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A Conceptual Review of the Human Factors Engineering Process in the Design of APR1400 Man Machine Interface System

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1. Introduction

It has become essential for the modern nuclear power plant (NPP) to be economically viable while operating under high safety regime. This raises the issues of improving safety, reliability and availability throughout the plant's operational lifetime. A significant aspect of these improvements is the modernization of the man-machine interface system (MMIS). This is particularly important because the instrumentation and control (I&C) system is considered as the plant's central nervous system that monitors numerous plant parameters and provides the capabilities for operators to safely control plant operations [1].

Basically, operators in the main control room (MCR) are tasked with the responsibility of operating I&C equipment and therefore play a vital role in the safe and efficient production of electric power. Operating experience of NPPs reveals that human error is a major contributing factor to incident causation that jeopardizes plant's safety, reliability and availability. For instance, insights into the events at the Three Mile Island (TMI), Chernobyl and Fukushima Daiichi suggest that human errors emanating from deficiencies in control room design, operating procedures, training, and control systems that support decision processes are a significant contributor to nuclear incidents and accidents [2].

In order to minimize human errors, human factors engineering (HFE) must be integrated into NPP design and a paradigm shift toward advanced control room architecture must be fully embraced. Moreover, MCR modernization becomes imperative as equipment obsolescence increases the cost of operation and maintenance (O&M) of plants. Thus, the integration of human factors principles is specifically important for existing plants that are planning to migrate from analog to digital technology, as well as for new plant designs.

In view of the changing topology of digital technology and the growth of artificial intelligence (AI) in the 4th industrial revolution, obsolescence will inevitably catch up with current digital systems. Moreover, current ergonomics criteria will become obsolete as factors such as anthropometrics and social consensus change over time. What this implies is that human factors criteria would need to be reviewed to reflect the change.

In this regard, this work benchmarks the current Advanced Power Reactor 1400 (APR1400) MMIS design for further improvement. As a preliminary research work, the objective of this paper is to present a conceptual-level description of the HFE process model of APR1400 MMIS design.

2. Overview of APR1400 MCR layout

The APR1400 MCR layout, shown in Fig. 1, consists basically of 5 workstations, a safety console, and a large display panel (LDP). The MCR is operated by 5 member crew namely reactor operator (RO), turbine operator (TO), electric operator (EO), shift supervisor (SS), and shift technical advisor (STA). The workstations are designed with redundancy such that the unavailability of one workstation does not prevent the functional operation of the MCR. Each workstation is capable of controlling the plant processes. Each operator console contains multiple flat panel displays (FPDs), engineered safety features-component control system (ESF-CCS) soft control, and laydown area.

The LDP which is located in front of the operator workstations is visible to all operators and displays plant parameters which are required for quick assessment of overall plant status.

The key design considerations for the MCR include size and visibility of the LDP, workstation design with work and laydown area, communication, control room operation staffing in post-trip condition, accessibility and traffic patterns within the MCR, alarm annunciation, and information presentation.

Fig. 1: APR1400 main control room layout *[3]*

3. HFE model for APR1400

NUREG-0711 provides the criteria that the staff of the U.S Nuclear Regulatory Commission (USNRC) use in performing the review of the human factors engineering (HFE) programs of applicants for certification and licensing. The purpose of the review is to verify that applicants incorporate accepted practices and guidelines into their HFE programs [2]. The review criteria are arranged into 12 HFE elements:

i. HFE Program Management
ii. Operating Experience Review (OER)
iii. Functional Requirements Analysis and Function Allocation (FRA/FA)
iv. Task Analysis (TA)
v. Staffing and Qualifications (S&Q)
vi. Treatment of Important Human Action (TIHA)
vii. Human System Interface (HSI) Design
viii. Procedure Development
ix. Training Program Development
x. Human Factors Verification and Validation
xi. Design Implementation
xii. Human Performance Monitoring

The human-centered objectives of the HFE program to be achieved are shown in Fig. 2.

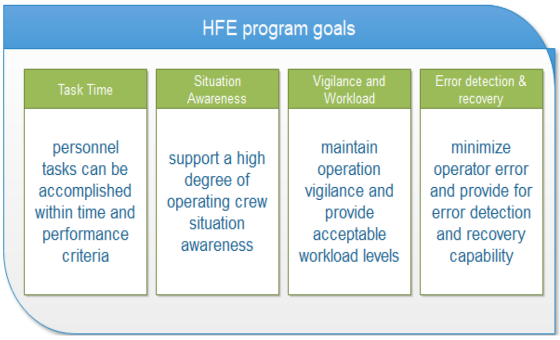

Fig. 2: Human-centered goals

Fig. *3* shows the HFE design process for APR1400 based on the NUREG-0711 HFE elements. The model comprises five stages of planning, analyses, human system interface (HSI) design, verification and validation (V&V), and operation. Basically, the model shows the progression of HFE activities from planning to operation of the HSI facility [4].

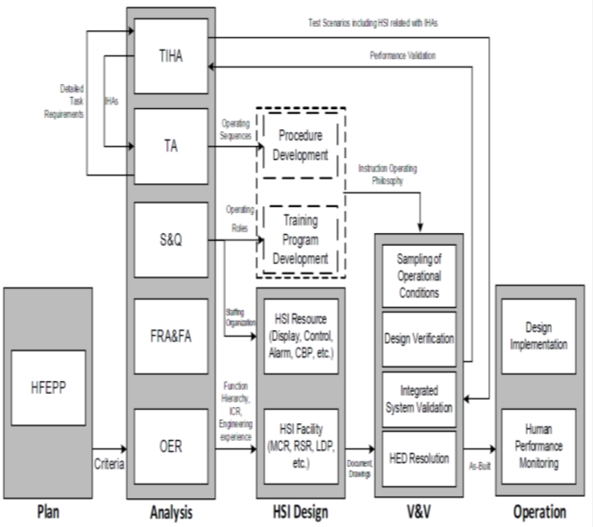

Fig. 3: APR1400 HFE process model [4]

3.1. HFE program management

In the APR1400 HFE model, a multidisciplinary HFE design team is responsible for the management of the HFE design program. The team manages the HFE elements by applying the HFE program plan (HFEPP). Additionally, each HFE element is implemented by applying its own Implementation plan. The model is an iterative design process, as such decisions relating to design issues and human engineering discrepancies (HEDs) are managed using issue tracking system (ITS) shown in Fig. 4. The ITS keeps a database of the review processes for issues and HEDs resolution. Also, issues and HEDs are prioritized depending on relevance to HFE related safety goals. The IP of each element provides the threshold criteria that determines when an HED is entered into the ITS. A result summary report is generated as an output for each HFE element.

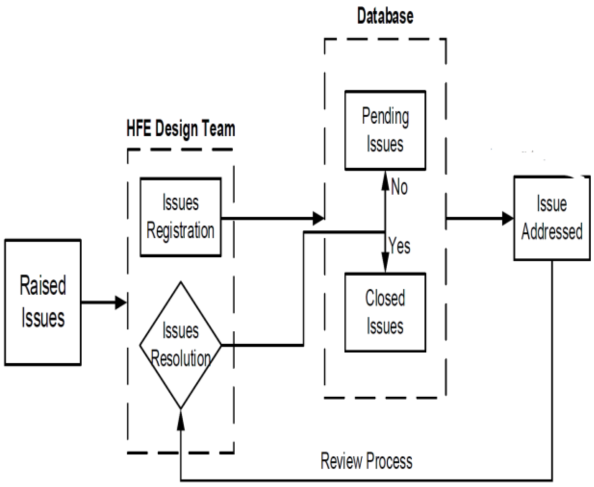

Fig. 4: Issue tracking system

3.2. Operating experience review

OER is performed by using predecessor plant information as well as international and U.S. HFE-related information, which are screened based on relevance so that only APR1400-related issues are applied. Relevant issues are identified as HEDs and are added to the ITS. The OER issue selection and screening is performed using priority classification as shown in Fig. *5*. Class 1 issues are those having high impact on HFE-related safety goals and health of the public and plant staff. Class 2 issues are those that do not impact safety goals directly but may have cumulative effects. Class 3 issues are those that are only reviewed for quality improvement.

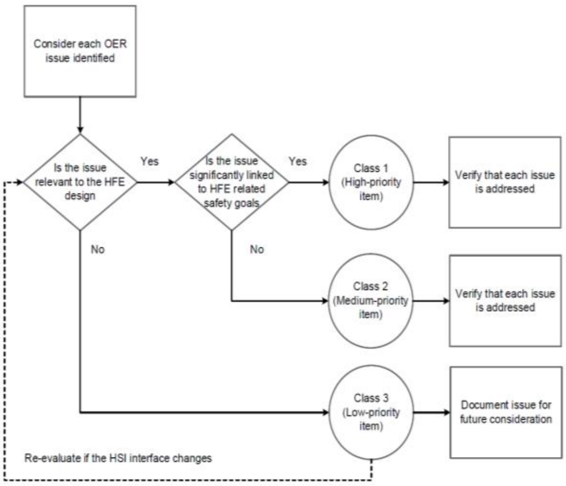

Fig. 5: Selection Process of OER Issues

3.3. Functional requirements analysis and function allocation

The FRA/FA defines all the functions that are required for plant safety and power production objectives in consideration of all the operating modes of the plant. The FRA/FA identifies the success path for critical safety functions, critical power production functions, and all supporting functions. As shown in Fig. *6*, the FRA/FA allocates control actions to human or system resources.

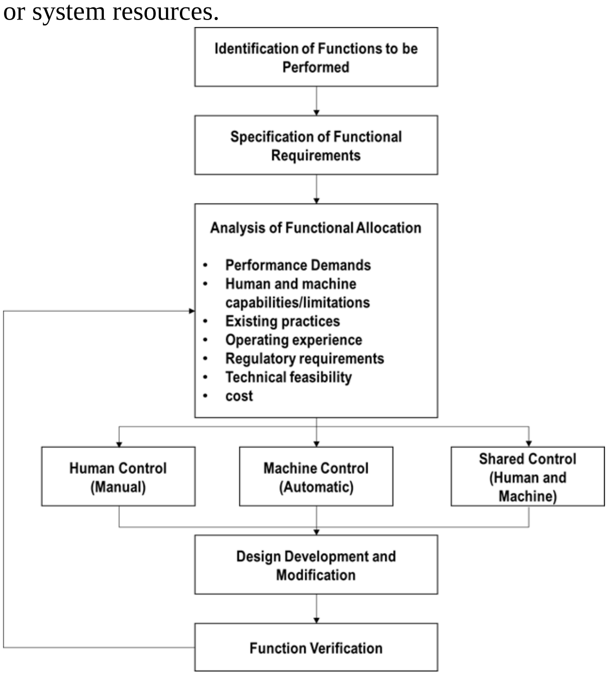

Fig. 6: Functions allocation [3]

3.4. Task Analysis

The TA examines the task assignments to operators. TA identifies the tasks required to achieve the functions assigned to operators. TA includes basic task analysis (BTA) and task timing analysis (TTA). BTA is used to define the inventory requirement for HSI design elements that are required for all tasks. TTA is used for evaluating the personnel workload and time margin between the available task time and the required time to complete a task. The output of TA provides input to the design of HSIs, procedures, personnel training programs, and HF V&V.

3.5. Staffing and qualification

The S&Q provides the staffing and qualifications needs to design the MCR. The S&Q provides staffing numbers and qualifications as inputs to the preparation of plant operating procedures and the operators training programs. Table 1 shows the S&Q assumption for APR1400 MCR

Table 1: Staffing and qualification assumption

Title	No	Qualification
Shift supervisor	1	Senior reactor operator
Shift technical advisor	1	Senior reactor operator
Reactor operator	1	Reactor operator
Turbine operator	1	Reactor operator
Electric operator	1	Reactor operator

3.6. Treatment of important human actions

The TIHA identifies risk-important human actions (RIHAs) and deterministic important human actions (DIHAs) which are integrated into the HFE program and the HSI design process so that human errors are minimized and their detection and recovery capabilities are enhanced.

3.7. Human system interface design

In general, the scope of APR1400 HSI facilities are the MCR, remote shutdown room (RSR), technical support center (TSC), and local control stations (LCSs) associated with IHAs. The outputs of the analyses stage are used to identify the input requirements for the HSI design. Also, the plant system requirements as well as the regulatory requirements and industrial standards establish the input requirements for the HSI design. An HSI style guide which is based on the guidelines of NUREG-0700 is used for the detailed design of HSI resources. The HSI resources include large display panel (LDP), console information display, soft control, alarms, computer-based procedure (CBP) display, safety parameter display system, and minimum inventory control.

3.8. Verification and Validation

V&V is performed to confirm that the HSI design is based on accepted HFE design principles and that the

HFE requirements are met. The V&V process, shown in Fig. 7, consists of sampling of operational conditions, design verification, integrated system validation (ISV), human engineering discrepancies (HEDs), and documentation of results of the HF V&V program. The operational condition sampling is to select representative operational conditions that may occur during the lifetime of the plant and to reflect the characteristics that may affect system performance.

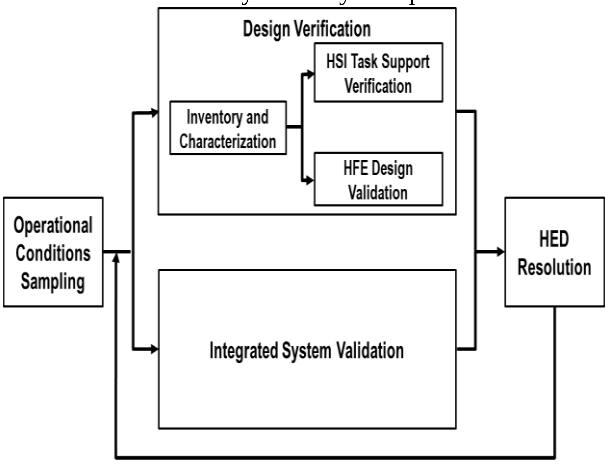

Fig. 7: HFE Verification and Validation

4. Consideration for artificial intelligence

Machine learning, deep learning, artificial neural network, genetic algorithms, and cognitive computing are the terminologies that are commonly used when describing artificial intelligence (AI). AI is an assemblage of advanced technologies that allows machines to behave rationally, much like the reasoning of humans, through sensing, processing or learning, and acting. Since the inception of AI in the 1950's, its applications have been explored in many fields, particularly in areas involving large data volumes. Advancement in algorithms, computing power and storage has made AI become the highlight of the 4^{th} industrial revolution.

Current AI applications include robotics, big data analytics, intelligent sensing, image and voice recognition, fault detection, and in decision making processes. These applications are readily applicable to support operator actions in task management, sensor surveillance, diagnostics and calibration to mention a few. Already many research work have been done in the use of AI-based guidance system in the MCR. One of such research work is the MITI Man-Machine System Project in Japan [5]

5. Conclusions

A conceptual review of the human factors engineering process model for the APR1400 MMIS has be presented. The Model is consistent with the guidance provided in NUREG-0711 for the evaluation of human factors engineering program. As artificial intelligence become prominent in the 4^{th} industrial revolution, a new approach to human factors engineering must be given consideration.

Acknowledgement

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