Measures to Secure On-site Applicability of Nuclear Power Plant Decommissioning Equipment (Dismantling/Decontamination)

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1. Introduction

In the nuclear power plant decommissioning process, dismantling(cutting) and decontamination are key processes that account for a significant portion of the total project cost and determine worker safety (ALARA). To dismantle large structures in a high-radiation environment and minimize waste, it is critical to ensure "field applicability"-optimizing laboratory-proven technologies for actual nuclear power plant sites.

This study aims to present specific technological advancement and verification strategies for the stable applicability of previously developed cutting and chemical decontamination technologies at commercial nuclear power plant decommissioning sites, such as Kori Unit 1.

2. Current status and verification data of key technologies in cutting and decontamination fields

2.1 Remote cutting technology: high-power laser and underwater applicability

The reactor pressure vessel (RV) and its internal structures (RVI) must be remotely cut underwater in high radioactivity [1]. The following summarizes the technical specifications, performance indicators, and key components of remote cutting technology.

- Technical specifications: the 6 kW high-power fiber laser developed domestically has proven its ability to cut stainless steel plates up to 100 mm thick underwater.
- Performance indicators: experimental results have shown that the optimal speed for underwater cutting of 50 mm thick stainless steel is 30 mm/min, with speeds up to 130 mm/min achievable.
- Key components include a remote laser cutting machine, an underwater dry cavity nozzle, and an assist gas control system.

2.2 Advanced decontamination technology: decontamination factor (DF) and waste reduction

Decontamination is key means of reducing waste disposal costs by reducing radioactivity levels. The following presents the decontamination coefficients and waste reduction results from previously developed decontamination technologies [2].

- System decontamination: performance of DF 100 or higher was secured in stainless steel pipes by circulating a dilute hydrochloric acid series reducing agent
- Large-scale equipment decontamination: a DF 45 level was achieved by applying a gel-type decontamination agent inside the tank, which significantly improves worker accessibility.
- Regeneration technology: the amount of secondary waste has been drastically reduced through an electrolytic regeneration process that recovers more than 70 % of the hydrochloric acid-based decontamination agent and separates more than 90 % of the metal components.

3. Three major strategies to ensure field applicability

Most of the previously developed technologies are in the 'pilot scale' verification stage, and the following step-by-step strategy is required to upgrade them to 'full scale'.

3.1 Utilizing physical verification infrastructure (mock-up) and test-beds

Repeated testing in an environment identical to the actual environment before field applicability is an essential process for eliminating technical uncertainty, and the following are some ways to utilize this.

- KRID demonstration infrastructure: utilizing the mock-up facility built within KRID, the performance of high-dose area remote cutting and large-scale waste decontamination equipment will be comprehensively verified.
- Priority applicability of non-radiation zones: development equipment will be deployed first for pipe cutting work in non-radiation zones, such as the turbine building of Kori Unit 1, to secure actual field operation date (track record).
- Underwater cutting training simulator: minimize failure rates in field operations by utilizing the underwater cutting training simulator developed to improve the proficiency of remote operators.

3.2 Process optimization based on digital twin and virtualization technology

Considering the nature of on-site access being restricted due to radiation risks, verification in a digital virtual environment is being enhanced [3]. The following are related details.

- XR virtual training system: improve accuracy by practicing the cutting angle and direction of the robot arm in advance in a virtual workshop modeled after the pressure vessel of Kori Unit 1
- Real-time virtual reality linkage: optimizes remote cutting algorithms through a two-way linkage system that maches the movements of the virtual space with the actual robot arm.
- Exposure simulation: visualize the expected exposure of workers (or robot) for each decontamination and cutting path to establish an optimal path that complies with the ALARA principle.

3.3 KEPIC standardization and regulatory conformity verification

To ensure reliability across the entire industry, it is necessary to standardize technical specifications and establish a certification system to ensure safe and economical decommissioning of nuclear power plnat [4]. The following are related matters.

- Development of KEPIC nuclear power plant decommissioning standards: establish KEPIC standards for key areas such as metal cutting and demolition, and system and equipment decontamination to establish a legal and technical basis for field application.
- Standardization of radiation characteristics assessment: standardize the methodology for assessing the radioactivity distribution of structures and sites to objectively determine decontamination targets and clearance.
- Performance indicator management: establish quantitative evaluation indicators for cutting speed, decontamination coefficient, secondary waste generation, etc., and continuously monitor the suitability of field application.

4. Conclusions

Domestically secured technologies in cutting and decontamination already possess global competitiveness at the laboratory level. However, to successfully decommissioning Kori Unit 1, these technologies must be transformed into "site-specific technologies" tailored to the complex structure and high-radiation environment of an actual nuclear power plant.

To achieve this, first, full-scale mock-up testing in conjunction with KRID must be routinely conducted to fully verify equipment reliability. Second, digital twin technoligy must be advanced and virtual rehearsals mandated to eliminate the possibility of on-site accidents. Third, the establishment of KEPIC standards and regulatory frameworks must be accelerated to create an environment where domestically developed equipment can be used without discrimination in the field. Securing field applicability based on this kind of evidence will establish a strong track record for future advancement into the global decommissioning market.

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