The Overview in Safety Review of Human Factors Engineering and Control Room Design in Chinese Ap1000 Nuclear Power Plant

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Abstract: The first AP1000 nuclear power plant is constructed in Sanmen county in Zhejiang Province in China, which has creative and distinctive design characteristics. Human factors engineering disciplines are applied to the design of the AP1000. In addition to the elements of the program review model(including human factors engineering program management, operating experience review, functional requirements analysis and allocation, task analysis, staffing, integration of human reliability analysis with human factors engineering, human system interface design, procedure development, training program development, human system interface verification and validation, design implementation, human performance monitoring),the minimum inventory of controls, displays, and alarms present in the main control room and at the remote shutdown workstation. These contents mentioned above are reviewed according to standards, rules and regulations. This article introduces review process, and several important issues during the reviewing are described in detail. These issues include many elements, such as operating experience review, task analysis, human system interface design, verification and validation ,and so on. This paper emphasizes on the main control room design(including environment and layout). Background noise in the actual main control room may exceed too much to design value. Another important issue is about main control room habitability systems(VES) changes to satisfy post-actuation performance requirements in AP1000 design change proposal. All the wall panel displays will be closed in this design change proposal. Review process and proposal are described in the paper. Since the AP1000 unit in China is the first constructed all over the world, verification and validation are especially important and necessary. The plan of verification and validation, the results summary report of verification and validation, the report of human engineering discrepancies are focus attention. Verification and validation in human factors engineering include HSI task support verification, HFE design verification and integrated system validation. This paper introduces the review process of verification and validation, the issues found in verification and validation.

Keywords: Nuclear Power Plant; HFE**;** Safety Review, Verification and validation

1. Introduction

AP1000 nuclear power plant is two loop unit with a single reactor. The plant design objective is 60 years without the planned replacement of the reactor vessel, since it has a 60 year design objective based on conservative assumptions. The design provides for the ability to replace other major components, including the steam generators. The plant adopts the digital instrument control system and the design of advanced main control room. The main control room is able to control the plant during normal and anticipated transients and design basis accidents. It includes indications and controls capable of monitoring and controlling the plant safety systems as well as the nonsafety-related control systems. The remote shutdown workstation contains the indications and controls that allow an operator to achieve and maintain safe shutdown of the plant following an event when the main control is unavailable. Both the main control room and the remote shutdown workstation are designed in accordance with human factors engineering principles and practices. Because of the rapid changes that are taking place in the digital computer and graphic display technology employed in a modern human system interface, design certification of the AP1000 focuses upon the process used to design and implement human system interfaces. The application of the human factor engineering disciplines to the design of the AP1000 includes 12 elements: human factors engineering program management, operating experience review, functional requirements analysis and allocation, task analysis, staffing, integration of human reliability analysis with human factors engineering, human system interface design, procedure development, training program development, human system interface verification and validation, design implementation, human performance monitoring.

2. Review process

Sanmen Units 1&2 PSAR had been reviewed from March, 2008, and the review period is one year. There are 182 staff participating in the review work. During the review, National Nuclear Safety Administration issued 《Technical Position of safety reviewing AP1000 self-reliance supporting project》, and identified the review basis.

Sanmen Units 1&2 FSAR has been reviewed from October, 2012, and there are 119 staff participating in the review work. Now Sanmen Units 1&2 FSAR is also during review.

3. Review Concerns

3.3.1 Background noise in the main control room

Background noise refers to any interference that is not relevant to the useful signal in the occurrence, inspection, measurement and recording system. Ambient noise refers to the noise produced by industrial production, construction, transportation and social life. In the design control room working environment of nuclear power plant, background noise refers to the noise that equipment is working in the main control room.

There are many standards stating the requirement about background noise in the main control room.

NUREG0700 (Human-system interface design review guidelines)refers to that the acoustic design of the control room should ensure that verbal communications among personnel are not impaired; auditory signals are readily detected; and auditory distraction, irritation, and fatigue are minimized. And background noise should not impair verbal communication between any two points in the main operating area. NUREG0700 also considers that verbal communications should be intelligible using normal or slightly raised voice levels. Figure 1 shows the voice levels needed for spoken communication over specified distances in the presence of different levels of background noise. Intelligibility of speech in noise is affected by the frequency spectra of the noise and of the speakers' voices and by the speakers' hearing sensitivity.

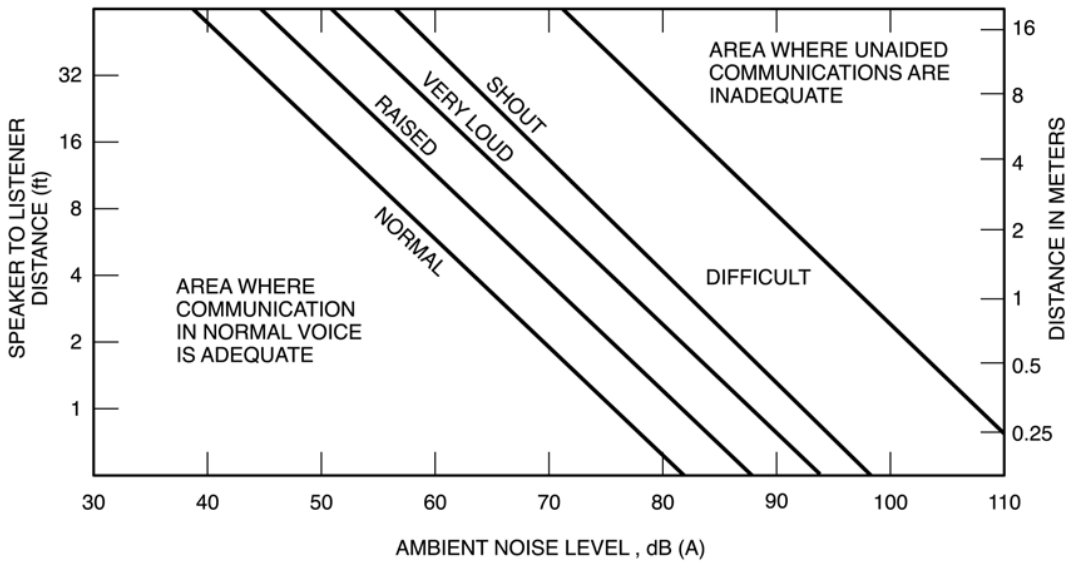

Figure 1 Voice level as a function of distance and ambient noise level

Auditory environment is also addressed in the IEC 60964-2009(Nuclear power plants – Control rooms – Design). Design of the auditory environment shall ensure easy communication within the operating team, minimal disturbance by ambient noise, and reliable perception of acoustic messages, alarms and emergency signals. Guidance for environmental specifications under normal conditions is provided in ISO 11064.

ISO 11064-6(Ergonomic design of control centers, Part 6: Environmental requirements for control centers) sets that the ambient noise in the control room should not exceed 45 dB LAeq,T and the background level should be in the range 30 dB to 35 dB LAeq,T. LAeq,T means equivalent continuous A-weighted sound pressure level, and is given by the equation as following:

$$L_{\mathrm{Aeq},T} = 10\ \mathrm{lg}\left(\frac{1}{t_2 - t_1} \int_{t_2}^{t_1} \frac{p_{\mathrm{A}}{}^{2}(t)}{p_0^2} \mathrm{d}t \right)$$

where t2- t1 is the period T over which the average is taken started at t1 and ending at t2.

EUR 2.10 also addresses the ergonomic design of main control room. Each control station, which is continuously manned on a routine basis such as the MCR(main control room) and TSC(technique support center), shall have an ambient noise level no greater than 50 dB from installed equipment in its immediate neighbourhood and plant equipment which may be operated for long periods. This limit shall be met for all normal or emergency HVAC(Heating, Ventilation and Air Conditioning) system line-ups in all areas.

In Sanmen nuclear power plant, the background noise in main control room should not exceed 50 dBA, and noise peaks should not exceed 65 dBA . During the review of FSAR, the applicant submits the technical support document: Plant startup human factors engineering main control room (MCR) and remote shutdown room (RSR) environment verification specification. This document provides the detailed guidance and identifies the specific methods for performing the human factors engineering (HFE) design verification assessment at plant startup on the as-built working environmental conditions, including the noise in the main control room and remote shutdown room. The applicant should measure and collect data on noise in the MCR and RSR when the Nuclear Island Nonradioactive Ventilation System(VBS) is in operation and data on noise when the Main Control Room Emergency Habitability System (VES) is in operation. The real data is still measured and collected.

3.3.2 Main control room habitability system(VES) changes to satisfy post-actuation performance requirements(DCP4733)

The license limit value of the main control room temperature is less than the effective temperature 85 degrees Fahrenheit (29.5 degrees C) within 72h after emergency habitability system (VES) operation in accident conditions, considering the requirement of main control room habitability of personnel and equipment qualification. According to the description of the DCP4733 report, combined with the heating intensity of the internal heat of the main control room, the existing design of the VES system can not achieve the requirement of controlling the temperature rise. To maintain the main control room pressure boundary (MCRE) in requiring qualification of equipment and personnel activities, the existing design for license related must be changed. The specific approach about DCP(design change proposal) is to close the non-safety related instrument equipment in the MCR after starting VES. The equipment includes WPIS(wall panel information system), ELS(no battery supply lighting system), the main control room area radiation monitor / processor, TVS video controller, office equipment, kitchen equipment. When the VES system is started in the design basis accident (DBA) after the implementation of the change, air temperature in MCR will not exceed the relevant requirements of the license application. At the same time the non- safety related instrument equipment can be manually operated.

According to the content of the specific implementation of the design change, applicant addresses that the non-safety level of heat load will be closed into two stages after VES triggers. The equipment needed to shut down in the first stage includes 15, 16 LAN large screen display and a main control room area radiation monitor / processor, TVS video controller, water heater, convection heater (shift office), water dispenser, refrigerator and printer etc.. There is no impact for safety function of nuclear power plant after closing the first stage equipment, so reviewers think that the influence on nuclear power plant is acceptable. At the same time, the applicant analyzes by test the influence after closing the ELS, and shows that the light illumination is changed litter in MCR, so reviewers think that the closure of ELS is acceptable. But reviewers think the operator may gain less information of nuclear power plant, or not easy and rapid access to information after closing the 14 large screens in the second stage. Thus the operator's load may increase to some extent, and the main control room temperature may rise at the same time, human error may cause under accident conditions. Also other personnel to enter the main control room can not quickly understand the current state of nuclear power plant after closing the large screen displays in second stage, so that reviewers think that it is not appropriate for closing all the large screen displays concerning the operation of MCR and the staff load.

3.3.3 Integrated system validation

Integrated System Validation (ISV) is an evaluation, using performance-based tests, to determine whether an integrated system's design (i.e., hardware, software, and personnel elements) meets performance requirements and supports the plant's safe operation. Human engineering discrepancies(HEDs) are identified if performance criteria are not met. The applicant should provide either an IP(implement plan) or a completed RSR(results summary report) for ISV. If the applicant submits an IP, it should describe the complete methodology for conducting ISV, including: the complete set of detailed scenarios for ISV (and how they were identified through the Sampling of Operational Conditions), performance measures, acceptance criteria, and the methods by which HEDs will be evaluated. Then the applicant will submit the RSR when the work described by the IP is completed. If the applicant submits a completed RSR, at a minimum, the RSR should include details of the results of the ISV, including a statement of how the validation demonstrates the ability to safely operate the plant, and a list of HEDs generated from the V&V, the analyses associated with these HEDs, and their resolutions.

The scenarios for ISV should be performed using a simulator, or other suitable representation of the system, to determine the complete design's adequacy to support safe operations. Validation should be performed after the resolution of all significant HEDs identified in verification reviews.

ISV shall be carried out by the operator on a highly realistic training simulator. According to the relevant laws and regulations, standards and guidelines of NUREG0711, the integrated system validation test will use a specific, full-scope simulator. The simulator should have the following characteristics: interface completeness, interface physical fidelity, interface functional fidelity, environmental fidelity, data completeness fidelity, data content fidelity, data dynamic fidelity. Participants in the applicant's validation tests should be representative of plant personnel who will interact with the HSI (e.g., licensed operators, rather than training personnel or engineers). To properly account for human variability, the applicant should use a sample of participants that reflects the characteristics of the population from which it is drawn. In selecting personnel for participating in the tests, the applicant should consider the minimum shift staffing levels, nominal levels, and maximum levels, including shift supervisors, reactor operators, shift technical advisors, etc. Testing personnel should avoid selection with bias.

The ISV of Sanmen nuclear power plant is as follows:

The applicant addresses the full-scope simulator will be used for HFE V&V when needed. The simulator includes a representation of the main control room with consoles, panels, large screen displays, operator workstations, and the latest available control logic and operator graphics. In the implement plan for ISV, applicant thinks that in actual operation, the AP1000 MCR and HSI resources will be used only by highly trained and qualified pressurized water reactor (PWR) operating crews. The hypothetical group of qualified crew members is the target user population. The ISV crews are samples taken from this target population(although training will not be completed at the time of ISV, as described above), drawn from the crews of the AP1000 customer utilities.

Up to now, the applicants show that they had carried out four ISV activities:

(1)The first activity was the China AP1000 Standard Plant ISV executed on the China standard plant simulator with Westinghouse Electric Company operations instructors as test subjects. The results of the China AP1000 Standard Plant ISV can found in “China AP1000 Standard Plant Human Factors Engineering Integrated System Validation Report”.

In the report, applicant points out that the Early China ISV is an interim ISV activity, and is incomplete with respect to the requirements for final ISV, thus the need for the subsequent ISV activities. At the same time, the applicant summarizes limitations for this ISV: simulator limitations; procedure limitations; participant limitations and test method limitations.

① simulator limitations.

The simulated plant model used for the Early China ISV test-bed did not include some plant systems, while other plant systems were based on input that was still evolving. Additionally, this software did not satisfy the testing prerequisites.

② procedure limitations.

Plant operating procedures had not been aligned with or validated against the HSI and simulator model used for the Early China ISV, included missing information, were not always aligned with one another, and did not always support the practice of “continuous use.” This required the use of verbal prompts and alternate testing methods in order for the crews to progress through the scenario, and led to many of the problems encountered during the Early China ISV.

③ participant limitations.

In summary, only two crews of operators were available for the Early China ISV. These operators were American or Spanish training instructors who were not Chinese AP1000 operators.

④ test method limitations.

The HSI used for the Early China ISV had not undergone design verification or task support verification prior to use for validation. Thus, many findings that would have been identified and resolved as the result of a verification activity were discovered during the Early China ISV.

Given the limitations associated with the plant design as documented above, the applicant thinks that many plant parameters were not available to monitor, which affected the ability to evaluate pass/fail criteria associated with the Technical Specifications and the scenarios that could not be run prevented some RIHAs, also pass/fail criteria, from being evaluated.

(2)The second activity was the China AP1000 Standard Plant ISV executed on the AP1000 Standard Plant Simulator during AP1000 Standard Plant ISV preparation activities with U.S. operator trainees as subjects. This includes re-run of ISV scenarios from early China AP1000 Standard Plant ISV (which contained Priority 1 HEDs) and the execution of ISV scenarios that could not be covered in the earlier China ISV.

(3)The third activity was the observation of China operators during simulator training. The observation of operators during training was undertaken twice. The first tie was at the Sanmen site, and the second time was at the Haiyang site. There are two reports about operator training observation. But there were some limitations for the Sanmen observation activities.

The detailed content of the training scenarios was significantly different from that of the ISV scenarios. The training simulator itself was not sufficient to address the full scope of scenarios. In addition, the observation was not permitted to directly collect any subjective data or comments from the trainees or trainers in the operator simulator training. This further limited the results of the observation to meet any ISV objectives.

(4)The fourth activity is the AP1000 Standard Plant ISV executed on the AP1000 Standard Plant simulator, and address remaining open issues and HEDs from the earlier China ISV, as applicable.

In view of the above ISV activities for ISV for Sanmen nuclear power plant , we believe that:

The state of the simulator during ISV is different from the actual state (the new simulator was handed over in November 2015). At the same time, the Chinese operators ISV did not participate in the test in ISV activity, but only the American or Spanish training instructors. Moreover, relevant performance data of the operators were not collected in the observation of China operators during simulator training, and the task is not the same as that of ISV, and the operator's proficiency is not enough. Also many design change about important system for operate have not been verified and validated sufficiently, and the AP1000 Standard Plant ISV is not applied incompletely for Sanmen nuclear power plant. So we think it is necessary that Re-ISV test shall be carried out.

4. Conclusions

China Ap1000 nuclear power plant is the first built in the world, and it has no much operating experience. So there are many problems about China AP1000 nuclear power plant and it is necessary for sufficient verification and validation.