An Approach to Human Factors Evaluation for Staffing and Qualifications in a Light Water-cooled SMR

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***Keywords :** small modular reactor, control room, staffing and qualifications, human factors evaluation

1. Introduction

Specific design characteristics of small modular reactors (SMRs) are distinguished from those of large light water reactors. There are specific design characteristics of light water-cooled SMRs, such as multi modular reactors, inherent safety characteristics, integrated reactor design, passive safety systems, higher level of automation, shared common facility, mutualized operation, integrated control room, reduced minimum control room staffing level, and so on [1]. With these novel design characteristics, both design and regulatory issues have been raised and being addressed nationally and internationally [1]. Specifically in aspect of human factors engineering (HFE), potential regulatory issues related to design characteristics of the light water-cooled SMR were identified in [2].

Minimum staffing level in a SMR control room is one of the main issues in design and regulation of a light water-cooled SMR. In general, the minimum staffing level in a SMR control room is not satisfied with or beyond the current prescriptive regulation (e.g., 10 CFR 50.54(m)). The issue of the minimum staffing level is generally addressed through a performance-based test. In aspect of HFE, a performance-based test is performed to assess whether the proposed minimum staffing level in a SMR control room is adequate to safely operate SMRs and human performance of operators is acceptable to multi modular reactors. However, it is challenging to evaluate the minimum staffing level in a SMR control room based on the current human factors evaluation on account of the proposed minimum staffing level out of the current prescriptive regulation, no operating experience of multi-module SMRs, and the need of evaluation criteria reflecting design characteristics of light water-cooled SMRs.

Therefore, this study was performed to propose an approach to evaluate staffing and qualifications in a light water-cooled SMR from a HFE perspective. In the study, framework, evaluation process, and evaluation criteria for human factors evaluation of staffing and qualifications in a light water-cooled SMR were described.

2. Approach

The main purpose of the proposed approach is to aid human factors evaluation of the minimum staffing level, does not satisfied with the current prescriptive regulation, with regard to adequacy of task and human performance. The evaluation approach presented in the existing standards or guidance of human factors are useful to evaluate the proposed staffing levels in a control room; however, they are not efficient to novel HFE design features such as staffing levels in a SMR control room or not enough to provide confidence of human factors evaluation results. Therefore, the approach in which the current or planned standard and regulatory guidance were mutually applied so as to provide efficacy and flexibility of human factors evaluation.

2.1 Framework

The main direction of the proposed approach is to be acceptable to human factors evaluation; flexible according to design maturity; and adaptable to specific design characteristics of a light water-cooled SMR. Therefore, high-level framework for human factors evaluation for the staffing level was established using NUREG-0711 [3] and NUREG-1791 [4,5], a concept of multi-stage validation [6,7], and scalable HFE review plans [8].

Basically, NUREG-0711 and 1791 documents are internationally used HFE guidance. Although these are regulatory guidance, they are practical to human factors evaluation of staffing and qualifications in not only regulation but also design. In NUREG-0711 and 1791, evaluation objective, subject, criteria, considerations in other HFE elements in NUREG-0711, and steps based on the HFE program are presented. The evaluation subject, criteria, considerations, and steps are comprised in the proposed approach in order to provide acceptable human factors evaluation.

In IEEE-2411 or IEC-63351, multi-stage validation methods are provided. The basic concept of multi-stage validation in both standards is to assess not only HFE products (e.g., human-system interface or integrated system) but also design options or outputs from HFE process (e.g., staffing and qualifications) and support reasonable confidence for new and unproven plant

designs (e.g., multi-module SMRs) [6,7]. The main concept and framework from the IEEE and IEC standards were adopted to make the proposed approach flexible to evaluation objective, scope, criteria in any design stages.

In multi-stage validation and evaluation process described in NUREG-1791, prerequisites including performing HFE program activities are required. However, it may not be possible for new plant or reactors with novel design characteristics in earlier design stages. In DRO-ISG-2023-03, scalable HFE review plans are presented. The overview of scalable HFE review plans being developed by U.S. NRC is to identify design characteristics and operation from a HFE perspective, determine HFE elements that will be evaluated, and assemble and conduct human factors evaluation. In the proposed approach, HFE elements to be evaluated in the process were scalable depending on the characteristics of staffing level or design stages.

2.2 Evaluation Process

For staffing and qualifications in a light water-cooled SMR control room, human factors evaluation process was established as follows:

Step 1: identify design characteristics and concept of operation and a type of proposed staffing levels and control room.

Step 2: set multi-stage and iterative human factors evaluation process and HFE elements to be evaluated, and define objective and scope according to design stages.

Step 3: apply differential evaluation criteria and acceptable criteria in aspect of HFE in the corresponding design stage.

Step 4: perform human factors evaluation of staffing levels based on applicable HFE analysis and human performance-based test in the corresponding design stage.

Step 5: iterate human factors evaluation of staffing levels in the next design stage (steps 3 and 4) before integrated system validation.

Step 6: do integrated system validation.

Step 7: conclude the human factors evaluation results and determine acceptance of staffing levels.

The proposed evaluation process may be applicable to any types of the staffing levels in a light water cooled SMR and in the earlier design stages. However, it is recommended that concept of operation at least and, if possible, operation strategy or some of the HFE analysis be available in proposed approach in order that the result of human factors evaluation will be supportive.

2.3 Evaluation Criteria

Evaluation criteria are important considerations to determine whether the minimum staffing levels are appropriate and acceptable from a HFE perspective. In the proposed approach, evaluation criteria were basically adopted from NUREG-0711 and 1791. However, the existing evaluation criteria may not be fully adaptable to specific design characteristics of light water-cooled SMRs. Thus, differential evaluation criteria were elicited.

For differential evaluation criteria, the safety characteristics and potential human performance issues of light water-cooled SMRs according to identified general design characteristics of the SMRs were reviewed in the study. The differential evaluation criteria will be augmented by reflecting ongoing innovative SMR (i-SMR) project, especially including HFE and control room design characteristics.

3. Conclusions

In the study, the approach to human factors evaluation for staffing and qualifications in a light water-cooled SMR was proposed. In the proposed approach, high-level framework, evaluation process, and evaluation criteria were presented based on the existing or planned standards and regulatory guidance. In future works, differential evaluation criteria will be augmented for human factors evaluation of new types of staffing levels. Also an narrative example of the proposed approach will be presented.

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