Technical Note https://doi.org/10.7733/jnfcwt.2024.005

A Study on the Radiological Emergency Plan for Decommissioning Nuclear Power Plant

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(Received November 15, 2023 / Revised December 13, 2023 / Approved December 14, 2023)

Safe radiation management is essential not only for operational nuclear power plants but also for nuclear plants to be decommissioned. When spent nuclear fuel is present on-site, meticulous radiation emergency plans are necessary to ensure safety. In Korea, numerous radiation emergency plans have been established for operational nuclear reactors. These plans delineate distinct response mitigation measures for white, blue, and red emergencies. However, clear regulations are yet to be devised for radiation emergency plans for reactors to be decommission. Therefore, this study investigated the decommissioning plan and status of Kori unit 1 to comprehensively analyze the current status of decommissioning safety in Korea. In this study, radiation emergency plans of decommissioning nuclear power plants abroad were reviewed to confirm radiation emergency action levels. Furthermore, radioactive waste treatment facilities, to be used for decommissioning reactors in Korea were evaluated. Moreover, the study assessed emergency plans (especially, emergency initiating conditions) for operational nuclear power plants in Korea for potential use in the decommissioning phase. This study proposed an emergency initiating condition that can be used for decommissioning reactors in Korea. Considering the anticipated introduction of plasma torch melting facility in Korea, this study examined the conditions of radiation emergency plans can be altered. This study identified effective measures and guidelines for managing radiological emergency initiating conditions, and effective decommissioning of nuclear power plants in Korea.

Keywords: Decommissioning, Radiological emergency plan, Radiological emergency levels, Emergency action levels, Emergency initiating conditions

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1. Introduction

A nuclear power plant has a lifecycle that encompasses a series of stages, including design, construction, commissioning, operation, permanent shutdown, and decommissioning. Since the commencement of commercial operation of Kori Unit 1 in 1978, Korea has constructed a total of 28 nuclear reactors and is currently operating 25 of them.

Kori Unit 1 reached the designed lifespan, spanning a total of 40 years, including 10 years of continuous operation. In June 2017, commercial operation was terminated, and it is now in a state of permanent shutdown. In May 2021, Kori Unit 1 submitted a decommissioning approval application to the regulatory body and is currently in the phase of preparing a decommissioning plan. Kori Unit 1 is planned to become Korea's first decommissioning nuclear power plant.

Throughout the lifecycle of nuclear power plants, the management of high-level radioactive materials, such as nuclear fuels, is a critical concern directly tied to nuclear safety. Therefore, operating nuclear power plants establish radiological emergency plans during their operation to prepare for unforeseen radiation emergencies and protect the residents.

Korea's radiation emergencies are categorized into three levels: Alert or Facility Emergency (referred as White Emergency), Site Area Emergency (referred as Blue Emergency), and General Emergency (referred as Red Emergency). "Alert" refers to an emergency where the radiation impact resulting from a radioactive material release is expected to be confine within the building of the nuclear facility. "Site Area Emergency" involves an emergency where the radiation impact is expected to be confined within the nuclear facility site. "General Emergency" refers to an emergency where the radiation impact is expected to extend beyond the nuclear facility site [1].

In contrast to operational nuclear power plants, decommissioning nuclear power plants remove high-level radioactive materials, such as nuclear fuel, from the reactor vessel and store them in a spent fuel pool for a designated cooling period. In the absence of a designated final disposal facility, countries employ temporary or interim storage methods based on their individual policies and circumstances before pursuing permanent disposal. Currently, Korea is establishing a high-level radioactive waste disposal facility while intending to temporarily store spent nuclear fuel from Kori Unit 1 in a dry storage facility.

In this study, the decommissioning plan for Kori Unit 1 is reviewed considering the installation of a radioactive waste treatment facility. Then, the emergency initiating condition for decommissioning nuclear power plants in the U.S. as well as the radiation emergency initiating condition for operation nuclear power plants in Korea are reviewed to determine the radiation emergency action levels needed during the decommissioning phases.

2. Current Status of Decommissioning Nuclear Power Plant in Korea

2.1 Decommissioning Strategy of Kori Unit 1

Kori Unit 1 being pursued for immediate decommissioning as a standalone project, aiming to foster the domestic decommissioning industry infrastructure and accumulate experience for subsequent reactor decommissioning.

The spent nuclear fuel stored within the Kori site will be temporarily managed by constructing a temporary storage facility before the operation of the interim storage facility [2]. Until the operation of the interim storage facility, Korea Hydro & Nuclear Power Company (the operator) has chosen the proven safety of dry storage method, temporarily operating a storage facility within the nuclear power plant site [3]. The plan involves constructing a temporary storage facility capable of accommodating a minimum of 2,880 fuel assemblies or more. The spent nuclear fuel will be stored in metallic containers inside the building. The facility site will be repurposed from the Shin-Kori Unit 1 &

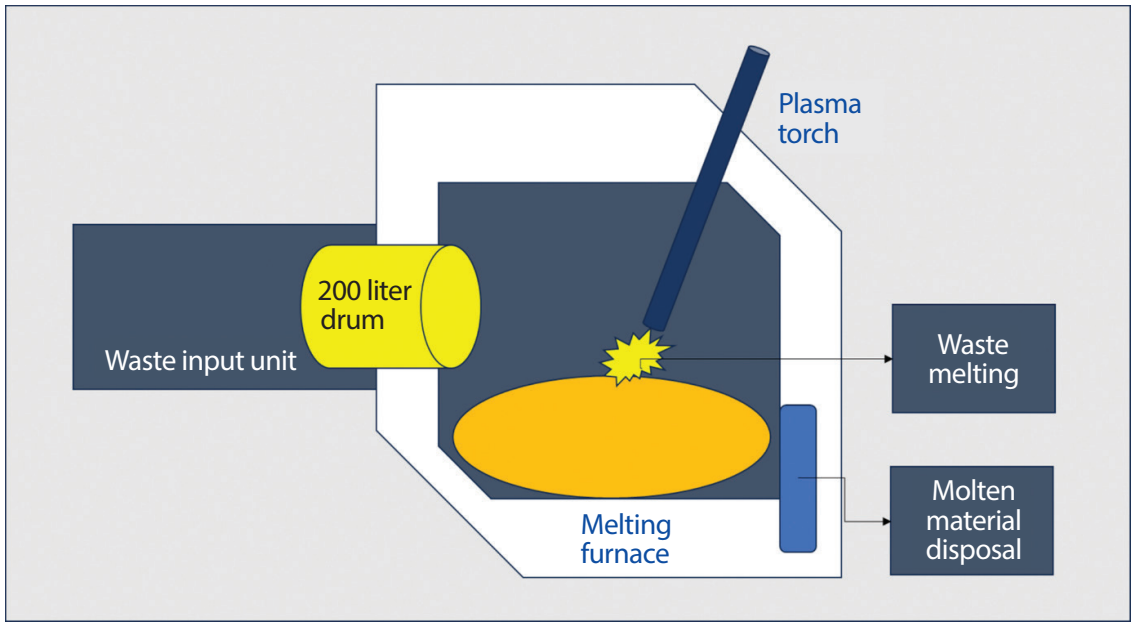

Fig. 1. Basic outline of plasma torch melting facility.

2 nuclear power plants' parking area [4]. Estimated project time is 7 years, and the overall timeline is estimated as follows:

- 2 years for the facility and dry storage cask design.
- 2.5 years for regulatory approval.
- 2.5 years for facility construction and dry storage cask production.

2.2 Radioactive Waste Treatment Facility of Decommissioning Nuclear Power Plant

The waste generated during the decommissioning of nuclear power plants varies in type and characteristics, including solids, liquids, and gases, and is produced in massive quantities within a brief period. Consequently, it is challenging to manage this waste using the waste treatment facilities designed for waste generated during normal plant operation. Therefore, there is a need for dedicated radioactive waste management facilities tailored to the decommissioning process, which will be constructed specially for waste generated through the decommissioning of nuclear power plants. The waste treatment facility is planned to be constructed with functions including decontamination, cutting, melting, compaction, and packaging [5].

Specially, during decommissioning, metal waste from solid radioactive waste is processed into ingot form through decontamination, cutting and classification processes, utilizing melting technologies such as electric furnace and plasm, thereby enhancing compaction efficiency and disposal safety [6].

The plasma torch melting technology utilizes a high current passing between internal electrodes within the torch, creating an arc phenomenon like lightning through gas ionization (such as nitrogen). This generates temperatures of approximately 1,600 degrees Celsius, which are used to melt radioactive waste materials like metals, concrete, soil, and asbestos, reducing waste volume by more than 80% [7]. Plasma torch melting facilities are incorporated into the decommissioning waste treatment facilities of Kori Unit 1 and Wolsong Unit 1 [7]. Fig. 1 shows a basic outline of plasma torch melting facility.

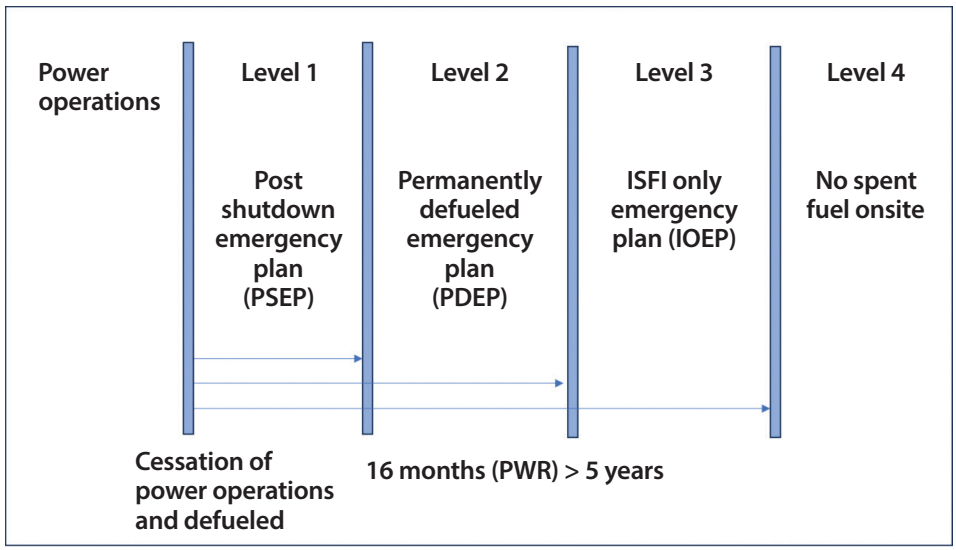

Fig. 2. Decommissioning emergency plan levels in the U.S. NRC [10].

3. Emergency Plan of Overseas Decommissioning Nuclear Power Plant and Plasma Melting Facility for the Nuclear Industry

3.1 Emergency Classification Levels in the U.S.

The U.S. NRC has categorized Emergency Classifications into levels based on potential or actual impacts, delineating onsite and offsite response actions accordingly. The emergency classifications increase in severity from Notification of Unusual Event; Alert; Site Area Emergency; and General Emergency [8]. Among the emergency classification levels, Notification of Unusual Event is currently not applied in emergency classification levels in Korea nuclear facilities. The other three emergency classifications align with Korea's White Emergency (Alert), Blue Emergency (Site Area Emergency), and Red Emergency (General Emergency) classifications.

3.2 The U.S. NRC Regulatory Guide-Emergency Planning for Decommissioning Nuclear Power Reactors

In the U.S., operating nuclear power plants establish their emergency plans based on NUREG (The U.S. Nuclear Regulatory Commission Regulation)-0654/FEMA (Federal Emergency Management Agency)-REP-1, "Criteria for the Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants". During reactor decommissioning, deviations from operational radiation emergency plans are submitted to the U.S. NRC, contingent upon factors such as spent fuel storage status. Corresponding safety reports are submitted as evidence to support these exception requests, allowing for the progress of decommissioning. The U.S. NRC has implemented Emergency preparedness requirements, categorizing the decommissioning plant status into four stages to reduce radiological risk; (1) permanently stopping operations and defueling from the reactor vessel, (2) fuel in the spent fuel pool (SFP) has sufficiently decays such that it would not reach ignition temperature within 10 hours under adiabatic heat-up conditions, (3) all fuel is in dry storage, and (4) all fuel is removed from the site [9].

An emergency plan is necessary of the first three levels. Level 4 stage does not require an emergency plan, as all fuel has been removed from the facility. The emergency

Table 1. Initiating conditions of ISFSI-IOEP, the U.S. NRC regulatory guide

Initiating condition	Emergency action level	Emergency classification level
Confirmed security condition, or threat, at the Independent Spent Fuel Storage Installation	1. A security condition that does not involve a hostile action as reported by the site-specific security shift supervision and impacting the Independent Spent Fuel Storage Instillation. 2. Notification of a substantiated security threat targeting the Independent Spent Fuel Storage Installation. 3. A validated notification issued by the U.S. NRC conveying information regarding an aircraft threat.	Unusual event
Hostile action within the Independent Spent Fuel Storage Installation or airborne attack threat within 30 minutes	1. A hostile action is occurring or has occurred within the Independent Spent Fuel Storage Installation as reported by the specific security shift supervision. 2. A verified notification issued by the U.S. Nuclear Regulatory Commission (NRC) conveying information regarding an aircraft attack threat within 30 minutes of the site.	Alert
Impairment to the containment boundary of a loaded canister	Impairment to the confinement boundary of a loaded cask, as evidenced by a radiation monitor reading surpassing the normal background level at or in close proximity to the cask.	Unusual event

plans for these initial three stages are as follows [9]:

(1) The activation of a post-shutdown emergency plan (PSEP) is permissible once the Nuclear Regulatory Commission (NRC) formally recognizes the operator's certifications confirming the permanent cessation of operations and the complete removal of fuel from the reactor vessel.

(2) After the Nuclear Regulatory Commission (NRC) acknowledges the operator's certifications of permanently ceasing operations and extracting, and a spent fuel decay period of 16 months for pressurized water reactors, a plan for permanent defueling and emergency response can be put into effect.

(3) The initiation of an Independent Spent Fuel Storage Installation (ISFSI) only emergency plan (IOEP) is permissible upon the completion of transferring all spent fuel to dry cask storage. When transitioning all fuel to dry cask storage, nuclear power reactor operators must comply with and maintain the efficacy of an emergency plan as outlined by regulatory requirements.

The U.S. NRC is in the process of developing draft Regulatory Guide 1346, concerning emergency planning for decommissioning nuclear power reactors, with plans to finalize the regulatory framework by 2024 following the conclusion of public input and feedback. Table 1 shows initiating conditions of ISFSI-IOEP according to the U.S. NRC regulatory guide (draft) [9].

3.3 Emergency Cases of Decommissioning Nuclear Power Plant in the U.S.

3.3.1 Maine Yankee Nuclear Power Plant

Maine Yankee nuclear power plant began commercial operation in 1972 and ceased operations in 1996, and in 1997 there was a board of directors' resolution for permanent shut-down. It was decommissioned and dismantled between 1997 and 2005. Spent nuclear fuel has been stored in SFP since 1998 and transferred to ISFSI for long-term dry storage in August 2002. The Maine Yankee Independent Spent Fuel Storage Installation (ISFSI) has been purposefully constructed as a vertical dry cask storage facility, exclusively intended for the storage of spent nuclear fuel. Fuel transfer activities were completed in late February 2004. The ISFSI pad currently holds a total of 60 spent fuel canisters and four Greater Than Class C waste (GTCC)

Table 2. Maine Yankee ISFSI emergency plan

Initiating conditions	Emergency action levels	Emergency classification level
Damage to a loaded vertical concrete cask (VCC) that may damage the fuel or GTCC confinement boundary	1. Natural Phenomena events affecting a loaded greater than class C waste (GTCC) or spent fuel cask confinement boundary. 2. Accident conditions affecting a loaded greater than class C waste (GTCC) or spent fuel cask confinement boundary. 3. ISFSI shift supervisor/emergency director judgment.	Unusual event
Verified security incident with the possibility of compromising the safety level of the Independent Spent Fuel Storage Installation.	Continuing security breach or an attempted unauthorized access that could lead to the potential loss of facility control.	Unusual event

Table 3. Summary of emergency action levels of SONGS ISFSI emergency plan

Alert	Unusual event
Hostile action within the Vehicle Barrier System (VBS) boundary.	Verified Security condition of threat.
Other conditions exist which in the judgment of the ISFSI shift supervisor/emergency director (ISS/ED) warrant declaration of an alert.	Other conditions exist which in the judgment of the ISS/ED warrant declaration of an unusual event.
-	Impairment to the confinement boundary of a loaded cask.

canisters, which are irradiated steel removed from the reactor vessel during the plant decommissioning process [11]. The Maine Yankee ISFSI Emergency Plan was effective in September 2004 when the Defueled Emergency Plan was terminated. Table 2 shows initiating emergency conditions, emergency action levels, and emergency classification levels of Maine Yankee ISFSI emergency plan. According to ISFSI emergency plan, the initiating emergency conditions are limited to damage to cask and security event [11].

3.3.2 San Onofre Nuclear Generating Station (SONGS)

The San Onofre Nuclear Generating Station (SONGS) has three units and the plant ceased operations in 2013. Subsequently, it entered the decommissioning phase. The fuel from San Onofre unit 2 reactor was transferred to the spent fuel pool in July 2013. On March 31, 2014, SONGS submitted a proposed “Permanently Defueled Emergency Plan (PDEP)” to the NRC. NRC Approval of Emergency Planning Exemptions in June 2015. In August 2020, all spent nuclear fuel at San Onofre has placed in dry storage. The site changed to an “Independent Spent Fuel Storage Installation (ISFSI)-only” [12].

SONGS has implemented emergency measures concerning the SONGS ISFSI, thus eliminating the likelihood of significant offsite dose consequences that would require offsite emergency planning. Emergencies are categorized into two levels: unusual event and alert [13]. Table 3 shows SONGS ISFSI emergency action levels and details.

3.4 Cases of Using Plasma Torch Melter for Treatment of Nuclear Plant Waste

Kozloduy nuclear power plants in Bulgaria has 6 reactors, Unit 1 and 2 were shut down in 2002 and Units 3 and 4 in 2006 [3-7]. Unit 5 and 6 reactors are operating. For reducing the waste volume from decommissioning reactors and operating reactors, Kozloduy introduced plasma melting facility and started to operate in 2018. Fig. 3 below illustrates the integrated systems: a primary treatment chamber with plasma systems, an off-gas cooling and cleaning system, a conveying, shredding and feeding system, and a slag collection and cleaning system [14].

Facility specifications are described as Table 4 below.

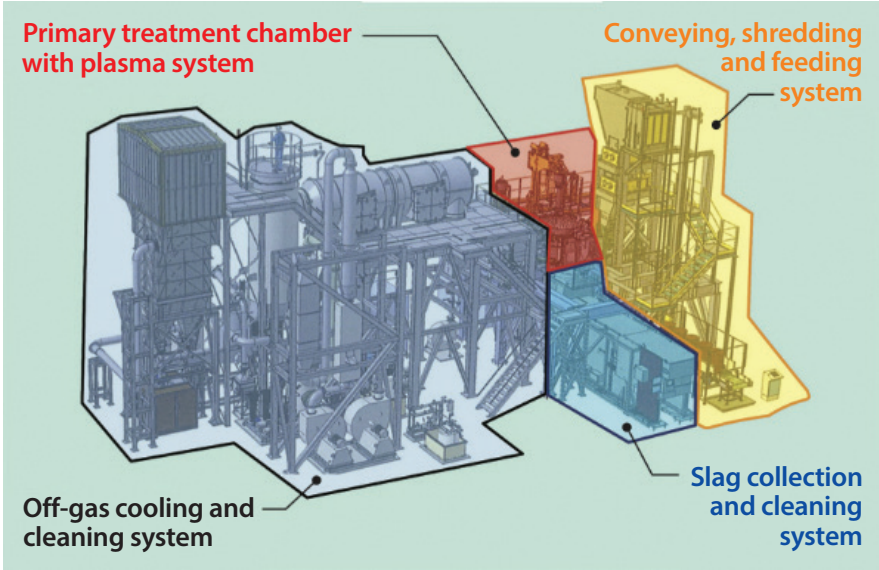

Fig. 3. Plasma facility in Kozloduy.

Torch capacity is 500 kW and annual treatment capacity is 250 t per year.

Table 4. Facility specification

Torch capacity	500 kW
Annual treatment capacity	250 t per year
Level of treated radioactive waste	low and intermediate level radioactive waste
Operational life	40 years
Cost of the plant	31 million euro

4. Analysis of Radiological Emergency Plan

4.1 Classification Level of Radiological Emergency Initiating Conditions for Operating Nuclear Power Plants

The emergency classification and initiating condition for the radiation emergency plan in operational nuclear power plants are categorized into three levels based on the severity and situation: White Emergency (Alert or Facility Emergency), Blue Emergency (Site Area Emergency), and Red Emergency (General Emergency). The initiating conditions for an Alert Emergency consist of a total of 20 items, while the conditions for a Site Area Emergency include 17 items. General Emergency situations are characterized by 4 items [15].

4.2 Review of Alert Emergency

The 20 Alert Emergency Conditions serve as operational guidelines for operational guidelines for nuclear power plants. Consequently, with Unit 1 permanently shut down and fuel removed from the reactor, the risk of radioactive material release diminished, leading to the exclusion of 9 of these criteria. Hence, this study examines whether the remaining 11 criteria, typically applied to permanently shut down nuclear power plants, are also essential for the decommissioning.

4.2.1 Review of Alert Emergency Initiating Condition 6: Radiation Levels or Airborne Contamination Which Indicate a Severe Degradation

in the Control of Radioactive Materials (e.g., Increase of Factor of 1,000 in Direct Radiation Readings Within Facility)

This emergency condition is triggered applicable when the area radiation monitor within the power plant detects indication values that rise several hundred to several thousand times above normal levels due to factors such as inadequate radioactive material management or equipment malfunctions. This perspective can also be applied to the increase in air contamination levels within the protected area. This situation entails declaring an emergency in response to a substantial rise in radiation levels and severe air contamination, prioritizing worker protection and preventing radiation disaster for the public.

All area radiation monitors installed within the power plant, including those in the main control room, spent fuel pool and new fuel storage, containment vessel, reactor coolant system, radioactive waste handling and storage facilities, and radioactive chemistry laboratories, are used to assess radiation levels. Air contamination levels are determined based on the concentration of airborne radioactive materials (^{131}I for radioactive gases or particulate radioactive materials such as ^{60}Co and ^{137}Cs) within the protected area. Emergency measures must be initiated if the monitoring devices detect levels exceeding 1,000 times the normal or baseline radiation levels.

In the case of Unit 1, which is scheduled for decommissioning, plans include the introduction of new facilities and building for the treatment of radioactive waste. As the radioactive waste treatment facilities may include features such as a melting facility and an incinerator, there is still an existing risk of handling radioactive materials. Therefore, it is necessary to install area radiation monitors in the radioactive waste treatment facilities to continuously monitor radiation levels, similar to operating nuclear power plants. In the event that radiation levels increase significantly, on the order of approximately 1,000 times, it should be considered whether to initiate a radiation emergency response, a precaution that should also be applicable in decommissioning nuclear power plants.

4.2.2 Review of Alert Emergency Initiating Condition 7: Loss of Offsite Power and Loss of All Onsite Alternating Current (AC) Power

The loss of all onsite AC power refers to a situation where all AC power sources, including backup power from emergency diesel generators, are lost, following the shutdown of the main electrical power source. This condition renders all motor-driven equipment inoperable, leading to a critical state where it becomes impossible to perform essential functions, such as starting emergency coolant pumps to cool down the reactor and depressurize it. If the loss of all AC power persists for more than 15 minutes, it transitions to a Site Area emergency initiating condition.

The AC power supply, both on-site and off-site the nuclear power plant, serves as the primary source of electrical power for various pumps and related equipment, particularly for the safety systems of the nuclear reactor and the cooling systems of spent fuel storage facilities in operational nuclear power plants. In case the use of AC power supply becomes difficult in operational nuclear power plants, contingency measures include the installation of Direct Current (DC) power sources or emergency facilities like diesel generators. However, these AC power supplies and associated emergency facilities are considerations primarily aimed at cooling the nuclear fuel decay heat. In the process of decommissioning nuclear power plants, when all nuclear fuel has been removed, there is no need for immediate safety measures in response to a complete loss of AC power supply. Hence, this emergency initiating condition may not be necessary in the context of decommissioning process.

4.2.3 Review of Alert Emergency Initiating Condition 8: Loss of All Onsite DC Power (Backup Power and Safety-related System Control Power, Including Batteries)

The loss of alternating current (AC) power results in the inoperability of drive equipment, whereas the loss of

DC power leads to the loss of power for safety-related instrumentation, control, and associated electrical equipment. The overall loss of control power can severely disrupt the safe operation of the power plant, so in the event of the loss of all DC power, including backup power, an emergency alarm is immediately activated. If a certain period of time (more than 15 minutes) elapses, it transitions to a Site Area Emergency. During the decommissioning of nuclear power plants, although independent power supply remains essential, implementing this emergency initiating condition is considered unnecessary. This is because the removal of radiation sources, such as nuclear fuel, has mitigated the potential for severe risks.

4.2.4 Review of Alert Emergency Initiating Condition 12: Accident Involving Fuel Damage Resulting in the Release of Radioactive Materials Into the Containment or Fuel Handling Building

This emergency arises from the physical impact or mishandling of spent nuclear fuel, and it is classified as a significant event even in the power plant's design. Since spent nuclear fuel contains highly radioactive materials, it is managed within specialized facilities equipped with shielding capabilities, such as spent fuel pools and temporary storage facilities. However, in the event of mishandling, such as drops, collisions, or exposure to the atmosphere during the handling of nuclear fuel assemblies, workers can be subjected to significant radiation exposure. Therefore, in cases where elevated radiation levels are indicated within the nuclear fuel handling area, such as the reactor containment building or fuel handling building, an emergency will be declared according to this emergency response condition. Emergency response condition can be initiated based on the radiation level readings from the radiation monitors installed in reactor containment building or fuel handling building. Alternatively, an emergency response will be triggered if incidents occur during the handling of spent nuclear fuel, such as drops, collisions, or exposure to the atmosphere.

As decommissioning nuclear power plants have already transferred all highly radioactive materials, such as spent nuclear fuel, into casks and temporary storage facilities, there is no concern for the release of high-level radiation from the dismantling buildings or other nuclear fuel handling areas. Hence, applying this emergency response condition is deemed unnecessary.

4.2.5 Review of Alert Emergency Initiating Condition 13: Fire Potentially Affecting Safety Systesms

During a nuclear power plant accident scenario, the reactor protection system is designed to act, including reactor shutdown, to protect the reactor core. If the engineering safety systems function properly, the design of the nuclear power plant is intended to prevent nuclear fuel melting or the release of radioactive materials to the environment. However, in the event of a fire inside the power plant, there is a possibility that the safety systems could become inoperable due to the impact of the fire. Depending on the circumstances, this could lead to a potentially serious situation.

Decommissioning nuclear power plants are expected to have basic fire protection measures in place, and in the case of domestic nuclear facilities, they often have their own fire brigades, so the actual fire risk is limited. Since the nuclear fuel has been removed from the reactor and transferred to temporary storage facilities, the operation of the reactor protection system, designed to shut down the reactor to protect the core in the event of a fire, may no longer be a primary concern in decommissioning nuclear power plant. Hence, it is concluded that this emergency initiating condition is not required during the decommissioning process.

4.2.6 Review of Alert Emergency Initiating Condition 14: Loss of Main Control Room's Key Alarm Function

Power plant operators safely operate the drive equipment such as pumps and valves using control equipment,

including instrumentation and control systems that allow them to monitor the state of power plant operating parameters. However, if the operator loses the assistance provided by alarm functions or status indication features, it becomes challenging to perform nuclear power plant operations correctly. Therefore, operating under circumstances where the plant's major alarm functions are lost can be considered unstable. In the event of a loss of the plant's major alarm functions, an emergency will be declared in accordance with the emergency initiating condition.

The control room is equipped with control and alarm systems to enable operators to safely monitor and control the power plant during normal, emergency, and abnormal operations. Regarding a decommissioning nuclear power plant, plant operation has been halted, the reactor has been defueled, and fuel has been transferred to temporary storage facilities. Therefore, there is no need for monitoring operational variables in this situation. Hence, it appears that this emergency condition may not apply to decommissioning nuclear power plants.

4.2.7 Review of Alert Emergency Initiating Condition 15: The Release of Radioactive Material is in Excess of Ten Times the Momentary Release Limit Specified in the Technical Guidelines, and it Continues for Over 15 minutes Due to a Control Issue in the Release System

The unintentional release or leakage of radioactive materials is generally not permitted in operational nuclear power plants. The emergency condition is applied regardless of the cause and include both following conditions:

1) When the indication from an on-site radiation monitor exceeds 10 times the normal alarm setpoint.
2) When control of a release path (e.g., isolation valve) is lost, and a release pathway persists for more than 15 minutes.

This emergency is declared when radiation monitors in the nuclear fuel handling area, reactor building ventilation system, multiple steam generator blowdown lines, and liquid radioactive waste system indicate levels exceeding 10 times the high-level alarm threshold. In the case of decommissioning nuclear power plants, even though high-level radioactive materials have already been removed from the area, for Kori Unit 1, the introduction of a radioactive waste processing facility and the associated disposal of waste materials, along with considerations for the release and discharge of radioactive materials, suggests that the application of this emergency initiating condition may need to be necessary.

4.2.8 Review of Alert Emergency Initiating Condition 16: Ongoing Security Compromise

A nuclear power plant operates under strict management and control from a security perspective. However, there are situations where an emergency is declared when there is a perceived threat to safe operation due to the intrusion of unauthorized individuals within the power plant. The alert emergency condition is limited to situations where areas outside the nuclear power plant's key zones breached, raising concerns for potential harm to nuclear operations. In urgent situations where the power plant's vital areas are violated, a site area emergency is issued. When the vital areas are compromised, a general emergency is either initiated or declared immediately. In this emergency declaration, the term 'power plant vital areas' refers to all locations within the power plant that are associated with nuclear operation, including the main control room, remote shutdown panel, auxiliary buildings, fuel handling buildings, emergency generator buildings, component cooling water buildings, and essential service water buildings.

Regarding a decommissioning nuclear power plant, there might be additional facilities and installations for radioactive waste treatment, and security threats can still exist. Although decommissioning nuclear power plants possess significantly lower-risk radioactive materials compared to operational ones. When a security threat arises that could jeopardize the safe proceeding of the decommissioning plant, it may be considered for an emergency declaration.

However, it is more suitable to consider emergency measures and plans for non-radioactive facilities rather than a radioactive emergency.

4.2.9 Review of Alert Emergency Initiating Condition 17: Severe Natural Phenomena Being Occurred or Projected

This emergency declaration is issued when there is an earthquake with a seismic intensity exceeding Operation Basis Earthquake (OBE), or when there is a flood, reservoir level close to design levels, tidal wave, or similar events. It also applies when there are strong winds that could affect the safety-related structures.

Nuclear power plants go through a process of site selection, environmental analysis, environmental impact assessment, and obtain permits before operation. However, emergency declarations are made according to the emergency response criteria in the event of natural disasters that approach or have the potential to approach design basis level, or when there is a risk of such disasters occurring. This emergency declaration can be assessed based on the indications or alarms from seismic monitoring devices.

In the case of a decommissioning plant where highly radioactive nuclear fuel has been completely removed, it is deemed unnecessary to apply this emergency declaration scenario to the decommissioning plant.

4.2.10 Review of Alert Emergency Initiating Condition 18: In the Event of Safety Concerns Arising From Operational Experience or Design Aspects

The detailed scenarios for this emergency conditions are as follows:

1) Aircraft crash into the power plant, 2) Impact of projectiles on power plant facilities, 3) Unexplained explosions causing damage to equipment affecting nuclear operation, 4) Influx of toxic or flammable gases near power plant facilities, 5) Damage to the turbine casing penetrating the turbine.

An emergency is declared in the event of a significant safety concern that was taken in into account during operating experience or the design phase, which could pose a significant hazard to personnel or the protection of critical facilities. The likelihood of cases corresponding to items 1) to 5) occurring in the decommissioning nuclear power plant is low.

4.2.11 Review of Alert Emergency Initiating Condition 20: Additional Plant Conditions are Present, Necessitating the Precautionary Initiating of the Technical Support Center and Putting the Near-site Emergency Operations Facility Into Standby Mode. Key Emergency Personnel are Also Put On Alert in Response to these Conditions

This emergency initiating condition is applicable when significant issues have occurred or there is a risk of their occurrence, extending beyond the defined criteria for emergency initiation, and authorization for emergency initiating is granted by the responsible plant manager. It is associated with the Site Area Emergency Condition 17 and in situations requiring the activation of the Emergency Technical Support Center or protective measures for nearby residents, it transitions to a site area emergency. Regarding a decommissioning nuclear power plant, its application and potential modifications are determined based on how the emergency response organization operates.

As for the U.S. SONGS, which permanently ceased operations in June 2013, transitioned to storing all spent nuclear fuel in dry storage by 2015. Nevertheless, an Emergency Response Organization (ERO) continues to operate. Therefore, it is considered that an emergency response organization may also be necessary for decommissioning plants. It is advisable to develop safety measures based on the composition, organization, and personnel of Emergency Response Organizations (EROs) operating in overseas nuclear power plants and apply them to the emergency plan for decommissioning plants. However, it should be noted

that this study does not pertain to the radioactive emergency declaration criteria but rather focuses on determining the applicability in the operational context of decommissioning plants, and therefore, it is excluded from the radiation emergency initiating condition.

4.3 Review of Site Area Emergency and General Emergency

The Site Area Emergency consists of a total of 17 emergency situations, and the General Emergency consists of 4 emergency situations. In the case of a permanently shut down nuclear power plant, 7 of the 17 Site Area Emergency situations are considered, and for the General Emergency, which adopts a conservative perspective, 3 specific scenarios are considered, such as radioactive material releases.

Given the withdrawal of spent nuclear fuel from the reactor and its safe transfer to an off-site temporary storage facility via dry cask storage, the risk of on-site radiation leakage is notably reduced. Consequently, it is deemed appropriate to forgo consideration of Site Area Emergency and General Emergency for decommissioning nuclear power plants and instead focus on reviewing and operating based on the Alert level criteria, which are deemed necessary.

5. Discussion of Radiological Emergency Plan for Decommissioning Nuclear Power Plant in Korea

A permanently shut down nuclear power plant stores its spent nuclear fuel in a spent fuel pool for an adequate cooling period before being transferred to temporary or interim storage facilities in accordance with the national spent nuclear fuel management approach. Once spent nuclear fuel is stored in temporary or interim storage facilities, with respect to the U.S., the ISFSI-ONLY radiological emergency response plan is applied. In Korea, Kori Unit 1, the first decommissioning nuclear power plant, has been eternally shut down, and its spent nuclear fuel is currently stored in the SFP. The spent nuclear fuel will be transferred to a dry storage facility.

In the U.S., there are cases where only one reactor unit is decommissioned without adjacent units. Consequently, they establish temporary storage facilities within the premises of each unit to store spent nuclear fuel. In Korea, instead of constructing temporary storage facilities within the Kori Unit 1 premises, they plan to utilize the area currently used as a parking lot for Kori Unit 3, which is in an excluded area, to establish temporary storage facilities. This approach differs in U.S., where ISFSIs are installed within the premises of decommissioning nuclear power plants, even if they apply emergency classification levels (such as the Unusual Event, although it is not applicable in Korea).

Therefore, a careful review of the Kori Unit 1 decommissioning plan and the applicable radiological emergency classification level is necessary to establish radiological emergency plan for the decommissioning nuclear power plant.

6. Conclusion

When examining decommissioning cases of nuclear power plants in the U.S., it is noted that once fuel is entirely moved to the spent fuel pool in a permanently shut down state and subsequently transferred to an Independent Spent Fuel Storage Installation (ISFSI), this eliminates the need for the General Emergency and Site Emergency Classification Levels. Consequently, only the Unusual Event and Alert levels are managed, as the radioactive materials no longer have an impact beyond the power plant site. For Kori Unit 1, which is in a permanent shutdown status, the radiological emergency response plan is in effect incorporating conditions from the operational nuclear power plant standards, while excluding conditions considered unnecessary.

Among the 20 conditions for an alert emergency condition, it has been confirmed that a significant portion becomes

unnecessary when an operational nuclear power plant undergoes permanent shutdown, and all spent nuclear fuel is safely transferred from the spent fuel pool to temporary dry storage facilities.

In case of Korea, a plasma torch melting facility is being developed and planned for implementation. Utilizing the plasma torch melting facility might require emergency initiating conditions for the radioactive waste treatment facility, especially for the plasma melting facility. To be specific, it might be necessary to consider the application of emergency response criteria for situations where radiation monitors detect levels exceeding 1,000 times the Alert 6 threshold. Additionally, the application of emergency conditions related to the release and leakage of radioactive materials, as indicated in Alert Initiating Condition 15, might also be necessary.

Radiological emergency response criteria for radioactive waste treatment facilities in decommissioning nuclear power plants may vary based on the type and quantity of radioactive waste processed. Nonetheless, ensuring the safety and stability of decommissioning nuclear power plants requires a meticulous review and establishment of radiological emergency response plans to address potential release of radioactive materials from these treatment facilities.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Acknowledgements

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning [KETEP Project No. 20204010600130] and the Ministry of Trade, Industry & Energy (MOTIE) of the Republic of Korea.

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