OPTIMIZATION OF HUMAN FACTORS METHODS WITHIN THE DESIGN CYCLE

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ABSTRACT

Amec Foster Wheeler developed and implemented the Human Factors Engineering program to analyze the design of a large-scale electrical component readying for installation in a nuclear facility. The HFE program applied the program elements from NUREG-0711 throughout the detailed design phase of the project. This paper provides: (1) a review of the Human Factors Engineering (HFE) program methodology that was implemented, and (2) a summary of the integrated approach to the design, verification, and validation of the Human-Machine Interface (HMI) display and mimic panel. In general, it was found that a collaborative approach between the design team, equipment vendor, HFE, and the end-users of the component created a more streamlined approach to the design and allowed for user feedback to be implemented throughout the progression of the design. However, the trade-off to this approach is that an integrated validation is likely required once all design aspects are complete, to ensure the modification is acceptable in the context of the overall system.

Key Words: Human Factors, Human-Machine Interface, Human-System Interface

1 INTRODUCTION

Amec Foster Wheeler developed and implemented the Human Factors Engineering (HFE) program to analyze the design of a large-scale electrical component readying for installation in a nuclear facility. The HFE program applied the program elements from NUREG-0711 throughout the detailed design phase of the project. As part of the modification, several different design disciplines were involved; namely Mechanical, Civil, Electrical, Instrumentation and Control (I&C), and Software design. HFE input was provided to all of the engineering change packages, which included updating the facility's Human-Machine Interface (HMI) with new software. In this project, the following human machine interfaces were impacted by the modification:

1. HMI: the HMI for the facility is the software interface for the existing system that is manipulated through computers in the control room of the facility.
2. Mimic Panel: the mimic panel is located in the control room for the facility and provides a high-level overview of the system. Key indications are provided on the mimic panel for the facility operators and the panel acts as a back-up for the HMI.
3. The remaining human machine interfaces for the system are the physical equipment located in the field.

However, while the HFE analysis activities were conducted at the beginning of detailed design, each of the separate design disciplines was proceeding on a different timeline and therefore required HFE inputs at different stages of the project. This paper provides: (1) a review of the HFE program methodology that was implemented, and (2) a summary of the integrated approach to the design, verification, and validation of the HMI display and mimic panel. At the time of writing this paper, the HFE program has not been fully executed as the modification is not yet installed in the facility.

2 HFE PROGRAM METHODOLOGY

2.1 Human Factors Engineering Program Plan

A Human Factors Engineering Program Plan (HFEPP) was created for the project with the following industry technical basis documents:

4. Canadian Nuclear Safety Commission (CNSC) Regulatory Guide G-276, “Human Factors Engineering Program Plans” [1];
5. CNSC Regulatory Guide G-278, “Human Factors Verification and Validation Plans” [2]; and
6. NUREG-0711, “Human Factors Engineering Program Review Model,” [3].

In addition to these industry documents, utility specific documentation was also used in the development of the HFEPP. The methodology provided in NUREG-0711 for HFE Programs was utilized in this project [3]; the program review elements are highlighted in Fig. 1.

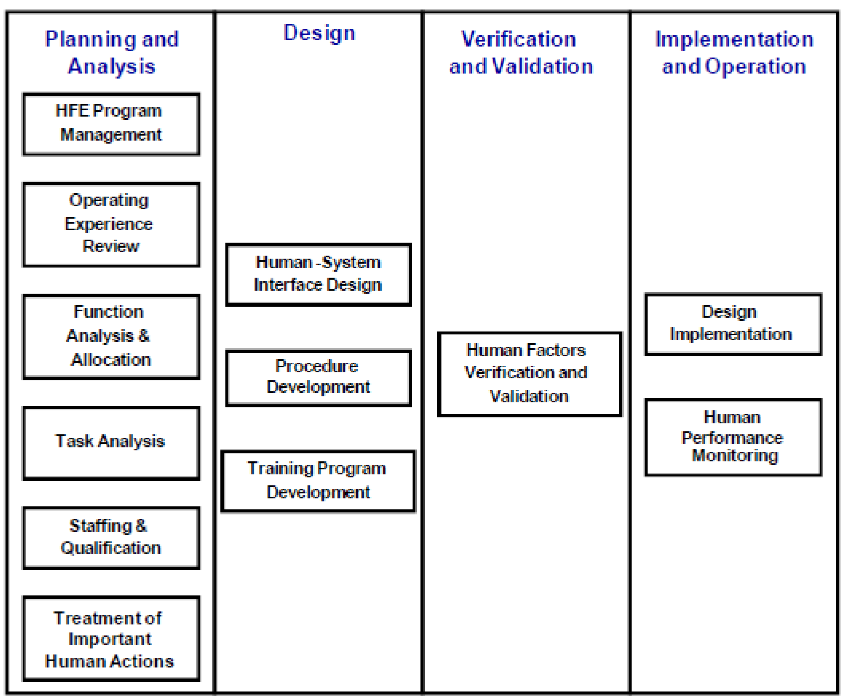

Figure 1. HFE Elements of the Program Review Model [3]

The specific program elements that were completed are: Operating Experience Review (OER), Function Analysis, Task Analysis, Human-System Interface (HSI) Design, and Verification and Validation. At the time of writing this paper, design implementation was not yet completed as the modification has not been installed in the facility. In the “Planning and Analysis” section, the following elements were not deemed necessary: “Staffing & Qualification” and “Treatment of Important Human Actions”. Staffing & Qualification was not required for this modification as it was determined that the number of staff required was not changing from the current requirements. In addition, any qualifications would be obtained through the training program for the new component. Although a separate analysis for the “Treatment of Important Human Actions” element was not completed, any possible human error in would be identified in the Task Analysis. In the “Design” section, Amec Foster Wheeler was only responsible for the “Human-System Interface Design”; the utility was responsible for the “Procedure Development” and “Training Program Development”. As previously mentioned, the modification has not yet been installed within the facility; therefore, “Design Implementation” will be completed through the installation of the component. “Human Performance Monitoring” will also be completed by the utility once the modification has been installed and in-use for a certain period of time.

2.2 Operating Experience Review

In general, the purpose of the OER in the HFE program is to review and use the knowledge gained from predecessor designs to avoid negative features in the new design while retaining the positive ones. The OER from this project consisted of reviewing several databases, including the utility’s internal Operating Experience (OPEX) database, and external databases such as CANDU Owners Group (COG), the World Association of Nuclear Operators (WANO), and the Institute of Nuclear Power Operators (INPO). However, the new electrical component selected was relatively novel within the nuclear industry; therefore, extensive operating experience was not available within the industry databases. As part of the project, OPEX was obtained by the utility from another facility which had the new component installed and had been operating for a short amount of time. HFE reviewed this OPEX to ensure that sufficient attention was paid to HFE/HSI topics.

Additional OPEX on the existing system was obtained from key stakeholders, such as Operations and Maintenance personnel. Interviews were used to identify of any aspects of the current design that users wanted to retain, and possible areas for improvement.

2.3 Function Analysis

The goals of this activity were to define the system functions that must be enacted to satisfy plant objectives, to ensure that these functions are allocated appropriately to system and human resources, and to provide a basis for definition of information and control requirements. Per IEC 61839 [4], the process for function analysis is two-fold:

a) Define functions and associated hierarchy; and

b) Assign functions to humans or machines.

In this project, the modification did not introduce new or significantly alter the system functions; therefore, a full function analysis and function allocation assessment was not completed. A functional change map was utilized, which identified changes to the existing functionality and/or function allocation, as well as changes to the monitoring and control requirements. The overall system functionality was decomposed to situate the modification within the overarching functional hierarchy. Each of the functions was analysed according to Price [5], using input from designers and design documentation. In general, the Function Analysis concluded that any new functions which were similar to existing functions should have a consistent allocation, which was largely that the system would be automated with monitoring requirements from the Human Operator (HO).

2.4 Task Analysis

Due to unavailability of vendor documents at the beginning of the detailed design phase, a preliminary task analysis was created based on the existing system. The existing Operating Manual (OM) steps were reviewed and identified where it was anticipated that the task might be impacted by the new component. Initially, a Task Decomposition was prepared for both standard and non-standard operating conditions within the system, following methodology specified by Kirwan and Ainsworth [6]. From the Task Decomposition, a tabular Task Analysis was then prepared with the tasks that were related to the specific component that was being replaced. The tabular Task Analysis included a task description, time restraints on completion of the task, work environment considerations, competing tasks and possible human errors.

Subsequent to the initial Task Analysis, an updated Task Decomposition and tabular Task Analysis was prepared using the component vendor's preliminary control scheme and alarms/trip list. A step-by-step walk through was completed with the component vendor to identify specific operating parameters of the system, potential human errors throughout the process and to provide additional context for the modified operating tasks. Using this collaborative approach, the Task Analysis was updated for the new component in the absence of Operating and Maintenance Manuals.

2.5 Human-System Interface Design

Similar to the other HFE analysis activities, the HSI design requirements were provided, based on outputs of the human factors analyses and HSI standards provided near the beginning of detailed design, prior to much of the design-specific information for the new electrical component being available. The completed HFE analyses, namely Function Analysis and Task Analysis, provided the information requirements which fed into the HSI requirements. For each of the information requirements, such as valve status and operating parameters, it was identified whether they were required on the mimic panel and/or HMI display. The HSI guidance provided incorporated inputs from the following sources:

1. Utility-specific HFE guidance for accessibility, reaching distances and space allocation around equipment;
2. Existing facility conventions for updates to the mimic panel and HMI display;
3. MIL-STD-1472G, "Department of Defense Design Criteria Standard – Human Engineering" [7];
4. NUREG-0700, "Human-System Interface Design Review Guideline" [8];
5. MIL-HDBK-759C, "Handbook for Human Engineering Design Guidelines" [9];
6. EPRI NP-4350, "Human Engineering Design Guidelines for Maintainability" [10]; and
7. DOE-HDBK-1140-2001, "Human Factors/Ergonomics Handbook for the Design for Ease of Maintenance" [11].

For updates to the mimic panel and HMI display, requirements from NUREG-0700 [8] were used in a ddition to the facility conventions since limited design information was available from the vendor at the time the HSI requirements were identified. Guidance provided from NUREG-0700 [8] included requirements for icons and pictorial symbols to ensure their meaning would be clear to the user population. Additional information regarding the evolution of the HMI Display and mimic panel designs is provided in Section 3.

2.6 Verification and Validation Planning

As part of the HFE Program a Verification and Validation (V&V) Plan was prepared, following guidance from CNSC Regulatory Guide G-278 [2], to outline the information required to execute the verification and validation activities. The plan also identified the specific scenarios that would be used in the validation exercise, the personnel groups required to participate in the validation, the performance measures and acceptance criteria, and other details relevant to the validation. The HFE V&V activities for this project included HSI task support verification (TSV), HFE design verification (DV) and a validation exercise; all of these activities were performed during detailed design, prior to the release of the design. The goal of Task Support Verification is to confirm that the HSI provides the necessary information and control identified in the HFE Task Analysis. The goal of Design Verification is to confirm that the HSI conforms to the HFE design guidelines.

In general, the objective of the V&V activities was to confirm the following criteria were satisfied:

1. Consistency: The HSI design is consistent with industry standards and facility conventions;
2. Minimum HSI Requirements: The HSI design provides the information and control capabilities required for personnel to adequately detect and diagnose a condition or state, determine the appropriate control actions, and execute those actions.
3. Task Performance: The design supports user tasks to the required performance level (i.e., personnel can complete tasks within the available time).
4. User Acceptance: The configuration and layout of the equipment supports user tasks in a manner acceptable to the users.

Additional information on the V&V activities are included in Sections 3.2.and 3.3.

3 INTEGRATED APPROACH TO DESIGN, VERIFICATION AND VALIDATION

As part of the modification, several different design disciplines were involved; namely Mechanical, Civil, Electrical, I&C, and Software design. As previously discussed, the HFE analysis activities were conducted at the beginning of detailed design. Therefore, while each of the separate design disciplines were proceeding on a different schedule, HFE input had to be integrated into each at different stages of the project. An initial HFE integration map was included as part of the HFEPP and is included in Fig. 2.

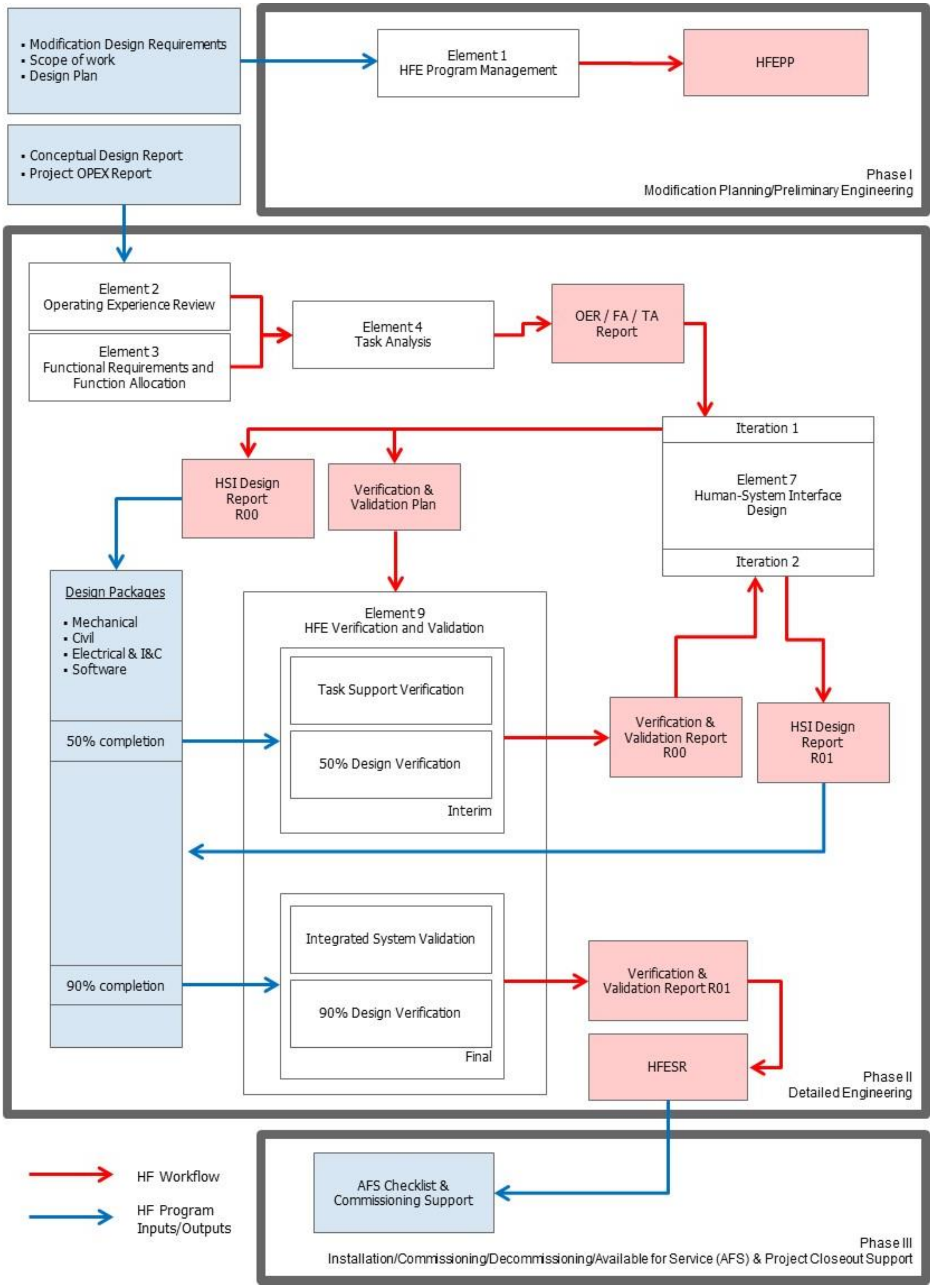

Figure 2. HFE Integration Map

3.1 HSI Design

In the initial planning stages, there were only two iterations planned for HSI design, as seen in Fig. 2. The preliminary HFE HSI requirements were provided to the design team as initial inputs early in the detailed design stage as inputs to the 50% design milestones. However, at the time the initial iteration of HSI requirements were provided, much of the vendor design information was not yet available. Thus, additional HFE input was required throughout the evolution of the design depending on the schedule for each respective design package and when vendor information became available. Each of the designs were developed using this initial set of HSI design requirements and, subsequently, through integration between the design team, equipment vendor and HFE in both team meetings and information reviews of the design documentation.

3.2 HFE Verification Approach

As discussed in Section 2.6, HSI TSV and DV were performed as part of this modification. Additional information on the integrated approach that was taken towards HFE DV is described in Sections 3.2.1, 3.2.2 and 3.2.3 below.

3.2.1 Mechanical, Electrical and I&C, and Civil Design Change Verification

For the Mechanical, Electrical and I&C, and Civil design, an interim HFE DV was performed when the design reached the 50% design milestone due to the varying schedules of the design changes. This all owed for HFE input to be provided early-on to the design team and more-easily incorporated into the design. All documents and drawings with HFE content were identified through discussions with the various design disciplines. A second HFE DV was performed prior to the 90% design submission for these design changes. HFE reviewed the previously identified documents and drawings to verify that prior HFE comments / design input had been incorporated, and that the design is consistent with station and general HFE guidelines. In addition, the second HFE DV provided an opportunity for HFE to review any new drawings and changes that had been implemented subsequent to the 50% design milestone. A final HFE DV was performed on the 100% design, just prior to submission.

In addition to the HFE DV at the 50% and 90% design milestones, an as-built verification checklist was compiled based on the HFE inputs to the design. The intent of this checklist was to incorporate it into the commissioning plan and use it after the modification has been installed to confirm that human factors specific requirements and recommendations have been implemented correctly. This checklist acted as a living document, where new HFE requirements could be added as they were identified throughout the project.

3.2.2 Mimic Panel

The verification of the mimic panel updates as a result of the modification were performed during HFE DV of the Electrical and I&C design submissions through comparisons to the existing mimic panel conventions and design documentation. The initial HSI requirements were identified in the HSI Design Report and provided to the design team as the initial HFE inputs, prior to the start of the design changes to the mimic panel. The design team provided the initial proposed changes to the mimic panel for HFE review as a starting point. From this initial mark-up, HFE and the Electrical and I&C Design Team worked through any of the changes required to the mimic panel to meet HFE requirements. Through this approach, HFE also completed their DV, ensuring that the HFE inputs were adequately addressed in the mimic panel design.

3.2.3 HMI Display

The HFE DV for the HMI display occurred at several intervals throughout detailed design, since the software design was progressing at a very different schedule from the rest of the project. Initial HFE input and requirements were provided in the HSI Design Report to the Software Design Team. From these initial requirements, HFE and the Software Design Team took a more collaborative approach to the design verification rather than the structured approach for the other design disciplines. HFE would provide input to the Software Design Team throughout the development of the new HMI Display. Once the input had been provided, revisions to the HMI Displays would be provided to HFE on an on-going basis, to confirm that the HFE requirements had been implemented satisfactorily. This integrated approach to HSI Design and HFE DV allowed for a smoother progression throughout the development of the HMI Display and eliminated the potential for last minute design changes towards the end of detailed design. The original HMI Display is shown below in Fig. 3. The updated HMI Display from the collaborative approach is shown in Fig. 4.

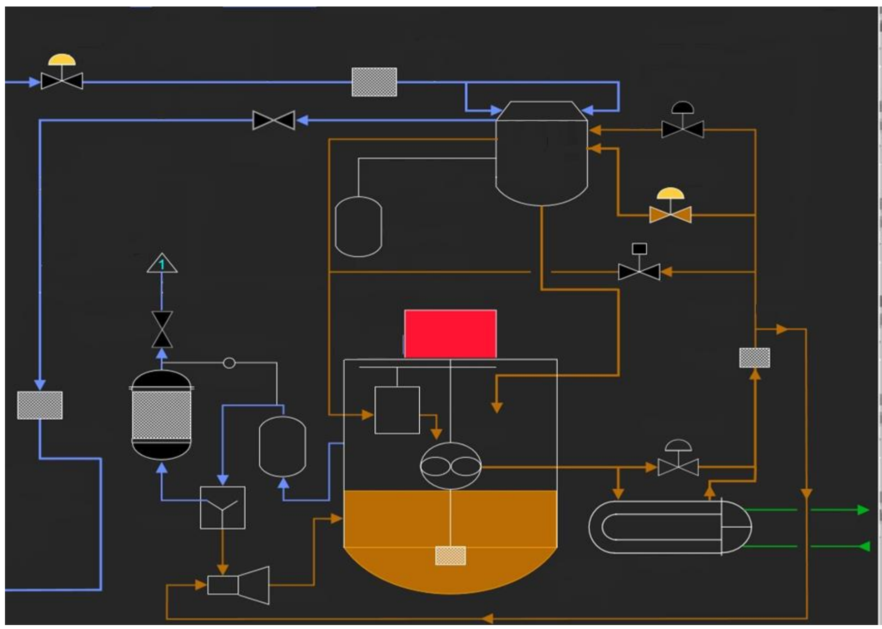

Figure 3. HMI Display for the Existing System

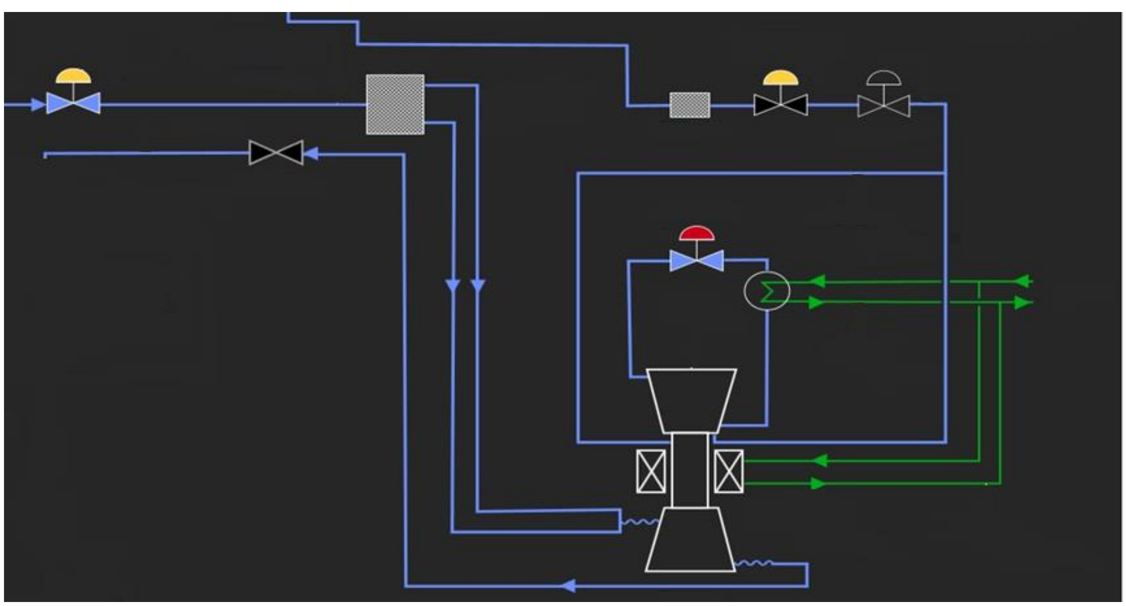

Figure 4. Updated HMI Display for the New System

3.3 HFE Validation

The validation exercise for the modification was planned to review new tasks in both normal and abnormal operating configurations with users of the system. Initially, only one validation exercise with each of the two user groups, Operations and Maintenance, was planned. However, due to the varying schedules of the design submissions, it was determined that a preliminary feedback session would be required to obtain user acceptance of the Mechanical, Electrical and I&C, and Civil modifications; this preliminary session is discussed further in Section 3.3.1. The validation exercises would then focus on walking users through the new tasks for normal and abnormal operating conditions, as well as using a prototype updated HMI display; this is further discussed in Section 3.3.2.

3.3.1 Preliminary Feedback Session

In order to provide HFE and user input to the 90% design submission for the Mechanical, Electrical and I&C, and Civil modifications, which were progressing on an earlier schedule than the software design, a preliminary feedback session was held with users. This session focused on changes to the Mimic Panel and field accessibility issues that were identified by HFE in the preliminary Task Analysis. The users were provided with a high level overview of the proposed modification, followed by a detailed walkthrough of the changes to the mimic panel and new field devices for the system. Through this session, the design team was provided with user feedback much earlier in the process to allow for easier implementation within the design.

3.3.2 Validation Exercise

Two Validation exercises were planned for the new modification, one with each user group. The first user group, Maintenance would participate in a table-top exercise, where they would be walked through the relevant design documentation and maintenance tasks from the HFE Task Analysis. The second exercise would be held in a simulator, where users would also be walked through applicable design documentation but would perform the new operations tasks using the updated HMI Display in the simulator. The validation exercises with both user groups were planned to be held during detailed design, prior to the 100% design milestone.

The Software Design Team requested that HFE conduct the validation exercise in the simulator with users prior to the start of the software testing, which would occur over approximately 5 months. The earlier user feedback would allow the Software Design Team to make the necessary changes to the software prior to the testing commencing, which would potentially eliminate the need to re-test some of the software functionality. In the exercise, the users were provided with each task that was specified in the HFE V&V Plan and asked to complete the task using the simulator. Specific tasks included operating the system with the new component installed, identifying key parameters, and diagnosing errors/alarms within the system. However, unlike typical validation exercises, some of the Software Design Team were present in the exercise in order to provide an overview of the HMI display. The users were able to try to complete the task first on their own and the Software Design Team observed how the users would approach the new tasks and improve their understanding of the users' mental model. In addition, since the users did not have any training on the new HMI Display when conducting the validation exercise, the Software Design Team also provided support throughout the exercise, should the users have encountered an issue when performing the tasks.

Conducting the validation exercises earlier in the design cycle allowed for the design team to implement the user feedback more easily, since the design was still in the development stage. However, this increasingly collaborative approach between the users, HFE and the design team within the detailed design stage of the project, meant that the validation exercise was not being conducted with a completed design. The scenarios that the Operations users performed were limited to only the new component and its associated operating parameters, rather than executing tasks on the system as a whole, including the new component. In addition, as previously mentioned, the users were not provided any training on the new HMI display prior to conducting the validation exercise. Therefore, it is more likely that an integrated validation may be required, with trained users, once the software has been fully updated.

4 CONCLUSIONS

This paper has summarized the HFE program that was implemented to analyze the design of a large-scale electrical component readying for installation in a nuclear facility. HFE input was provided to all of the design change packages, which included updating the facility's mimic panel and HMI with new software. However, while the HFE analysis activities were conducted at the beginning of detailed design, each of the separate design disciplines was proceeding on a different timeline and therefore required HFE inputs at different stages of the project. An integrated approach to the HSI design, and HFE V&V activities was taken. The main findings through use of this approach were:

1. Collaborative approach to the development of the HMI Display allowed for more streamlined process to implement HFE inputs and for HFE to conduct DV.
2. Preliminary feedback sessions with users can provide an opportunity to provide early feedback on the design, which allows for easier implementation of user feedback.
3. Feedback prior to software testing also made it easier to implement user feedback and prevented the need for multiple rounds of testing. In general, more validation and design verification hold-points within the design cycle allows for the design to be more iterative and proceed without requiring major design changes at the end of detailed design. However, the trade-off is that an integrated system validation is more likely to be required.

5 REFERENCES

1. Canadian Nuclear Safety Commission, “Human Factors Engineering Program Plans,” Regulatory Guide G-276, June 2003.
2. Canadian Nuclear Safety Commission, “Human Factors Verification and Validation Plans,” Regulatory Guide G-278, June 2003.
3. U.S. Nuclear Regulatory Commission, “Human Factors Engineering Program Review Model,” NUREG-0711 Rev. 02, February 2004.
4. International Electrotechnical Commission, "IEC 61839 - Nuclear Power Plants - Design of Control Rooms - Function Analysis and Assignment," 2000.
5. H. Price, "The Allocation of Functions in Systems," *Human Factors*, **vol. 27**, no. 1, pp. 33-45 (1985).
6. B. Kirwan and L. K. Ainsworth, *A Guide to Task Analysis: The Task Analysis Working Group*, Taylor & Lord Francis Ltd., London (1992).
7. Department of Defense, “Design Criteria Standard – Human Engineering,” MIL-STD-1472G, January 2012.
8. U.S. Nuclear Regulatory Commission, “Human-System Interface Design Review Guideline,” NUREG-0700 Rev. 02, May 2002.
9. Department of Defense, “Handbook for Human Engineering Design Guidelines,” MIL-HDBK-759C, July 1995.
10. Electric Power Research Institute, “Human Engineering Design Guidelines for Maintainability,” EPRI NP-4350, December 1985.
11. U.S. Department of Energy, “Human Factors/Ergonomics Handbook for the Design for Ease of Maintenance,” DOE-HDBK-1140-2001, February 2001.