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차세대 원자력 계측제어 시스템의 개발 방향 – 후쿠시마 사고 후 남은 인적오류 불확실성 대처*

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

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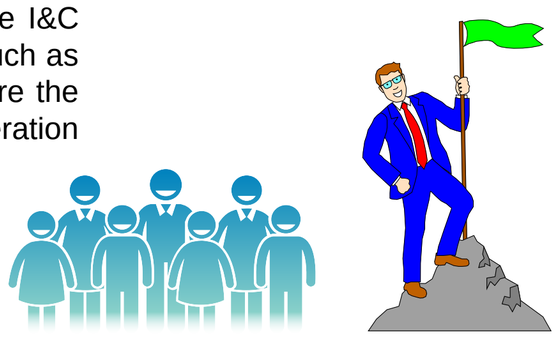
1. Introduction and Background

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.

I&C System in Nuclear
Achieved vs. Required



2. A Brief Review of I &C Systems in Nuclear : *History of I&C Systems in Nuclear*

Nuclear Instrumentations : SAR Chap. 7

- *New and Advanced Functions* For Monitoring Radiation with Safety : Measurable? => Range & Precision

~ safety-focused integration of human-made systems ~ Controls for T/H Behaviors of Rx. And others

2.1 Simple Aggregated I&C :
Not a System But Just an Aggregated Instruments within a Space for Human Operators

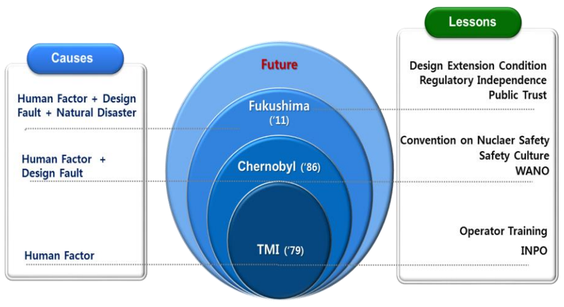
2.2 Improved I&C :
Electronics Devices => Instrument Panel => Control Area => Management Space

2.3 Improved I&C System :
Organized w.r.t. Operational Behavior by *Electronics Instrument Panel => Control Room*

2.4 Advanced I&C System : for TMI Safety Req's

- ***Structured by MMIS (Human-Machine Interface System) Paradigm***
- ***Advanced Electronics ~ Computerized Information Processing & Digital Control***

전통적인 계측제어 시스템 (기능 관점)	전통적인 계측제어 시스템 (대상 관점)
- 계측 instrument - 감시 monitoring - 보호 protection - 제어 control	- 원자로 - 열수력 생산설비 - 관리 전기 - 환경



3. Latest Requirements for I&C System in Nuclear

Q. What is the main Direction of Nuclear I&C System After Fukushima

Under Current Socio-Technical Changes ~ New Paradigm of Safety

cf. EU Taxonomy for Climate Crisis Alternative

cf. Safety II & III (2007 Hollnagel, 2025 Lee)

3.1 Socio-Technical Requirements: ~ Safely Manage the Electrical Generation rather than Reactor

- ***UI/UX driven Revolution ~ Efficiency rather than Safety***
- ***AI Applications ~ New Uncertainty over the Benefits of Automations***
- ***Social Expectations and Concerns ~ Fundamental Uncertainty of Human Error***
  cf. Human Error 3.0 Paradigm ~ Ultimate Responsibility to Future Security due to human-made artifacts

3.2 Social safety requirements: social acceptability over Fukushima Accident Uncertainty

- ***Prepare the Unpreparedness & Unexpected***
- ***Cope with unknown-unknown Risk ~ Safety-Culture***
  cf. Error Attribution of Safety Culture *(2022/2023 Lee)*
  (1) Causal Triviality (2) Convenience to terminate (3) Artificiality for Counter-measures

(대상 관점)	새로운 계측제어 (범위 관점)	(방법 관점)
- 원자로 - 열수력 설비 - 기타 설비 - 소프트웨어 - 종사자 - 관계자	- 운전 - 보수시험검사 - 기타 - 형상관리 - 설치/교체/폐로 - 사업 관리 - 사회적 관리	- 신호 - 상태 - 기타 - 데이터 - 정보/직무상황 - 의사결정/조직 - 전략/운영

+ 운전 외 업무
+ 종사자 + 직무
+ 조직 거동
+ 이해관계자

An Example Scheme of Layered Open Architecture

3.3. Design Directions to New I&C : SAR Chap. 7 + 13 + 15 + 18

Shift of Main I&C Functions *cf. SMR ~ Supervisory Management Station?*

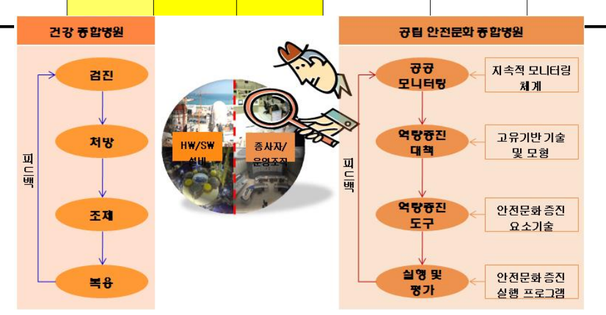
(1) What to Monitor and Control? Instrument for Monitoring and Control of HW Devices and Equipments
(2) When to Monitor and Control? Expansion of Scope ~ Operation Modes over the Power Generation Maneuvering **=> O/H, Refueling, Surveillances**
(3) Whom to Monitor and Control? Inclusion of Users ~ Operator and Safety Manager=> Configuration Manager
(4) How to Monitor and Control? : Signal to Data /Information ~ Accumulated into Data and Information
(5) How to Monitor and Control?(2) : Task Support -> Support Decision Making of Various Interest Parties
cf. Interest Parties of Nuclear Systems ~ more than Operation Crew Members
- Utility Managers, Regulator, NGO, Domestic Authority, Government, Specialist, Public, etc.

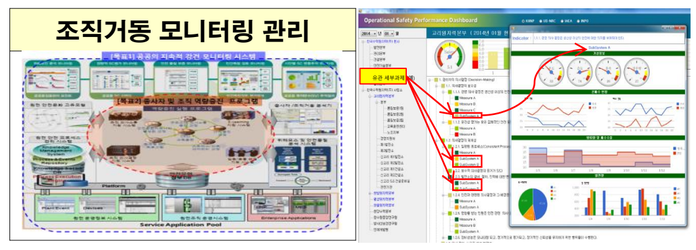
Safety by Functional Reliability (RAM)=>
+ Environmental -> Ecological Security + Societal Credibility/Dependability
~ Layered Open Architecture => See Diagram Proposed Scopes of New I&C
**** Extended Scope of I&C System For Revolutionary Nuclear Future =>***

3전

원전
안전
운전

Scope of I&C / Processing Level	Current H/W	Current S/W	Current Env.	Expanded Crew	Expanded Org.	Expanded Society
• Symbol (Inf.)						
• Sign (Data)						
• Signal						





4. Discussions and Conclusions : A Brief Review on the History of I&C Systems in Nuclear

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.

5. References

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