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A Discussion on the Development Direction of the Next Generation I&C System in Nuclear : To Cope with the Human Error Uncertainty Remaining after Fukushima Accident

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Abstract

Human error has been notorious as one of the safety uncertainties that still remains in the next generation of reactors, which are emerging as a future energy alternative against to climate crisis and carbon neutrality. The development of the I&C system has contributed greatly to the successful resolution of the human error uncertainty in nuclear systems. In this paper, the historical development process is briefly reviewed that I&C system has been resolved the human error uncertainty in the nuclear system so far. And the direction of development of the I&C system required for the next generation reactor is discussed. Effective use of rapidly developing technologies such as AI and big-data processing in recent years will contribute to resolving the risk of human error in next generation reactors and securing the safety required as a future energy alternative.

**Keywords: nuclear, I&C system, human error 3.0, safety culture, next generation, man-machine interface system*

1. Background and Introduction

Despite the painful experience of Fukushima accident, the possibility of next-generation reactors has been emerging again due to the up-roaring issues of carbon neutrality and the climate crisis. The prerequisite for this adoption of next-generation reactors as eco-friendly energy taxonomy is that it should be turned out to be an alternative eco-energy solved the existing dangers fundamentally. (Please refer to EU taxonomy) Nuclear systems have pioneered in securing high safety through continuous technological development. In particular, the I&C system has played an important role in solving safety challenges raised recurrently. If the most rapidly developing I&C technologies such as AI are incorporated properly, it might be possible to solve the remaining human error risks within next-generation reactors and secure the safety required as a future energy alternative. In this paper, the direction of the I&C system development required for the next-generation reactors through the I&C system has been discussed.

2. A Brief Review on the Developments of I&C Systems in Nuclear

In a nuclear system, the I&C system includes functions such as measurement, monitoring, protection, and control necessary for the control of the reactor. It can be said to be a brain and neural network that actually determine movement by operating various functions of a pre-designed reactor. In this section, the development process of I&C system is briefly reviewed in chronological order and according to milestone events experienced in nuclear.

2.1 Aggregated I&C System

In the early days of the development of nuclear systems, it was a simple collective set of instruments that monitored the status of various individual functions included in the system and controllers that operated the functions. Individual functions were developed to include sufficiently safe and convenient measuring instruments and controllers. The development of various nuclear unique measuring instruments such as neutron meters as well as various remote control devices enabled the construction of a nuclear system safe from radiation exposure. Measurement and controllers included in individual functions could be spatially collected through electrical instruments and circuits for the convenience of reactor operators. In early nuclear systems, the control room was the collective appearance of aggregated I&C system that simply gathered devices capable of remote processing.

2.2 Improved I&C System

The movement of the nuclear system must be based on the knowledge and judgment of the controller. In a simple collective I&C system, most of the movement can be performed in the control room. However, in order to effectively select the necessary functions, sufficiently well-organized instruments and controllers must be provided by the operator. The TMI accident in 1979 was not adequately designed in the control room. This immediately caused human errors, leading to unexpected failures and their overlap. In the nuclear field, as the core of TMI follow-up measures, the uncertainty of human errors that threaten the safety of nuclear systems was greatly improved through ergonomic suitability by reinforcing additional devices such as SDS, which secures the compatibility of devices provided to pilots in the control room and provides necessary information.

2.3 I&C system with MMIS concept

After the TMI accident, a new design concept was proposed in the United States to overcome the negative situation about nuclear power. In order to solve the uncertainty of human error, the notion of Man-Machine Interface System (MMIS) is applied as a new design concept that presupposes solving the problem in the interaction with the reactor pilot without staying in the retrofitting of the existing I&C system. In particular, it is possible to design an interface that is compatible by utilizing the rapidly developing computerization technology and freely select and configure the necessary measurement and control functions. This appeared before us in the form of a highly advanced control room that has been greatly developed to physically and functionally meet most of the requirements to nuclear systems.

3. Demands and A Direction for a New I&C System in Nuclear

3.1 Demands for a New I&C System in Nuclear

In order to recognize the next generation of reactors as one of the alternatives to address environmental and climate problems, at the very least, the known risks must be addressed. Uncertainty of human error due to the lack of ergonomic compatibility and suitability of the I&C system known in the TMI accident has been sufficiently reduced and largely resolved with advances in electronic engineering and computer technology. However, after reviewing the experiences of the Chernobyl and Fukushima nuclear accidents(succeeding to JCO and TEPCO's cover-up of absurdity), the uncertainty of human error has not been completely resolved and turned out to be one of the important tasks remaining. This is because it has been revealed that the operators and many of the people involved in determining the reactor operation have exceeded designed expectations and are unable to cope with the risks arising from wrong judgments and choices, or rather create unthinkable new risks. It is clear that these new types of human error cannot be easily resolved upto now. As a result of recognizing the new human error uncertainty problem, it has caused a fundamental rejection even among those who even recognize the enormous utility and practical benefits of nuclear systems. Since it is extremely difficult to handle this type of uncertain human error risk on my hands, the avoidance-first value system might enforce some people to exclude nuclear system nowadays.

These experiences of accidents have raised a new level of human error that is different from the previous human error. While human errors so far have generally been centered on slip and rope, the new human error is centered on decision-making errors such as situation judgment and selection. In addition, rather than arising from the interaction between the driver and the nuclear system device, it is a human error task that occurs in complex interactions involving many stakeholders at various levels involved in the operation of the reactor.

There is a tendency to diagnose the cause of such human error as a lack or defect of safety culture, especially after Fukushima accident and its after-math. However, some point out that safety culture is an attribute error that is misused as a cause of human error as the concept and definition are uncertain (2018, 2020 Lee). In the safety of large systems involving numerous devices and various personnel, pointing out safety culture as the cause of the problem can be a typical post-explanation (*Ad-Hoc*) error. In addition, it is used as a misleading means of (1) the trivial cause of all problems, (2) easy convenience to terminate the open-ended analysis of safety issues, and (3) artificiality to select countermeasures without enough evidences and on purpose.

- *causal triviality*
- *termination convenience*
- *counter-measure artificiality*

3.2 A Design Direction proposed for a New I&C System in Nuclear in response to Fukushima Questions

Now, the new I&C system required for nuclear systems is not sufficient only with the current level of design that sufficiently reduces the uncertainty of human error that may occur by securing compatibility and suitability in the human-machine interface connection. Compatibility and suitability must be secured, including interactions between workers as well as human-machine connection. The role of the traditional operator in charge of operating the reactor and related parts, which has introduced the latest safety concepts such as passive as well as inherent safety, is very limited. It might be changed rapidly with the introduction of AI. Basic strategy of operation and mission functions allocated to I&C system might be changed drastically. Therefore, the following requirements can be discussed further.

First, the traditional monitoring and control functions given to the driver are greatly reduced, and most of the remaining duties associated with them can be handed over to the automatic function. It is common to adopt automation as a design concept to exclude errors in the driver. However, from the concept of human error 3.0 that the ultimate responsibility of humans cannot be avoided, automation is a design concept that can never be simply selected and satisfied. This is because, from the perspective of function analysis and allocation, the functions assigned to the driver are not just executives (see more details in NUREG-0711). This includes initiation and termination of a given function, as well as interrupt and conditioning. However, while the execution of duties assigned to drivers is usually prescribed by procedures, other functions are not properly specified. In particular, the preparation of functions is usually assigned separately and defined independently such as maintenance and surveillance duties. Therefore, careful consideration of the scope of automation in terms of human error and the possibility of new additional jobs and related human error arising as a result of automation should be considered.

Second, most of the accidents frequently experienced in nuclear systems in recent years are related to secondary activities such as preservation rather than the driving job itself. Due to the importance of the driving job, it is a phenomenon in which the secondary job, which has not had a significant impact on safety, threatens the overall safety. (This is called the *law of minimum*.) These secondary jobs cause problems and errors when the core is not sufficiently considered in the connection with the driving job. Looking at the case of tripping the maintenance test ripple failure occurring in power plants, it can be seen that it is difficult to fully consider the overall safety because each of the independently performed jobs is segmented. (This is called a *segmentation* problem.)

Third, when the main job allocated to human, such as driving most of engineering functions, is automated, it becomes very difficult to secure and adjust the linkage of incidental jobs. Therefore, what is necessary to prevent human error uncertainty in I&C system of next-generation reactors is not the automation of jobs based on well-designed driving procedures, but the development of new supervisory control functions over the traditional tasks. Representatively, a new comprehensive management function is to be provided to handle multiple reactors together in a modular nuclear system. In particular, administrative or comprehensive supervision control of incidental jobs is required, not nuclear reactor operation. However, it is essential to synthesize the incidental jobs in order to synthesize the job of driving the reactor. Compared to the main driving jobs, it will be necessary to provide coordination and more comprehensive management of various incidental jobs that are not automated and remain. There will be no more operator in future I&C system, rather a supervisor of a power station or an administrative manager of power(electricity) company.

Fourth, in order to achieve the comprehensive job management function required for the new I&C system to a level that eliminates human error uncertainty, it requires a transition from the traditional design concept. It will be necessary to support not only the connection of machines such as facilities and parts, but also between workers. The design of the engineering system was fundamentally limited to machines and parts, but after the TMI accident, the introduction of the concept of a man-machine system was able to greatly innovate the I&C system. Now, an expanded design concept that supports human-to-human interaction is needed. In order to manage current safety culture issues with specific data, an attempt has been made to develop a system that provides data by monitoring the behavior of power plant workers and related organizations. (2015/2018 Lee, et al. 2016 Jang, et al.) This is intended to provide dual monitoring and control functions so that the safety and performance of nuclear systems can be achieved more comprehensively.

Fifth, in the case of expanding the monitoring and control of interactions between stakeholders in the new I&C system, the range of stakeholders to be considered should be expanded. There is a need for expanded consideration of the range of not only drivers or workers but also people who can influence the decision-making of the reactor system. In the next-generation reactors, operators will switch beyond supervisors to operational managers' roles. In this case, it is because the operation manager must communicate and coordinate with the operator of the system and external stakeholders. In the Chernobyl accident, it was impossible for the operator to communicate and coordinate with the organization conducting the experiment. In the Fukushima nuclear accident, which followed the concealment accident of JCO and TEPCO, human errors were inevitable due to insufficient or inadequate function to support the interaction between internal personnel of the system and external organizations (including administrative headquarters, regulators and government).

4. Conclusions and Further Applications

In this paper, after a brief review on the I&C system designs in nuclear, the direction of development of a new I&C system necessary was discussed to minimize the uncertainty remaining in terms of human error after Fukushima and others. In addition to the existing I&C system focusing on monitoring and control of machine aspects such as nuclear reactors, a dual monitoring and control system capable of collecting and analyzing information on the behavior of workers and related organizations is needed. It is desirable to move on to a new design concept after current notion of MMIS. It is natural to prioritize automating important driving jobs in the development process to utilize new technologies such as AI. Considering human error and its uncertainty that still remains in nuclear system over operation itself, a new paradigm of *Human Error 3.0* and extended scope of more human involvements (such as human to human interactions) to I&C system is recommendable rather than simple automation by incorporating AI and advanced technologies in nuclear.

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