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Proposal of Safety Analysis Platform for Building Big Data on Nuclear Power Plant Accidents

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1. Introduction

Looking at the R&D topics of the nuclear power plant industry over the past decade, there have been various attempts using AI, and among them, one of the most prominent areas of interest is accident prediction through AI. Everyone agrees that there must be sufficient data for learning in order to successfully apply AI, which is the most core technology of the 4th Industrial Revolution technology. However, accidents at nuclear power plants are not as common as traffic accidents, and there should not be much accident data. Therefore, in order to predict nuclear power plant accidents with AI, various accidents must be simulated through safety analysis codes and used as learning data. However, engineers who performed safety analysis have all done it on their personal computers, so the results have not been aggregated in the form of big data. Therefore, this paper aims to propose a safety analysis big data platform that can produce and store such safety analysis data, as well as process it to develop AI models.

2. Current status and necessity

Nuclear safety analysis is to assess potential hazards associated with nuclear facilities and activities and must be performed to demonstrate that all safety standards associated with the design of nuclear facilities are met. This safety analysis process is shown in Fig. 1, and in this process, the safety analysis code determines whether the safety acceptance criteria are satisfied.[1]

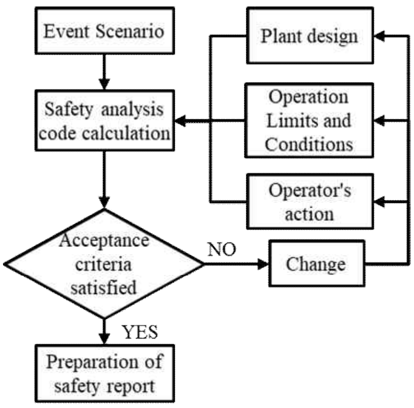

Fig. 1. Conceptual diagram of performing safety analysis[1]

The safety analysis codes used in the nuclear industry are very diverse, and most of them analyze accident with a text-based input format, execute input through command-line interfaces, and evaluate the results in the form of CSV time-series data, which are then visualized with graph plot programs. However, compared to engineering processes in other industries, these procedures are considerably less efficient in terms of work efficiency. Moreover, because safety analyses are performed on personal computers, the resulting analysis data is scattered and the I/O format is not standardized, which has prevented decades of nuclear safety analysis data from being transformed into big data.

The core of digital transformation (DT) is data, which produces data for AI learning by separately calculating safety analysis codes for this DT, so it is urgent to collect safety analysis codes and build big data through the introduction of an engineering platform.

The safety analysis code is a computer program that analyzes the thermal-hydraulic behavior of nuclear power plants under virtual accident conditions and evaluates the integrity of fuel rods and containment buildings.[1] It is essential to have various computer codes as shown in the Fig. 2 for the safety analysis of transient conditions and design basis accidents of nuclear power plants, usually using programs developed in the United States. Most of the nuclear-related computational analysis codes are in the form of stand-alone programs that have not developed user-centered UI/UX and have been developed mainly in research institutes rather than the industry. Related workers are also accustomed to this text-oriented pre/ post-processing and tend to be conservative in accepting changes, which takes a lot of time to train new experts.

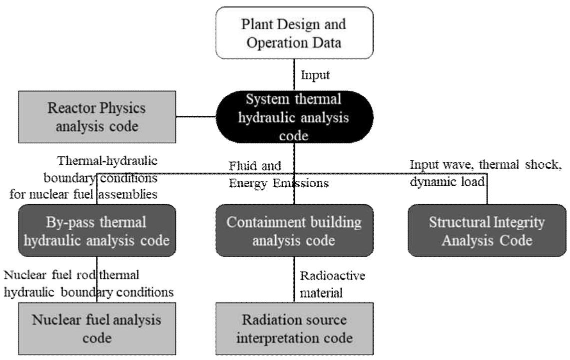

Fig. 2. Safety analysis code interconnection diagram[1]

Various efforts are being made to advance the nuclear safety computational analysis system, but there seems to be no effort to move away from the existing framework, such as establishing an engineering data platform using networks. This seems to reflect the characteristics of the nuclear industry, which emphasizes thorough verification of safety and security in introducing new technologies and the conservative attitude of the industry, which makes careful decisions through close review. The developers of computational codes in the United States are also attempting to improve their UI, but the improvements have not considered user experience or convenience and are being ignored by actual users. After the improvements, the codes still remain in stand-alone form, preventing data sharing among analysis experts, and they delete data that is difficult to secure on personal disks after a certain period.

3. Implementation strategies

3.1 Establishment of Nuclear Safety Analysis Engineering System

The safety analysis computational codes include reactor physics analysis codes, nuclear fuel analysis codes, thermal-hydraulic analysis codes, containment analysis codes, radiation source analysis codes, and structural integrity analysis codes, which interact with each other centered on the thermal-hydraulics analysis code. To select the most commonly used code in the engineering industry among these codes, the current status of nuclear engineering is analyzed, and the process of the most popular field is established. The established safety analysis engineering process is diagrammed, and the interface between the codes is defined, and the situation of data exchange between them is visualized.

3.2 Safety Analysis Code Selection and Interface Analysis

While it would be ideal to incorporate all the analysis codes from the fields of reactor physics, nuclear fuel, thermal-hydraulics, containment building, radiation source, and structural integrity into the platform, it is not only practically difficult to obtain all the computer codes but also necessary to narrow down the scope of the platform to essential analysis codes in each field for the successful execution of the project. The most useful and in-demand computer codes in the safety analysis process will be selected, and collaboration with nuclear engineers who use these codes will be established to analyze the interface between the codes.

3.3 I/O standardization and data linkage design

The initial events are incidents that can lead to anticipated operational transients or accidents, and they are derived through a series of repeated processes of design and analysis, engineering judgments, and the experience of power plant design and operation. To standardize the input of the target code, a standard input system is established for each initial event, and a standard input system is established for each system based on accident progression analysis and analysis of operator actions. To increase user convenience, the output is standardized by providing functions such as plotting time-series data or displaying the progress of accidents. A Hadoop-based big data platform is built for data collection, storage, processing, analysis, and visualization, and data linkage is designed to provide engineering services by collecting all safety analysis-related data into a data lake.

3.4 Establishment of analysis platforms and service systems

A system is established to build a safety analysis platform based on computer codes and provide it as a service in Fig. 3. This service will provide the public with a clear understanding of the safe operating conditions of the power plant and step-by-step safety measures and response scenarios in the event of an accident, as well as radiation exposure levels in the vicinity of the power plant. In the event of a nuclear accident, the system will simulate the response of operators to visualize the state and level of danger of the power plant, thereby enhancing public awareness of nuclear safety.

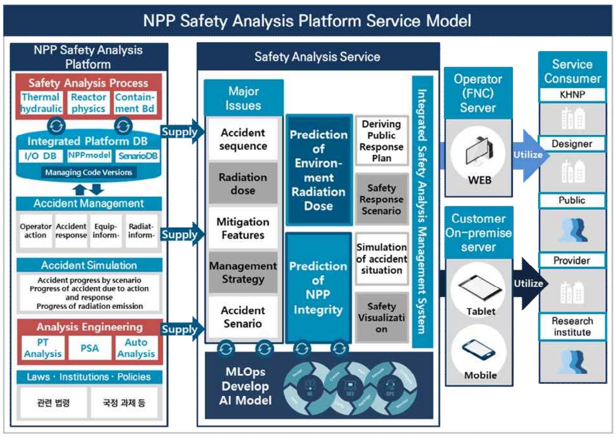

Fig. 3. Safety Analysis Platform Service Schematic Diagram

3.5 AI platforms (MLOps) and pipelines construction

An AI platform will be built using Kubernetes-based Docker containers that provide GPU memory virtualization to users, creating an MLOps platform. To ensure continuous operation of the AI services, a pipeline will be established to collect and version new training data, efficiently preprocess the data for new training and validation, and continuously analyze, validate, and deploy tuned models.

4. Expected effect and utilization plan

To facilitate the digital transformation of nuclear safety analysis, a data lake will be established and the safety analysis system will be integrated and systematized. This will lead to the development of an advanced

engineering system that can manage and share safety analysis tasks which are currently performed individually. Similar safety analysis tasks can be easily handled through the use of AI models, while large amounts of data required for safety analysis can be interpreted more accurately, resulting in reduced costs for repetitive tasks. The platform will also enable the development of various AI models by collecting and utilizing data, thereby transforming conventional analysis methodologies into new digital forms.
In addition, the platform can evolve into a community like Stack Overflow, which shares and provides solutions to problems encountered during safety analysis processes. It can also evolve into an AI model development and analysis platform like Kaggle, by providing secure and comprehensive training data for power plant engineering procedures. It is expected that this safety analysis engineering platform will significantly contribute to the competitiveness of Korean nuclear power in the government's efforts to foster the nuclear industry and expand the export market.

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