Analysis of Radioactive Characteristics for Robot Input in NPP Emergency

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1. Introduction

The NPP safety analysis report analyzes various situations such as a decrease in the flow rate of the reactor coolant, an abnormality in the reactivity and power distribution, and an increase and decrease in heat removal by the secondary system. The characteristic of these scenarios is that high-temperature, high-pressure, and high-radiation environments occur, creating an environment in which it is difficult for workers to take initial measures. There is a need for emergency work unmanned platform technology that can improve, replace, and supplement NPP safety. The Enforcement Decree of the Domestic Nuclear Safety Act presents safety standards for operating NPPs and requires safety evaluation periodically. In this study, cases using domestic and foreign unmanned support robots were analyzed to initially cope with situations that could lead to safety, emergency, and serious accidents at operating NPPs. In addition, we would like to investigate the system currently being applied to NPPs and analyze the accident types presented in the FSAR to review the applicability of unmanned support robots. This is intended to be used as basic data for improving the safety of operating NPPs and establishing a platform that can replace and support field workers.

2. Methods and Results

2.1 Analysis of the Enforcement Decree of the Nuclear Safety Act

Article 37 of the Enforcement Decree of the Domestic Nuclear Safety Act established the legal basis for the 10-year periodic re-evaluation of operating NPPs by adding PSA as a new factor to the contents of periodic safety evaluation, and used this to establish safety standards for operating NPPs (Table 1) [1].

Table 1. Safety Standards for Operating NPP to Article 37 of the Enforcement Decree of the Nuclear Safety Act

Risk Criteria	Critical Accident Policy Statement	Accident Management Plan (Nuclear Law, `16)
1 Step: CDF	< 1.0E-4/ry	<1.0E-4/ry (New NPP: 1/10)
2 Step: LERF	<1.0E-5/ry	<1.0E-5/ry (New NPP: 1/10)
^{137}CS, 100 TBq Sum of excess emission frequency	-	<1.0E-6/ry

2.2 Analysis of Accident Types Presented in the FSAR of Shin-Kori Units 3, 4

The types of accidents presented in the FSAR of Shin-Kori Units 3 and 4 are as shown in Table 2, and the types of accidents were analyzed by classifying them into increased/decreased heat removal by the secondary system, abnormal reactivity and power distribution, and increased/decreased inventory of reactor coolant [2].

Table 2. Accident Types Presented in the FSAR

Note	Accident Type
Increased Heat Removal by Secondary Sys.	Reduced Water Supply Temperature, Increase in Waster Flow, Careless Opening of Main Steam Flow, etc.
Reduced Heat Removal by Secondary Sys.	Loss of off-site Load, Turbine Stop, Loss of Ventilation, Closing of Main Steam Isolation Valve, etc.
Reactor Coolant Flow Rate Reduction	Stuck of single reactor coolant pump rotor with loss of off-site power, etc.
Reactivity and Power Distribution Abnormalities	Uncontrolled Control Rod Collection Withdrawal with Loss of Off-Site Power, Single Control Rod Drop, Start-Up of Non-Operating Reactor Coolant Pump, etc.
Increase Reactor Coolant Inventory	Careless Operation of the Emergency Core Cooling System, Malfunction of Chemical and Volumetric Control Systems, etc.
Decreased Reactor Coolant Inventory	Breakage of the Outflow Pipe Outside the Reactor Building, S/G Heat Transfer Tube Rupture, Loss of Coolant Accident, etc.
Sub-Sys/Equipment Radiation Emission	Damage to the Gas-Radiated Waste System, Leakage or Breakage of the Liquid Radioactive Waste System, etc.

2.3 Environmental Analysis of NPP System

In the event of a severe accident at a NPP, the most important radiation sources that affect the human body and the environment are Cs and I, and the substances are released into aerosol or gas in the form of compounds such as CsI, CsOH, and I_2. In addition, the NPP system exists in the environment as shown in Table 3, so it may be difficult for workers to access in the event of a severe accident [3].

Table 3. Environment within the System of NPP

System	Environment
Primary Sys.	- Temperature: 288 ~ 343 ℃ (Hot leg, Cold leg) - Pressure: max 175 kg/cm^2 G - Nuclide: ^{51}Cr, ^{54}Mn, ^{55}Fe, ^{60}Co, ^{95}Zr etc.
Secondary Sys.	- Temperature: 300 ℃ - Pressure: 1,100psig

2.4 Application of Unmanned Emergency Support Robot

In this study, cases of applying unmanned support robots at home and abroad that were actually used in NPPs and cases of using unmanned support robots that were actually used in the event of an accident at Fukushima NPPs.

2.4.1 Development of Unmanned Robots in Korea

In Korea, the Korea Atomic Energy Research Institute developed an unmanned disaster prevention robot that supports nuclear emergency work, and in fact, participated in radiation disaster prevention training designated as a legal training for nuclear facilities to evaluate its practicality. Table 4 shows the investigation of robots developed in Korea for fire suppression/life rescue purposes.

Table 4. Domestic Unmanned Robot Application Cases

Robot	Specification
Kaerot QuadTrack	- 1.2 * 0.8 * 0.7 m - Max Speed: 2 km/h - 0.4 m Vertical Obstacle Climbing
Indoor Hovering Robot II	- Diameter: 500 mm, Weight: 1.1 kg - Operating Time: 20 min.
Outdoor Fire Suppression Robot (Fibot II)	- 3.4 * 1.75 * 1.8m, Weight: 1.5 t - 6 * 6 Independent Driving/Fireproof

As described above, basic research on robots has been conducted in Korea to prepare for emergency situations at NPPs, but there are no cases of application based on specific safety such as emergency situations [4].

2.4.2 Fukushima NPPs Unmanned Support Robot Application

After the hydrogen explosion at Fukushima's First NPP, Honeywell's unmanned helicopter T-Hawk small unmanned aerial vehicle was deployed, and the characteristics are shown in Table 5 [5].

Table 5. Honeywell company's T-Hawk Specification

Robot	Specification
T-Hawk	- Diameter: 30cm - Weight: 7.7 kg (Max 10km Wireless Support) - Equipped with GPS and gasoline engine

Honeywell's unmanned flying robot entered the top of the reactor building and was used to monitor the situation at the top of the reactor building. In addition, Table 6 shows the unmanned robots actually deployed inside the Fukushima NPP.

Table 6. Unmanned Robots Deployed at Fukushima NPP

Robot	Specification
Packbot, Warrior	- Manufacturer: Irobot (USA) - Main Function: Image Observation, Radiation Measurement and Robot ARM and Robot Arms Handling etc. - Nuclear Reactor and Iraq War Input
Dragon Runner, Talon	- Manufacturer: QinetiQ (USA) - Main Function: Image Observation, Radiation Measurement and Robot ARM and Robot Arms Handling etc. - Nuclear Reactor and Iraq War Input
Quince	- Manufacturer: Chiba Tech, Tohoku University (Japan) - Main Function: Image Observation, Radiation Measurement and Robot ARM and Robot Arms Handling etc., Mock Up Test Level

Using the robots introduced in Table 6, the dose, internal temperature, humidity, and oxygen concentration can be identified in the Fukushima nuclear accident, and the cumulative dose of the robot was investigated in various ways from about 3.23 to 18.9 mSv/h. However, in high-dose areas (1,120 to 4,000 mSv/h), additional data acquisition failed due to dose, high-humidity environments, etc.

3. Conclusions

This study investigated unmanned support robots deployed to domestic and foreign nuclear facilities or emergency situations, and through this, the following results could be derived. First, it was necessary to develop a robot that understands the emergency situation of the NPP and takes into account the working conditions of the target, work path, and field environment and the characteristics of the facility. Second, when looking at domestic and foreign cases, robots were studied to respond to various emergency situations with world-class robot technology, but there were no practical robots suitable for actual input. Finally, it was urgent to develop a robot that could achieve the mission in cooperation with several robots specialized in each part. Considering this situation, it is expected that developing unmanned support robots will strengthen the safety of nuclear facilities and maximize the reliability of Korean NPPs. In addition, it is believed that market competitiveness can be secured through economic effects such as preventing damage to residents by mitigating and preventing accidents.

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