GE Hitachi Nuclear Energy

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Non-Proprietary Information

BWRX-300 Darlington New Nuclear Project (DNNP) Human Factors Engineering Program Plan

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Revision #	Section Modified	Revision Summary
0	All	Originally Issued as Proprietary Version NEDC-3398P2 Rev 0
1	All	Initial Issue as Non-Proprietary Version

1.0 INTRODUCTION

This Human Factors Engineering Program Plan (HFEPP) supports development of the BWRX-300 design in a manner that addresses human factors (HF) risks that could occur throughout the lifecycle of the plant. As described in the Product Requirements Document - BWRX-300 (Reference 8-1), the BWRX-300 is a ~300MWe water-cooled, natural circulation Small Modular Reactor. The reactor design is based, in large part, on the U.S. Nuclear Regulatory Commission (NRC) licensed ESBWR design as well as other previous generation boiling water reactor plants. It is considered an "evolutionary" plant design rather than a completely new design, although some aspects of its design and operation are new.

The high-level goal of the HFE Program is to identify and assess the risks and consequences that arise from human interactions with the plant at all phases of its lifecycle and to reduce those risks through the design as far as is reasonably achievable. This HFEPP specifies a proportionate, integrated, and effective Human Factors Engineering (HFE) program for the design of the BWRX-300 Standard Plant design as well as the first site-specific ("project-specific") design stage. It also forms the basis for any future site-/customer-specific BWRX-300 design HFE programs, carried out in other "project-specific" design stages. This HFEPP supports BWRX-300 licensing and workplans that fall within the timeframe of the standard plant and first project-specific design stages. HFE Program(s) for any future project-specific design stages, as well as any future stages of the plant lifecycle will be developed through separate HFEPPs as appropriate for the future customer, site and Licensee operating organization requirements, arrangements, and commitments.

This HFEPP describes and defines the following, to a level of detail appropriate for an overarching program plan:

- Technical considerations for HFE work during design of the plant, including descriptions and methods, intended tools, and technical guides
- Processes and procedures that establish the general steps taken for effective implementation and the measures used to ensure consistency across the work performed for each HFE activity or "Technical Element"
- The role of HFE within the project, including the interaction between HFE and other engineering disciplines, the flow of work and information within and between each of the HFE Technical Elements (see Section 5.1), and the infrastructure to communicate requirements and issues across disciplines within the project
- The scope of the Structures, Systems, and Components (SSCs) to which HFE Technical Elements are applied and the approach used to determine the level of HFE application in these areas
- The HFE outputs to be created for the BWRX-300 project, a summary of the processes implemented to produce these outputs, and the relative timeline under which the activities occur

Where necessary and appropriate, reference is made to additional, more-detailed planning and methodology documents.

Ultimately the HFE Program is designed to achieve the following general human-centered HFE design goals:

- Design of HSIs reduces the likelihood of error and provide for timely, clear error detection
- Personnel tasks can be accomplished within time and performance criteria

- Information systems support a high degree of situation awareness of the state of the plant and actions required
- Allocation of Function (AOF) maintains human vigilance and provides acceptable workload levels that minimize periods of human underload and overload
- HSI design supports the capability of the personnel to recover from previous decisions and actions that did not achieve intended results
- Application of ergonomic principles to working areas and their environments ensure these areas are safe and designed for the human to perform operations, maintenance, inspection, and test activities

This HFEPP defines how these goals are operationalized and verified during the design process, through application of the HFE Technical Elements, Tools, and Technical Guides, described in Sections 5.1, 5.2, and 5.3, respectively. Effective achievement of the above HFE goals is confirmed using the design tools, evaluation prototypes, and testbeds described in Section 5.2.2, during HFE Verification and Validation (V&V), as described in Section 5.1.10.

1.1 Scope

The BWRX-300 HFE Program described in this plan applies to design activities that consider HF risks that might arise in all phases of the plant lifecycle, including:

- Construction[1]
- Commissioning
- Operation
- Decommissioning[1]

The BWRX-300 HFE Program applies to all BWRX-300 HSIs, including those at the following locations:

- Main Control Room
- Secondary Control Room
- Emergency Response and Support Facilities
- Radwaste Building Control Room or Control Stations
- Local Control Station interfaces
- Equipment- and process line-mounted interfaces (e.g., control actuators and gauges)
- HSIs related to auxiliary and support facilities located outside of the main buildings (e.g., hydrogen tanks or fuel oil supplies).

The HFE Program applies to all plant conditions in the design basis, including normal, outage (refueling and maintenance outages, including extended refurbishments), abnormal, emergency,

1 Note that for some phases of the plant lifecycle, particularly Construction and Decommissioning, the HFE activities described in this plan are focused at a high level; by nature of the plant stage, they generally do not involve analysis of operationally-related functions and tasks. HFE in design related to these non-operational phases is around providing basic guidelines and ensuring design strategies that aid in the achievability of the overall goals of the phase. For example, for Decommissioning, HFE design guidelines and requirements for maintainability may equally apply, especially clearance and access for removal of large components and equipment, and consideration of radiological safety through plant design.

and accident conditions. The HFE Program in design also applies across the full scope of users and activities that support BWRX-300 operation, testing, inspection, and maintenance, including functions such as fuel handling, chemistry, radioactive waste processing, and radiation protection. However, the application of HFE support and activities to the scope of each phase and task location is graded (or proportionate), as discussed in Section 3.0, to apply a higher level of emphasis and rigor for important human interactions that are safety-critical or hazardous.

A risk-based approach to HFE design and task support requirements, and testing methodologies is also applied to security considerations for the BWRX-300 design. While the same general HFE methodologies and tools described within this HFEPP are also applied to security, the specific details of security risk-rating, credited Human Actions (HAs), security success criteria, applicable HSI and task scope, procedures, and validation scenarios are detailed in the BWRX-300 Robustness of Design (Reference 8-2).

1.2 Constraints and Drivers

Constraints and drivers for the HFE Program and the content of this plan include:

1. Adherence to regulations, international nuclear good practice, and overarching company and project requirements
2. Achieving the project HFE-related goals for task performance optimization and HF risk reduction through design, as described in Section 1.0
3. A “Design to Cost” initiative, governed by the Design to Cost Plan for BWRX-300 (Reference 8-3).
4. Related to or resulting from the Design to Cost initiative, the goal to design and build a “fleet solution” or standardized plant that eliminates the need for customization for different customers and regulators in as much of the plant design as possible
5. Various considerations and controls arising from GEH standard design and quality assurance processes, and identified in the BWRX-300 Standard Plant Design Plan (Reference 8-4), and discussed further in Section 6.0, such as project-wide requirements for:
    a. Deliverable types
    b. Data-centric versus document-centric paradigm
    c. Discipline division of responsibility
    d. Interface control between systems and disciplines
    e. Classification of SSCs
    f. Design oversight and verification
    g. Design and configuration control
    h. Communication/correspondence
    i. Technical issues management

There are currently no assumptions that were required to be made to develop the HFE Program and prepare this plan. Note that specific assumptions for the various activities will be identified and captured within the respective planning and results summary documentation for the activity.

2.0 REQUIREMENTS AND TECHNICAL BASIS

This section contains the requirements and guidance documents that form the technical basis of the development and implementation of the HFE Program. Additional requirement and technical basis input documents for HFE design or specific Technical Element areas are included in the applicable sections of this document.

The HFE Program as described in this HFEPP has been developed to comply with requirements stated in the documents listed below.

- Canadian Nuclear Safety Commission (CNSC) REGDOC-2.5.1, General Design Considerations: Human Factors (Reference 8-5)
- CNSC REGDOC-2.5.2, Design of Reactor Facilities: Nuclear Power Plants (Reference 8-6)
- Canadian Standards Association (CSA) N290.12-14 (2019), Human factors in design for nuclear power plants (Reference 8-7)
- U.S. Nuclear Regulatory Commission (NRC) 10 CFR 50.34(f)(2) ii and iii, Domestic Licensing of Production and Utilization Facilities (Reference 8-8)
- BWRX-300 Composite Design Specification (Reference 8-9)

The program has also been developed to comply with requirements derived from the following good-practice guidance documents:

- NRC NUREG-0711, Human Factors Engineering Program Review Model (Reference 8-10)
- UK Office for Nuclear Regulation (ONR), Safety Assessment Principles for Nuclear Facilities (Reference 8-11)
- UK ONR NS-TAST-GD-058, Technical Assessment Guide: Human Factors Integration (Reference 8-12)
- International Atomic Energy Agency (IAEA) SSG-51, Human Factors Engineering in the Design of Nuclear Power Plants (Reference 8-13)
- Institute of Electrical and Electronic Engineers (IEEE) STD-1023, IEEE Recommended Practice for the Application of Human Factors Engineering to Systems, Equipment, and Facilities of Nuclear Power Generating Stations and Other Nuclear Facilities (Reference 8-14)

In addition to the programmatic requirements and guidance documents above, the technical elements that form part of the HFE program were developed using the relevant requirements set out in the following documents:

- CSA N290.4-19, Requirements for reactor control systems of nuclear power plants (Reference 8-15)
- CSA N290.6-16, Requirements for monitoring and display of nuclear power plant safety functions in the event of an accident (Reference 8-16)
- International Electrotechnical Commission (IEC) standard IEC 61839, Nuclear power plants – Design of control rooms – Functional analysis and assignment (Reference 8-17)
- IEC 60964, Nuclear power plants – Control rooms – Design (Reference 8-18)

- IEC 61771, Nuclear power plants – Main control room – Verification and validation of design (Reference 8-19)

Guidance for development of the individual technical elements was also elicited from the following documents:

- NRC NUREG-1764, *Guidance for the Review of Changes to Human Actions* (Reference 8-20)
- Electric Power Research Institute (EPRI) 3002004310, Human Factors Guidance for Control Room and Digital Human-System Interface Design and Modification (Reference 8-21)

Further technical basis for the individual technical elements is provided within the respective sections for each, as applicable.

3.0 HUMAN FACTORS ENGINEERING LEVEL OF EFFORT

3.1 Risk Level Determination

A graded (or proportionate) approach to HFE is applied to the BWRX-300 project and provides the appropriate focus for analysis and design. The graded approach provides basic HFE attention to all human interactions within the system and provides emphasis on important human interactions. The HAs for grading are those functions and tasks allocated to humans in AOF as discussed in Section 5.1.3. The grading of HAs for the BWRX-300 project is performed in two stages. In the first stage, a minimum HFE Application Level is determined based on four key risk categories:

1. Nuclear Safety
2. Personnel Safety
3. Asset Protection
4. Generation Capability

As shown in Table 3-1, Risk Level Assessment Matrix, these risk categories are assessed against criteria that result in a High, Medium, and Low-Risk Level. [[

]] The overall Risk Level for the HA is determined by the highest Risk Level assigned within the four key risk categories. The criteria for each risk category are described in the following sections.

3.1.1 Nuclear Safety

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3.1.2 Personnel Safety

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3.1.3 Asset Protection

Risk to equipment that involves a safety risk to the public or plant personnel is addressed in the Nuclear Safety or Personnel categories [[ ]]. This approach maintains an appropriate heightened focus on Nuclear and Personnel Safety. However, it is recognized that equipment damage creates requirements for forced outages and corrective maintenance, as well as impacting production goals, all of which has an indirect impact on personnel and nuclear safety. [[

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3.1.4 Generation Capability

As with Asset Protection, the inclusion of a rating criterion related to commercial power generation capability is not intended to detract from the heightened focus on Nuclear and Personnel Safety. However, without consideration of aspects of equipment reliability and production risks, tasks outside of operations have an increased likelihood of all being classified as Low-Risk Level. In addition, loss of power generation and production shortfalls equate to loss of income for the plant which can clearly have a “trickle-down” effect on plant condition, organizational health and, ultimately, nuclear safety culture. [[

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Table 3-1: Risk Level Assessment Matrix

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3.2 Determination of Human Factors Engineering Application Level

The minimum HFE Application Level applied to an HA is determined by the overall Risk Level using the criteria ratings in Table 3-1. The minimum HFE Application Level dictates the minimum degree of application when considering each HFE Technical Element. [[

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Appendix A (Section 9.0) Human Factors Engineering Application Levels by Technical Element contains a matrix of HFE Technical Element application grading based upon HFE Application Level.

3.3 Rationale

It is of the utmost importance to provide support for the human within the system design. However, some human interactions with the systems are more important than others. As stated above, to provide the appropriate focus for analysis and design, a graded approach to HFE is applied. The graded approach provides basic HFE attention to all human interactions within the system and provides emphasis on important human interactions.

The graded approach described above is based upon relevant approaches in NUREG-1764 (Reference 8-20) for risk-informed reviews that consider both probabilistic and deterministic considerations. It is also based on recent U.S. industry work on the HFE application detailed in EPRI 3002004310 (Reference 8-21). These approaches represent industry good practices for risk-informed evaluations and decision making.

In addition to the formal task grading method for determining proportionate effort during design, the scope and level of effort of HFE activities is also proportionate to project lifecycle risk and change management considerations. This is done by applying greater scope, focus and degree of support on HFE activities that occur earlier within the design lifecycle, when changes are more effectively and easily managed. For example, while not all HSIs receive a full HFE V&V, all HSIs receive some degree of HFE support during the design phase.

4.0 HUMAN FACTORS ENGINEERING ORGANIZATION

HFE is positioned within the BWRX-300 team at GEH such that HFE has the same level of placement and authority as the traditional engineering design teams (disciplines).

To supplement this role, as noted in Section 4.2, many of the disciplines represent an extended part of the HFE team. This is due to the cross-functional nature of a completely integrated HFE design process. Though the exact organizational structure may change, the fundamental principal is upheld that HFE is integrated with the other disciplines to ensure safety aspects of designs or design changes are properly assessed.

4.1 Roles and Responsibilities

4.1.1 Roles

The GEH HFE team consists of a core and extended team dedicated to HFE implementation. The extended team includes members from other disciplines within the engineering design team and is discussed in Section 4.2. The role definitions of the combined team align with those in NUREG-0711 (Reference 8-10).

The core HFE team is comprised of a Technical Lead and two specialist HFE roles: Human Factors Engineer and HFE Operations/Maintenance. The total of all the qualifications for a role (i.e., all the points in each of A.2, B.2 and C.2 below) may be met by individuals or collectively by the HFE team. Note that each individual qualification (e.g., A.2.a.ii or B.2.b) is expected to be met in full by at least one team member, not shared between team members. All roles are expected to have deep familiarity with the BWRX-300 design as it develops.

A. Technical Lead
   1. Contributions:
      a. Provide technical and program oversight and review
      b. Responsible for ensuring that HFE activities, interfaces, and outputs meet HFE requirements and align with HFE Program objectives
      c. Point-of-contact for schedule development, integration, and management
      d. Coordinates HFE activities with other discipline Technical Leads to ensure HFE and interfacing discipline inputs, outputs and activity timings align with the schedule and this plan
   2. Minimum qualifications:
      a. Equivalent to either an HF Engineer or HFE Operations/Maintenance role with the following additional qualifications:
         i. HFE capability across a breadth of HFE competence areas suitable for the full scope of the HFE Program
         ii. Three years project management-related experience, preferably managing HFE or other technical, cross-cutting programs

B. Human Factors Engineer
   1. Contributions:
      a. Provide knowledge of human capabilities and limitations, applicable HFE design and evaluation practices, and HFE principles, guidelines, and standards

   b. Develop and perform HFE analyses
   c. Participate in the resolution of identified HFE problems

Human Factors Engineer sub-specialties include cognitive science, ergonomics, HSI, and testing/experimental design.

2. Minimum qualifications:
   a. Bachelor's degree in HFE, Engineering Psychology, or related science
   b. Four years of cumulative experience related to the HFE aspects of human-computer interfaces
      i. Qualifying experience should include at least the following activities within the context of large-scale human-machine systems (e.g., process control): design, development, and test and evaluation
   c. Four years of cumulative experience related to the HFE aspects of workplace design
      i. Qualifying experience should include at least two of the following activities: design, development, and test and evaluation

C. Human Factors Engineering Operations/Maintenance

1. Contributions:
   a. Provide knowledge of operations and maintenance activities, including task characteristics, HSI characteristics, environmental characteristics, and technical requirements related to operational activities
   b. Provide knowledge of operations and maintenance activities in support of activities such as development of HSIs, procedures, and training programs
   c. Participate in the development of scenarios for Human Reliability Analysis (HRA) evaluations, task analyses, HSI tests and evaluations, validation, and other evaluations
   d. Provide knowledge of operations and maintenance tasks and procedure formats
   e. Provide input for developing Emergency Operating Procedures, procedure aids, and computer-based procedures
   f. Develop content and format of personnel training programs and training systems
   g. Coordinate training issues that arise from HFE design activities

HFE Operations/Maintenance sub-specialties include Operating Experience (OE) Review, operations analysis (Functional Requirements Analysis (FRA), AOF, and Task Analysis (TA)), alarm design, HRA, procedure development, and training.

2. Minimum Qualifications:
   a. Bachelor's degree in a technical field
   b. Has been licensed or certified in senior reactor operations or qualified as a senior maintenance technician
   c. Five or more years of plant experience, including exposure to plant procedure development, personnel training, and operational nuclear plant programs

d. Two or more years of experience in qualified areas of HFE analysis, design, testing, and evaluation

Note that many HFE team members, although assigned a specific role within the team, have experience and qualifications in the other HFE specialist role as well as potentially outside the HFE discipline. For example, several of the HFE Operations/Maintenance specialists are experienced in advising and reviewing design development, designing interfaces, or planning and executing HFE validation. Similarly, several of the Human Factors Engineers have plant experience or extensive familiarity with plant operations and maintenance through years of HFE support and analysis work.

4.1.2 Responsibilities

The responsibilities of the GEH HFE team as a whole are to establish and perform the activities as defined in this plan. The HFE team's specific duties are to guide and oversee the design activity and ensure the execution and documentation of each step in the activity is carried out in accordance with the established program and procedures. Specifically, the HFE team is responsible for:

1. Development of HFE plans and procedures including treatment of any identified OE and unresolved previous plant HFE issues
2. Oversight, participation in, and review of design and safety analyses development, and conduct of timely HFE T&E activities, including identification of in-process HFE issues
3. Recommendations for, and support to implementation of design-based resolutions for issues identified in the implementation of the HFE requirements and analysis results
4. Verification of correct and robust implementation of HFE requirements, analysis results and issue resolution into the design
5. Assurance that HFE activities comply with GEH management system processes and project HFE plans and methods
6. Managing informal and formal documenting of HFE activities and issues management
7. Planning and implementing HSI design configuration control during design implementation

HFE program activity assignments are allocated by the Technical Lead based on the team member's role and their specific experience. For example, not all the team Human Factors Engineers are experienced in HFE safety analysis, identifying, and evaluating important HAs. Only those team members with adequate experience and training (if applicable) in a particular HFE activity will be assigned to those activities.

However, to ensure there are no singleton specialisms within the team and associated vulnerability to knowledge loss, more than one team member will be required to be deemed competent for each activity. Team members that do not meet the full qualification of an HFE team role, or who are not deemed suitably qualified for a specific activity, will receive mentoring and technical oversight to support developing the skills required for the role or work assignment.

The HFE Technical Lead is responsible for the overall planning and implementation of the HFE program as described in this plan. The HFE Technical Lead ensures the effective integration of the HFE program activities with other design, safety analysis and project activities through regular technical and planning touchpoints with other discipline counterparts; raising, communicating, and helping to resolve HFE technical and programmatic issues; and ensuring suitable number and qualification of resources are assigned each activity such that they can be performed in a timely manner.

4.2 Related Groups Within GE Hitachi Nuclear

The integration of related groups with HFE is formally addressed through an integrated, detailed schedule and with deliverable standards as discussed in Section 6.1, as well as through the HFE technical project management role of the HFE Technical Lead.

In addition, at least one member of each of the following disciplines receives HFE fundamentals training, as discussed in Section 4.3. This discipline team member acts as liaison to HFE for technical queries and elicitation of HFE support/clarification, and ensures that HFE requirements and issues are appropriately managed via their embedded position within the discipline team.

The discipline-specific HFE Liaisons have the following responsibilities:

- help to facilitate requirements management by acting as the discipline's champion of requirements allocated from HFE to that discipline
- act as the single point of contact between their discipline, other disciplines with interfacing HFE requirements, and the HFE team
- review and accept HFE design requirements and ensure these requirements are incorporated into the design and working environment as early as possible
- work with the HFE team to resolve HFE issues and Human Engineering Discrepancies (HEDs) in a manner that addresses the HFE concern
- perform cross-disciplinary review of HFE documents identified as having impact or interface with that specific discipline
- participate in design reviews as the HFE representative as needed and appropriate to HFE risk level

The descriptions of the following disciplines and groups and their contributions to HFE are aligned with NUREG-0711 (Reference 8-10). The actual engineering design team disciplines may vary, but the scopes described must be covered.

4.2.1 Mechanical and Electrical System Engineering

A. Provide knowledge of the purpose, operating characteristics, and technical specifications of major plant systems

B. Provide input to HFE analyses, especially function and task analyses

C. Allocate and implement HFE requirements and recommendations relevant to their scope of design, including management of those requirements flowed down to suppliers

D. Participate in developing procedures and scenarios for TA, validation, and other analyses

4.2.2 Instrumentation and Control Engineering

A. Provide detailed knowledge of the physical hardware aspects of HSI design, including control and display hardware selection, design, functionality, and installation

B. Support identification of inputs and outputs for information display design, content, and functionality

C. Participate in designing, developing, testing, and evaluating the HSIs

D. Provide knowledge of data processing associated with displays and controls

E. Allocate and implement HFE requirements and recommendations relevant to their scope of design, including management of those requirements flowed down to suppliers

F. Participate in designing and selecting computer-based equipment, such as controls and displays

G. Participate in developing scenarios for HRA, validation, and other analyses that involve failures of the HSI data processing systems

4.2.3 Civil Engineering

A. Provide knowledge of the overall structure of the plant, including performance requirements, design constraints, and design characteristics of the following:

   1. Containment (Confinement) Building

   2. Control Rooms (CRs)

   3. Local Control Stations

B. Provide knowledge of the configuration of plant components

C. Allocate and implement HFE requirements and recommendations relevant to their scope of design, including management of those requirements flowed down to suppliers

D. Provide input to plant analyses, especially function analysis, TA, and development of scenarios for TA and validation

4.2.4 Plant Integration Engineering

A. Prepare the DSA establishing the SSC and HAs that are credited for successful event mitigation

B. Provide knowledge of maintenance, inspection, and surveillance activities based on previous plant design and consideration of evolving new plant design, including:

   1. Development of maintenance and outage strategy and plan documents

   2. Expected tasks

   3. Relevant SSCs and HSIs

   4. Task performance requirements

   5. Environmental characteristics

   6. Technical information related to the conduct of these activities

C. Allocate and implement HFE requirements and recommendations relevant to their scope of design, including management of those requirements flowed down to suppliers

D. Support the design, development, and evaluation of the CRs and other HSIs throughout the plant to provide reasonable assurance that they can be inspected and maintained to the specified reliability in conjunction with Plant Architecture, I&C and HFE.

E. Provide input in the areas of maintainability and inspectability to the development of procedures and training

F. Participate in the development of scenarios for HSI evaluations, including task analyses, HSI design tests and evaluations, and validation

G. Oversee security system development, supporting required integration of HFE activities.

4.2.5 Risk and Reliability Engineering

A. Perform PSA and HRA to quantify the human contribution to risk and inform HFE analyses

B. Provide knowledge of plant component and system reliability, availability, and assessment methodologies to the HSI development activities

C. Participate in the development of scenarios for HSI evaluations, especially validation

D. Provide input to the design of HSI equipment to provide reasonable assurance it meets reliability goals during operation and maintenance and maintains the specified availability

4.2.6 Simulation Assisted Engineering

A. Lead and integrated discipline development of the Simulator Assisted Engineering models used for design development, used for HFE T&E and early validation activities

B. Develop part-task and full-scope simulators, used for HFE V&V activities

4.2.7 Product Management Training

A. Interface with HFE team to gather inputs for and provide feedback on any training-related OE and issues identified during training development

B. Conduct Systematic Approach to Training (SAT) to develop base training package

C. Adapt base training package to project-specific needs

4.3 Use and Management of Supplier Engineering Services

The BWRX-300 project may make use of one or more engineering firms to further the BWRX-300 design. If a supplier engineering arrangement occurs, the HFE Design Authority is still vested in GEH, and the engineering firms are expected to perform their contracted scope of work and division of design responsibility in strict adherence with GEH HFE requirements. Any HFE work done by other engineering firms is overseen by the GEH HFE Team.

4.4 Project Human Factors Engineering Training Needs

HFE awareness training is provided to all disciplines (designers and engineers). At least one member of each discipline receives more in-depth HFE fundamentals training. These engineers act as the HFE Liaisons for technical queries and elicitation of HFE support/clarification.

HFE awareness training consists of a high-level overview explaining what HFE is and how HFE relates to the different areas of design.

The more in-depth HFE fundamentals training consists of training sessions designed to give the HFE Liaisons an understanding of the following HFE processes and work products:

- HFE Technical Elements, design inputs, and tools
  - Explanation of each HFE Technical Element, and how that element relates to the plant- and system-level work being done by the other disciplines
- Schedule and interdependencies
  - HFE work product inputs and outputs and how they are related to which parts of the design and design process, which inputs are need from disciplines outside of HFE, and where this occurs within the design process and project schedule

- HFE requirements
  - Documents and work products containing HFE requirements, which subsets of requirements are applied where (e.g., mechanical heating, ventilation, and air conditioning need to be aware of ambient noise level, temperature, and humidity design requirements from HFE), and expected level of requirements traceability and documentation for HFE requirements
- HFE V&V
  - Needs and expectations of HFE for design verification, task support verification, and Integrated System Validation (ISV)
- HFE issue and discrepancy resolution
  - Identified HFE issues and discrepancies; how they are prioritized, assigned, tracked, and resolved; and the role of HFE and the designers in this process
- Escalation to HFE subject matter expert
  - When to ask for help interpreting requirements, performing design optioneering, or developing design solutions to address HFE issues and discrepancies

5.0 TECHNICAL CONSIDERATIONS

5.1 Technical Element Descriptions and Methods

The following sections provide a general overview of each HFE Technical Element in alignment with NUREG-0711 (Reference 8-10) and REGDOC-2.5.1 (Reference 8-5). Figure 5-1, Humans Factors Engineering Technical Elements Relationship illustrates the relationship between Technical Elements. Note that, as with all design processes, this representation is simplified for clarity and is indicative only. The HFE activities are iterative and progressive, such that results from analysis and activities later in the program, for example Staffing Analysis or Procedure Validation, is used to refine and feed back into the AOF, TA, HSI Design and Procedure Development as appropriate and necessary. Section 9.0, APPENDIX A – Human Factors Engineering Application Levels by Technical Element details how TA, HSI Design, Procedure Development, HFE V&V, and Design Implementation are graded and applied, using the approach described in Section 3.0. Section 10.0, APPENDIX B – Human Factors Engineering Program Integration Map provides a more detailed overview of the interfaces between each of the HFE Technical Elements, and related design and safety analysis activities, showing inputs, outputs, and dependencies.

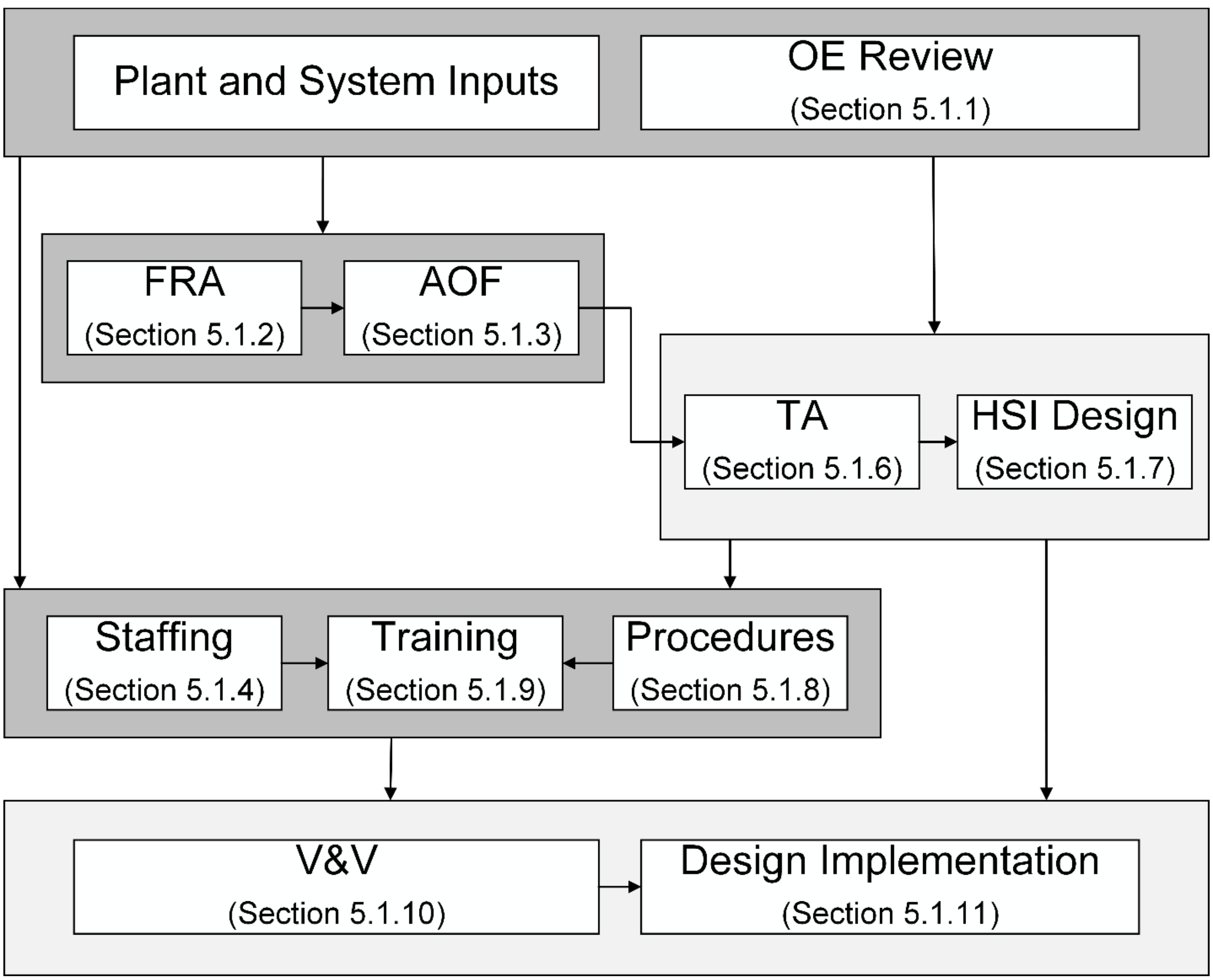

Figure 5-1: Humans Factors Engineering Technical Elements Relationship

For application to a new plant design, the techniques selected for performing HFE analysis include OE Review, FRA, AOF, and TA (including link analysis). These types of analyses are based on the HFE program expectations in REGDOC 2.5.1 (Reference 8-5), with further guidance and rationale for their selection and use provided in NUREG-0711 (Reference 8-10). Application of TA, Human Error Analysis (HEA), workload analysis, physical demands analysis, and link analysis techniques are graded and applied proportionately to risk using the approach described in Section 3.0. Where necessary, additional detail and rationale for selection and application of HFE analysis methods are provided within the process plan for that HFE Technical Element (referenced within each respective section in this plan).

The HFE Technical Elements are executed in a systematic and iterative fashion. They are integrated with the wider plant design processes as discussed in Section 6.1. The HFE Technical Elements utilize the most relevant and proven methods as discussed in the sections below.

The HFE Technical Elements of this plan include:

- OE Review
- FRA
- AOF
- Staffing
- Treatment of Important HAs
- TA
- HSI Design
- Procedure Development
- Training and Qualification Program Development
- HF V&V
- Design Implementation

5.1.1 Operating Experience Review

The main purpose of conducting an OE Review is to identify HFE issues related to plant or personnel safety. GEH HFE conducted an early concept OE Review to identify OE relevant to the HFE program at the earliest possible stage of design. The issues and lessons learned from OE provide a basis for improving the plant design in a timely way (i.e., at the beginning of the design process). The OE Review addresses the following:

- Literature review on any previous deployment of the same reactor technology with an HFE focus
- Personnel interviews or questionnaires on any previous deployment of the same reactor technology with an HFE focus
- OE reviews related to HSI technology employed to support HAs included in the PSA and DSA
- Focused reviews of HAs from predecessor designs that are similar to HAs included in the PSA and DSA
- Fukushima HFE lessons learned

Included in the OE Review is the use of the GEH Legacy OE database. The database, which has over 11,000 entries and is used for engineering design, contains industry HF issues, including identification of human errors, and positive and negative system features. The database was compiled from many sources, including:

- Institute of Nuclear Power Operations (INPO) and World Association of Nuclear Operators database searches
- Nuclear industry literature review
- GEH lessons learned
- HSI technology benchmarking reports

Of these entries, over 570 had been tagged by operations and HF experts as being related to HFE.

Outputs of the OE Review may influence the design or design processes in each of the other HFE Technical Elements. The objective of OE Review is to identify and analyze issues in previous designs that are like the current designs. This allows negative features associated with predecessor designs to be avoided and positive features to be retained.

To capture the above initial OE review, the BWRX-300 Operating Experience Review Process and Results (Reference 8-24) has been developed. The report describes the personnel and methodology used for the preliminary OE capture, the evaluation process, and the resulting OE summary data created from this process.

Four OE items from the preliminary OE Review were identified as being allocated to this HFEPP for resolution, as follows:

- OE_0039: The V&V team should have at least two experienced operations personnel familiar with the plant design and HSI – addressed in Section 4.1.1
- OE_0042: The HSI team should have a discipline group specifically chartered with specifying and enforcing a common, uniform, display user interface ("look and feel") – addressed in Section 4.1.1 and also through the HSI Style Guide, described in Section 5.3
- OE_0088: There should be one group that has master responsibility to specify and consistently design the inventory of displays – addressed in Section 4.1.1 and also through the HSI Style Guide, described in Section 5.3
- OE_0118: Operators (versus system engineers) with integrated plant knowledge should be used to define and identify alarm priority – this OE item will be passed forward to the Alarm Management Design Guide when it is developed (see Section 5.3)

Additional OE reviews are also conducted as a normal part of the BWRX-300 design development, through an ongoing process described in the BWRX-300 Operating Experience Review (Reference 8-25).

5.1.2 Functional Requirements Analysis

FRA is performed to define the necessary functions that satisfy the principal design requirements of the BWRX-300. These principal design requirements are necessary to meet plant goals and objectives. They include meeting regulatory and customer requirements [[

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FRA is part of the overall GEH engineering design [[ ]] and in particular part of the requirements management process [[ ]] The requirements management process for BWRX-300 consists of the following activities, which apply equally to all types of requirements including the functional ones: elicitation, analysis, documentation, allocation (to specific system(s)), tracing, and requirements verification and validation. This process is a multi-discipline activity jointly undertaken by GEH design teams including the HFE team. Note that, because BWRX-300 is an evolutionary plant with some of the same or similar plant- and system-level safety and performance goals, FRA elicitation is not required to the extent it would be for a completely new design. Eliciting functional requirements can be done through importing functions that exist in current plant designs and are expected to apply to BWRX-300. The result of this analysis is the definition of the full set of functions that support achievement of the plant goals and can be traced to the principal design requirements of the BWRX-300.

[[ ]]

This documentation sets the framework to determine the role of the controllers (whether human or machine) in regulating active (non-passive) functions. These functions from the FRA are input into the AOF Process described in the next section. When the analysis is complete, the document [[ ]] will contain the full list of functions with detailed characterizations of relevance to HFE, particularly those required to perform AOF and feed to the TA and HSI design activities.

5.1.3 Allocation of Function

AOF establishes a plant control scheme that enhances plant safety and reliability by taking advantage of human and machine strengths and avoiding human and machine limitations. The allocation arrangement can enhance plant performance by specifying overlapping and redundant responsibilities to the human and machine.

The AOF strives to provide personnel with logical, coherent, and meaningful tasks, and establishes a design that maintains human vigilance and situational awareness. The goal of the AOF is to provide acceptable workload levels per job role that minimize periods of human underload and overload to the extent possible. This is done through review of the initial allocation as a whole and using expert judgement to determine if the assigned functions per job role are suitable and sufficient. Further analysis of workload and requirements for situational awareness are then undertaken through downstream activities such as TA, HSI Testing and Evaluation (T&E) and HFE Validation (see Sections 5.1.6, 5.1.7, and 5.1.10).

The AOF Process is based on the relevant good practice methodology presented in IAEA-TECDOC-668, The Role of Automation and Humans in Nuclear Power Plants (Reference 8-33). The methodology identifies functions that should not be assigned to humans due to criteria such as:

- Physical demands (forces, posture)
- Cognitive demands (multitasking, stress)
- Combination of physical and cognitive demands (accuracy, response time)
- Environmental conditions (temperature, radiation)

The AOF Process takes additional input for criteria from NUREG/CR-2623, The Allocation of Functions in Man-Machine Systems: A Perspective and Literature Review (Reference 8-34). These are criteria that limit or preclude human participation in a function, and criteria that make human participation mandatory. The criteria for human participation, along with the related criteria in IAEA-TECDOC-668 (Reference 8-33), are top-level, overriding criteria in the AOF Process.

The AOF Process establishes an initial (hypothesized) allocation based on expert judgment from a panel that includes an HF Engineer, an HF Operations/Maintenance representative, an Integrated Plant Design representative, and a System Engineer for the respective system. The panel can make use of OE to determine how similar applications were allocated and evaluate how they have performed.

The function input to the AOF is described in Section 5.1.2. In addition, with the conversion of functions to tasks, multiple tasks may be necessary to support the function. For example, to fulfill a core protection function, a task to perform a system readiness surveillance test supports the eventual task of safety system initiation. The support tasks require a “task allocation” that uses the same criteria applied to AOF. The PSA also provides input to the AOF, specifying when HAs are modeled to backup automatic (machine) actions.

Output from AOF is the initial allocation of functions to Human, Machine, or Shared (both Human and Machine). For Machine or Shared allocations, it may be necessary to establish backup actions when redundancy of like allocations is not possible or reasonable. For these cases, the allocation categories Machine-Human Backup, Shared-Human Backup, or Shared-Machine Backup are used. The initial allocation is then used to perform the task (HA) grading to determine HFE Application Level, as described in Section 3.0. The initial allocation also becomes the design and TA starting point, feeding into both HFE activities and plant I&C architecture and automation. If necessary, the initial AOF is iterated as plant design progresses.

The overall plant AOF is evaluated and iterated as part of Staffing Analysis, HSI T&E, and early integrated testing, if necessary, until a final AOF is established for ISV testing to verify performance, workload, and situation awareness. Further details on the AOF Process can be found in the Allocation of Function Methodology Report for BWRX-300 (Reference 8-35).

5.1.4 Staffing

Plant staff and their qualifications are important considerations in the HFE design. A Staffing Analysis Plan has been developed to systematically determine the minimum staff complement for BWRX-300 (Human Factors Engineering Staffing Analysis Plan for BWRX-300 (Reference 8-36)). This plan was developed to meet the expectations and requirements of REGDOC-2.2.5, Minimum Staff Complement (Reference 8-37), and to ensure that staffing goals are met with the appropriate staffing levels.

Assumed job roles and responsibilities have been identified based on experience in existing plants and industry OE, as captured in the BWRX-300 Human Factors Engineering Concept of Operations (Reference 8-38) (the HFE COO). These assumptions allow undertaking the initial HFE activities and act as a basis for the formal staffing analysis activities.

The results of TA are an input to workload analysis which is itself an input to the staffing analysis. However, because the BWRX-300 is a new plant with highly automated control and modern HSIs, the early assumptions in the HFE COO (Reference 8-38) are to be revisited through some preliminary staffing analysis. This is then used to provide early confirmation of the roles and complement used in the TA, to ensure that any major oversights or invalid assumptions are identified much earlier in the HSI design. The early staffing analysis also determines the maximum staffing expected in collaborative facility spaces (e.g., CRs), for early identification of maximum occupancy to inform civil and structural determination of room sizes.

The early analysis is done using an informal, expert judgement-based assessment rather than formalized minimum staff complement analysis as is planned to be performed later in the program. The early staffing analysis is a desktop (talk-through) exercise led by an HFE Operations/Maintenance team member and is supported by personnel from Plant Integration Engineering and safety analysis specialists. The assumed staffing in the HFE COO (Reference 8-38) is used to analyze the most resource-intensive credible events postulated for all operating states, including normal operations, design basis events, and emergencies, and the assumed complement is either confirmed or corrected.

The confirmed minimum and maximum staff and shift design information is then assessed for any impact on any TA performed on the basis in the HFE COO. The staffing information and any analysis or design activities reliant on it is then assessed and updated further based on the later, more formal staffing analysis activities. The confirmed job role composition and complement are also an input to Training Program Development, where base qualifications are established, and the preliminary training program is designed. This program is adjusted based on the findings of the second staffing analysis stage, if required.

Staffing analysis is further confirmed through workload analysis and evaluated using mock-ups, modeling, or simulation as appropriate with the HSI T&E described in Section 5.1.7. The staffing design is finalized once it is validated with the ISV, as discussed in Section 5.1.10.

5.1.5 Treatment of Important Human Actions

Consideration and integration of HFE within the safety analyses, and consideration of the results and assumptions of the safety analyses within the other HFE activities both comprise the technical element of Treatment of Important Human Actions.

HRA is conducted by the Risk and Reliability Engineering and is an integral part of the development of a complete PSA. HRA seeks to evaluate the potential for, and mechanisms of, human error that may affect plant safety. The core HFE team presented in Section 4.1 contributes to the HRA by participating in the definition of the task (steps) for the HRA. In addition, the HFE design (TAs, HSIs, Procedures, and Training) is an input to the definition of performance shaping factors for the HRA.

However, HFE safety analysis activities provide assurance that the full set of HAs that are important to safety are explicitly identified, characterized, and substantiated and achievable within the required task performance criteria. The full complement of safety analysis outcomes, including the PSA and HRA, impacts all the HFE technical elements. The set of activities supporting this technical element was developed based on requirements for HFE expertise in safety analyses per IAEA SSG-51 (Reference 8-13), REGDOC-2.5.1 (Reference 8-5), CSA N290.12-14 (2019) (Reference 8-7) and international best practice.

The important HAs are determined using both deterministic and probabilistic means, and include identification of the HAs that might cause or contribute to the cause of Postulated Initiating Events within the safety analyses. Inclusion in the DSA, PSA or Severe Accident (SA) analysis, or other identified contribution to risk, determines the risk level in the nuclear safety category for determining the initial HFE Application Level to apply to the HFE activities. Ensuring that the HA contribution to safety is fully identified and substantiated ensures that the risk-based graded approach used in the HFE program is based on valid information, which in turn ensures that all HSIs and tasks associated with important HAs are analyzed and designed with a full detailed and robust HFE effort.

The safety functions that are performed to maintain the plant within or return to a safe operating envelope are identified through various means using DSA, PSA and SA analysis. HFE safety analyses activities that form part of this technical element include:

1. Perform a Human Operation Hazard Evaluation (HOHE)
2. Review the DSA for explicit and implied HAs, e.g., HAs related to maintenance that ensure safety-class SSC availability, and ensure claimed HAs are achievable through qualitative HEA
3. Review the PSA and substantiate the HRA and related analyses by:
    a. Ensuring event sequences introduce a Human Performance Limiting Value (HPLV)
    b. Performing qualitative HEA to substantiate or refine the Human Error Probabilities used for all HAs claimed in the HRA
    c. Providing HFE qualitative basis and substantiation for any dependency assumptions and analysis
    d. Providing HFE qualitative basis and substantiation for any timeline assumptions and analysis
4. Review the SA analysis, including Level 2 and 3 PSA, to identify explicit and implied HAs, determine task achievability in required timescales, and capture input for procedure development and emergency planning and response
5. Compile a database of all important HAs claimed in the safety analyses, including the source of the claim, their key characteristics, related assumptions and any associated HSIs

The outputs from the activities that form this technical element include internal design basis records, a Human Action Claims database containing all important HAs and critical information for each, allowing them to be adequately and robustly considered in the design, and an HFE Safety Analysis Summary Report.

The results are also communicated directly to the appropriate design, safety analysis and HFE workgroups to ensure timely consideration of the full set of HAs important to safety in their respective activities.

5.1.6 Task Analysis

TA is the identification of task requirements to accomplish the functions and tasks allocated in whole, or in part, to humans. These allocations to human in whole or in part are designated in the AOF results as Human, Shared, Shared-Human Backup, Machine-Human Backup, or Shared-Machine Backup.

TA considers input from existing operating and maintenance instructions from the equipment vendor or similar applications when they exist. TA also includes considerations based on OE collected during the OE Reviews.

TA assigns tasks to the job positions specified by the staffing process described in Section 5.1.4. TA determines the steps needed to accomplish HAs and documents the task details and required task support (e.g., HSI controls, indications, alarms, tools, physical space, job aids). The TA process also assesses the HFE Application Level, assessed through the process described in Section 3.0, to determine if a change to the HFE Application Level is warranted based on task characteristics.

The BWRX-300 Human Factors Engineering Task Analysis and Human-System Interface Design Methodology Report (Reference 8-39) specifies the systematic process for BWRX-300 TA and provides the steps and criteria used for TA. This includes aspects of job design and spans all operating states of the facility (i.e., startup, operation, and shutdown).

For the Detailed TA described in Appendix A (Section 9.0), [[
]] the following information is documented for each task:

- Descriptive narrative of the task
- Cue that determines the need for the task
- Prerequisites for the task
- Time available versus time required to complete

Further information is documented for each step of the task:

- Step sequence
- Action to be taken
- Information needed
- Controls needed
- Alarms needed
- Personnel involved
- Communication needs
- Location and access considerations
- Workspace needed
- Job aids, tools, or equipment needs
- Environmental considerations and potential hazards
- Special or protective clothing needs
- Time available versus time required to complete (if needed on a step basis)

The Detailed TA is informed by and coordinated with the qualitative HEA (see Section 5.1.5) and the HRA when applicable, as describe in Reference 8-39. The results of the Detailed TA are used as input to HSI design, Procedure Development, and Training Program Development.

The Detailed TA also includes preliminary workload analysis and assessment of requirements for situational awareness, to inform the HSI design requirements and provide a baseline for HSI T&E activities.

For the Basic TA [[ ]] documents the necessary tasks that support functions from the AOF. [[ ]] then reviews the HSIs, and other task support measures specified by the system designer for overall acceptability to support expected task performance. If problems with task support are noted, an HFE issue or HED is created to track the problem to resolution (see Section 6.5).

Additional forms of TA are used to support the evaluation and design of the HSI used for the [[ ]] HAs. For these HAs, Link Analysis coupled with Timeline Analysis is used to evaluate/inform the layout of HSIs to optimize task performance. These analyses are performed as part of the Integrated TA and Workload Analysis activity in each of Concept and Detailed Design stages. The integrated TA takes the system-level TAs and the results from the HEAs (see Section 5.1.5) and performs higher-level "whole sequence" analyses such as progressive workload analysis and timeline analysis. The scope of the integrated TAs automatically includes each event sequence that contains an [[ ]] HA.

5.1.7 Human-System Interface Design

The HSI Design Process represents the translation of task requirements provided by the TA into HSI design. The HSI includes the regions or points at which a person interacts with SSC in the CRs and the plant. Another input at this stage is gathering OE on new HSI technologies or new uses of existing HSI technologies.

HSI design uses a structured methodology to guide HF Engineers in:

- Developing concepts
- Defining requirements
- Developing and supporting detailed design
- Performing tests and evaluations

A detailed methodology for HSI development and testing is provided [[

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The HSI concept design scope includes development of the HFE COO (Reference 8-38), which describes the ways in which users interact with the HSI and with each other to monitor and control the plant. This includes job design aspects such as the definition of staffing, user population characteristics, HSI user roles, work coordination, and personnel communications. The HFE COO (Reference 8-38) also describes:

- The concept design for the key HSIs throughout the plant, defining the basic HSI technologies, content, equipment, layout, and environment used by plant personnel to monitor, maintain, and control the plant
- The Alarm Philosophy, which describes the alarm concept at a high level, and defines basic goals for alarm management

Creation of the HFE COO (Reference 8-38) is a cross-disciplinary collaboration, [[ ]]. The HFE COO (Reference 8-38) provides input for the development of BWRX-300 Human Factors Engineering Design Requirements Document (Reference 8-40) (the HFE DRD) by defining the user population for which the design is being created, and also by defining the expected plant HSIs at concept, which helps bound the scope of HSI Elements covered by the HFE DRD (Reference 8-40).

The HSI Design Process includes the development and use of HFE design requirements tailored to the unique aspects of design. These requirements define design-specific conventions and ensure standardization and consistent application of HFE principles (similar "look and feel" across

HSI). These HFE design requirements are housed in the HFE DRD (Reference 8-40). These requirements are derived from HFE relevant good practice such as NUREG-0700, Human-System Interface Design Review Guidelines (Reference 8-41), codes, standards, and regulations. To support implementation of the HFE DRD (Reference 8-40) and achieve HSI design consistency across the plant, the HSI Design Technical Element also includes development of an HSI Style Guide and an Alarm Management Design Guide during Concept Design stage. Additional detail regarding the HFE DRD (Reference 8-40) and its related design guides is provided in Section 5.3.

Detailed HSI design develops the features selected in the basic design process. HFE design requirements contained in the HFE DRD (Reference 8-40), and task support requirements generated by TA, are used to generate detailed HSI designs. Applicability and allocation of the HFE DRD (Reference 8-40) and task support requirements are determined by the HFE team. The detailed design process addresses physical design features, hardware, software, layout (space, equipment and HSI panels), formatting, and features incorporated into the HSI design to meet human-centered design goals. The standard plant alarm system logic detailed specification, including rationalization and prioritization results, is also developed and input in the I&C team alarm system design activities.

Applicable requirements are applied to the developing design, and compliance is documented and maintained by the other engineering disciplines. Where exception to a requirement is needed, HFE provides design support to the discipline to develop and document an HFE-approved justification for the design to take exception to an HFE Design Requirement. When evaluating commercial off-the-shelf (COTS) products that do not comply with the HFE DRD (Reference 8-40), special considerations are applied by the HF Engineer to determine and document acceptability of the discrepancy (based on the base intent of the requirement and assessment of HF risk in each specific case):

- Tradeoff of benefits of using a proven, standard solution compared to the benefits of a custom solution that more closely meets the HFE DRD (Reference 8-40) requirements
- Analysis of COTS equipment vendor HFE design basis and documentation in relation to HFE codes, standards, and relevant good practice
- Evaluation of COTS HSI design applicability to the defined user population, conventions, and stereotypes
- Degree of design and task support integration and consistency between the COTS product and the rest of the overall HSI
- Identification of usability or human performance concerns with the proposed application of the COTS product

If COTS products are to be considered, HFE specification and review of such products is done as early as possible in the design lifecycle, following completion of the HFE COO (Reference 8-38) and the HFE DRD (Reference 8-40).

HSI T&E are part of the iterative HSI development process. Personnel representative of end users (nuclear power plant operators or personnel with plant operations/maintenance experience) evaluate an HSI design concept to show the design’s efficiency and efficacy for the intended population. The purpose of early, smaller-scope usability testing is to find and correct issues immediately rather than waiting for later V&V activities. The HSI T&E also provides a progressive assessment of the preliminary workload analysis. HSI test and evaluation scope ranges in complexity from simple user questionnaire responses and comments to empirical, performance-based techniques. Any issues that are identified during the HSI development process are entered into the appropriate section of the HFE Issue Tracking System (HFEITS) database for tracking, reviewing, and resolution (see Section 6.5).

The HSI design products are created through the interaction and coordination of the HFE team and discipline engineers. Degree and type of interaction is based on the Risk-Based HFE Application Level, discussed in Section 3.0 and Appendix A (Section 9.0).

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The output of the HSI element is a CR design and HSI inventory. The detailed HSI design feeds into the development of the Simulator Assisted Engineering model for HFE T&E, the full-scope simulator for HFE V&V, operator training, and validation of procedures.

5.1.8 Procedure Development

Procedures are essential to plant safety because they support and guide personnel interactions with plant systems and personnel responses to plant-related events. The objective of this HFE technical element is to apply HFE principles and guidance to develop procedures that are technically accurate, comprehensive, explicit, easy to use, and validated. By using output from the relevant HFE Technical Elements, such as TA and HSI Design, as input to the procedure development, the procedures relate directly to, and reflect the actual BWRX-300 expected task steps and available HSIs to support them.

To support these objectives, the BWRX-300 Procedure Development Plan (Reference 8-42) has been developed and specifies the inputs and process for procedure development, as discussed below. The plan addresses procedures for the operations, maintenance, and inspection/testing of the plant and includes in its scope:

- Procedure Writer's Guides
- Plant and System Operations Procedures (startup, at power operations, and shutdown)
- Maintenance, Inspection, Testing and Surveillance Procedures (including Refueling and Outage Planning Procedures)
- Alarm Response Procedures

- Abnormal Operating Procedures (AOPs)
- Emergency Procedure Guidelines for EOP development
- Emergency Operating Procedures (EOPs)
- Severe Accident Management Guidelines (SAMGs)
- Emergency Mitigating Equipment Guidelines (EMEGs)[2]

Procedures that support HAs that are specified in Appendix A (Section 9.0) for HFE Application Levels [[ ]] are validated by individuals that are independent of the design. [[ ]]

Procedures to support HAs specified in Appendix A (Section 9.0) for HFE Application Level [[ ]] are validated by the discipline. [[ ]].

The BWRX-300 Procedure Development Plan (Reference 8-42) addresses the relevant good practices for procedure content and creation provided in IAEA-TECDOC-1058, Good Practices with Respect to the Development and Use of Nuclear Power Plant Procedures (Reference 8-43).

For each procedure type, a Procedure Writer's Guide is established. The Procedure Writer's Guide establishes objective criteria so that the procedures developed with it are consistent in organization, style, and content. The Procedure Writer's Guide provides instructions for procedure content and format, writing of steps, and specifying lists of terms used. The Procedure Writer's Guide considers the industry relevant good practices reflected in PPA AP-907-005, Procedure Writer's Manual (Reference 8-44), authored by the Procedure Professionals Association. Following development of the Procedure Writer's Guide for each procedure type, when suitably mature input information is available, the procedures themselves are developed using an iterative process. The process and inputs for each procedure type are illustrated in the BWRX-300 Procedure Development Plan (Reference 8-42).

The procedures developed by this HFE Technical Element are used for ISV as described in Section 5.1.10. Following ISV, the procedures are provided to the plant operator to use as the bases for pre-operational testing, startup testing, and eventually continued operation of the plant.

5.1.9 Training and Qualification Program Development

A training program for plant personnel is important to ensure nuclear power plants are operated in a safe manner. For BWRX-300, a core training package is developed by the Product Management Training team, with inputs and support from the HFE team.

In order to specify the HFE interfaces required by, and activities to support a SAT program, a Training and Qualification Plan for the BWRX-300 (Reference 8-45) has been developed. The plan meets REGDOC-2.2.2, Personnel Training (Reference 8-46) for Canada. It is the intention that a Training Program Development Plan will be written for each BWRX-300 project application

2 For the purposes of this HFEPP, which is for BWRX-standard plant design and therefore not country- or project-specific, the term EMEG is used to equally mean Diverse and Flexible Coping Strategies (FLEX) Equipment Guidelines, which is the term used in some countries.

to meet the country or region-specific requirements. The approach is applied to positions included in the minimum staff complement established by the Staffing Analysis Plan described in Section 5.1.4.

Each project Training Program Development Plan addresses the HFE activities and inputs related to the following fundamental stages of a SAT program:

1. Analysis
2. Design
3. Development
4. Implementation
5. Evaluation

The Analysis Stage determines the training needed for the specified job position based on assigned tasks. Tasks that support plant functions are identified as part of Detailed and Basic TA, described in Section 5.1.6. Tasks are selected for training based on difficulty, importance, and frequency. Depending on the difficulty, importance, and frequency ranking, a decision is made to determine if initial training and periodic retraining is needed. This evaluation of training tasks is the training equivalent to grading HAs presented in Section 3.0. The results of the analysis presented in Section 3.0 inform the difficulty, importance, and frequency importance selection.

Tasks that are selected for training are then analyzed to determine the required skill, knowledge, and attributes. The skill, knowledge, and attributes necessary for each job position, including entry-level education, training, and experience, are established to support optimal training design.

During the Design Stage, learning objectives are developed and a description of the plan for training, including purposed methods and settings, is established. The completion of the Design Stage establishes the input that is needed for the Development Stage.

In the Development Stage, lesson plans and instructional materials are created, and assessment tests are established. At the end of the Development Stage, the training package is reviewed, piloted on trainees, and revised if necessary.

In the Implementation Stage, instructors prepare for and deliver the training. Trainees are tested to determine if they have mastered the objectives. The results of trainee tests are examined during the Evaluation Stage. The Evaluation Stage examines the effectiveness of the training as delivered. This appraisal is done through the review of training results, training feedback, and continual monitoring of work performance.

The training program, developed as discussed above, provides assurance that plant personnel have the skill, knowledge, and attributes needed to perform their roles and responsibilities. Participants used for ISV, as described in Section 5.1.10, are trained using this program and provide validation of the integrated design.

5.1.10 Human Factors Engineering Verification and Validation

HFE V&V is a verification and validation of plant HSIs and the working environment where HSIs are used. HFE V&V is conducted in two major activities: HFE Verification (design and task support) and ISV. HFE V&V is conducted by a team of HFE Engineers independent from the design development process. HFE V&V is performed on a configuration-managed, baselined design and includes the following areas:

- Control area and equipment layout

- Panel and console dimensions
- Hardware-based indications, controls, alarms, and panel layout
- Software-based HSI displays, controls, alarms, and display layout

HFE Design Verification verifies that the HSIs, as defined and baselined in the HSI inventory and characterization, are evaluated against the HFE design requirements contained in the HFE DRD (Reference 8-40). HFE Task Support Verification verifies that the HSIs, as defined and baselined in the HSI inventory and characterization, include all the necessary features (e.g., controls, information displays, and alarms) required to support tasks and that there are no unnecessary features.

As per the BWRX-300 Human Factors Engineering Verification and Validation Plan (Reference 8-47) [[ ]] are first reviewed as part of the Operational Conditions Sampling. [[

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]]. The HFE Verification activities are performed, and any resulting HEDs are resolved prior to the initiation of ISV.

HFE Validation (which includes both early validation testing and ISV) is an integrated, dynamic, performance-based usability test activity in which participants are subjected to a set of simulated scenarios that represent a realistic, challenging, and generalizable set of conditions to ensure that the integrated HSI supports safe operation of the plant.

For the BWRX-300, a multi-phased testing and validation approach is used, to allow for the identification and resolution of HFE issues earlier in the design process. Once the HSI design, procedures, simulation model, and test platform are sufficiently mature to support the necessary fidelity to obtain meaningful results (findings being due to an actual HFE issue and not due to testbed limitations), dynamic scenarios are run on a testbed using a set of participants that represent the users defined in the HFE COO (Reference 8-38).

During conceptual and the early portions of basic design, testing is smaller scale and iterative in nature, focusing primarily on HSI usability and compatibility with task performance. This testing is performed by the HSI designers for rapid feedback back into the design process and is not considered a validation because it does not include the same independence requirements for test designers, administrators, and observers; the same level of training, qualifications, and independence for participants; nor the same level of design maturity and configuration control. This very early usability testing is considered part of the HFE T&E which forms an integral part of the design process, as described in Section 5.1.7.

Once portions of the design (HSI, simulation, and procedures) reach a sufficient level of maturity, fidelity, and configuration control, partial validations can be conducted on a part-task simulator or vendor system mock-up, or at Factory Acceptance Testing. Validation is performed by sufficiently qualified test personnel and participants who are independent from design of the HSI and procedures, in accordance with the BWRX-300 Human Factors Engineering Verification and Validation Plan (Reference 8-47). The participants selected for early validation activities can include personnel with plant operating and maintenance experience or system designers familiar with the set of systems being tested.

The HFE ISV pilot and ISV are performed on a simulator or virtual reality model (for plant-based ISV scenarios) that is a high-fidelity representation of the hardware-based and software-based controls, indications, alarms, and user input devices at the HSI. The participants used during ISV activities include people trained to become BWRX-300 operators, maintainers, and trainers. ISV can also be performed on as-built plant as part of Commissioning and pre-operations testing if that is the first opportunity to have a high enough fidelity testbed. However, this is not optimal timing since if there are any issues identified, it is difficult to make changes to the design unless the HFE risk introduced is significant. The purpose of early HFE T&E and early partial validations is to identify any significant HSI design issues early when the design can still be altered.

The Operational Condition Sampling process is used to ensure that a broad and representative range of operating conditions is included in the sample population of ISV scenarios. A weighted list of operational conditions is developed to ensure a representative sample emphasizes safety significance, risk, and challenges to all types of users. [[

]] The output of the operational conditions sampling and scenario development process is a group of simulator scenarios that thoroughly evaluates the plant design.

HFE ISV evaluates the performance of the integrated HSI design in terms of plant metrics, personnel tasks, personnel communications and coordination, situation awareness, workload, anthropometric, and physiological factors. HFE ISV scope includes validation of:

- The role of plant personnel
- Adequacy of procedures
- Acceptable shift staffing, assignment of tasks to personnel, and task coordination (both within the control room as well as among the control room and local field interfaces and support centers). This includes validation of nominal shift levels, minimal shift levels, and shift turnover
- Automation functions (allocation of functions and the degree of task dependence on procedures)
- Adequacy of the integrated HSI configuration for achieving HFE program goals consistent with HFE guidelines, principles, and methods
- Adequacy of the HSI to support personnel in accomplishing functions and tasks identified through the Operational Condition Sampling; for each task, the design shall provide adequate alerting, information, control, and feedback capability for human functions performed under normal plant evolutions, transients, design-bases accidents, and selected, risk significant events that are beyond-design basis
- The effect of HSI characteristics on operator workload
- Ability of personnel to make effective transitions between the HSIs and procedures during accomplishment of their tasks; interface management tasks such as display configuration

and navigation are not a distraction or increase the user's cognitive burden such that it interferes with accomplishing the plant-related tasks

- HSI facilitation of search and retrieval of information and controls in a manner and with a speed that does not increase the user's cognitive burden or slow down their ability to accomplish their plant-related tasks
- Accomplishment of specific personnel tasks within time and performance criteria, with a high degree of shared situation awareness, and with acceptable workload levels that provide a balance between a minimum level of vigilance and operator burden
- HSI minimization of operator error and provision for error detection and recovery capability when errors occur
- Integrated system tolerance of human error, system faults, and failures of individual HSI features
- HAs categorized as risk-important in the PSA and HAs credited in the DSA for mitigating events

In addition to these, ISV identifies any additional aspect that may negatively impact human performance. Discrepancies identified during previous verification and validation activities are corrected prior to ISV to prevent unwanted impact on the ISV results.

The HFE V&V Plan (Reference 8-47) has been developed to detail the approach to HFE V&V and provide an overview of the methods to be used. The plan includes the following content:

- HFE V&V schedule and dependencies, including process maps illustrating the overall HFE V&V and the staged HFE validation processes
- HFE V&V personnel roles, qualifications, and independence criteria
- HFE Verification proportionate sampling methodology, procedures, tools, and documentation
- HFE phased validation comprised of early and partial system validation, as well as ISV activities; these include operational condition sampling and scenario development; testbed definition and fidelity requirements; participant selection criteria, qualifications, and training; test design; performance measures and acceptance criteria; data collection, analysis, and interpretation; and documentation
- HFE V&V HED identification, documentation, prioritization, analysis, and resolution

The HFE V&V Plan (Reference 8-47) was developed to meet the requirements of REGDOC-2.5.1 (Reference 8-5). In addition, the HFE V&V Plan includes relevant good practices provided in NUREG/CR-6393, Integrated System Validation: Methodology and Review Criteria (Reference 8-48) and IEC 61771 (Reference 8-19).

5.1.11 Design Implementation

The Design Implementation addresses the final "As-Built" implementation of the HFE design requirements into plant design. By its definition, this Technical Element sits outside the timeframe of this design stage HFEPP. However, it is included as it is an important "close-out" confirmation that the design as implemented meets the HFE design intent and supports user task performance in the optimized manner expected.

The following activities are conducted during Design Implementation, and the detailed methodology will be developed in the HFE Design Implementation Methodology Plan:

- Confirm that the final HSIs, procedures, and training ("As-Built") conform to the design resulting from the HFE design process and V&V activities
- Evaluate any deviation from the design during implementation and identify their impact on the HFE aspects of the design
- Perform final procedure validation on the physical plant hardware
- Verify aspects of the design that may not have been evaluated previously in the V&V process
    - This includes any hardware/software, new or modified displays that were absent from the simulator-based integrated V&V process, and any physical or environmental (e.g., noise, lighting) differences between those present at the V&V process and the "As-Built" control areas
- Verify resolution of remaining HEDs and open items from the HFEITS
- Verify HFE Application Level as provided in Section 3.0 are based on the final set of inputs

Design Implementation activities are performed by the HFE team, with support from Commissioning, Vendor, and Pre-Operations Testing teams. All HFE deficiencies identified during commissioning are to be addressed prior to declaring the system available for service.

5.2 Intended Tools

5.2.1 Human-System Interfaces Design Tools and Testbeds

HSI evaluation and usability testing is an integral and iterative part of the design process. The results of each segment are used to adjust the design as necessary to meet HFE requirements and goals.

It is necessary to employ multiple evaluation tools and testbeds based upon design maturity, HSI features to be tested, and test objectives. This creates efficiency in terms of time and resources and supports design-oriented, successive refinement.

Evaluation methods may include the following:

- Paper-based analysis using drawings to evaluate static design features (e.g., dimensions, layouts, labelling, access)
- 3D model human interactions with HSIs to evaluate physical characteristics of the work environment
- Walk-throughs using physical mock-ups
- Simulation

5.2.1.1 Drawings

Paper-based and software-based drawings are used to perform preliminary user checks to ensure design assumptions or design concepts are viable. Drawings may also be presented to gain early user feedback on design change concepts as the project progresses.

5.2.1.2 3D Mock-Ups

Mock-ups are constructed and used as tools in the development of the HSI to evaluate the system design before the actual manufacture of system hardware. Mock-ups provide a basis to resolve access, workspace, and related human engineering problems and incorporate the solutions into HSI design. Mock-ups may be physical or virtual.

Physical mock-ups may be used to illustrate and evaluate proposed HSI hard switch, indication layouts, and positioning using walk-through/talk-throughs. Additional fidelity may be added to a physical mock-up through the inclusion of interactive video display units. Video display units allow users to sit at the display and interact with software-based controls and indications within the context of the control area.

3D virtual mock-ups may be used to make ergonomic assessments of general console and panel shape. Software-based 3D models can be used for designing and testing room layouts with revision management for tracking design iterations. HSI designers use 3D technology to rapidly prototype and test designs against ergonomic requirements and recommendations. For ergonomic evaluations, 3D human models are used to represent the upper and lower bounds for target user population anthropometric measurements. Human models can be used within the proposed design to test sightlines, reach, and access.

5.2.1.3 Simulation

A generic plant simulation model may be used by the HFE team for HSI development and usability testing. Once a site-specific system model becomes available, tests and evaluations may be conducted using site-specific models. Dynamic simulation is used as an HFE design tool, for HFE Validation testing, and for training. Simulation can be run with user interfacing though a computer-based video display unit workstation, a Glass-Top Simulator (virtual controls and indications), or a hardware-based simulator (physical controls and indications).

5.2.2 Human Factors Engineering Verification and Validation Tools

HFE Design Verification and Task Support Verification utilize multiple evaluation tools and testbeds, as appropriate to the verification scope, to verify the overall HSI design (including task sequencing, timing, and procedures) conforms to the HFE design requirements contained within the HFE DRD (Reference 8-40) and the task support requirements contained within the TAs, respectively. Verification methods are:

- Analysis using paper-based or software-based drawings to verify static design features (e.g., dimensions, layouts, labelling, access)
- 3D mock-ups (virtual or physical) to verify physical characteristics of the CR layout, panels, and consoles
- Simulation/stimulation using a computer-based workstation platform or a Glass-Top Simulator platform to verify dynamic design features and HSI function

ISV simulator testbeds are developed to provide the fidelity required for the validation conducted to be meaningful and valid. Testbed development informed by IEEE Standard 2411-2021 IEEE Guide for Human Factors Engineering for the Validation of System Designs and Integrated Systems Operations at Nuclear Facilities (Reference 8-49) provides assurance of high-fidelity in accordance with common industry standards, regulatory standards, and definitions.

5.3 Technical Guides

5.3.1 Document Scope

The HFE DRD (Reference 8-40) is a plant-level requirements document containing the HFE design requirements and technical guidance to help ensure that a consistent design is applied across plant HSIs. The HFE DRD (Reference 8-40) scope includes requirements for the following areas:

- Workplace Design (including environmental)
- Maintainability (including equipment layout for operability and maintenance)
- Access and Egress
- Materials Handling
- Information Display (hardware- and software-based)
- User Interface Management
- Controls (hardware- and software-based)
- Alarm System
- Safety Function and Parameter Monitoring System
- Group View Display System
- Computer-Based Procedures
- Computerized Support System
- Communication System
- Workstation Design
- Labels and Signs

The HFE DRD (Reference 8-40) and subordinate HFE design documents are developed to comply with the industry codes and standards listed in the HFE DRD. The HFE DRD (Reference 8-40), is written to account for variation between target user populations and to avoid conflict with user population conventions and stereotypes, as defined in the HFE COO (Reference 8-38).

5.3.2 Document Development Process

Within the BWRX-300 project requirements structure, the HFE DRD (Reference 8-40) is a common requirements document, containing the HFE product design requirements. Due to the cross-cutting nature of the HFE DRD (Reference 8-40) requirements, during document creation, system designers are included in the HFE DRD (Reference 8-40) review to ensure awareness, understanding, and acceptability of the HFE requirements that are input into each design area.

The initial revision of the HFE DRD (Reference 8-40) is focused on providing HFE requirements that can affect building layout, environment, and hardware. The initial revision of the HFE DRD (Reference 8-40) begins by taking input from applicable requirements, codes, and standards as defined in this plan. For the initial HFE DRD (Reference 8-40) revision, document development is in parallel with, and informed by, the OE Review (Reference 8-24) and the HFE COO (Reference 8-38). HFE findings from the OE Review relating to HSI design are allocated to the HFE DRD (Reference 8-40) to provide input identifying positive HSI features to be included as applicable and negative HSI features to be avoided as applicable. The initial HFE COO, which includes CR concept, provides the expected uses of the primary and secondary CRs, the assumed population of users and their characteristics and anthropometric data, and the initial HSI technology choices. The HFE DRD (Reference 8-40) takes input from the HFE COO in relation to selection of requirements which are applicable to the selected HSI technology choices. As the design matures and new or different HSI technologies are the subject of optioneering, prototyping, and testing, the HFE COO CR concepts evolve, and the HFE DRD (Reference 8-40) content is updated to contain requirements for the latest HSI concepts and technologies.

The next revision of the HFE DRD (Reference 8-40) contains updates to any existing requirements resulting from OE Review findings as well as CR concept optioneering. This revision of HFE DRD (Reference 8-40) also includes the addition of new requirements for software-based HSI design and user interaction. This revision is also informed by the HFE COO (Reference 8-38) regarding expected software-based HSI use, assumed user population characteristics and coding stereotypes, and software-based HSI design compatibility and optimization with HSI technology choices (e.g., mouse or touchscreen-based input devices).

The last HFE DRD (Reference 8-40) development stage includes agile, iterative HSI usability testing using small samples of personnel who are representative of the end users (as defined in the HFE COO) to test, adjust, and solidify HSI concepts, conventions, and technologies. Early HSI T&E includes evaluations and user feedback on areas such as visual coding, font readability, control interaction and feedback, and navigation. Once HSI design concepts are deemed acceptable for the defined user population, these design conventions are confirmed and documented through the final HFE DRD (Reference 8-40) revision.

As a design specification supporting implementation of the HFE DRD (Reference 8-40), the HFE team also develops a detailed HSI Style Guide, which defines the user interaction scheme, alarm presentation design, information architecture, and navigation, as well as the development of display templates and an HSI element library to support consistent application of the HFE DRD (Reference 8-40) during HSI detailed design.

Effective alarm management is an essential aspect to optimized HSI design. To augment the Alarm System requirements in the HFE DRD (Reference 8-40), the HFE Team develops an Alarm Management Design Guide. The guide provides detailed alarm system and presentation guidance, including outlining the principles for alarm identification, prioritization, filtering, and suppression, in line with human cognitive capacity and required response. This design guide is used by the HFE designers in deriving the alarm system prioritization and rationalization specification. The specification is then used by the I&C Team to implement the alarm system alarm presentation logic.

As detailed system design continues, the HSI T&E activity continues and builds in complexity and fidelity as the testing platform and simulation logic are further developed. When there is sufficient fidelity, HSI T&E includes evaluation of workload, situation awareness, personnel communications, and task support.

The HSI T&E results feed back into the HSI design at the appropriate level using the HFE issue tracking process (as described in Section 6.5 and Section 10.0 APPENDIX C – Human Factors Engineering Issue and Human Engineering Discrepancies Identification and Disposition. HFE issue resolution may include adjusting an individual system display design, updating an HSI element in the HSI Library, or revising a requirement in the HFE DRD (Reference 8-40) as appropriate to address the HFE concern identified in the HFE issue.

6.0 PROCESS AND PROCEDURES

6.1 General

The HFE Program is developed and executed in accordance with the GEH quality management system and relevant controlling procedures, within the GEH nuclear safety culture framework. As described in the BWRX-300 Standard Plant Design Plan (Reference 8-4), all engineering work is performed in an integrated manner, coordinated through a detailed schedule that identifies the activities and deliverables necessary to complete the design. The schedule includes activities and deliverables for all disciplines (e.g., I&C, HFE, Mechanical, Electrical) and orders them with logic connections to ensure they are completed in the required sequence. A summarized overview of this integration of HFE with the related design and safety analyses activities, and integration of the HFE Technical Elements with each other is shown in Appendix B (Section 10.0).

A list of the HFE activities that are associated with documents, including internal records and formal deliverables is contained within the Plant and System Design Document (PSDD) list. The PSDD is maintained for the entire project as a live matrix that tracks what activities and documents are associated with which systems, including plant level disciplines such as HFE, what their basic logic links are to other activities and documents, and which stage of design they are required to be completed in. This list does not include integrated HFE design support level of effort activities but includes all other HFE technical elements activities and outputs described in this plan.

To help ensure cross-discipline communication and coordination, design stages include scheduled periodic formal design reviews conducted by representatives of each discipline; HFE is identified as a required stakeholder in those reviews.

6.2 Documentation

The BWRX-300 design process is intended to be data-centric rather than document-centric (see Section 1.2). This allows focus on effective timely integration between design disciplines, and production of fewer but higher-quality, more meaningful documents[3]. The documentation for the BWRX-300 HFE Program makes use of GEH standard design process internal design records to capture inputs and outputs, as well as providing the basis for formal deliverables. Deliverables are completed in accordance with a deliverable standard, which specifies the required content and format for consistency and quality and specifies the required discipline reviewers for each document.

The information in the design records is incorporated into the design by HFE and other disciplines as appropriate and in accordance with the BWRX-300 work breakdown structure. This is managed through the project-wide Plant and System Design Documents (PSDD) list. All project and design documents, including HFE, are either plant-level documents that are included in a plant-level documents list, or system-level documents, which are assigned to SSC per the Main Parts List (MPL). These two lists comprise the complete set of design activities and outputs for the BWRX-300. The PSDD list contains both lists and clearly identifies the logic ties between the documents, the MPL code(s) they relate to (where applicable), and the design stage(s) in which they are produced.

In this way, using the above tool, the design activities related to HFE are conducted in a timely, logic-linked manner, and documented, through design records, internal documents, and formal deliverables, such that basis rationale is provided for design decisions whenever applicable. All

[3] Documents are differentiated from deliverables to ensure consistent use of the term deliverables to those documents required to be delivered as part of contract arrangements.

HFE recommendations are addressed by incorporation into the design, provision of alternate solutions acceptable to HFE, or tracking as an HFE issue as discussed in Section 6.5.

Each technical element described in this plan is intended to have a summary report capturing all the records associated with the completed activities. In addition, a final "wraparound" HFE Summary Report ties together the documentation and deliverables associated with the HFE Program, acting as a single concise repository of the results and resolution of issues, demonstrating the effective implementation of the HFE Program and integration of HFE into the design.

6.3 Timelines

HFE work occurs within the context of an integrated schedule where workflows are timed and sequenced to ensure appropriate interaction. This includes inputs from and outputs to other disciplines at the correct times and project phases. The PSDD list provides the foundation for creating the logic links within the various intra- and inter-discipline activities in the schedule. Licensing submittals, interaction, communications, and time frames are as specified in the respective project's workplan.

6.4 Requirements Management

HFE requirements management is performed in accordance with the BWRX-300 Requirements Management Plan (Reference 8-26). Requirement management and traceability is developed and maintained to:

- Ensure HFE requirements relevant to each scope of work are clearly identified, allocated, communicated, and understood by all relevant project personnel
- Outline how the requirements are met
- Reference evidence that demonstrates compliance has been achieved

HFE requirements are categorized and dispositioned as follows:

A. Process Requirements – Requirements for how the HFE Program is conducted and the interfaces between HFE and other disciplines

   1. HFE Process Requirements are allocated to the HFEPP and are fulfilled via the construction and implementation of the architecture and processes defined within this document. As such, all HFE Process Requirements are allocated to, and end with, the HFEPP.

B. Product Requirements – Requirements for the design of or provision for plant workspace and working environment attributes, SSC and HSIs

   2. Product requirements are allocated to either the HFE DRD (Reference 8-40), or the HFE COO (Reference 8-38), [[

      ]]

      a. Product Design Requirements – Requirements pertaining to design attributes of HSI, layout, and environment

         i. [[

            ]]

b. Product Task Support Requirements – Requirements pertaining to the inventory of controls, indications, and alarms required to support operations, maintenance, inspections, and test tasks

   i. [[

]].

Where HFE inputs are not in agreement with one another or where they conflict with other discipline design requirements, precedence is given as follows:

1. Laws and Regulations
2. Regulatory Requirements and Guides
3. Requirements related to supporting, maintaining, or recovering the plant in a safe state
4. Nuclear Standards
5. Nuclear Industry Guidance Documents
6. Non-Nuclear Codes, Standards, and Guides

For a discrepancy between inputs from a “Mandatory” source and a “Voluntary” source (as defined in the BWRX-300 Requirements Management Plan (Reference 8-26)), the input from the “Mandatory” source is used. For a discrepancy between inputs from two “Voluntary” sources, subject matter expert judgment is used, based on conservatism, and taking into consideration which document is the most current source.

Conflicts between HFE design requirements and performance-based requirements that are identified during requirements consolidation for Design Implementation, HSI design tests and evaluations, and HFE Design Verification, are resolved using the HFE issue and HED resolution process described in Section 6.5. Decisions regarding trade-offs and design optimizations are conducted within the integrated design process described in the BWRX-300 Standard Plant Design Plan (Reference 8-4), using subject matter expertise informed by the plant integrated model and the integrated cost model to determine decision impact.

6.5 Identification and Disposition of Human Factors Engineering Issues

HFE issues and HEDs are tracked within an HFEITS. HFEITS facilitates resolution of problems, issues, and HEDs by providing the means to record and track issues throughout the design process life cycle, development, and evaluation. For BWRX-300, HFEITS functionality is housed within the project issue and action tracking system, in accordance with the design process and action tracking process included in the BWRX-300 Standard Plant Design Plan (Reference 8-4).

The HFEITS is used to support the following functions:

- Evaluation of HEDs to determine significance and whether the HED warrants correction when evaluated in the context of the integrated plant design
- Identification of appropriate solutions to address issues/HEDs, including, as appropriate, changes to HSI design, procedures, staffing/qualifications, or training
- Verification that the solutions implemented to address the issue/HED resolves the problem without generating additional issues/HEDs

- Documented traceability of the issue/HED resolution process, including documenting residual risks associated with any unresolved HFE issues/HEDs

Details regarding specific considerations and processes for HFE issues and HED management that are supplementary to the process described above are contained in Appendix B (Section 10.0).

7.0 ACRONYMS, DEFINITIONS, AND SYMBOLS

7.1 Acronyms

Acronym	Explanation
AOF	Allocation of Functions
CNSC	Canadian Nuclear Safety Commission
COO	Concept of Operation
COTS	Commercial Off-The-Shelf
CR	Control Room
CSA	Canadian Standards Association
DSA	Deterministic Safety Analysis
FRA	Functional Requirements Analysis
HA	Human Action
HEA	Human Error Analysis
HED	Human Engineering Discrepancy
HF	Human Factors
HFE	Human Factors Engineering
HFEITS	Human Factors Engineering Issue Tracking System
HFEPP	Human Factors Engineering Program Plan
HRA	Human Reliability Analysis
HSI	Human-System Interface
IAEA	International Atomic Energy Agency
IEC	International Electrotechnical Commission
INPO	Institute of Nuclear Power Operators
ISV	Integrated System Validation
MPL	Main Parts List
NRC	U.S. Nuclear Regulatory Commission
OE	Operating Experience
PSA	Probabilistic Safety Assessment
PSDD	Plant and System Design Document
SAT	Systematic Approach to Training
SSC	Structures, Systems, and Components
T&E	Testing and Evaluation
TA	Task Analysis
V&V	Verification and Validation

7.2 Definitions

Term	Definition
Human Engineering Discrepancy	A departure of the design from HFE design guidance and/or human performance criteria as identified during the execution of HFE V&V activities.
Human Factors Engineering	The application of knowledge about human capabilities and limitations to plant, system, and equipment design. HFE ensures that the plant, system, or equipment design, tasks, and work environment are compatible with the sensory, perceptual, cognitive, and physical attributes of the personnel who operate, maintain, and support it.
Human Factors Engineering Issue	A problem or finding that is known to the industry or is identified throughout the life cycle of the HFE aspects of design, development, and evaluation. Issues are items that need to be addressed later and are tracked to ensure they are not overlooked.
Human Factors Engineering Process Requirements	Requirements for how the HFE Program is conducted and the interfaces between HFE and other disciplines.
Human Factors Engineering Verification and Validation	HFE V&V evaluates completed design features including alarms, controls, indications, and their associated hardware. During HFE V&V, design features are compared with regulatory requirements and guidance, HFE requirements, and the requirements generated during analysis of operator tasks. HFE V&V consists of design verification, task support verification, and ISV.
Human-System Interfaces	The HSIs are the means through which personnel interact with the plant. This includes the alarms, displays, controls, and job performance aids. This includes interfaces for operations, maintenance, test, and inspection interfaces.
Serious Injury	An injury that is life threatening and requires immediate attention (on-site or emergency response) to prevent loss of life or permanent disability.

7.3 Symbols

Symbol	Definition
MWe	Megawatt Electric

8.0 REFERENCES

8-1 Product Requirements Document – BWRX-300, GE Hitachi Nuclear Energy Americas, LLC.

8-2 BWRX-300 Robustness of Design, GE-Hitachi Nuclear Energy Americas, LLC.

8-3 Design to Cost Plan for BWRX-300, GE-Hitachi Nuclear Energy Americas, LLC.

8-4 BWRX-300 Standard Plant Design Plan, GE Hitachi Nuclear Energy Americas, LLC.

8-5 REGDOC-2.5.1, General Design Considerations: Human Factors. Canadian Nuclear Safety Commission, 2019.

8-6 REGDOC-2.5.2, Design of Reactor Facilities: Nuclear Power Plants. Canadian Nuclear Safety Commission, 2014.

8-7 CSA N290.12-14 (2019), Human factors in design for nuclear power plants, Canadian Standards Association, 2019.

8-8 10 CFR Part 50, Chapter 1. CFR 50.34(f)(2) ii and iii, Domestic Licensing of Production and Utilization Facilities. U.S. Nuclear Regulatory Commission.

8-9 BWRX-300 Composite Design Specification, GE Hitachi Nuclear Energy Americas, LLC.

8-10 NUREG-0711, Rev. 3, Human Factors Program Review Model, U.S. Nuclear Regulatory Commission, November 2012.

8-11 2019/367414, Safety Assessment Principles for Nuclear Facilities, 2014 Revision 1 (January 2020), UK Office for Nuclear Regulation.

8-12 NS-TAST-GD-058, Technical Assessment Guide: Human Factors Integration (HFI), UK Office for Nuclear Regulation, 2022.

8-13 IAEA SSG-51, Human Factors Engineering in the Design of Nuclear Power Plants, International Atomic Energy Agency, 2019.

8-14 IEEE 1023-2020, Recommended Practice for the Application of Human Factors Engineering to Systems, Equipment, and Facilities of Nuclear Power Generating Stations and Other Nuclear Facilities, Institute of Electrical and Electronics Engineers, 2020.

8-15 CSA N290.4-19, Requirements for reactor control systems of nuclear power plants, Canadian Standards Association, 2019.

8-16 CSA N290.6-16, Requirements for monitoring and display of nuclear power plant safety functions in the event of an accident, Canadian Standards Association, 2016.

8-17 IEC 61839:2000, Nuclear power plants - Design of control rooms - Functional analysis and assignment, International Electrotechnical Commission, 2000.

8-18 IEC 60964:2018, Nuclear power plants – Control rooms – Design, International Electrotechnical Commission, 2018.

8-19 IEC 61771:1995, Nuclear power plants – Main control room – Verification and validation of design, International Electrotechnical Commission, 1995.

8-20 NUREG-1764, Rev. 1, Guidance for the Review of Changes to Human Actions, U.S. Nuclear Regulatory Commission, 2007.

8-21 EPRI 3002004310, Human Factors Guidance for Control Room and Digital Human-System Interface Design and Modification, Electric Power Research Institute, 2015.

8-22 BWRX-300 Outage Plan, GE Hitachi Nuclear Energy Americas, LLC.

8-23 BWRX-300 Reliability, Availability, Maintainability, and Inspectability Program, GE Hitachi Nuclear Energy Americas, LLC.

8-24 BWRX-300 Operating Experience Review Process and Results, GE Hitachi Nuclear Energy Americas, LLC.

8-25 BWRX-300 Operating Experience Report, GE Hitachi Nuclear Energy Americas, LLC.

8-26 BWRX-300 Requirements Management Plan, GE Hitachi Nuclear Energy Americas, LLC.

8-27 BWRX-300 Plant Architecture Definition – Major Functions and Interfaces, GE Hitachi Nuclear Energy Americas, LLC.

8-28 BWRX-300 Fault Evaluation, GE Hitachi Nuclear Energy Americas, LLC.

8-29 BWRX-300 Operational Concept – Normal, GE Hitachi Nuclear Energy Americas, LLC.

8-30 Operational Concept – Off-Normal, GE Hitachi Nuclear Energy Americas, LLC.

8-31 System Functional Performance Requirements, GE Hitachi Nuclear Energy Americas, LLC.

8-32 Functional Requirements Analysis, Allocation of Function, and Task Grading Results Report for the BWRX-300, GE-Hitachi Nuclear Energy Americas, LLC.

8-33 IAEA-TECDOC-668, The Role of Automation and Humans in Nuclear Power Plants, International Atomic Energy Agency, 1992.

8-34 NUREG/CR-2623, The Allocation of Function in Man-Machine Systems: A Perspective and Literature Review, U.S. Nuclear Regulatory Commission, 1981.

8-35 BWRX-300 Allocation of Function Methodology Report, GE Hitachi Nuclear Energy Americas, LLC.

8-36 Human Factors Engineering Staffing Analysis Plan for BWRX-300, GE Hitachi Nuclear Energy Americas, LLC.

8-37 REGDOC-2.2.5, Minimum Staff Complement, Canadian Nuclear Safety Commission, April 2019.

8-38 BWRX-300 Human Factors Engineering Concept of Operations, GE Hitachi Nuclear Energy Americas, LLC.

8-39 BWRX-300 Human Factors Engineering Task Analysis and Human-System Interface Design Methodology Report, GE Hitachi Nuclear Energy Americas, LLC.

8-40 BWRX-300 Human Factors Engineering Design Requirements Document, GE Hitachi Nuclear Energy Americas, LLC.

8-41 NUREG-0700, Rev. 3, Human-System Interface Design Review Guidelines, U.S. Nuclear Regulatory Commission, 2020.

8-42 BWRX-300 Procedure Development Plan, GE Hitachi Nuclear Energy Americas, LLC.

8-43 IAEA-TECDOC-1058, Good Practices with Respect to the Development and Use of Nuclear Power Plant Procedures, International Atomic Energy Agency, 1998.

8-44 PPA AP-907-005, Rev. 2, Procedure Writer’s Manual, Procedure Professionals Association, 2016.

8-45 Training and Qualification Plan for the BWRX-300, GE Hitachi Nuclear Energy Americas, LLC.

8-46 REGDOC-2.2.2, Personnel Training, Version 2, Canadian Nuclear Safety Commission, 2016.

8-47 BWRX-300 Human Factors Engineering Verification and Validation Plan, GE Hitachi Nuclear Energy Americas, LLC.

8-48 NUREG/CR-6393, Integrated System Validation: Methodology and Review Criteria, U.S. Nuclear Regulatory Commission, 1997.

8-49 IEEE 2411-2021, IEEE Guide for Human Factors Engineering for the Validation of System Designs and Integrated Systems Operations at Nuclear Facilities, Institute of Electrical and Electronics Engineers, 2021.

9.0 APPENDIX A: HUMAN FACTORS ENGINEERING APPLICATION LEVELS BY TECHNICAL ELEMENT

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Table 9-1: Human Factors Engineering Application Levels

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Table 9-1: Human Factors Engineering Application Levels

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10.0 APPENDIX B: HUMAN FACTORS ENGINEERING PROGRAM INTEGRATION MAP

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Figure 10-1: Human Factors Engineering Program Integration Map

11.0 APPENDIX C: HUMAN FACTORS ENGINEERING ISSUE AND HUMAN ENGINEERING DISCREPANCIES IDENTIFICATION AND DISPOSITION

The following appendix contains supplementary HFE discipline-specific definitions, criteria, and processes.

11.1 Identification

An HFE issue is placed into HFEITS when:

- The HFE issue is discovered "out-of-process" and therefore cannot be currently resolved through the normal HFE process.
- The HFE issue requires tracking until it can be resolved via the normal HFE process.

An HED is placed into HFEITS when:

- A deviation from an HFE design requirements Document requirement is discovered during HFE Design Verification.
- There are information and control requirements identified by TA that have not been met by an HSI during Task Support Verification.
- There are HSIs identified during Task Support Verification that are not needed to support personnel tasks.
- Acceptance criteria are not met during ISV.

11.2 Prioritization

Table 11-1, Human Factors Engineering Issue and Human Engineering Discrepancies Prioritization Criteria Summary provides guidance for classification of HFE issues and HEDs. HFE priority is included in the summary of issue. HFE priority classification is then determined as described below. Information is to be initially populated by the Originator and updated, as needed, by the Issue Owner.

Table 11-1: Issues and Discrepancies Prioritization Criteria Summary

HF Priority	Definition
1 – Highest	The issue or HED has/will have a safety consequence, either direct or indirect.
2 – High	The issue or HED has/will have an impact on plant or personnel performance.
3 – Low	Enhancement – The issue or HED does not/will not have a safety consequence nor performance impact.

11.2.1 Priority 1 – Safety Consequences

A condition (equipment, HSI, procedure, training, or staffing deviation, deficiency, or nonconformance) or adverse trend that has the potential to impact an [[
]](either directly or indirectly).

11.2.2 Priority 2 – Plant or Personnel Performance Impact

A condition (equipment, HSI, procedure, training, or staffing deviation, deficiency, or nonconformance) or adverse trend that has the potential to impact an [[
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11.2.3 Priority 3 – Enhancement

A condition (equipment, HSI, procedure, training, or staffing deviation, deficiency, or nonconformance) or adverse trend that deviates from the HFE design requirements Document or HFE principles that has neither safety or other risk consequences, and does not impact plant or personnel performance.

11.3 Cumulative Effects Analysis

The cumulative effects or impact of HEDs on the HSI resources, CR layouts, operator training, plant procedures, or staffing and work organization may have greater impact on operator performance and the likelihood of operator errors than the individual HEDs. Thus, cumulative effects result from HEDs that are individually minor but collectively significant.

Cumulative effects analysis is conducted by the Issue Owner, using qualitative techniques and subject matter expertise and judgment. After becoming familiar with the HEDs through the process of reviewing, prioritizing, and categorizing the HEDs, the Issue Owner will determine if there are individual HEDs that merit grouping together to assess the cumulative effects of the HEDs and to facilitate resolution.

Related HEDs are grouped for analysis of interactions and combined effects:

- HEDs that affect the same HSI resource
- HEDs that affect the same function/task
- HEDs from different originating activities but are related to the same issue
- HEDs related to inconsistency between HSIs
- HEDs with the same underlying cause
- HEDs for separate HSI resources that share the same problem

Any HED that meets the above criteria is placed in the respective group for analysis of interactions between HEDs and their combined effects on operator performance. Additionally, during analysis, it is determined if priority escalation is needed for any of the HEDs due to concerns raised by cumulative effects.

When examining related HEDs in the context of other existing HEDs, the Issue Owner is to note any potential conflicts that may occur when determining resolutions to the individual HEDs. The results of this evaluation are used to help determine the most appropriate overall resolutions.

Based on the information resulting from the above analysis, the Issue Owner may draw conclusions about the cumulative effects to operator actions [[

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Once the Issue Owner has determined what potential cumulative effects exist, the Issue Owner next uses the results of the analysis to determine the severity or magnitude of the cumulative effect and how this impacts the priority of the affected HEDs. If priority is changed, rationale is

also to be included. [[
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The results of cumulative effects analysis are attached to the relevant issues, including reference to the tracking number of the HEDs. The results also provide any suggestions for addressing or mitigating the identified effects.

11.4 Confirmation of Resolution

Once the Assignee has completed design revision or disposition actions, the Issue Owner determines, based on the HED types described below, the appropriate means by which to check the adequacy of the revised design, procedures, training program, or staffing plan.

The Issue Owner then assigns, notifies, and briefs the individuals needed to conduct review, verification, or validation of the HED resolution.

11.4.1 Justification Review

Justifications are reviewed and verified [[

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If the justification is not deemed acceptable, the Issue Owner revises the justification based on feedback or escalate the issue as needed.

If justification is acceptable, acceptance is included in issue resolution documentation, and the HED proceeds to closure.

11.4.2 Performing Static Human Factors Engineering Verification

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Verification may only occur on completed, approved, formally issued, configuration-controlled product releases.

Verification results and methodology are included in issue resolution documentation.

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If new HEDs are found as a byproduct of the verification process, these HEDs are fed back into the HFE Issues Tracking Process as new HEDs.

11.4.3 Performing Dynamic Human Factors Engineering Retesting

For HEDs that originated from HFE ISV activity, the Issue Owner determines the appropriate validation strategy, using a graded approach, based on the complexity and impact of the changes. For this category of HED, the HFE Verifier acts as lead on retesting activities, implementing the verification plan laid forth by the Issue Owner, overseeing the testing, generating the test report (as needed), and documenting conclusions and acceptability.

Priority 1 and 2 HEDs require retesting with participants not previously exposed to the test scenario(s). This is to provide assurance that the HSI resources, CR layout design, operator training, operating procedure, or staffing changes now satisfy the applicable test criteria.

For Priority 3 HEDs, where HED resolution was relatively straightforward, changes minimal, and where it is unlikely that the changes would impact the performance of the integrated system as a whole, alternate re-assessment methods may be utilized. In these cases, the assessment of the effectiveness of the resolution may be done using one or more of the following methods, as appropriate:

- Walk-through assessment
- Performance-based, small-scale retesting utilizing personnel with an operations background as subjects

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If any of the re-assessment activities result in the identification of the same HEDs, these HEDs are updated and rejected back to the Issue Owner for resolution.

If any of the re-assessment activities result in the identification of new HEDs, these HEDs are fed back into the HFE Issues Tracking Process as new HEDs.

11.4.4 Deferred/As-Built Resolutions

For HEDs that cannot be resolved or verified until a specific design lifecycle milestone is reached, the Issue Owner makes this designation in HFEITS and ensures the HEDs are tracked until resolution can occur.