

Certifying Advanced Plants: A US NRC Human Factors Perspective

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Abstract

The U.S. NRC began the process of certifying advanced nuclear power plants in the early 1990's. The design certification process requires an applicant to comply with technically relevant portions of the regulations established as a result of Three Mile Island. Included as a requirement is to provide a control room design that reflects state-of-the-art human factors principles before building the human system interfaces (HSIs) for plant locations such as the main control room and remote shutdown facility. To address this requirement, the NRC developed a Human Factors Engineering Program Review Model (NUREG-0711) as guidance for the staff to use in reviewing the human factors engineering (HFE) portion of applicant submittals. To date, the NRC has reviewed applications from three designers, General Electric, ASEA Brown Boveri-Combustion Engineering, and Westinghouse Electric Corporation. Each designer has provided a different approach to developing the HSIs for their plants which has presented the NRC with a unique challenge.

Introduction

Design certification is a process whereby standard, commercial nuclear power plants are approved by Federal Government rulemaking. Title 10 of The Code of Federal Regulations Part 52 (10 CFR Part 52, "Early Site Permits; Standard Design Certifications; and Combined Licenses for Nuclear Power Plants"), governs the process for the Nuclear Regulatory Commission's review of advanced plant designs. 10 CFR Part 52 encourages standardization and streamlining the licensing process.

To date, the Commission has evaluated for certification designs from two applicants for light water reactors, the Advanced Boiling

Water Reactor (ABWR) from General Electric Corporation (GE) and the System 80+ from ASEA Brown Boveri-

Combustion Engineering (ABB-CE). The NRC is presently reviewing a third light water reactor design, the AP600, from Westinghouse Electric Corporation (WEC).

The designs submitted by GE and ABB-CE are known as "evolutionary" designs because they are based upon improvements to conventional light water reactor designs. The WEC AP600 design is known as a "passive" design because it takes advantage of natural, "passive" forces such as gravity, natural circulation, and compressed gas to make its safety systems work.

10 CFR Part 52 Design Review and Certification Process

Obtaining a standard design certification under 10 CFR Part 52 requires the applicant for certification (e.g., designer) to submit a Standard Safety Analysis Report (SSAR) for review and approval by the NRC. The NRC's review of the SSAR is issued as a Final Safety Evaluation Report (FSER). Based on the FSER, the Commission will issue a final design approval (FDA) for the design. The Commission then makes a rule certifying the design to provide final resolution of design issues that were evaluated, making them no longer subject to litigation.

The rule certifying a design will contain a sufficient level of detail so that it provides for a standardized design and provides for early resolution of design issues while allowing for the flexibility to accommodate necessary changes to a facility, such as site-specific details, during its construction and operation lifetime. The rule only certifies a selected portion of the

information submitted by the designer. This information is referred to as "Tier 1" information. This portion of the design information will be verified by the NRC and can only be changed by rulemaking.

The remainder of the design information, typically that contained in the SSAR, is less stringently controlled, with some potentially requiring NRC review and approval before changes can be made. The certified design then can be referenced by an applicant for a combined operating license (COL) which will allow the applicant to both build and operate the plant ("one step" licensing). In contrast, plants currently operating were licensed under a "two-step" process, in accordance with 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities".

Human Factors Engineering Review

10 CFR Part 52 states that an applicant may seek a standard design certification for an "essentially complete nuclear power plant design...". 10 CFR Part 52 also stipulates that an application for design certification must comply with the "technically relevant portions" of the Three Mile Island requirements that are contained in 10 CFR 50.34(f). It is this rule that establishes human factors engineering as a significant requirement that must be addressed by applicants for design certification.

Though 10 CFR Part 52 indicates that design certification may be sought for "an essentially complete design", in practice the designs that have been submitted for review have not been complete, especially with regard to human factors considerations. This is because of, in large part, the changing human-system interface technology which makes it difficult for applicants to submit a completed design for an advanced plant which may be years away from construction.

It has been an equally difficult challenge for the NRC to review these incomplete designs. To address this challenge, the NRC has been performing reviews of applicant's human factors engineering design process rather than the final product of their HFE design, which was what was done during the post-TMI detailed control

room design reviews of the 1980's conducted by the NRC.

To aid the NRC in reviewing less than complete designs, a unique evaluation tool has emerged from the early stages of reviewing advanced reactor designs. Called Inspections, Tests, and Acceptance Criteria (ITAAC), this concept assists the staff in making its safety findings before plant construction begins. ITAAC allow the staff to confirm that the facility will be built in accordance with the design before the actual operation of the plant.

ITAAC consist of various inspections, tests, and analyses which the COL performs for significant aspects of their facility, measuring the results against certain acceptance criteria. For example, if the manual actuation of a pump has particular safety significance for the design, the COL can perform various inspections, tests or analyses and compare the results to the acceptance criteria to verify the operator's ability to operate the pump. It is through ITAAC that the NRC can confirm, before fuel loading, that the plant was built and will operate according to the approved design.

As the principal guidance for performing its human factors engineering reviews, the NRC developed NUREG-0711, "Human Factors Engineering Program Review Model" (1994). NUREG-0711 is an evaluation methodology based on a design and implementation process. The methodology includes ten essential elements for designing and implementing a human factors engineering program for advanced nuclear power plants (Fig. 1). NUREG-0711 contains review criteria for the NRC to use in the programmatic review of HSIs for advanced reactor designs. The review model was developed in a generic form allowing it to be applied or "tailored" to address the specific needs of the review being performed.

--- insert fig.1 here ---

Fig.1 HFE Program Review Model
(from NUREG-0711, 1994)

The "flexibility" of NUREG-0711 has made it easier for the staff to accommodate the different degrees of design detail for HFE programs that have been submitted for certification to date. The overall purpose of NUREG-0711 is to ensure that: (1) the HFE has been integrated into the plant development and design; (2) the HSI's, procedures, and training reflect state-of-the-art human factors principles and satisfy all other appropriate regulatory requirements; and (3) the HSI's, procedures, and training promote safe, efficient, and reliable performance of operation, maintenance, test, inspection, and surveillance tasks.

Also included as part of the NRC's review criteria, though not part of NUREG-0711, is a concept known as Minimum Inventory of Controls, Displays, and Alarms or simply, "Minimum Inventory". This concept was developed to ensure that an advanced reactor control room would consist of, at a minimum, key displays, controls, and alarms necessary to carry out operator actions associated with performing emergency operating procedures and those risk important operator actions that were identified from Probabilistic Risk Assessment/Human Reliability Assessment (PRA/HRA) analyses.

Human Factors Engineering Review Experience

Each of the three advanced reactor design reviews performed by the staff has been different. In the early 1990's, the GE ABWR was selected to be the lead plant for certification under Title 10 CFR Part 52. NUREG-0711 did not exist at that time and the staff, with assistance from Brookhaven National Laboratory, began developing the Human Factors Program Review Model (which later became NUREG-0711). For example, at the time the staff performed the ABWR review, the HFE PRM consisted of the first four elements of Fig. 1 and, elements 7, 8, and 10. Element 9,

Training, was identified as a responsibility of the COL and Element 6, Human Reliability Analysis, was addressed as part of the PRA review for GE. The staff's evaluation criteria included the additional criterion of Minimum Inventory of Controls, Displays, and Alarms for the Main Control Room and Remote Shutdown Facility.

GE ABWR Review

GE submitted a "design and implementation process plan" for certification, together with ITAAC. The first part of the plan presented GE's plant and system design elements; the second part described the elements that must be implemented by a COL to complete the design activity. What existed for the staff to review may be termed a "design concept" for human factors engineering which lacked a high level of detail. Ultimately, the lack of detail resulted in all elements of the program being developed into ITAAC; that is the entire program must be completed by the future licensee. What is to be certified for GE (the "designer") is the human factors engineering "design process"; no results or products of the application of the HFE design process are being certified for the GE ABWR although GE did develop a Minimum Inventory for the main control room and remote shutdown system technical guidelines (EPGs) for use by the licensee in developing their emergency operating procedures.

The staff performed its review of the GE ABWR Human Factors Engineering Program in two phases. A preliminary review was performed on early versions of the SSAR and was documented in a Draft Safety Evaluation Report (DSER). From their initial review, the staff concluded that the human factors engineering program was inadequate and did not provide sufficient information to support the staff in making their safety determination. The principal reasons for the staff's decision were: 1) HFE design bases were specified in the SSAR without supporting

rationale; 2) a design process was presented with insufficient detail and without results; 3) design requirements were presented without evidence that they were derived from the design process and without supporting tests and evaluations, and; 4) the documentation did not provide sufficient detail to support the review of the ABWR human factors efforts to a level necessary for design certification.

Together with personnel from GE, staff from the NRC also visited a Japanese ABWR control

ABB-CE System 80+ Review

ABB-CE presented the staff with a different submittal for HFE design from that of GE. At this time, the HFE PRM had the same elements as were used for the ABWR review. The NRC's review criteria also included the criterion of Minimum Inventory. The staff generally used the same two phase approach to review the ABB-CE System 80+ design as they used in reviewing the GE ABWR. An initial review of the ABB-CE SSAR produced open issues that were documented in a DSER and responded to by ABB-CE resulting in revisions to the SSAR and, subsequently, the staff's FSER.

ABB-CE, unlike GE, completed the first three elements of Fig. 1 as part of their submittal for design certification. ABB-CE provided the NRC with a formal human factors engineering program to guide HFE activities, detailed operating experience review which took into consideration a substantial amount of pertinent commercial nuclear power plant experience, and a satisfactory functional requirements analysis and allocation. They also submitted detailed methodologies for the COL to use in completing Elements 5 and 7 and a less detailed plan for developing a verification/validation (Element 10) methodology. As with GE, procedures was identified as a COL responsibility for ABB-CE. Like GE, ABB-CE developed technical bases (Emergency Operations Guidelines) to support the development of plant-specific emergency operating procedures. ABB-CE also submitted a Minimum Inventory for the main control room and remote shutdown facility and ITAAC for those programmatic elements that were not completed by ABB-CE for design certification. In addition, ABB-CE submitted a partial design of the main control room for NRC evaluation.

room prototype as part of the review process to address open issues from the DSER evaluation. With DSER open issues satisfactorily addressed by GE in their SSAR and ITAAC, the NRC issued their Final Safety Evaluation Report (FSER) for the GE ABWR in July, 1994. At the time this paper was written, the NRC was nearing publication of the final rule for the ABWR.

To address the specific aspects of the ABB-CE HFE submittal, in addition to the conducting a review of GE's proposed human factors engineering design process, the NRC performed a "design features review" to evaluate important elements of the System 80+ main control room (also designated as "NUPLEX 80+"). The review focused on evaluating seven design features of the NUPLEX 80+, including a large wall panel overview screen (IPSO).

The objective of the design features review was to determine the acceptability of the basic design features of the System 80+ advanced control room with regard to consistency with established human factors engineering standards, guidelines, and principles. The control room design was also reviewed against Supplement 1 to NUREG-0737 requirements for the Safety Parameter Display System (SPDS). The staff relied on guidance such as NUREG-0700, "Guidelines for Control Room Design Reviews"; NUREG/CR-5908, "Advanced Human/System Interface Design Review Guideline"; and NUREG/CR-6105, "Compilation of Alarm System Guidelines and Evaluation of Their Applicability to Hybrid and Advanced Control Rooms", to conduct the design features review.

The ABB-CE main control room mockup was used in the review. The mockup consisted of selected panels of the master control console in a static representation as well as portions of the reactor coolant system and chemical and volume control system panels in a dynamic simulated mockup. The IPSO was represented by a rear projection display device. In August, 1994, the NRC issued their Final Safety Evaluation Report (FSER) for the ABB-CE System 80+ after determining that all open issues identified from the DSER design process review and the design

features review were satisfactorily addressed by ABB-CE. At the time this paper was written, the NRC was nearing publication of the final rule for the System 80+.

WEC AP600 Review

The staff is currently completing its human factors engineering review for the WEC AP600 passive reactor design. As mentioned previously, the WEC submittal has posed yet a third set of circumstances for the staff to address in preparing their safety evaluation. As with the previous two reviews, the staff approached evaluating the AP600 SSAR in two phases, issuing a DSER and resulting open items that are required to be resolved before design certification can be granted for WEC's human factors engineering program. The same HFE PRM criteria have been used to evaluate the WEC AP600 design. However, three items have been formally added to the model: Staffing (Element 5); Human Reliability Analysis (Element 6); and Training (Element 9), for a total of ten elements comprising NUREG-0711 (Though these elements were not in the HFE PRM at the time the ABWR and System 80+ reviews were completed, they were applied by the NRC as evaluation criteria and were addressed by each applicant). The staff-generated requirement of Minimum Inventory also remains as an integral part of the evaluation criteria as does ITAAC.

Like GE and ABB-CE, WEC did not present the staff with a completed control room, fully designed and based upon "state of the art human factors principles and practices". WEC, in their initial SSAR, presented the staff with the contents of an HFE program description that could be characterized as being "somewhere between GE and ABB-CE". Unlike ABB-CE, WEC did not submit for design certification design details for standard features. However, WEC did provide a level of detail for three NUREG-0711 elements which enabled the staff to review them at a complete element level. Consequently, future COLs selecting the AP600 design will not be required to address these elements as part of the license process. They must, however, ensure that the results WEC has produced from completing these elements are used in designing the human system interfaces of their advanced passive plants.

WEC also used a different approach to assess operator behavior in a nuclear power plant. It is the author's opinion that GE and ABB-CE take a more "traditional" approach in assessing the operators' behavior than does WEC. For example, GE and ABB-CE propose using "traditional" task analysis methods to determine required operator behaviors. WEC, however, has proposed to determine required AP600 operator behaviors based more on "cognitive systems engineering theory". Specifically, WEC has based their design process on the mental models of Jens Rasmussen. Their approach requires a decomposition of plant equipment purposes to form a structure that is used for designing the organization and presentation of information to control room operators. WEC acknowledges, to a greater degree than the other two designers, the potential effects of cognitive influences on the performance of the AP600 operator. "A competent operator is defined as one who is mentally ahead of the processes that he controls. Ideally, for this operator, there are no surprises"¹. WEC has, for example, a behaviorally-based task analysis and a cognitively-based task analysis, the latter emphasizing the decision-making tasks required by the operator.

WEC has also chosen, unlike GE and ABB-CE, to propose the use computerized procedures as the primary medium for presenting emergency operating procedures. The actual development of plant procedures for the AP600 design remains the responsibility of the COL as with GE and ABB-CE. Of the three advanced control room designs submitted for certification, the AP600 design also makes the greatest use of compact operator workstations.

At the time this paper was written, the AP600 review was still in progress. WEC was refining their human factors engineering ITAAC for submittal to the NRC and the staff was preparing their Final Safety Evaluation Report.

Summary

¹WCAP-14695, "Description of the Westinghouse Operator Decision-Making Model and Function-based Task Analysis Methodology, (1996), p.2-1.

As discussed, each of the three designers of advanced plants have submitted to the NRC human factors engineering programs for design certification that have significant differences from each other. All the submittals, however, are alike in that none represented completed designs of the required HST's for their advanced plant. To meet the challenge presented by individual designers, the NRC has been using NUREG-0711, the Human Factors Engineering Program Review Model, together with the concept of ITAAC for ensuring that the as-built advanced designs will result in acceptable human systems interfaces. Despite the differences presented to the NRC by the three advanced designs submitted for certification, the review process contained in NUREG-0711 is both robust and flexible to accommodate variations in the level of human factors engineering design detail. The tenets of NUREG-0711 have recently been incorporated into the NRC's Standard Review Plan (NUREG-0800, 1996).

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Acknowledgements

The author wishes to thank Dr. John M. O'Hara for his constructive technical comments on an earlier draft of this paper and Dr. Jane M. Arabian for her critique and encouragement in writing this paper.

The opinions, views and conclusions contained in this paper are those of the author and should not be interpreted as representing official policies, expressed or implied, of the U.S. Nuclear Regulatory Commission.

