent of re-testing, this evaluation will be documented.

4.6 ISV Conclusions

The conclusions of the integrated system validation will be based on:

- The specific HEDs as well as the extent of the identified performance issue
- The absolute number of new HEDs identified
- The objective performance of the HSI with the human in the loop as compared to the pretest developed success criteria
- The consensus of the observer's technical opinion
- Statistical subjective data analysis based on the phase 1 program and following that discussed in MUAP-08014 and MUAP-09019 (Reference 6-3 and 6-4)
- Design resolution of Pass/Fail Indicators

Validation limitations are considered in terms of identifying their possible effects on validation conclusions and impact on design implementation. These include:

- Aspects of the tests that were not well controlled
- Potential differences between the test situation and actual operations, such as absence of productivity-safety conflicts
- Potential differences, based on the V&V results, between the validated design and the as built plant
- Effects of bias and remaining uncontrolled bias that has been identified during the testing
- Unforeseen events that occurred during the V&V that effect the results

4.7 V&V HED Resolutions

HEDs resulting from the V&V and subsequent Validation Test data analysis will follow the documented HED resolution and closure process as summarized in Section 5.0 and described in detail in Appendix 2 and in Reference 6-4, Part 1.

4.8 Results

All results for the V&V Program will be developed in the form of a Results Summary Report as per NUREG-0711 (Reference 6-7).

The Results Summary Report will include:

- Verification;
  - A description of the application of this Implementation Plan in conducting the Verification program
  - Verification results based on Reference 6-5, examples of results presentation are contained in References 6-3 and 6-4
  - A copy of the Verification Test procedures
  - Names and qualifications of individuals involved in the Verification
- Validation;
  - A description of the application of this Implementation Plan in conducting the Validation program
  - A copy of the Validation test procedures
  - A description of the test personnel and plant test crew training program.
  - Qualifications of the test personnel, scenario developers and plant test crew.
  - A description of the test bed
  - A detailed description of all specific scenario sets used in the testing, including plant initial conditions, plant parameters of importance, event timing including expected operator actions, and applicable, scenario specific, performance measures and evaluation criteria
  - Data analysis at the level of depth as reported, as examples, in References 6-3 and 6-4
  - Validation results and conclusions as compared to the minimum set of test objectives described in Section 4.3.1.
  - A copy of the test data collection instruments used in the Validation
  - Names and qualifications of individuals involved in the Validation
  - A clear conclusion that the evaluation and criteria have been met
  - Identification of HEDs that will be evaluated for further HSI improvements

5.0 HUMAN ENGINEERING DISCREPANCY (HED)

An HED identification/ resolution and closure process was developed and successfully applied during the design process which included HEDs from the Phase 1 design process (Appendix 2). This process will be applied to all HFE elements, including V&V, as described in NUREG-0711 (Reference 6-7) as one of the program management coordinating mechanisms as described in MUAP-09019 (Reference 6-4, Part 1). Once a problem is identified, it will be evaluated and documented in the HED process by entering it into the HED database. The HED process includes review of and concurrence on the HED's resolution by the Design Team, the independent Expert Panel and, for the V&V program, the V&V team. As discussed in NUREG-0711 (Reference 6-7) issues resulting from the V&V program will be considered as HEDs if they cannot be resolved in a timely manner by agreement between the V&V team, the Design team, and the Expert Panel. If resolved, and not entered in to the HED process, the issue and resolution will be documented in the Results Summary report.

The full HED process applied to the HSI design is described in MUAP-09019 Part 1 (Reference 6-4) and restated for clarity of this Implementation Plan in Appendix 2 of this document, MUAP-10012.

6.0 REFERENCES

6-1 Design Control Document for the US-APWR, Chapter 18, Human Factors Engineering, MUAP-DC018, Revision 3, March 2011

6-2 MUAP-07007, "Human System Description and HFE Process," Revision 4, July 2011

6-3 MUAP-08014, "US-APWR Human System Interface Verification and Validation (Phase 1a)," Revision 1, May 2011

6-4 MUAP-09019, "US-APWR HSI Design," revision 2, October 2012

6-5 JEJC-1763-1001,"US-APWR HSI Design Style Guide," Revision 2, May 14 2008

6-6 ANSI/ANS 3.5- 1999, "Selection, Qualifications, and Training of Personnel for Nuclear Power Plants," Revision 1

6-7 NUREG-0711, "Human Factors Engineering Program Review Model," Revision 2, February 2004

6-8 NUREG/CR-6393, "Integrated System Validation: methodology and Review Criteria," January 1997

6-9 NUREG-0700, "Human-system Interface Design Review Guidelines," Revision 2, May 2002

6-10 ISO-11064," Ergonomics design of Control Centers- Part 1: Principals for Design of Control Centers," 2000

6-11. NUREG-0800,"Chapter 18 of the U.S.NRC Standard Review Plan for the Review of Human Factors Engineering for Nuclear Power Plants," Revision 2, March 2007

6-12 Tenney, Y.J & Pew, R.W. (2007), "Situation Awareness Catches on. What? So What? Now What? R.C. Williges (Ed). Reviews of Human factors and Ergonomics," (Vol. 2, pp. 89-129). Santa Monica, CA; Human Factors and Ergonomics Society.

6-13 Wickens, C.D. (2008), "Situation Awareness: review of Mica Endsleys 1995 Articles on Situation Awareness Theory and Measurement," Human Factors, vol.50, no 3 pp 397-403.

6-14 Roth, E. Scott, R. Whitaker, R. Kazmierczak, T. Truxler, R., Ostwald, J., and Wampler, J. "Designing Work-Centered Support for Dynamic Multi-Mission Synchronization," Proceedings of the 2009 International Symposium on Aviation Psychology, Dayton, Oh,. Scott, R. Whitaker, April 2009.

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6-16 NUREG-1021 Operator Licensing Examination Standard for Power Reactors, Revision 9, July 2004.

6-17 MUAP-10013, "US-APWR Design Implementation Plan," Revision 2, October 2012

Appendix 1: Examples of Scenarios of Design Certification Validation Phase 2b Scenario Event Sequence Descriptions and Evaluation criteria

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Appendix 2: HED Process Description

Human Engineering Discrepancies (HEDs) are the means or mechanism by which deficiencies in the HSI are identified throughout the HFE process (reference 6-4, part 1). The V&V program will use the HED process to identify, resolve, close and track issues resulting from the Task Support verification, Design Verification and Integrated System Validation described in this V&V Implementation Plan.

2.1 Human Engineering Discrepancy Process (Reference 6-4 Part 1)

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

1. Discrepancy Identification and 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, resolving and closing HEDs. HEDs may be generated as the result of issues discovered during 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 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 HSI Design Team shall generate the functional requirements for the HSI design change. The design change shall be developed and implemented by the HSI Design Team. Some HEDs may require simple changes to the HSI Inventory. Others may require changes to the US-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 HSI Design 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 HSI Design 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 HSI design team. The HSI Design Team shall assess the resolutions proposed by the Expert Panel, and may propose alternative design solutions.

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

The HED resolution will also define the HED closure requirements. HED closure will occur when the requirements of the HED closure requirement are considered satisfied by the HFE team and by an independent documented review by the Expert Panel. Closure for some HEDs may be based on updated documentation. Other HEDs may require testing. The HSI Design Team and Expert Panel shall agree on the closure requirements. The HSI Design Team and Expert Panel shall document their basis for considering the HED closed or for considering the HED closure requirements unsatisfied. The closure requirements establish the Evaluation 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.

2.2 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 HSI Design Team and the Expert Panel.

2.3 HED Evaluation

Outstanding HEDs will 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. However, this is not necessary. If preferred, each HED may be evaluated individually. HEDs that address unique issues are expected to be evaluated individually. 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.

2.3.1 NRC Grouping

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

- Scope
- HSI Component
- Plant System
- Personnel Tasks
-

However, as noted above, HEDs are grouped only to facilitate evaluation efficiency. Therefore, other groupings may be defined by the HSI Design Team and/or the Expert Panel. Grouping is not required if each HED is evaluated and closed individually.

2.3.2 HFE Grouping

To assist HED evaluation, resolution, and explanation it may be constructive to group HEDs by 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
- Physical workload
    - How much physical activity is required to respond to emergency events (e.g., pushing, pulling, turning, controlling, activating)
- 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
  -

2.4 HED Classification

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

2.4.1 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, 1 or 2, or a weighted score of 3 or lower by 20% of the individual operators on the test crews, RO, SRO, STA and other participants in the test as augmented MCR crew, on the V&V Questionnaire.
2. The HEDs have a significant frequency of independent repeat occurrences.
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.

2.4.2 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 equivalent to a ranking of NRC Priority 1.

2.5 HED Closure Requirement

All HEDs shall be processed to closure. Each HED will include clear, unambiguous closure requirements. Typical closure requirements are listed below. 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.

Where a resolution and closure requirement is applicable to multiple HEDs, the related 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.

2.6 HED Closure

Some HED closure requirements may require only updated documentation; others may require a documented plan for testing. This determination is made by the HFE Design Team and the Expert Panel based on considering the extent of the change and the degree of confidence in the resolution. Where a documented test plan is required, HED closure does not require the test to be completed, since if the test is not successful, additional HEDs will be generated during that test. This HED closure process avoids keeping HEDs open for extended durations, since there may be several years between the time when an HED is first identified and when an actual retest will occur. The US-APWR HSI will be considered acceptable only when all testing is completed with no significant HEDs generated.

An HED can be closed when the solution is documented and the closure requirements are met, as defined by the HED closure requirement. HED closure agreement must be reached between the HSI Design Team and the Expert Panel.

2.7 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.

2.7.1 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.

2.7.2 HED Database Description

The HEDs 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 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 HEDs 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 four 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	Expert Panel or HFE team completes its evaluation of the issue.
Resolve	Resolved	Expert Panel and HFE team agree on the resolution and closure requirement.

Table 1 HED Workflow Steps

Workflow Step	Issue Status	Workflow Description
Close	Closed	Expert Panel and HFE team agree that the resolution and closure requirement has been implemented.

2.7.3 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 2 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.
Week Number	The week number identifies which week during the project phase that the HED was identified.
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.

2.8 HED Evaluation

A number of data fields in the HED Data Base 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 3 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.

2.8.1 HED Resolution and Closure Requirement

A number of data fields are available to add information to an HED during the resolution and closure requirement workflow step. The data fields associated with this workflow step are shown in the Table 4 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 detailed design implementation)

2.8.2 HED 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. The data fields associated with this workflow step are shown in Table 5 below.

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

Appendix 3: Validation Questionnaires