A Study on the Design of i-SMR MMI Considering Human Performace Issues

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1. Introduction

It is very important to perform Man-Machine Interface(MMI) design for reliablly operating multi-units not bringing unnecessary transient plant status in one Main Control Room(MCR). Particularly, Small Modular Reactor(SMR) is very small size and has harsh environmental condition due to the new approach design such as passive safety system and compact structure. Also, one SMR plant includes several modules, each module is composed of 1 reactor and 1 turbine/generator unlike conventional large Nuclear Power Plant. Therefore, there are many issues to resolve design problem with operation strategy including automation and the proper number of operator. In this paper, we would like to introduce new approach design for MCR and automation considering SMR related human performance issues.

2. Considerations for MCR and MMI Design

Main considerations are as follows to perform MCR and MMI design.

① How many operating staffs in normal and accident operation mode are required in the MCR
② What functions and tasks are performed in the MCR
③ The sizing of control facilities and arrangement & number of operator workstations for control and monitoring
④ Capability to perform operation tasks in various operation modes by single operator
⑤ The level and algorithm of automation applied for operation in the plant
⑥ The role of MCR operators & local operators and communication method between MCR and LCS(Local Control Station)

Particularly, SMR operators have to manage different status and conditions of several modules in one MCR. For efficient response of the plant, it is necessary to effectively configure MCR and provide simple communication among operators and between MCR and LCS. Normally, digital based MCR includes group view display, operator workstation, and hardwired backup control switches. SMR also has to contain module based monitoring & control means in one MCR. In this SMR environment, human errors can occur due to the commission or omission errors and sequential error such as selection of false module and misunderstanding of situation awareness due to operators' mistake. According to the NUREG-1791[1], human performance issues by concept of operation dimension are described[2]. Main issues are described in Table 1.

Table 1: Main Human Performance Issues

ConOps Dimension	Human Performance Issues	Related HFE Process
Plant Mission	Novel Designs and Limited Operating Experience from Predecessor Systems	○(OER)
Agents' Roles and Responsibilities	Multi-unit Operations and Teamwork	○(S&Q)
	High Levels of Automation for All Operations and Its Implementation	○(MMI)
	Function Allocation Methodology to Support Automation Decisions	○(FRA/FA)
Staffing, Qualifications, and Training	New Staffing Positions	○(TA)
	Staffing Models & Levels	○(S&Q)
Management of Normal Operations	Different Unit States of Operation & Unit Design Differences	○(MMI)
	Operational Impact of Control Systems for Shared Aspects of SMRs	○(MMI)
	Load-following Operations	○(MMI)
	Control Room Configuration and Workstation Design for Multi-Unit Teams	○(MMI)
	HSI Design for Multi-unit Monitoring and Control	○(MMI)
Management of Off-normal Conditions and Emergencies	Safety Function Monitoring	○(MMI)
	Handling Off-Normal Conditions at Multiple Units	○(MMI)
	Passive Safety Systems	○(MMI)
	Loss of HSIs and Control Room	○(MMI)
Management of Maintenance and Modifications	Modular Construction and Component Replacement	○(MMI)
	New Maintenance Operations	○(S&Q)

3. Proposed MCR Configuration and Operating Failities

The number of operating crew will be optimized through the staffing analysis and validation process of the NUREG-1791. Figure 1 shows that MCR configuration and operating facilities for multi-unit operation in view of efficient operation in one MCR. To reduce operators' burden such as secondary task like searching MMI display, module dedicated displays are provided to monitor and control module. Consistent and

continuous arrangement is required for single operator to effciently monitor and control each module without confusion. The number of display is determined considering the main role of operator. Main role of operator is activities that monitor plant or system parameter, detect alarm or abnormal status, respond to the plant or system according to the procedure, and supervise automation. When considering that operating process, it is necessary to include dedicated FPD(Flat Panel Display) such as monitoring FPD, alarm FPD, procedure FPD, automation function FPD, and control FPD at each operator console as shown in Figure 1.

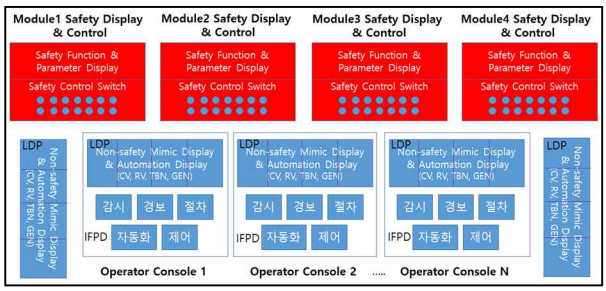

Figure 1 Operator Console and Module based Safety Display & Control

Each LDP provides overview information for 4 modules. Also, display sharing function is provided for mainly monitoring the operating status of a specific operator in two LDPs located in the right and left side of MCR. This function helps to confirm and correct operation activities of other operator for preventing human error.

4. New Issues about Automation and Design Consideration

Automation is required to operate multi-units simultaneously in one control room[3]. But, conventional large nuclear power plant does not experience multi-units operation. This automation environment makes new issues as shown in Table 2. According to the NUREG-0700[4], automation concept includes that the role of automation extends to other application such as supporting operator decision making and managing MMI. Today's automation can be designed to work with operators, each "agent" having defined roles and responsibilities[4]. Therefore, agent as another operator has to be defined through FRA(Functional Requirement Analysis)/FA(Function Allocation) of the HFE(Human Factors Engineering) process. Task load including automation should be analyzed through the TA(Task Analysis) process and adequacy of task load should be confirmed according to the NUREG-0711[5].

Table 2: Automation Issues and Design Consideration

New issues about automation	Design Consideration
Change in the overall role of personnel that does not support human performance	Training, procedure, and related MMI should be provided not to decrease human performance as much as possible
Difficulty understanding automation	Display and alarm related MMI should be provided to easily understand automation logic
Low workload, loss of vigilance, and complacency	Periodically essential information should be provided at a glance in MMI
Out-of-the-loop unfamiliarity, and degraded situation-awareness	Plant level function and system status should be provided with LDP or dedicated display including automation function
Difficult workload transitions when operators must assume control when automation fails	When automation fails, response guideline and process should be provided with the CPS for step by step operation
Loss of skills since automated tasks are seldom performed	Training of simple manual process instead of automated tasks should be performed periodically.
New types of human error, such as "mode" error	Related mode corresponding module should be explicitly provided in fixed location of the display to discriminate mode and module

5. Conclusions

SMR related human performance and automation issues are addressed and SMR MCR design, automation design and considerations are proposed in this paper. Most of all, we have to focus on reliable multi-unit operation in one MCR and effective application of automation function. Systematic and startegic approach should be performed for flexible MCR and automation design based on APR1400 design and operation experience.

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