THE HUMAN FACTORS VERIFICATION AT PLANT STARTUP FOR THE AP1000 PLANT

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ABSTRACT

The Human Factors (HF) verification at plant startup is the final HF assessment for the **AP1000**® HF program and is performed using the as-built plant design. This HF verification has been implemented for the China AP1000 Standard Plant. The scope and objectives of the HF verification at plant startup met the requirements for Verification & Validation (V&V) as described in NUREG-0711, "Human Factors Engineering Program Review Model". The majority of the verifications have been completed. Overall, the results confirmed the adequacy of the China AP1000 Standard Plant operating procedures and operator training. A number of design issues were identified and were categorized as safety issues, operability and maintainability issues or minor issues. These issues are being addressed and tracked as site test deficiencies. Based on the current results, it can be concluded that the China AP1000 Standard Plant is safe, operable and maintainable, pending completion of the outstanding verifications and resolution of the identified issues. This paper will describe the overall strategy and discuss the lessons learned in respect to providing HF support to the startup activities for the AP1000 plant.

Key Words: HF Verification, Plant Startup, AP1000, As-Built Plant.

1 INTRODUCTION

The Westinghouse **AP1000**®[1] plant is an advanced pressurized light water reactor with passive safety design features. Westinghouse has implemented a comprehensive Human Factors (HF) program to ensure the safety, operability and maintainability of the AP1000 plant from a HF perspective. As an integral part of the overall HF design process, a series of Verification & Validation (V&V) assessments have been performed. These included design verification, task support verification, Integrated System Validation (ISV) and verification at plant startup, as required by NUREG-0711, "Human Factors Engineering Program Review Model" [1].

The HF verification at plant startup is the final HF assessment for the AP1000 plant, and is performed using the as-built plant design. The objectives of this verification are summarized below:

- Confirm the HF adequacy for those aspects of the Operation and Control Centers System (OCS) and Human System Interface (HSI) design that could not be fully evaluated in previous HF V&V activities. This comprises the following:
    - Verification of work environment conditions, such as lighting, noise, ambient temperature and humidity in the Main Control Room (MCR), Remote Shutdown Room (RSR), local operator workstations and at local plant areas associated with the completion of the Risk Important Human Actions (RIHAs).

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- Verification of the HSIs against HF design guidelines which requires further information that can only be obtained from the site.
- Maintainability HF assessment of a subset of risk-important Structures, Systems and Components (SSCs).

- Confirm that the as-built HSIs, operating procedures and training material at the site which have been assessed by the HF program are the latest and correct versions.
- Confirm that any required design, procedures and training material changes for Human Engineering Discrepancy (HED) resolution have been implemented.
- Confirm the HF adequacy of the RIHAs carried out in local plant areas, including the ability for the tasks to be completed within the time windows as required by the Probabilistic Risk Assessment (PRA).

The ultimate objective of the HF verification at plant startup is to ensure that the final as-built plant is safe, operable and maintainable from a HF perspective.

2 METHODOLOGY

There are various alternative methods of implementing the plant startup HF verification. One option was to have qualified and experienced HF Specialists at the site. This approach was ruled out because of schedule uncertainty with site testing activities, especially given the site is in China. Another option was to combine the verifications into the existing site test procedures where possible. This approach was not adopted because site test procedures were already developed and any changes to these procedures would not be cost-effective.

It was concluded that the most efficient and feasible approach was for HF Specialists to develop stand-alone verification specifications for implementation by site startup test personnel. The verification specification documents provided comprehensive instructions on how to perform the HF verifications, using detailed worksheets for the collection of test results. Therefore, HF Specialist qualifications and experience were not necessary.

The startup test personnel performed the steps contained in the worksheets, collected the data, and determined if the results indicated a ‘pass’ or ‘fail’ based on the criteria provided in the worksheets. This approach enabled a large amount of work to be completed at the site in a resource efficient manner. The final analysis of the results was completed by experienced HF Specialists.

2.1 Verification of As-Built Working Environment

The verification worksheets for environmental conditions were organized by plant rooms (e.g. MCR, RSR, local operator workstations, and local plant areas associated with RIHAs) and systems (e.g. the operating Heating, Ventilation and Air Conditioning systems and the lighting system) to facilitate the data collection process. To ensure that the results are representative of the operating plants, the data related to the climatic and auditory environment was collected during two Hot Functional Test plateaus (i.e. at ambient pressure and temperature and at normal operating pressure and temperature).

The following are the aspects of the working environment which were verified, where applicable and practical:

- Climatic Environment: Temperature, relative humidity, air speed, amount of fresh air introduced to the room, temperature difference at the floor and head levels and the existence of any unpleasant odors.
- Visual Environment: Illumination levels in normal and emergency lighting conditions, glare and reflections, illumination uniformness and light fixture features.

- Auditory Environment: Ambient noise levels, reverberation rate and the intensity of alarm signals.

Figure 1 gives an example of the environmental verification worksheet.

Part 1. MCR Temperature (R2.168)					
Room No.	**Measurement Location**	**Recorded Temp (°C)**	**Acceptance Criteria (°C)**	**SAT or UNSAT**	**Initials/Date**
12401	At RO-A Console in Main Control Area		20 to 26°C		
12401	At RO-B Console in Main Control Area		20 to 26°C		
12401	At RO-C Console in Main Control Area		20 to 26°C		
12401	At SRO Console in Main Control Area		20 to 26°C		
12401	In front of PDSP in Main Control Area		20 to 26°C		
12401	In front of SDSP in Main Control Area		20 to 26°C		
12401	In front of DAS Panel in Main Control Area		20 to 26°C		

Figure 1. A snapshot of the environmental verification worksheet.

2.2 Verification of As-Built Plant against HF Design Guidelines

The verification worksheets were organized by areas or systems to facilitate the data collection process. Examples of the HSI resources, areas or systems which were assessed using HF design guidelines include the MCR, RSR, local operator workstations, fire protection system, closed circuit television system and communication systems.

In order for the site startup test personnel to perform the HF verifications, each HF guideline was developed into specific steps, which provided details on the assessment actions and the data to be recorded. Specific criteria were given so that a 'pass' or 'fail' conclusion could be determined.

2.3 Maintainability HF Assessment

The plant and equipment HF maintainability assessment was performed on a subset of the risk-important AP1000 SSCs. The subset of SSCs was selected by an expert panel representing HF, system design, plant operations and maintenance personnel. The purpose of the sampling approach was to focus on the risk-important SSCs in which maintenance was of most concern. This included new or unique equipment, complex or potentially problematic or stressful maintenance tasks.

A generic verification worksheet was used for the maintainability HF assessment. The worksheets contained HF guidelines specific to assessing the maintainability of the SSCs identified in the scope of this assessment. The worksheets addressed physical and visual access, laydown space, protection from hazards, manual forces, alarms, color coding, labeling and the environmental conditions. In order for the site startup test personnel to perform the maintainability assessment, HF Specialists developed each guideline into specific assessment steps as described above in Section 2.2.

2.4 Verification of As-Built HSIs, Procedures and Training

The worksheet for the as-built HSIs was applied to the HSIs assessed in the HF V&V activities. This included the hardware and software in the MCR, RSR and at the local operator workstations. The final versions of the HSIs installed in the as-built plant were checked to confirm that: 1) they were the same or newer versions than those used in the HF V&V activities, and 2) they were the correct versions required for supporting fuel load.

The worksheet for the operating procedures was applied to the plant operating procedures which were used as inputs to the HF V&V activities. This comprised a subset of normal, emergency and abnormal operating procedures, alarm response procedures and Maintenance, Testing, Inspection and Surveillance (MTIS) Procedures. The final versions of the operating procedures provided at the site were checked to confirm that: 1) they were newer versions than those used for the HF task support verification and ISV, and 2) they were verified and validated to be consistent and compatible with the as-built design.

The worksheet for operator training was applied to the training program material that covered the scope of the ISV scenarios. This included a sample of the operator training material for normal, emergency, abnormal and MTIS tasks. The final versions of the material used to train the plant operators were checked to confirm that: 1) they were newer versions than those initially provided to the plant operators at the time of the ISV and 2) they referenced the latest design documentation and operating procedures consistent with the as-built plant design.

2.5 Confirmation of Implementation of HED Resolutions

The approach for the verification of HED closure was to verify that the hardware and software installed in the MCR, RSR and at the local plant areas, along with the operating procedures and training provided at the time of plant startup, included the changes that resolved the HEDs. Worksheets detailed the method with which to verify that the associated HSI resource, operating procedures or training material included the change that effectively closed the HEDs.

2.6 Assessment of Local Plant Actions Involved in RIHAs

The following two RIHAs contain operator actions in local plant areas that were required to be assessed in the as-built plant environment:

1) Deactivate a safety control system cabinet involved in a fire.
2) Close containment equipment hatches and personnel airlocks following core damage during a shutdown event.

The worksheets detailed the series of required local operator actions in the two RIHA scenarios based on procedural steps. The worksheets were used to collect the following information:

- The total time taken to complete the local actions
- Any HF issues identified during the performance of the RIHA local actions. This included assessing the ease of personnel movement, labelling, accessibility of controls and equipment, provision of feedback, warnings and the environmental conditions.

The two RIHAs were included in the ISV scenarios. However, since the ISV was conducted in the plant simulator, the local plant actions were not able to be performed at the time the ISV was conducted. Therefore, the task completion times obtained from the field activities were required to determine whether the RIHAs could be completed within the time windows as specified in the PRA.

3 RESULTS

3.1 Analysis of Data

All data was analyzed and the results were documented in a report by HF Specialists. Note that at the time of writing this paper, not all of the verifications have been completed because the plant conditions do not yet satisfy the test prerequisites.

Any verification that 'passed' was identified as a positive finding. Any verification that 'failed' was identified as an 'issue'. The results were evaluated to determine if they were adequate in terms of supporting successful operator performance in respect to safety, operability and maintainability of the plant from a HF perspective. The identified 'issues' were categorized in terms of their potential impact on safety, operability, maintainability or whether they were just minor issues of no impact.

3.2 Positive Results

The majority of the verifications of the as-built plant design against HF design guidelines, especially those related to the MCR and RSR including displays, alarm presentation system and computerized procedure system, resulted in a 'pass' with some relative minor issues being identified. It was confirmed that the MCR and RSR designs complied with the HF guidelines and supported good operator performance. The performance of the displays, alarm presentation system and computerized procedure system provided immediate responses to operator actions with appropriate feedback.

The verification confirmed that the hardware, operating procedures and training program provided and utilized in the plant, which have been assessed by the HF program, were the latest and correct versions. This demonstrated the readiness of the hardware, operating procedures and training program to support initial fuel load. Note that at the time of writing this paper, software changes and enhancements supporting fuel load continue because commissioning testing is still in progress.

The confirmation of HED closure demonstrated that the hardware and software design changes, operating procedures and training updates, which were required to resolve HEDs, were implemented at the site.

The completion time of the local actions involved in the RIHA to deactivate a safety control system cabinet involved in a fire demonstrated that these actions can be successfully completed within the time window as defined by the PRA. The assessment addressed both a 'large' and 'small' fire. In addition, the assessment concluded that the design of the battery chargers, switch boxes and the safety control system cabinets comply with the HF design guidelines in terms of supporting the successful operation of the breakers or switches. No HF issues were identified.

The positive results on the as-built HSI resources in the MCR and RSR, procedures and training provided in the plant demonstrated the success of the AP1000 HF program in terms of incorporation and resolution of HEDs identified from earlier HF V&V activities. This has contributed to the readiness of the MCR and RSR ensemble, including software, hardware, plant operating procedure and operator training, to support initial fuel load and plant startup.

3.3 Identified Issues

A number of design issues were identified and these issues are being addressed and tracked at the site. For example, high background noise level was identified as an issue in the MCR. Engineering solutions have been identified and are currently being implemented. This will ensure that the auditory environment supports effective communication and successful operator performance.

Lack of space was identified as a maintainability issue in local plant areas. This made it challenging to perform maintenance activities for some items of equipment.

The action to close one of the equipment hatches took significantly longer to complete than the allowable time window as specified in the PRA. However, the majority of the time was spent on erecting scaffolding and reconfiguring the scaffolding to obtain access to the hatch. The actual closure of the equipment hatch was completed in the time allowed. A lack of pre-planning and pre-staging was a major contributor to the excessive time. The plant administrative and maintenance procedures can be improved to support meeting the allowable time window. For example, the completion time could be substantially reduced if the scaffolding is erected beforehand or a fixed ladder is provided to eliminate the need for scaffolding. In addition, a manual wrench was used to tighten the bolts, instead of an electric wrench, which would also significantly reduce the time taken to tighten the bolts.

Most of the issues identified were in local plant areas, and this indicates a need for an improvement of the AP1000 HF program, which was more heavily focused on the MCR, RSR and local operator workstations. The results clearly demonstrated the importance of incorporating HF throughout the design process for local plant areas and equipment.

4 LESSONS LEARNED

As the first-of-a-kind activity for the AP1000 project, there were challenges, successes and identified improvements in respect to the strategy and process for the HF verification at plant startup.

The biggest challenge was to coordinate the HF verification activities with the site testing schedule. For example, the verification of emergency lighting inside the containment was delayed due to other ongoing testing activities which would not support securing normal lighting inside containment. Therefore, careful planning and coordination were required to prevent reestablishing plant conditions to solely support the HF verification.

The biggest success was the excellent teamwork established between the HF team in the US and the startup team in China. The joint team consisted of HF Specialists, operators, training instructors, procedure writers, I&C engineers and maintenance personnel. Bi-weekly meetings were held with open issues and action items being tracked for resolution. Unlike earlier HF V&V activities, the focus of the HF verification at plant startup was shifted to the plant site. Therefore, the plant owner played a larger role during the planning and execution stages of the verification. Collaboration and support from the plant owner was critical for the success of HF verification at plant startup.

A major improvement opportunity was in the quality of the data collected. Although extremely detailed worksheets were provided, the absence of an HF Specialist at the site made control of the verification process and interpretation of the data difficult. The analysis of the results was based on the completed worksheets as provided by the test personnel at the site. In a number of cases, information recorded in the worksheets was inaccurate or the level of detail was limited. Additional effort was needed to interpret the results. Examples of documentation issues including the following:

- In many instances, when an issue was identified, supporting details were not provided. This limited the ability to provide an accurate summary description and determine an appropriate resolution of the issue. Additional information had to be requested from the site.
- When measuring noise levels, the results were reported in dBC, instead of the correct reading in dBA. This resulted in artificially high noise levels being recorded. Those noise levels higher than the acceptance criteria will be rechecked during the resolution process.
- Pictures of identified issues from the site were not provided and should have been specified as being required in the worksheet as part of the results. This would have been beneficial in terms of understanding the issue and identifying the most appropriate solution.

5 CONCLUSIONS

The verification at plant startup was performed to satisfy the objectives and complete the scope as required by NUREG 0711 [1]. The results confirm that the AP1000 design has attained a high standard of human factors adequacy and conforms to the human factors principles and guidance as specified in NUREG-0711.

Some issues were identified during the verification process, mainly in respect to the maintainability of local components. This highlights the importance of the incorporation of HF in all aspects of the plant design. Successful verification was achieved in areas where HF input had been incorporated early in the design process, as was the case for the MCR, RSR, and local operator workstations.

Efficient verification of plant startup activities requires early planning and close coordination with site testing personnel. Although successful, the approach taken for the China AP1000 Standard Plant could have been improved through the use of HF Specialists, on site, to ensure any identified issues were properly documented and questions readily answered.

Overall, the results of HF verification at plant startup provided further assurance that the plant is safe, operable and maintainable, pending completion of the outstanding verifications and resolution of the identified issues.

6 REFERENCES

1. NUREG-0711, Rev. 2, "Human Factors Engineering Review Model," U.S. Nuclear Regulatory Commission (2004).