Human Factors Verification and Validation Implementation Plan

Revision 2

Non-Proprietary

January 2018

REVISION HISTORY

Revision	Date	Page	Description
0	December 2014	All	First Issue
1	March 2017	xii (Acronyms and Abbreviation)	Terminology changed. (SAGAT -> SART) R_352-8205(74)
		4 (3)	Description for DIHA added. R_358-8449(89)
		8 (4.1.1.2)	Description that DIHA credited in TAA and D3CA added. R_358-8449(89)
		10 (4.1.1.3)	Description for error tolerance and recovery added. R_352-8205(62)
		14 (Table 4-3)	Editorial correction. R_352-8205(61)
		16 (4.1.3)	Description that DIHA credited in TAA and D3CA added. R_358-8449(89)
		22 (4.3.3)	Description for HEDs information added. R_352-8205(64)
		25 (Figure 4-2)	Design verification process modified. R_352-8205(65)
		26 (4.4.2)	Description for design verification process modified. R_352-8205(65)
		28 (4.5)	Description for independent team’s responsibility added. R_352-8205(66)
		30 (4.5.1)	Description for independent team added. R_352-8205(66)
		31 (4.5.2)	Description for error tolerance added. R_352-8205(62)
		33 (4.5.4)	Description for MCR composition added. R_352-8205(67), R_352-8205(67R)

Revision	Date	Page	Description
		35 (4.5.5)	Description for pass/fail measure criteria added. R_352-8205(69)
		35 (4.5.5)	Description for evaluation of convergence between measures added. R_352-8205(80)
		36 (4.5.5)	Editorial correction. R_352-8205(73)
		36 (4.5.5)	Terminology changed. (SAGAT -> SART) R_352-8205(74)
		37 (4.5.5.1)	Description for performance measure during scenario added. R_352-8205(69)
		37 (4.5.5.1)	Terminology changed. (SAGAT -> SART) R_352-8205(74)
		38 (4.5.5.1)	Description for measurement characteristic added. R_352-8205(73)
		39 (4.5.5.1)	Editorial correction. R_352-8205(71)
		40 (4.5.5.1)	Description for measurement characteristic modified. R_352-8205(73R)
		40 (4.5.5.1)	Editorial correction S_MES/KP-160186M
		41 (4.5.5.1)	Description for SAGAT deleted and SART added. R_352-8205(74)
		42 (4.5.5.2)	Description for observer questionnaire added. R_352-8205(71)
		44 (4.5.5.2)	Description for performance measure criteria added. R_352-8205(74)
		45 (4.5.5.2)	Description for performance evaluation measure modified. R_352-8205(75)
		46 (4.5.5.2)	Description for secondary task measure questionnaire added. R_352-8205(70)
		47 (Table 4-6)	Description for basis for performance criteria added. R_352-8205(74)
		47	Description for performance evaluation measure

Revision	Date	Page	Description
		(Table 4-6)	modified. R_352-8205(75)
		50 (4.5.6.2)	Description how test procedure minimize bias added. R_352-8205(77)
		50 (4.5.6.2.1)	Description that test procedure minimize bias deleted. R_352-8205(77)
		51 (4.5.6.3)	Description for validation team added. R_352-8205(66)
		53 (4.5.7)	Description for degree of freedom for scenario evaluation added. R_352-8205(78)
		53 (4.5.7)	Description for quantitative and qualitative method added. R_352-8205(78R)
		54 (4.5.7.1)	Description for scenario evaluation method added. R_352-8205(79)
		58 (4.5.7.2)	Description for time margin of DIHA added. R_358-8449(89)
		60 (4.5.7.3)	Description for margin of error added. R_352-8205(81)
		60 (4.5.7.3)	Description for margin of error modified. R_352-8205(81R)
		62 (4.5.8)	Description for qualitative method added. R_352-8205(78R)
		63-64 (4.5.9.2)	Description for HEDs selection modified. R_298-8356(41)
		63-64 (4.5.9.2)	Definition of HED modified. R_352-8205(82)
		xi, xii, 12, 20, 22, 23, 28, 36, 68 (Overall)	Editorial corrections (typos, acronyms, references)
2	January 2018	x (Figure 3-1)	Figure for ITTAAC Closure Schedule added R_553-9084(134R)
		4-5 (3)	Description and figure for ITTAC Closure Schedule added. R_553-9084(134R)

Revision	Date	Page	Description
		26 (4.4.2)	Editorial correction (Underlining, text line arrangement, deletion of unnecessary sentence) CR-17-J220
		37 (4.5.5.1)	Editorial correction (typo) CR-17-J220
		48 (4.5.6)	Editorial correction (typo) CR-17-J220
		60 (4.5.7.4)	Description for pilot test deleted. R_352-8205(78R) CR-17-J220
		61 (4.5.7.4)	Editorial corrections (text line arrangement, numbering) CR-17-J220
		61 (4.5.7.4)	Description for margin of error deleted. R_352-8205(78R) CR-17-J220
		68 (7.2,7.3,7.4, 7.6,7.7)	Revision No. and Issue Year/Month updated

ABSTRACT

This document provides the implementation plan (IP) for the Human Factors Engineering (HFE) Verification and Validation (V&V) program element, which is one of twelve program elements within the Advanced Power Reactor 1400 (APR1400) HFE Program. This IP governs the technical activities conducted within the verification and validation (V&V) program element by defining the scope and methodology of the V&V, including the output products generated and the qualifications of the personnel who will generate those products.

The main purposes of the V&V is to comprehensively determine that the human system interface (HSI) design conforms to HFE design principles and that it enables plant personnel to successfully perform their tasks to assure plant safety and operational goals.

The scope of the V&V program includes the main control room (MCR), remote shutdown room (RSR), and voice communications when it can influence the MCR crew's performance, between the MCR and the technical support center (TSC), emergency operations facility (EOF) and other off site emergency entities. The V&V program also includes local control stations (LCS) associated with important human actions.

This report contains the V&V IP describing five major V&V activities that are in full compliance with NUREG-0711, "Human Factors Engineering Program Review Model:

1. Sampling of operational conditions (SOC)
2. Design Verification
3. Integrated System Validation (ISV)
4. Human Engineering Discrepancy (HED) Resolution
5. Documentation of the results of the V&V program in a results summary report (ReSR)

It is impractical and unnecessary to review the entire HSI; therefore a SOC process is applied to support the selection of HSIs to include in the V&V. The resulting HSIs are applied as guidance for the design verification and are incorporated into realistic scenarios that are used in the ISV.

The design verification is composed of two types of evaluations, task support verification and human factors engineering (HFE) design verification. Task support verification will assess the HSI design to ensure that it supports the tasks identified in the task analysis (TA). The HFE design verification confirms that the HSI meets the HFE requirements of the Style Guide (Reference 2). The design verification is completed early in the V&V program so that any HSI modifications identified during the design verification and determined to require a change to the HSI design are completed before the start of the ISV.

The ISV confirms the acceptable performance of the integrated system through comprehensive performance based, human in the loop, testing on a verified dynamic MCR simulator using a set of scenarios based on the SOC. As needed, part task simulation and interface mockup are used to augment the application of the simulator. The use of these alternative test platforms is limited to cases where the use of the MCR simulator is not reasonable, e.g., local control stations identified by the treatment of important human actions (TIHA) and the TSC.

Acceptable performance of the HSI is based on measures of plant performance, human task performance, situation awareness, cognitive and physical workload, and anthropometric and physiological factors. Measures are divided into two types, pass/fail and diagnostic.

The human engineering discrepancies process is used to track, through closure, all discrepant findings resulting from the V&V program.

The V&V program uses results from the operating experience review (OER), TA, TIHAs, staffing and qualifications (S&Q) and human system interface design (HD). The V&V program also applies the results of the procedure and training development programs.

The V&V program confirms that the HSI design conforms to HFE design principals and that plant staff are able to perform their tasks to achieve plant safety and plant operational goals. The V&V results are documented in the ReSR. The ReSR confirms that the V&V program was conducted in accordance with this implementation plan and the HSI design is acceptable.

IP has the following contents:

- Section 1 of this IP presents the purpose of the V&V program and of this IP.
- Section 2 presents the scope of the V&V program.
- Section 3 is an overview of the V&V methodology and documentation program and discusses the link between the V&V program and other elements of the HFE program.
- Section 4 describes the details of the methodology criteria and documentation of the V&V program.
- Section 5 describes the makeup of the V&V team's personnel along with their professional qualifications.
- Section 6 describes the content of the ReSR
- Section 7 references
- Section 8 definitions
- Appendix A contains a matrix of how this IP meets the criteria from NUREG-0711 rev 3
- Appendix B contains the Behavioral Anchored Rating Scales (BARS) used to analyze ISV data
- Appendix C contains the NASA-TLX questionnaire to be used in the ISV.

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ACRONYMS AND ABBREVIATIONS

ANS	American Nuclear Society
ANSI	American National Standards Institute
APR1400	Advanced Power Reactor 1400
BARS	behaviorally anchored rating scale
BTP	Branch Technical Position
C&ID	control and instrumentation diagram
CCW	component cooling water
CFR	Code of Federal Regulations
CLD	control logic diagram
DBA	design basis accident
DCD	Design Control Document
DI	design implementation
DIHA	deterministically important human action
D3	diversity and defense-in-depth
EO	electrical operator
EOF	emergency operation facility
EOP	emergency operating procedure
FPD	flat panel display
FRA/FA	functional requirements analysis and function allocation
HA	human action
HD	HSI design
HED	human engineering discrepancy
HFE	human factors engineering
HFEPP	human factors engineering program plan
HSI	human-system interface
HVAC	heating, ventilation, and air conditioning
I&C	instrumentation and control
IAEA	International Atomic Energy Agency
IHA	important human action
IP	implementation plan
ISV	integrated system validation
ITS	issue tracking system
KEPCO	Korea Electric Power Corporation
KHNP	Korea Hydro & Nuclear Power Co., Ltd.
LCS	local control station

LDP	large display panel
LOCA	loss of coolant accident
MCR	main control room
NRC	Nuclear Regulatory Commission
NASA	National Aeronautics and Space Administration
OER	operating experience review
P&ID	piping and instrumentation diagram
PRA	probabilistic risk assessment
RCS	reactor coolant system
ReSR	results summary report
RIHA	risk-important human action
RG	Regulatory Guide
RO	reactor operator
RSC	remote shutdown console
RSR	remote shutdown room
SART	situation awareness rating technique
S&Q	staffing and qualifications
SG	steam generator
SI	safety injection
SIAS	safety injection actuation signal
SME	subject matter expert
SOC	sampling of operational conditions
SOP	system operating procedure
SRO	senior reactor operator
SS	shift supervisor
STA	shift technical advisor
TA	task analysis
TAA	transient and accident analysis
TIHA	treatment of important human actions
TLX	task load index
TO	turbine operator
TS	trade secret
TSC	technical support center
V&V	verification and validation
VDU	visual display unit

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1. PURPOSE

The purpose of the human factors verification and validation (V&V) is to comprehensively determine, through evaluations and performance tests, that the integrated system design of the Advanced Power Reactor 1400 (APR1400) conforms to accepted human factors engineering (HFE) design principles, and that the design ensures that plant personnel are able to successfully perform their tasks to achieve plant safety and power production goals.

The V&V ensures that the integrated system design:

- Consistent with the APR1400 design
- Remains within acceptable performance conditions under a broad set of operating modes and conditions
- Provides the alarms, displays and controls required to support personnel tasks as defined by the task analysis (TA) and
- Meet the guidance in the Style Guide (Reference 2)

The goals of the V&V implementation plan (IP) are to:

- Identify a sample of operating conditions that represent a broad range of events that could be encountered during operation, reflect the characteristics expected to contribute to variations in the APR1400 performance, and consider the safety significance of the HSI
- Ensure that the human-system interface (HSI) inventory and its characteristics accurately represent the HSI system per the sampling of operational conditions (SOC)
- Verify that the HSI contains the required alarms, information, controls and task support as defined by the task analysis (TA)
- Validate that the HSI design (HD) supports the safe operation of the plant through an integrated system validation (ISV)
- Identify and evaluate human engineering discrepancies (HEDs) that result from the V&V
- To achieve its purpose and goals, the V&V uses the output from the:
- Operating experience review (OER)
- TA
- Treatment of important human actions (TIHA)
- Staffing and qualification (S&Q)
- HD
- Operating procedures development and training programs

The V&V IP provides a description of the methods, measures, and acceptance criteria that are required to be performed to achieve an effective V&V evaluation that fully meets NUREG-0711, Human Factors

Engineering Program Review Model.

The results from the V&V are documented in the V&V results summary report (ReSR), which serves to demonstrate that the V&V was performed in accordance with this IP and its implementation procedures and that the HD is acceptable.

2. SCOPE

The HF V&V Implementation Plan applies to all HSIs in the main control room (MCR), remote shutdown room (RSR), and voice communications when HSI design can influence the MCR crew's performance, between the MCR and the technical support center (TSC), emergency operation facility (EOF) and other off site emergency entities. This IP also applies the V&V process to the HSIs at the local control stations (LCSs) associated with important human actions (IHAs).

The V&V process consists of five activities:

1. Sampling of operational conditions (SOC):
   - Identify conditions that are representative of the range of events that could be encountered during plant operation,
   - Reflect the characteristics expected to contribute to variations in the operation performance and consider the safety significance of HSIs

2. HFE design verification:
   - Determine the HSI inventory and characterizing of the HSI displays, controls, and related equipment that are within the scope defined by the selected sample of operational conditions.
   - Verify through task support verification that the HSI provides the needed alarms, information, controls, and task support defined by the TA for personnel performing their tasks.
   - Verify through HFE design verification that the HD conforms to the Style Guide

3. Integrated system validation (ISV):
   - Validate, through human in the loop performance tests, that the integrated system design (e.g., hardware, software, procedures, personnel elements) supports the safe operation of the plant.

4. HED resolution:
   - Evaluate HEDs to determine whether they require corrections
   - Identify design solutions to address HEDs that must be corrected
   - Verify the completed implementation of the HED design solutions and documents the HED in the issue tracking system (ITS)

5. ReSR
   - Documents the results of the V&V

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7. REFERENCES

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8. DEFINITIONS

1. Bias

   Bias is an aspect of an evaluation methodology that systematically modifies performance or its interpretation.

2. Important Human Actions (IHAs)

   Important human actions consist of those actions that meet either risk or deterministic criteria in terms of plant safety.

   - Risk-important human actions: Actions defined by risk criteria that plant personnel use to assure plant safety. There are absolute and relative criteria for defining risk important human actions. For absolute criteria, a risk-important human action (RIHAs) is any action whose successful performance is needed to reasonably assure that predefined risk criteria are met. For relative criteria, the risk-important actions are defined as those with the greatest risk compared to all human actions. Risk-important human actions based on relative criteria can be identified quantitatively from risk analyses, and qualitatively from various criteria, such as an evaluation of the task performance based on considering performance-shaping factors.
   - Deterministically identified important human actions: Deterministic engineering analyses typically are completed and described as part of the APR1400 DCD. Such analyses include instrumentation and controls (I&C) as described in Chapter 7 and transient and accident analyses, as described in Chapter 15. These deterministic analyses also credit human actions.

3. Human-System Interface (HSI)

   A human system interface (HSI) is that part of the system through which personnel interact to perform their functions and tasks. Major HSIs include alarms, information displays, controls, and procedures. HSI use can be influenced directly by factors such as (1) the organization of HSIs into workstations (e.g., consoles and panels); (2) the arrangement of workstations and supporting equipment into facilities, such as a main control room, remote shutdown station, local control stations, the technical support center (TSC), and the emergency operation facility (EOF); and (3) the environmental conditions in which the HSIs are used, including temperature, humidity, ventilation, illumination, and noise. The use of HSIs also can be affected indirectly by other aspects of plant design and operation, such as personnel training, shift schedules, work practices, and management and organizational factors, such as the safety culture of the plant staff.

4. Plant

   The operating unit of a nuclear power station, including the nuclear steam supply system, the turbine, electrical generator, and all associated systems and components (commonly referred to as the balance of plant). For a multi-unit plant, the term “plant” refers to all systems and processes associated with a specific unit’s ability to produce electrical power, even though other units might share some systems or portions of systems.

5. Primary Tasks

   Primary Tasks are those tasks performed by personnel to supervise the plant (e.g., monitoring, detection, situation assessment, response planning, and response implementation).

6. Operating Procedures

   Written instructions providing guidance to plant personnel for operating and maintaining the plant, and for handling disturbances and emergency conditions.

7. Secondary Tasks

   Secondary tasks are those tasks personnel must complete when interfacing with the HSI, such as navigation through computer screens to find a needed display and HSI configuration. Complicated secondary tasks often have negative effects on the performance of primary tasks.

8. Simulator

   A facility that physically represents the HSI configuration and that dynamically represents the operating characteristics and responses of the plant in real time.

APPENDIX A NUREG-0711 REVIEW CRITERIA CONFORMANCE TABLE

NUREG-0711 Rev. 3 Criteria	IP Section(s)
11.4.1 Sampling of Operational Conditions As stated in Section 11.2, the objective of the Sampling of Operational Conditions review is to verify that the applicant identified a sample of operational conditions that (1) includes conditions representative of the range of events that could be encountered during the plant's operation, (2) reflects the characteristics expected to contribute to variations in the system's performance, and (3) considers the safety significance of HSIs. These sample characteristics are best identified by using a multidimensional sampling strategy to reasonably assure that V&V evaluations include variation along important dimensions. The sampling methodology will identify a range of operational conditions to guide Task Support Verification, HFE Design Verification, and ISV. The NRC's review of this activity considers the dimensions to be used to identify and select conditions, and their integration into scenarios.	4.1 Sampling of Operational Conditions Table 4-1, 4-2, 4-3
11.4.1.1 Sampling Dimensions The following sampling dimensions are addressed below: Plant conditions, personnel tasks, and situational factors known to challenge personnel performance. (1) The applicant should include the following plant conditions: • normal operational events including plant startup, shutdown or refueling, and significant changes in operating power • I&C and HSI failures and degraded conditions that encompass: - The I&C system, including the sensor, monitoring, automation and control, and communications subsystems; [e.g., safety-related system logic and control unit, fault tolerant controller, local "field unit" for multiplexer (MUX) system, MUX controller, and a break in MUX line] - common cause failure of the I&C system during a design basis accident (as defined by BTP 7-19) - HSIs including, loss of processing or display capabilities for alarms, displays, controls, and computer-based procedures • transients and accidents, such as: - transients (e.g., turbine trip, loss of off-site power, station blackout, loss of all feedwater, loss of service water, loss of power to selected buses or MCR power supplies, and safety and relief valve transients) - accidents (e.g., main-steam-line break, positive reactivity addition, control rod insertion at power, anticipated transient without scram, and various-sized loss-of coolant accidents) - reactor shutdown and cooldown using the remote shutdown system - reasonable, risk-significant, beyond-design-basis events that should be determined from the plant-specific PRA	4.1.1 Sampling Dimensions
(2) The applicant should include the following types of personnel tasks: • Important HAs, Systems, and Accident Sequences – The sample should include all important HAs, as determined in Section 7. Additional factors that contribute highly to risk, as defined by the PRA, also should be sampled: - dominant accident sequences - dominant systems (selected through PRA importance measures, such as Risk Achievement Worth or Risk Reduction Worth • Manual Initiation of Protective Actions – The sample should include	4.1.1(B) IHAs, Systems and Accident Sequences

NUREG-0711 Rev. 3 Criteria	IP Section(s)
manual system level actuation of critical safety functions. • Automatic System Monitoring – The sample should include situations in which humans must monitor a risk-important automatic system. • OER-Identified Problematic Tasks – The sample should include all personnel tasks identified as problematic during the applicant's review of operating experience. • Range of Procedure Guided Tasks –The sample should include tasks that are well defined by procedures. Personnel should be able to understand and execute the specified steps as part of their rule-based decision-making. Regulatory Guide 1.33, Appendix A, contains several categories of "typical safety-related activities that should be covered by written procedures." The sample should include appropriate procedures in each category: - administrative procedures - general plant operating procedures - procedures for startup, operation, and shutdown of safety-related systems - procedures for abnormal, off-normal, and alarm conditions - procedures for combating emergencies and other significant events (e.g., reactor accidents, and declaration of emergency-action levels) - procedures for controlling radioactivity - procedures for controlling measuring and test equipment and for surveillance tests, procedures, and calibration - procedures for performing maintenance - chemistry and radiochemical control procedures • Range of Knowledge-Based Tasks – The sample should include tasks that are not well defined by detailed procedures. • Range of Human Cognitive Activities – The sample should include the range of cognitive activities that personnel perform, including: - detecting and monitoring (e.g., of critical safety-function threats) - situation assessment (e.g., interpreting alarms and displays to diagnose faults in plant processes and in automated control and safety systems) - planning responses (e.g., evaluating alternatives to recover from plant failures) - response implementation (e.g., in-the-loop control of plant systems, assuming manual control from automatic control systems, and carrying out complicated control actions) - obtaining feedback (e.g., feedback of the success of actions taken) • Range of Human Interactions – The sample should include the range of interactions among plant personnel, including tasks performed independently by individual crew members, and those undertaken by a team of crew members. These interactions among plant personnel should include interactions between: - main control room operators (e.g., operations, shift turnover walkdowns) - main control room operators with auxiliary operators and other plant personnel performing tasks locally (e.g., maintenance or I&C technicians, chemistry technicians) - main control room operators and the TSC and the EOF - main control room operators with plant management, the NRC, and other outside organizations (3) The applicant should include the following situational factors or error-	

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forcing contexts known to challenge human performance. It also should include situations specifically designed to create human errors to assess the system's error tolerance, and the ability of personnel to recover from any errors, should these occur, for example: • High-Workload Situations – The sample should include situations where variations in human performance due to high workload and multitasking situations can be assessed. • Varying-Workload Situations – The sample should include situations wherein variations in human performance due to workload transitions can be determined. These include conditions where there is (1) a sudden increase in the number of signals that must be detected and processed after a period in which signals were infrequent, and (2) a rapid reduction in the need for detecting signals and processing demands following a time of high sustained task-demand. • Fatigue Situations – To the extent possible, the sample should include situations that may be associated with fatigue, such as work on backshifts and tasks performed frequently with repetitive actions, such as repeated inputs to a touch screen during plant operations or pulling rods. • Environmental Factors – To the extent possible, the sample should include environmental conditions that may cause human performance to vary, e.g., poor lighting, extreme temperatures, high noise, and simulated radiological contamination.	
11.4.1.2 Identification of Scenarios (1) The applicant should combine the results of the sampling to identify a set of V&V scenarios to guide subsequent analyses.	4.1.2 Identification of Scenarios Table 4-1, 4-2, 4-3
(2) The applicant should not bias the scenarios by overly representing the following: • scenarios for which only positive outcomes are expected • scenarios that, for ISV, are relatively easy to conduct (e.g., scenarios should not be avoided simply because they are demanding to set up and run on a simulator) • scenarios that, for ISV, are familiar and well structured (e.g., which address familiar systems and failure modes that are highly compatible with plant procedures, such as “textbook” design-basis accidents)	4.1.2 Identification of Scenarios, Scenario Design Requirements
11.4.1.3 Scenario Definition (1) The applicant should identify operational conditions and scenarios to be used for HSI Task Support Verification, Design Verification, and ISV. The applicant should develop detailed scenarios suitable for use on a full-scope simulator. The level of detail should be comparable to what one would include in a test plan. For each one, the following information should be defined to reasonably assure that important dimensions of performance are addressed, and to allow the scenarios to be accurately and consistently presented for repeated trials: • a description of the scenario and any pertinent prior history necessary for personnel to understand the state of the plant at the start-up of the scenario • specific initial conditions (a precise definition of the plant's functions, processes, systems, component conditions, and performance parameters, e.g., similar to that at shift turnover) • events (e.g., failures) that will occur during the scenario and their initiating conditions, e.g., based on time, or a value of a specific	4.1.3 Scenario Definition Reference 4 4.1.4 Scenario Components

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parameter • precise definition of workplace factors, (e.g., environmental conditions, such as low levels of illumination) • needs for task support (e.g., procedures and technical specifications) • staffing level • details of communication content between control room personnel and remote personnel (e.g., load dispatcher via telephone) • scripted responses for test personnel who will act as plant personnel in the test scenarios • the precise specification of what, when, and how data are to be collected and stored (including videotaping, questionnaires, and rating-scale administrations) • precise specifications on simulator set up • specific criteria for terminating the scenario (2) The applicant's scenarios should realistically replicate operator tasks in the tests; then, the findings from the test can be generalized to the plant's actual operations. (3) When the applicant's scenarios include work associated with operations remote from the main control room, the effects on personnel performance due to potentially harsh environments (e.g., high radiation) should be realistically simulated (e.g., additional time to don protective clothing, and access radiologically controlled areas).	
11.4.2 Design Verification Review Criteria 11.4.2.1 HSI Inventory and Characterization As stated in Section 11.2, the objective of the review is to verify that the applicant's HSI inventory and characterization accurately describes all HSI displays, controls, and related equipment lying within the scope defined by the sampling of operational conditions. Applicants may document their HSI inventory in different ways. They should describe the means by which this is done, and provide it to the NRC's staff for review using the criteria in this section.	4.2 Design Verification 4.2.1 HSI Inventory and Characterization
(1) Scope – The applicant should develop an inventory of all HSIs that personnel require to complete the tasks covered in the validation scenarios that were identified by the applicant's Sampling of Operational Conditions. The inventory should include aspects of the HSI used for managing the interface, such as navigation and retrieving displays, as well as those that control the plant.	4.2.1.1 Scope
(2) HSI Characterization – The applicant's inventory should describe the characteristics of each HSI within the scope of the verification. The following is a minimal set of information for this characterization: • a unique identification code number or name • associated plant system and subsystem • associated personnel functions and tasks • type of HSI, e.g., - computer-based control (e.g., touch screen or cursor-operated button and keyboard input) - hardwired control (e.g., J-handle controller, button, and automatic controller) - computer-based display (e.g., digital value and analog representation) - hardwired display (e.g., dial, gauge, and strip-chart recorder) • display characteristics and functionality [e.g., plant variables/parameters, units of measure, accuracy of variable/	4.2.1.2 HSI Characterization

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parameter, precision of display, dynamic response, and display format (e.g., bar chart or trend plot)] • control characteristics and functionality [e.g., continuous versus discrete settings, number and type of control modes, accuracy, precision, dynamic response, and control format (method of input)] • user-system interaction and dialog types (e.g., navigation aids and menus) • location in data-management system (e.g., identification code for information display screen) • physical location in the HSI (e.g., control panel section), if applicable The applicant should include photographs, copies of display screens, or similar samples of HSIs in the HSI inventory and characterization. (3) Inventory Verification – The applicant should verify the inventory description of HSIs to ensure that it accurately reflects their current state.	
11.4.2.2 HSI Task Support Verification HSI Task Support Verification addresses the availability of items needed to support task requirements. As stated in Section 11.2, the objective of the HSI Task Support Verification review is to ensure that the applicant verified that the HSI provides the needed alarms, information, controls, and task support for personnel to perform their tasks, defined by the task analysis.	4.2.1.3 Inventory Verification 4.3 Task Support Verification
(1) Verification Criteria – The applicant should base the HSI task support criteria on the alarms, controls, displays, and task support needed by personnel to complete their tasks as identified by the applicant's task analysis.	4.3.1 Verification Criteria
(2) General Methodology – The applicant should compare the HSIs and their characteristics (as defined in the HSI inventory and characterization) to the needs of personnel identified in the task analysis for the defined sampling of operational conditions, noted in Section 11.4.1.	4.3.2 General Methodology Steps 1, 2, 3, 4, 5
(3) HED Identification – The applicant should identify and document an HED when: • An HSI needed for task performance (e.g., a necessary control or display) is unavailable. • HSI characteristics do not match the requirements of the personnel task (e.g., a display may show the needed plant parameter but not within the range or precision needed for the task). • HSIs are available that are not needed for any task.	4.3.3 HED Identification 4.5.9 HED Resolution Review Criteria
(4) HED Documentation – The applicant should document HEDs to identify the HSI, the tasks affected, and the basis for the deficiency (what aspect of the HSI was identified as not meeting task requirements).	4.5.9.5 HED Evaluation Documentation
11.4.2.3 HFE Design Verification HFE Design Verification addresses the suitability of the HSI with regard to human capabilities and limitations. As stated in Section 11.2, the objective of the HFE Design Verification review is to evaluate the applicant's verification that the design of the HSIs conforms to HFE guidelines.	4.4 HFE Design Verification
(1) Verification Criteria – The applicant should base the criteria used for HFE Design Verification on HFE guidelines.	4.4.1 Verification Criteria
(2) General Methodology – The applicant's HFE Design Verification methodology should include the following: • Procedures for comparing the characteristics of the HSIs with HFE guidelines for: (1) the defined sampling of operational conditions, as noted in Section 11.4.1, and (2) the general environment in which HSIs are sited, including workstations,	4.4.2 General Methodology Steps 1, 2, 3, 4 5

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control rooms, and environmental characteristics (e.g., lighting and noise). • Procedures for determining for each guideline whether the HSI is "acceptable" or "discrepant." If discrepant, it should be designated as an HED, tracked, and evaluated (see Sections 2.4.4 and 11.4.4). • Procedures for evaluating whether an HED is a potential indicator of additional issues.	
(3) HED Identification – The applicant should identify an HED when a characteristic of the HSI is "discrepant" from a guideline.	4.4.3 HED Identification
(4) HED Documentation – The applicant should document HEDs in terms of the HSI involved, and how its characteristics depart from a particular guideline.	4.5.9.5 HED Evaluation Documentation
(5) Additional Considerations for Reviewing the HFE Aspects of Plant Modifications – In addition to any of the criteria above that relate to the modification being reviewed, the applicant should address the following considerations: • The scope of HFE design verification may be restricted to the modified HSIs and their interactions with the rest of the HSIs. • When both old and new versions of similar HSIs are available, this verification should offer reasonable assurance that their means of presentation and methods of operation are compatible, such that personnel performance will not be impaired when alternating the use of each one. • HEDs should be identified for the following: - failure to meet "personnel-identified" functionality in addition to that specified by system designers. When a digital system replaces an existing system, it is important to ensure that all operational uses of the former system were addressed, even those that were not intended in the original design. The replacement system's design should consider the ways in which personnel actually used the former system - poor integration with the rest of the HSI - poor integration with procedures and training • Temporary configurations of the HSIs and plant systems that operations and maintenance personnel may use when the plant is not shutdown, should be reviewed to verify that their design is consistent with the principles of good HFE design, including consistency with the rest of the HSIs.	
11.4.3 Integrated System Validation As stated in Section 11.2, the objective of the ISV review is to verify that the applicant validated, using performance-based tests, that the integrated system design (e.g., hardware, software, procedures and personnel elements) supports the safe operation of the plant. The scenarios for ISV should be performed using a simulator, or other suitable representation of the system, to determine the complete design's adequacy to support safe operations. Validation should be performed after the resolution of all significant HEDs identified in verification reviews. Applicants submitting an ISV IP for staff review should follow the general guidance in Section 1.2.2. The IP should describe the methodology of the tests that will be performed. It should identify the specific scenarios to be used, and detail them at a level that will support the staff's review, using the criteria stated in this section. The level of scenario detail should be comparable to that in a test plan. For each scenario, the applicant should specify the specific	4.5 Integrated System Validation

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performance measures used for pass/fail along with the criteria for diagnostic evaluations to be used in assessing the results. The NRC will not accept submittals that merely provide a plan for developing the detailed ISV methodology. 11.4.3.1 Validation Team (1) The applicant should describe how the team performing the validation has independence from the personnel responsible for the actual design. 11.4.3.2 Test Objectives (1) The applicant should develop detailed test objectives to provide evidence that the integrated system adequately supports plant personnel in safely operating the plant, to include the following considerations: • Validate the acceptability of the shift staffing level(s), the assignment of tasks to crew members, and crew coordination within the control room, between the control room and local control stations and support centers, and with individuals performing tasks locally. This should encompass validating minimum shift staffing levels, nominal levels, maximum levels, and shift turnover (see Section 6 for definitions). • Validate that the design has adequate capability for alerting, informing controlling, and feedback such that personnel tasks are successfully completed during normal plant evolutions, transients, design-basis accidents, and also under selected, risk significant events beyond-design basis, as defined by sampling operational conditions. • Validate that specific personnel tasks can be accomplished within the time and performance criteria, with effective situational awareness, and acceptable workload levels that balance vigilance and personnel burden. • Validate that the HSIs minimize personnel error and assure error detection and recovery capability when errors occur. • Validate the assumptions about performance on important HAs. • Validate that the personnel can effectively transition between the HSIs and procedures in accomplishing their tasks, and that interface management tasks, such as display configuration and navigation, are not a distraction or an undue burden.	
11.4.3.3 Validation Testbeds A testbed is the HSI representation used to perform validation evaluations. One approach an applicant can use to acceptably meet criteria 1 through 7 in this section is to use a testbed that is compliant with "Nuclear Power Plant Simulators for Use in Operator Training" (ANS, 2009). (1) Interface Completeness – The applicant's testbed should represent completely the integrated system. It should include HSIs and procedures not specifically required in the test scenarios. (2) Interface Physical Fidelity – The testbed's HSIs and procedures should be represented with high physical fidelity to the reference design, including the presentation of alarms, displays, controls, job aids, procedures, communications equipment, interface management tools, layout, and spatial relationships. (3) Interface Functional Fidelity – The testbed's HSI and procedure functionality should be represented with high fidelity to the reference design. All HSI functions should be available. (4) Environmental Fidelity – The testbed's environmental fidelity should be represented with high physical fidelity to the reference design, including the expected levels of lighting, noise, temperature, and humidity. Thus, for example, the noise contributed by equipment, such as air-handling units,	4.5.3 Validation Testbed 3 Methodology Overview 4.1 Sampling of Operational Conditions 4.5.1 Validation Team 4.5.2 Test Objectives 1 Purpose

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computers, and communications equipment should be represented in validation tests. (5) Data Completeness Fidelity – Information and data provided to personnel should completely represent the plant's systems they monitor and control. (6) Data Content Fidelity – The testbed's data content fidelity should be represented with high physical fidelity to the reference design. The presentation of information and controls should rest on an underlying model accurately mirroring the reference plant. The model should provide input to the HSI such that the information accurately matches that which is presented during operations. (7) Data Dynamics Fidelity – The testbed's data dynamics fidelity should be represented with high fidelity to the reference design. The process model should be able to provide input to the HSI so that information flow and control responses occur accurately and within the correct response time; e.g., information should be sent to personnel with the same delays as occur in the plant. (8) For important HAs at complex HSIs remote from the main control room (e. g., a remote shutdown facility), where timely, precise actions are essential, the use of a simulator or mockup should be considered to verify that the requirements for human performance can be met. (For less important HAs, or for non complex HSIs, human performance may be assessed on analysis, such as task analysis, rather than on simulations.) (9) The applicant should verify the conformance of the testbed to the testbed-required characteristics before validation tests are conducted.	4.5.3 Validation Testbeds
11.4.3.4 Plant Personnel (1) Participants in the applicant's validation tests should be representative of plant personnel who will interact with the HSI (e.g., licensed operators, rather than training personnel or engineers). (2) To properly account for human variability, the applicant should use a sample of participants that reflects the characteristics of the population from which it is drawn. Those characteristics expected to contribute to variations in system performance should be specifically identified; the sampling process should reasonably assure that the validation encompasses variation along that dimension. Determining representativeness should include considering the participants' license type and qualifications, skill/experience, age, and general demographics. (3) In selecting personnel for participating in the tests, the applicant should consider the minimum shift staffing levels, nominal levels, and maximum levels, including shift supervisors, reactor operators, shift technical advisors, etc. (4) The applicant should prevent bias in the sample of participants by avoiding the use of participants who: • are members of the design organization • participated in prior evaluations • were selected for some specific characteristic, such as crews identified as good performers or more experienced	4.5.4 Plant Personnel (Participants) Table 4-4
11.4.3.5 Performance Measurement ISV employs a hierarchal set of performance measures including measures of plant performance, personnel task performance, situation awareness, cognitive workload, and anthropometric/physiological factors. Errors of omission and commission also are identified. A hierarchal set of measures provides sufficient information to validate the integrated system design and affords a basis to	4.5.5 Performance Measures

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evaluate deficiencies in performance and thereby identify needed improvements. Pass/fail measures are those used to determine whether the design is or is not validated. Diagnostic measures are used to better understand personnel performance and to facilitate the analyses of errors and HEDs.	
11.4.3.5.1 Types of Performance Measures (1) The applicant should identify the specific plant performance measures applicable to each ISV scenario. (2) The applicant should identify the primary task measures applicable to each ISV scenario. • For each scenario, the applicant should identify the primary tasks operators must perform to accomplish scenario goals, so that such measures can be developed. • The measures chosen to evaluate personnel task performance should reflect those aspects of the task that are important to system performance, such as: - time - accuracy - frequency - amount achieved or accomplished - consumption or quantity used - subjective reports of participants - behavior categorization by observers • The analysis of primary tasks will support the identification of errors of omission (primary tasks not performed). Also, any actions and tasks that operators actually perform that deviate from the primary tasks should be identified and noted. These actions should be used to identify errors of commission. (3) The applicant should identify the secondary task measures applicable to each scenario. (4) The applicant should identify the measures of situation awareness applicable to each scenario (5) The applicant should identify the workload measures obtained for each scenario. (6) The applicant should identify the anthropometric and physiological measures obtained for each scenario.	4.5.5.1 Types of Performance Measures used
11.4.3.5.2 Performance Measure Information and Validation Criteria (1) The applicant should describe the methods by which these measures are obtained, e.g., by simulator data recording, participant questionnaires, or observation by subject-matter experts. (2) The applicant should specify when each measure is obtained (recorded), such as continuously, at specific points during the scenario, or after the scenario ends. (3) The applicant should describe the characteristics (see Table 11-1) of the performance measures.	4.5.5.2 Performance Measure Information and Validation Criteria
Table 11-1 Characteristics of Performance Measures Construct Validity A measure should represent accurately the aspect of performance it is intended to measure. Reliability A measure should be repeatable; e.g., same behavior measured in exactly the same way under identical circumstances should yield the same results. Sensitivity A measure's range (scale) and its frequency (how often data are collected) should be appropriate to that aspect of performance being assessed.	Table 4-6

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Unobtrusiveness A measure should minimally alter the psychological or physical processes that are being investigated. Objectivity A measure should be based on easily observed phenomena. (4) The applicant should identify the specific criterion for each measure used to judge the acceptability of performance and describe its basis. Table 11-2 Basis for Performance Criteria Requirement The observed performance of the integrated system is compared with a quantified performance requirement; e.g., the requirements for the performance of systems, subsystems, and personnel are defined through engineering analyses. Benchmark The observed performance of the integrated system is compared with a criterion established using a benchmark system, e.g., a current system is predefined as acceptable. Norm The observed performance of the integrated system is compared with a criterion using many predecessor systems (rather than a single benchmark system). Expert Judgment The observed performance of the integrated system is compared with a criterion established by subject-matter experts. (5) The applicant should identify whether each measure is a pass/fail one or a diagnostic one.	
11.4.3.6 Test Design The criteria in this section are divided into the following subsections:	4.5.6 Test Design
11.4.3.6.1 Scenario Sequencing (1) The applicant should balance scenarios across crews to provide each crew with a similar, representative range of scenarios. (2) The applicant should balance the order of presentation of scenarios to crews to provide reasonable assurance that the scenarios are not always presented in the same sequence (e.g., the easy scenario is not always used first).	4.5.6.1 Scenario Sequencing Table 4-7
11.4.3.6.2 Test Procedures (1) The applicant should use detailed, unambiguous procedures to govern the conduct of the tests. These procedures should include the following: • the identification of which crews receive which scenarios, and the order in which they should be presented • detailed and standardized instructions for briefing the participants • specific directions for the testing personnel on conducting the test scenarios, as elaborated in Scenario Definition (Section 11.4.1.3)	4.5.6.2 Test Procedures 4.5.6.2.1 Test Procedure Requirements
• guidance on when and how to interact with participants when difficulties occur in simulation or testing • instructions on when and how to collect and store data. These instructions should stipulate which data are to be recorded by:	Appendix B Appendix C
- simulator computers - special-purpose instruments and devices for collecting data (such as situation awareness-and workload-questionnaires, or physiological measures)	4.5.6.2.1 Test Procedure Requirements
- video recorders (locations and views) - test personnel and subject-matter experts (such as via observational checklists)	4.5.6.2 Test Procedures
• procedures for documentation: - identifying and maintaining files of test records including details of the crew and scenarios - data collected - logs created by those who conducted the tests	See Reference 4

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The procedures should detail the types of information that should be logged (e.g., when the tests were performed, deviations from the test procedures and why they occurred, and any unusual events that may be important to understanding how a test was run or for interpreting the findings from it). The procedure also should state when the types of information should be recorded. (2) The applicant's test procedures should minimize the opportunity for bias in the test personnel's' expectations and in the participant's responses.	5 Implementation Team
11.4.3.6.3 Training Test Personnel (1) The applicant should train test personnel (those who conduct or administer the validation tests) on the following: • the use and importance of test procedures • bias and errors that test personnel may introduce into the data through failures to follow test procedures accurately or to interact with participants properly • the importance of accurately documenting problems arising during testing, even if they were due to an oversight or error of those conducting the test 11.4.3.6.4 Training Participants (1) The applicant's training of participants should be very similar to the training plant personnel receive. It should reasonably assure that the participants' knowledge of the plant's design, and operations, and the use of the HSIs and procedures represents that of experienced plant personnel. Participants should not be trained specifically to carry out the selected validation scenarios. (2) To assure that the participants' performance is representative of plant personnel, the applicant's training of participants should result in near asymptotic performance (e.g., stable, not significantly changing from trial to trial) and should be tested for such before conducting the validation.	4.5.6.3 Test Personnel Training
11.4.3.6.5 Pilot Testing (1) The applicant should conduct a pilot study before the validation tests begin to offer an opportunity for the applicant to assess the adequacy of the test design, performance measures, and data-collection methods. (2) The applicant should not use participants in the pilot testing who will then be participants in the validation tests.	4.5.6.5 Pilot Testing
11.4.3.7 Data Analysis and HED Identification (1) The applicant should use a combination of quantitative and qualitative methods to analyze data. The analysis should reveal the relationship between the observed performance and the established performance criteria. (2) The applicant should discuss the method by which data is analyzed across trials, and include the criteria used to determine successful performance for a given scenario. (3) The applicant should evaluate the degree of convergence between related measures (e.g., consistency between measures expected to assess the same aspect of performance). (4) When interpreting test results, the applicant should allow a margin of error to reflect the fact that actual performance may be slightly more variable than observed validation-test performance. (5) The applicant should verify the correctness of the analyses of the data. This verification should be done by individuals or groups other than those who performed the original analysis, but may be from the same organization.	4.5.7 Data Analysis and HED Identification

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(6) The applicant should identify HEDs when the observed performance does not meet the performance criteria. (7) The applicant should resolve HEDs identified by pass/fail measures before the design is accepted. 11.4.3.8 Validation Conclusions (1) The applicant should document the statistical and logical bases for determining that performance of the integrated system is, and will be acceptable. (2) The applicant should document the limitations in the validation tests, their possible effects on the conclusions of the validation, and their impact on implementing the design.	
11.4.4 Human Engineering Discrepancy Resolution Review Criteria HEDs are identified in the V&V process during: • Task Support Verification (Section 11.4.2.2, criterion 3) • HFE Design Verification (Section 11.4.2.3, criterion 3 and criterion 5 for plant modifications) • ISV (Section 11.4.3.5.2, criterion 4) As stated in Section 11.2, the objectives of the NRC staff's review is to verify that the applicant has (1) evaluated HEDs to determine if they require correction, (2) identified design solutions to address HEDs that must be corrected, and (3) verified the completed implementation of these HED design solutions. The applicant's resolution of HEDs is reviewed by the NRC staff using the guidance is this section. HED Resolution can be performed iteratively throughout V&V. Thus, issues identified during one V&V activity can be addressed and resolved before starting another.	4.5.9 HED Resolution Review Criteria
(1) HED Analysis – The applicant's HED analyses should include the following: • Personnel Tasks and Functions – The impact of HEDs on personnel tasks and the functions supported by those tasks. • Plant Systems – The impact of HEDs on plant systems, considering the safety significance of that system(s), their effect on accident analyses, and their relationship to risk-significant sequences in the plant's PRA.	4.5.9.1 HED Analysis
• Cumulative Effects of HEDs – The analysis of HEDs should identify the cumulative effects that multiple HEDs may have on plant safety and personnel performance. • HEDs as Indications of Broader Issues – As well as addressing specific HEDs, the applicant's analysis should determine whether the HEDs point to potentially broader problems.	4.5.7.3 Extent of the Issue Determination
(2) Selection of HEDs to Correct – The applicant should conduct an evaluation to identify which HEDs to correct. The evaluation should identify those HEDs that are acceptable as is (The Additional Information below provides examples). The remaining discrepancies should be denoted as HEDs to be addressed by the HED-resolution process.	4.5.9.2 Selection of HEDs to Correct
HEDs the applicant should correct are those with direct safety consequences, namely, those that could adversely impact personnel performance such that the margin of plant safety may be reduced below an acceptable level. Unacceptability is indicated by such conditions as violations of Technical Specification safety limits, operating limits, or limiting conditions for operations, or failing an ISV pass/fail criterion. HEDs with potential safety impact, not as severe as those described above, also should be corrected unless the applicant justifies leaving the	4.5.9.2 Priority 1 4.5.9.3 Priority 1

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condition as is. The applicant should correct HEDs that may adversely impact personnel performance in a way that has potential consequences to plant performance or SSC operability, and personnel performance or efficiency. This may include failing to meet personnel information needs or violating HFE guidelines for tasks associated with plant productivity, availability, and protecting investment. (3) Development of Design Solutions – The applicant should identify design solutions to correct HEDs. As part of the design solution, the application should evaluate the interrelationships of individual HEDs. (4) Design Solution Evaluation – The applicant should evaluate design solutions to demonstrate the resolution of that HED and to ensure that new HEDs are not introduced. Generally, the evaluation should use the V&V method that originally detected the HED. (5) HED Evaluation Documentation – The applicant should document each HED, including: • the basis for not correcting an HED • related personnel tasks and functions • related plant systems • cumulative effects of HEDs • HEDs as indications of broader issues	 4.5.9.5 HED Evaluation Documentation

APPENDIX B BARS QUESTIONNAIRE

Date: ______________________________

Rater: ______________________________

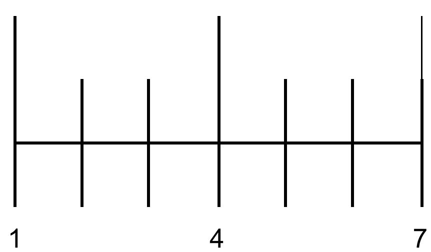
During the last set of exercises that you observed, did you observe any items listed below that significantly affected the work outcome? Place an **X** on the team members who were involved. If the incident took place more than once, please indicate the number of occurrences.

1. Communication

Communication	SS	RO	TO	EO	STA
Sufficient amount of communication – information that needed to be stated was stated.					
Information was informative, not chatter.					
Information was relevant to the situation.					
Information was correct.					
Information had the desired effect – the targeted person responded appropriately.					
Information was given at the appropriate time in the scenario.					

Did you observe any examples of extremely effective or extremely poor communication?

Please place an **X** over the rating which you feel best describes the crew's performance on this dimension.



1: Failed to communicate or communicated misleading information

4: Communicated the important issues, but neglected other issues

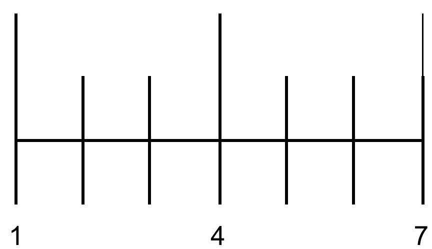
7: Optimal communication – communication was informative, effective and timely

2. **Team spirit**

Team spirit	SS	RO	TO	EO	STA
Joking in a positive manner.					
Appropriate degree of informal discussion.					
Silence due to hostility (negative).					
Gestures of hostility (negative).					
Arguing over trivial issues (negative).					
Information was given at the appropriate time in the scenario					

Did you observe any examples of extremely effective or extremely poor team spirit?

Please place an **X** over the rating which you feel best describes the crew's performance on this dimension.



1: Were openly negative, hostile

4: Were neutral

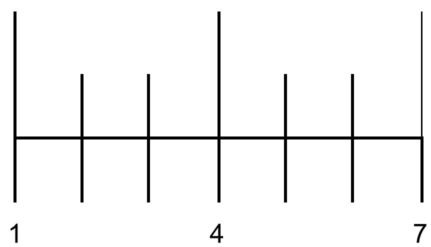
7: Demonstrated encouraging, positive and reinforcing behaviors

3. **Openness**

Openness	SS	RO	TO	EO	STA
Helpful in giving information to crew members.					
Asking for/providing assistance when needed.					
Seeking confirmation when appropriate.					

Did you observe any examples of extremely open or extremely closed team openness?

Please place an **X** over the rating which you feel best describes the crew's performance on this dimension.



1: Were not willing to give assistance or ask for assistance

4: Moderate openness – provided/received some assistances, but more would have been better

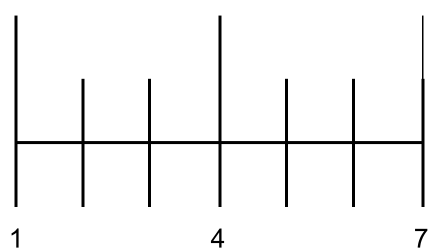
7: Optimal openness – provided/received assistances as often as needed

4. **Coordination as a crew**

Coordination as a crew	SS	RO	TO	EO	STA
Good ability to work together.					
Able to shift roles when needed.					
Work together to find facts needed for decision making.					
Appropriate degree of delegation of task					
Good utilization of technical support					

Did you observe any examples of extremely good or extremely poor crew coordination?

Please place an **X** over the rating which you feel best describes the crew's performance on this dimension.



1: Unable to work together

4: Moderately effective as a crew

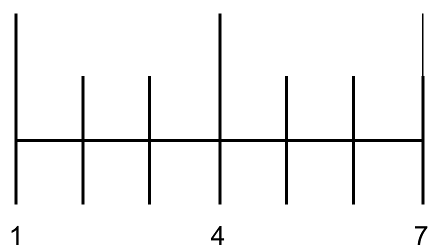
7: Delegated wisely, shifted roles as needed – the team work together highly effectively

5. **Task focus/Decision making**

Task focus/Decision making	SS	RO	TO	EO	STA
Considering alternative actions					
Staying with chosen primary task (remaining focused on main task)					
Prioritizing tasks					
Solving the correct problem					
Decisions appropriate to diagnosis					

Did you observe any examples of extremely effective or extremely poor task focus/decision making?

Please place an **X** over the rating which you feel best describes the crew's performance on this dimension.



1: Unfocused, poor decision making

4: Moderately effective decision making

7: Optimal degree of consideration of alternatives and focus on task

APPENDIX C NASA-TLX QUESTIONNAIRE

Title	Endpoints	Description
Mental Demand	Low / High	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, etc.)?
Physical Demand	Low / High	How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low / High	How much time pressure did you feel due to the rate or pace at which the task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Good / Poor	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low / High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration	Low / High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Crew Number: ____________________ **Scenario:** __________________

Date: ____________________ **Evaluator:** __________________

1. Metal Demand

0 1 2 3 4 5 6 7 8 9 10

Low Medium High

2. Physical Demand

0 1 2 3 4 5 6 7 8 9 10

Low Medium High

3. Temporal Demand

0 1 2 3 4 5 6 7 8 9 10

Low Medium High

4. Effort

0 1 2 3 4 5 6 7 8 9 10

Low Medium High

5. Performance

0 1 2 3 4 5 6 7 8 9 10

Low Medium High

6. Frustration

0 1 2 3 4 5 6 7 8 9 10

Low Medium High