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# A Preliminary Plan for the Human Factors Safety Verification of a Digital Device in Unexpected Situations of Nuclear Power Plants

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## 1. Human Factors Verification in Nuclear

Human factors(HF) in nuclear installations has been crucial and become more critical with succeeding accidents such as TMI #2, Chernobyl, JCO and Fukushima #1. Since the kinds of human errors have been turned out to be a main cause of such accidents, huge amount of efforts has been conducted back-fitting works to eliminate the human factors defects and devoted to identify any further potential of human errors in any level and/or any part of nuclear systems. Regulations in nuclear after the main accidents defined a few formal requirements for HF safety analysis in form of systematic application of HFE approaches including HF verification(refer to IEC-60964, NUREG-0711, IEEE-std-1023, etc.). However it becomes doubtful that the current HF verifications might be strong enough to cover the basic concerns raised after Fukushima accident. IAEA, for example, raised the *fundamental surprise* in unprepared conditions with unknown risks to verify the HF safety (2015 IAEA).

This paper describes the arguments for the technical considerations required to HF verifications after Fukushima. They are mainly focused to the experiments in severe accident issues like a challenge of Fukushima. And I will discuss the strategy to cope with them and propose a preliminary plan for the HF safety verification of a digital device in practice.

## 2. Current Approaches and Issues to Human Factors Verification after Fukushima

### 2.1 Current HF Verification Approaches and Arguments for the Safety Verification

Every HFE process includes different kinds of verification method(s) and step(s) on HF requirements during the design as well as in operation. The different HF verification methods can be categorized into 8 types available around nuclear (Lee, 2018b). Figure 1 shows a typical scheme for the HF verification approach described in NUREG-0711 by US-NRC.

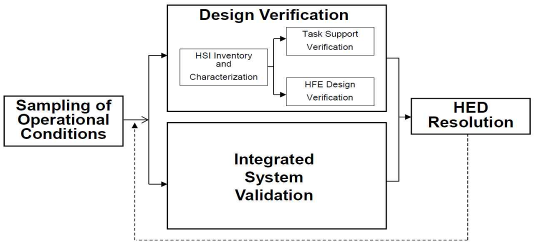


Figure 1. A Typical HF V&V (adopted from NUREG-0711, Rev.2, US-NRC)

Many technical issues and tasks on the current HF verification approaches were discussed in detail on *Task Support Verification* and *HFE Design Verification* (Lee, 2018a). However most verifications may finally require empirical evidences from the experimental process of human-in-the-loop test such as ISV (Integrated System Validation).

Many arguments have been raised to the empirical/experimental approach for the HF verification in form of ISV not only for nuclear but also for other generic HFs. HF experts in nuclear has ever summarized the technical issues on ISV as followings 4 topics (revised from 2018a, Lee; 2016, OECD/NEA);

- the scopes & objectives : not clear
- the sampling of subjects: limited
- the scenarios : not realistic nor full-cover
- the outcome data : lack of significances

For the emphasis on the safety in HF verification, I would like to focus to the following arguments to ISV.

Firstly, the current experiments to the human in-the-loop utilize simulated conditions (refer to the *Sampling of Operational Conditions* in Figure 1). However they can not be the same conditions with the sampled from real system in practice. The validity of test results can not be supported without the fidelity enough to prove the confidence of condition. IAEA is now challenging nuclear safety up to the level of "*Prepare the Unpreparedness*" to unknown risks. (refer to Figure 2). There should be different kinds of fidelities within experimental setups such as psycho-physiological fidelity as well as physical and situational fidelity.

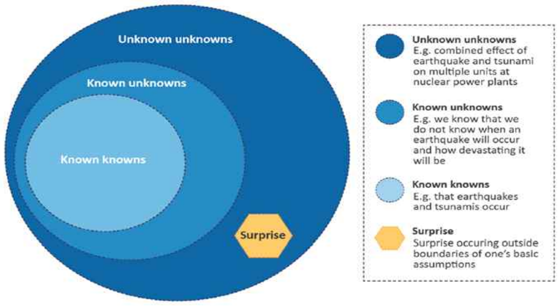


Figure 2. Three Different Risk Areas (adopted from Fukushima Accident Report, IAEA)

Secondly, HF experiments normally focused to the verifications by the average performance rather than the safety. Average data may be not difficult in statistical and experimental treatments, but the safety data require different level of efforts in experimental design. In case that we want to get enough number of data about the low frequency phenomena, the number of trials should be large enough to prove the statistical significance. For example, IAEA pushed the technical considerations about the *fundamental surprise* with unknown risks in unknown future Therefore HF verifications through experimental approach may not so simple especially about the safety aspect of nuclear devices and technologies.

## 2.2 Issues and Proposed Approach to Integrated System Validation after Fukushima

ISV is established to be in an realistic manner focused to the integrated effectiveness, which frequently means the final resolution of HEDs in iterations. I developed a strategy for ISV plan to accomplish the HF verification on a digital device. All issues for HF verification exhaustively keep going on for ISV as the following topics of test concerning (revised from 2018b, Lee).

- Test beds and Measurement Facilities
- Test Objectives and Goals
- Test Design : Scenario, Task and Subjects
- HED Resolution and Validation Statistics

Current ISV experiments have been so limited in number of trials and scope of tasks to verify the HF safety of various decision makings in forms of individual, team and organization, even more with unknown tasks on unknown situations. However, by virtue of psychological progress on risk behaviors, the combinatorial enumerations of unexpected encounters between human tasks and the situations could be considered to extend the scope and the validity of ISV by incorporating 3F (*Flee, Fight, and Freeze*) behaviors and their combinatins (2018a Lee).

3F behaviors may externally represent the *fundamental surprise* that could happen in the unknown-unknowns (refer to Figure 2 of IAEA). KAERI developed measurement methods to verify the internal immersion (2017, Kim), the team incorporation (2016, Jang), and the erroneous state (2013, Oh & Lee) through EEG signals.

Different considerations on the test setup may required to the test scenarios/tasks imposed to subjects and simulations if ISV would cover the so-called *unknown-unknown* risks in practice. Figure 3 shows an additional example of test scenario when operators wear protective cloths in limited illumination and scrambled working environments (the figure is adopted from a video screen for explaining the Fukushima accident)

Figure 3. A Condition Required Protective Cloths (adopted from Kim & Kim 2018)

The test situations and tasks could be *unexpected, unexperienced, and unprepared* (**3U** in short) finally only when the target subject is deceived by the team member(s) and the test organizer as well as the simulated phenomena and data.

Additional test strategies such as *adversarial intrusion, bothering, negligence, role change, and reconfiguration* can be utilized during ISV. They should be incorporated to experiments in form of uninformed deception if intended to induce 3U state to the subject(s). The conditioning for the subject(s) should be carefully designed to get evidences of fidelities and validity within a limited number of trials.

## 2.3 A Proposed Implementation Plan of ISV for a Digital Device

A new plan for the ISV implementation is proposed to cope with the arguments and considerations after Fukushima. Followings describes additional considerations for ISV verifications of an ESCM of APR-1400 MCR prepared by KAERI. The ultimate goal of ISV on a digital device should be an concrete confidence on the human error-free design by incorporating objective fidelity of test scenarios and subjects' mental status, and validity in statistics. However, more practical earnings may be detailed implications to the design enough to enhance the design to such an error-free in iterative manner. The plan is emphasized to design rather than HF itself.

For test beds of ISV, KAERI has developed an experimental integration under the name of *Nu-TEB* (*Nuclear TEst-Bed*). (see Figure 4.) It includes many HF evaluation techniques and measurement methods supposed to support the issues to current ISV after Fukushima.

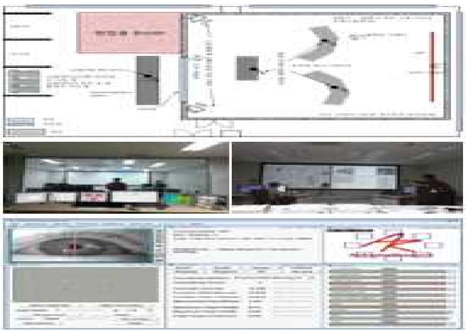

Figure 4. NU-TEB(adopted, KAERI 2018)

Additive simulation by virtue of AR/MR techniques is to consider the unexpected situations induced by external events such as earthquake, flooding, fire, and etc. more precisely during ISV. For the experiments, especially for ISV, many new emerging techniques such as psycho-physiological signal (such as ECG, HRV, GSR, EEG, and skin temperature, and others) based measurements and observations are developed on team coordination and intrusiveness as well as individual behaviors.

The plan includes a set of test scenarios such as more challenging conditions of loss of total illuminations and harsh environments to subjects. Emerging techniques are adopted to simulate those challenging habitability in form of AR/MR fire and devised earthquake. And psycho-physiological monitors could verify the 3U condition of subjects in such test scenarios. Figure 4 shows a example of test setup in NU-TEB when including mixed reality fires and simulated earthquake conditions. (adopted from Kim & Kim 2018)

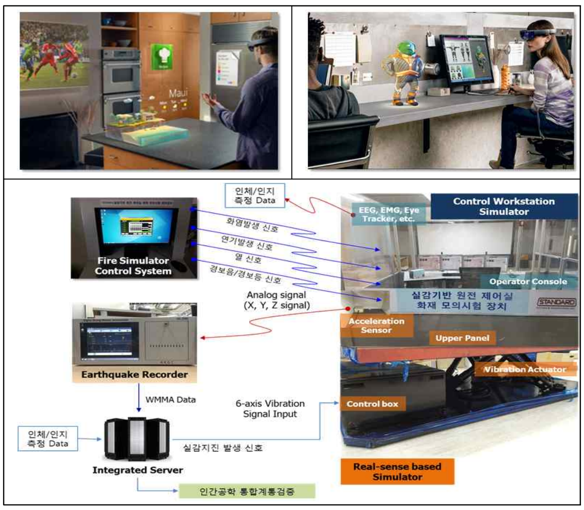


Figure 4. An Example setup of Nu-TEB with mixed reality of earthquakes and fire.(Kim & Kim 2018)

Though the target object is a ESCM in this plan, there should be other devices such as LDP wall, CPS, IPS monitors, and the workstation in form of practical operational setup of APR-1400 MCR. The reason why those devices are required for ISV of ESCM is that they are tightly coupled each other in the level of cognition and information as well as connected in the level of data and signals. ISV should be conducted in form of more realistic manner of ESCM operations if it is designed for valid conclusion on HF safety.

## 3. Discussions and Further Works

HF safety verification becomes prevailing again in nuclear for digital features incorporating especially intelligent techniques. Recently two succeeding accidents of *Boeing-737 Max* revealed disastrously such requirements of more precise verification on HF safety before (and during) the design. The HF safety verification of a design is required to consider the human understanding and internal states more carefully. It can not be straightforward even when the design may incorporates performance-enhanced features such as new digital and intelligent functions.

This paper describes additional arguments and considerations on HF verification and propose implementation strategies focused to concerns after Fukushima. And an example plan of ISV implementation for ESCM is proposed. The proposed strategy and plan can be incorporated into stress tests and tested with an example ISV of a digital ESCM.

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