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Technical Note

Development of classification criteria for non-reactor nuclear facilities in Korea

Dong-Jin Kim, Byung-Sik Lee*

Department of Energy Engineering, Dankook University, Cheonan, 31116, Republic of Korea

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ABSTRACT

Non-reactor nuclear facilities are increasing remarkably in Korea combined with advanced technologies such as life and space engineering, and the diversification of the nuclear industry. However, the absence of a basic classification guideline related to the design of non-reactor nuclear facilities has created confusion whenever related projects are carried out. In this paper, related domestic and international technical guidelines are reviewed to present the classification criteria of non-reactor nuclear facilities in Korea. Based on these criteria, the classification of structures, systems and components (SSCs) for safety controls is presented. Using the presented classification criteria, classification of a hot cell facility, a representative non-reactor nuclear facility, was performed. As a result of the classification, the hot cell facility is classified as the hazard category 3, accordingly, the safety class was classified as non-nuclear safety, the seismic category as non-seismic (RW-IIb), and the quality class as manufacturers' standards (S).

1. Introduction

In Korea, the radiation industry is booming by creating high value-added service through convergence with cutting-edge technologies such as life and space engineering. Consequently, various types of cyclotrons, isotope production facilities, and hot cell facilities are being constructed. However, the classification criteria for safety management of these non-reactor nuclear facilities (NRNFs) are insufficient. Accordingly, in this paper, we present safety classification criteria for structures, systems, and components (SSCs) for the safety control of NRNFs, and how to establish overall classification criteria using them.

In general, the safety classification of NRNFs is determined based on deterministic hazard analysis results for anticipated design basis accidents (DBAs). In this study, the safety class for NRNFs is determined by applying the principle for determining the safety class of a nuclear power plant. First, the safety class is determined for the SSCs of the NRNF. Then the seismic category, quality class, and electrical class are classified by referring to the classification criteria of Korean standard nuclear power plants.

Safety classes for SSCs in nuclear power plants are classified as safety classes 1, 2, 3 and non-nuclear safety in accordance with the Nuclear Safety and Security Commission (NSSC) Notice No. 2018-6 "Regulation on Safety Class and Classification of Nuclear Reactor Facilities" and ANSI/ANS 51.1-1988. In Article 3 paragraph 4 of the NSSC Notice 2018-6, safety function defines that to secure the integrity of reactor coolant pressure boundaries in nuclear power plants, the functions for the safely shutdown of a reactor must be maintained, as well as preventing or mitigating situations that may exceed the off-site exposure limit prescribed in NSSC Notice 2017-15 "The technical standards for the location of nuclear reactor facility" [1]. NSSC Notice 2017-15 stipulates that 10 CFR 100.11, "Determination of Exclusion Area, Low Population Zone and Population Center Distance" is applied, so it is classified as safety class or non-nuclear safety depending on whether the whole-body or thyroid dose to the public exceeds 0.25 Sv (25 rem) or 3 Sv (300 rem), respectively [2,3].

Currently, there is no stand-alone technical standard and regulation for the classification of NRNFs in Korea. Therefore, for the safety classification of NRNFs in Korea, a corresponding safety analysis must be performed on such facilities and the results must be applied to the relevant standards for nuclear power plants to determine their safety class. Thus, considering the domestic demand for NRNFs, it is necessary to enact the technical standards for the classification of NRNFs as soon as possible.

* Corresponding author.
E-mail address: bslee@dankook.ac.kr (B.-S. Lee).

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2. Current international technical standards for non-reactor nuclear facility classification

The U.S. Department of Energy (DOE) proposes criteria for preparing and reviewing the hazard categorization and hazard analysis of all DOE-operated NRNFs through DOE-STD-1027. This standard presents a hazard category decision process and provides thresholds for radionuclides to determine the hazard category based on the radionuclide inventory handled within the NRNF [4]. In addition, a graded approach to hazard analysis is presented for the hazard categorization of NRNFs [4,5].

DOE-STD-1027 recommends classifying hazard categories and designing and operating facilities accordingly. To distinguish hazard categories, it stipulates that facilities be classified as shown in Table 1 based on the hazard analysis for “unmitigated radioactive material release".

ANSI/ANS-58.16 provides the guidelines for establishing the safety classification of NRNFs, which are applicable to many types of nuclear facilities, including nuclear fuel manufacturing and enrichment facilities as specified in 10 CFR 70, and to other nuclear and radioactive material storage and treatment facilities as specified in 10 CFR 830 [6].

For the safety classification, DBAs are derived, and a hazard analysis must be performed to identify the radiological effects of DBAs. Through this analysis, in the ANSI/ANS-58.16 safety category (SC) is classifies as three (3) SCs according to the level of radiological effects on workers and the public due to the DBAs as shown in Table 2. The higher the SC number, the more stringent the design requirement.

ANSI/ANS-58.16 unofficially presents the relationship between the safety category of ANSI/ANS-58.16 and DOE's non-reactor nuclear facilities, as well as the US Nuclear Regulatory Commission (NRC) Regulatory Guide 1.143 [7]. Table 3 further reflects the DOE Hazard Category in the comparative table of ANSI/ANS-58.16.

For the ANSI/ANS-58.16 safety categories, numerical criteria are presented in Table 2. In the case of SC-3, the public dose is 0.25 Sv or higher; therefore, according to the NSSC Notice No. 2018-6 it is equivalent to the Safety Class 3 of nuclear power plants. However, in the case of SC-1 and SC-2, the resident exposure dose is 0.25 Sv or less, so it corresponds to the Non-Nuclear Safety class of nuclear power plants. Accordingly, the seismic classification based on USNRC Regulatory Guide 1.143 in Table 3 is appropriate, in which is SC-2 corresponds to RW-IIa and SC-1 to RW-IIb, which in turn is the same as the seismic classification method for nuclear power plants.

3. Proposed safety classification criteria of non-reactor nuclear facilities in Korea

The safety classification of NRNFs in Korea is proposed by applying the hazard categorization method proposed by the DOE, as various DOE technical documents show the hazard categorization in detail [4]. Once the hazard category is determined, the safety class and the seismic category for the NRNF can be assigned using Table 3.

In the early design stages of a NRNF, it is not possible to quantitatively perform a hazard analysis on all risks due to uncertainties in the relevant design data. Therefore, the US DOE recommends that hazard analysis of the NRNF should be performed via the graded approach. Additionally, as there is no extensive experience in dismantling nuclear facilities, the International Atomic Energy Agency (IAEA) also recommends that hazard analysis should be carried out via the graded approach method for dismantling nuclear facilities [5,9]. Therefore, it is considered appropriate to perform the hazard analysis of NRNFs via the graded approach method.

The application of the graded approach is based on the engineer's judgment and experience, and hazard evaluation techniques such as preliminary hazard analysis and HAZOP are selected. The experience and ability of a hazard analysis engineer is a major consideration for an efficient and comprehensive hazard evaluation. Therefore, in this section, a hazard categorization method is presented as a graded approach hazard analysis method. The NRNF design is performed through the following phase, and the main considerations for each design phase are as follows.

- F09F Pre-conceptual Design Phase: develop a basic conceptual framework for the project as a whole based on gap analysis.
- F09F Conceptual Design Phase: understand any design issues and find a solution to identify the preferred alternative for basic design.
- F09F Basic Design Phase: initiate the process of converting concepts to a design appropriate for procurement or construction.
- F09F Detail Design Phase: complete the design effort and produce approved design documentation necessary to permit procurement, construction, testing, checkout and turnover to proceed.

Since there are no domestic requirements and any design experience for these NRNFs, there are many difficulties in performing the classification of SSCs in the pre-conceptual design phase of NRNF, so the focus was on the development of the classification methodology in the early stages of design. In addition, the classification criterion setting in the pre-conceptual design phase plays an important role in planning for domestic NRNF construction and calculating construction costs. In this paper, we focus on the safety classification method of NRNFs in the pre-conceptual and conceptual design phases with insufficient design data. This is because sufficient design data have been developed for basic and detailed design phases; therefore, hazard and accident analyses can be performed quantitatively using a normal methodology.

3.1. Initial hazard screening method

Hazard analysis is required for hazard categorization, and information on radionuclide inventory, chemical form of radionuclide

Table 1
Nuclear hazard categorization summary [4].

Category	Hazard category 1	Hazard category 2	Hazard category 3
Definition	Hazard analysis shows the potential for significant off-site consequences.	Hazard analysis shows the potential for significant on-site consequences.	Hazard analysis shows the potential for only significant localized consequences.
Interpretation	DOE Category A reactors and facilities[a] designated by PSO (Program Secret Officer). Exempt from DOE Order 5480.23	Facilities with the potential for nuclear criticality events or with sufficient quantities of hazardous material and energy, which would require on-site emergency planning activities.	Facilities with quantities of hazardous radioactive materials, which meet or exceed the values in Table A.1 in DOE-STD-1027.

[a] Those production, test, and research reactors designated by DOE based on power level (i.e., design thermal power rating of 20 MW steady state and higher), potential fission product inventory, and experimental capability.

Table 2
Safety criteria for safety categorization ANSI/ANS-58.16

Safety category	Unmitigated consequence		
	Facility worker	Collocated worker	Public
SC-1 (Low Consequence)	F09F Radiological exposures less than that of SC-2, but above regulatory limits (defense-in-depth) F09F No permanent health effects to workers.	F09F Radiological exposures less than that of SC-2, but above regulatory limits (defense-in-depth)	F09F Radiological exposures less than that of SC-2, but above regulatory limits (defense-in-depth)
SC-2 (Intermediate Consequence)	F09F Significant radiological exposures and potentially serious effects (workers' long-term health in question) F09F Exposure <10 Sv	F09F Significant radiological exposures and potentially serious effects (collocated workers' long-term health in question) F09F Exposure <10 Sv	F09F Radiological exposures are not expected to cause health effects, but may require emergency response actions F09F 0.05 Sv < Exposure <0.25 Sv
SC-3 (High Consequence)	F09F Radiological exposures that are potentially dangerous if not limited F09F If radiation dose is greater than SC-2, add more than one control device to SC-2	F09F Radiological exposures that are potentially dangerous if not limited F09F If radiation dose is greater than SC-2, add more than one control device to SC-2	F09F Radiological exposures that may potentially cause long-lasting health effects F09F Exposure <0.25 Sv

Table 3
Relationship between safety categories, DOE safety/hazard categories and NRC requirements.

ANSI/ANS-58.16 safety category	DOE		NRC RG 1.143 Seismic category
	Safety Cat.	Hazard Cat.	
SC-3	Safety Category (STD-3009, STD-1189)	Hazard Cat. 1	Seismic Cat. I [8].
SC-2	Significant for safety with Protection Function	Hazard Cat. 2	RW-IIa [7].
SC-1	Safety Important and Defense in Depth	Hazard Cat. 3	RW-IIb [7].

and disability is required for the hazard analysis. However, this information cannot be obtained until the concept design phase, so the initial hazard screening method is used to classify the NRNF into Hazard Category 1, 2, or 3, depending on the amount of radioactive material in the facility, and thresholds are provided for each nuclide. The engineer in charge can quickly determine the hazard category of the NRNF using the initial hazard screening method in Fig. 1 and the thresholds for each nuclide in Table 4 without performing quantitative hazard analysis [4].

If the sum of the ratios of each radionuclide to the thresholds of Hazard Category 2 or 3 exceeds unity, it is designated as Hazard Category 2 or 3, respectively [8].

3.2. Qualitative hazard analysis in the conceptual design phase

A qualitative analysis of the potential hazards (a) describes the initial major hazards and other risk areas that could affect the project cost and schedule and (b) identifies significant hazard scenarios and the initial suite of facility DBAs. This hazard analysis should evaluate inherently safer design concepts to eliminate and reduce hazards where possible.

Qualitative potential hazard analysis methods typically include Preliminary Hazard Analysis (PHA) and Failure Modes and Effects Analysis (FMEA). PHA is based on accident scenarios, in which hazardous situations (e.g., radioactive material release, fires and explosions) are assumed at first, and then systematic surveys (safety feature of systems) are conducted to determine how such situations can occur. The PHA for the facility derives events that trigger potential incidents, prevention and mitigation functions, expected consequences, and safety enforcement (e.g., procedures, system improvements, additional accident analysis) necessary to adequately address existing risks [10].

FMEA is a complementary evaluation method that analyzes the influence of hazard based on systematic failure. Unlike PHA, FMEA first subdivides the facility into several system elements. A failure mode of each system element is assumed, and the effect of each failure mode is systematically reviewed. FMEA also derives the required prevention and mitigation functions and expected accident consequences.

As the design variables for NRNFs are not sufficiently developed until the conceptual design phase, it is desirable to analyze potential hazards using the PHA method. The PHA results becomes basic data that can rank potential hazards and can be used to develop potential hazard scenarios. The ranking of potential hazards can be obtained by qualitatively reviewing the frequency and consequence estimates for each hazard or accident scenario developed in the PHA. Tables 5 and 6 show a risk ranking

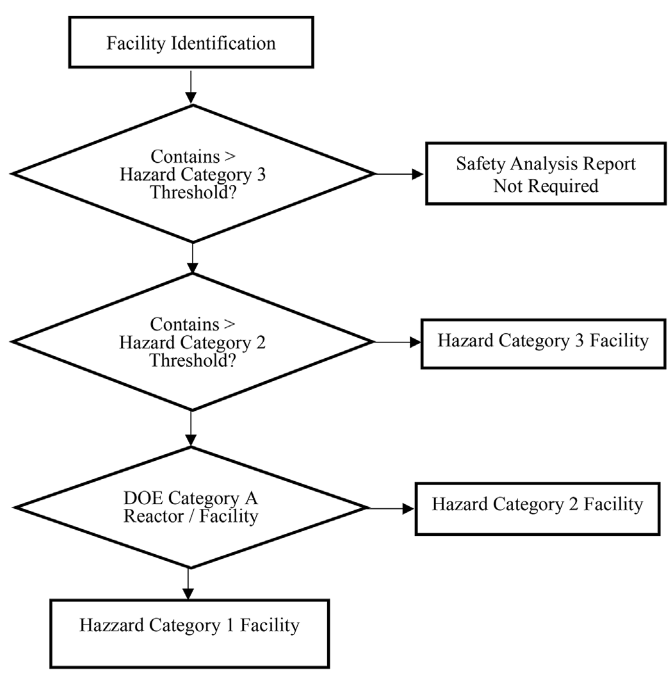

Fig. 1. Initial hazard classification decision process [4].

Table 4
Radionuclides thresholds for hazard categorization [4].

Isotope	Threshold for hazard category 2 (Curies)	Threshold for hazard category 3 (Curies)
H-3	3.00E+05	1.60E+04
C-14	1.40E+06	4.20E+02
Cr-51	1.00E+08	2.20E+04
Mn-52	4.00E+06	3.40E+02
Mn-54	4.30E+05	8.80E+02
Fe-53	4.30E+05	1.00E+04
Fe-55	1.10E+07	5.40E+03
Fe-59	1.80E+06	6.00E+02
Ni-59	4.30E+05	1.18E+04
Co-60	1.90E+05	2.80E+02
Ni-63	4.50E+06	5.40E+03
Sr-90	2.20E+04	1.60E+01
Mo-93	4.30E+05	2.20E+03
Nb-94	8.60E+04	2.00E+02
Tc-99	3.80E+06	1.70E+03
I-125	2.40E+03	5.60E-01
I-131	1.80E+03	9.20E-01
Cs-137	8.90E+04	6.00E+01
Eu-152	1.30E+05	2.00E+02
Eu-154	1.10E+05	2.00E+02
Eu-155	7.30E+05	9.40E+02
Am-241	5.50E+01	5.20E-01
Cm-242	1.70E+03	3.20E+01
Cm-245	5.30E+01	5.20E-01

framework used to classify these events (each result and frequency). Each event-specific consequence and frequency estimate is based on the engineering judgment based on experience or reference technical documents. The consequence severity is based on the conservative assumption that the release of radioactive materials and their resulting radiation exposure are mitigated only by the inherent physical form of hazardous materials and the physical shielding and ventilation systems of the facility.

Table 7 can be used to rank all hazard and accident scenarios identified in the PHA by considering the consequence severity and frequency from the analysis results. Risk ranking results are used as basic data to determine whether a more detailed and quantitative analysis of a specific hazard or accident scenario is necessary.

Each risk ranking can be defined as follows:

F09F Risk Ranking 1

The hazard or accident scenario poses a high risk to the public or workers. Immediate actions should be taken by the facility manager to reduce the potential consequences or likelihood of these events. Risk Ranking 1 events are analyzed quantitatively in the accident analysis.

F09F Risk Ranking 2

The hazard or accident scenario poses a moderate risk to the public or workers. Near to moderate-term actions should be taken by the facility manager to reduce the potential consequences or likelihood of these events. Risk Ranking 2 events are analyzed quantitatively in the accident analysis.

Table 5
Consequence severity category [10].

Category	Public	Worker
A	Immediate health effects	Loss of life
B	Latent health effects	Severe injury or disability
C	Irritation or discomfort but no permanent health effects	Lost time injury but no disability
D	No offsite impacts	Minor or no impact or disability

F09F Risk Ranking 3

The hazard or accident scenario poses a minor risk to the public or workers. Moderate to long-term actions should be taken by the facility manager to reduce the potential consequences or likelihood of these events. No further analysis is required for Risk Ranking 3 events.

F09F Risk Ranking 4

The hazard or accident scenario poses a very minor risk to the public or workers. Long-term actions should be considered by the facility manager to reduce the potential consequences or likelihood of these events. No further analysis is required for Risk Ranking 4 events.

Typical hazards commonly associated with NRNFs are identified in Table 8, which provides potential accident categories and energy/material sources [10].

4. Application of safety classification criteria to the NRNF in Korea

The classification criteria presented in Section 3 are applied for the safety classification of the Hot Cell Facility (HCF) for the characterization of irradiated Reactor Vessel Internals (RVIs) generated after the decommissioning of a nuclear power plant in Korea.

Hazard categorization up to the conceptual design phase of the NRNF in Korea can be performed using the initial hazard screening methodology in Fig. 1 with the thresholds for each nuclide in Table 4, as described in Section 3.1. To derive the target hazard of hazard analysis that should be performed quantitatively in the basic design phase, the PHA is used to qualitatively evaluate the potential consequences of hazards, mitigation functions, and impacts on public and worker safety.

4.1. Initial hazard screening method in the conceptual design phase

An initial hazard screening method is conducted to determine the hazard category by confirming the radioactivity inventory for characterization in the HCF through the radioactivity inventory thresholds in Table 3 and the design base radioactivity inventory of the HCF should be compared. As it is difficult to officially obtain the radioactivity inventory data of Kori Unit 1 irradiated RVIs to be analyzed at this HCF, the design base radioactivity inventory is obtained based on the internal specimen analysis data of the Point Beach Nuclear Power Plant (PWR) in the United States [11]. (Point Beach 1 is a 2-loop nuclear power plant of the Westinghouse PWR type like Kori Unit 1, and the radioactivity inventory of reactor vessel internals based on its 30 EFPY was open to the public.) If ten (10) samples (approximately 100 kg per each sample) were handled simultaneously in the HCF, the total radioactivity inventory is shown in Table 9.

As a result of the preliminary analysis (see Table 10), the HCF is Hazard Category 3 or lower facility that does not require a Safety Analysis Report based on DOE requirements [4]. Therefore, all structures and components of the HCF can be classified as below the Hazard Category 3.

Considering the characteristics of intermediate-level radioactive waste to be handled by the HCF, it is considered appropriate to classify the structure, system and components of the facility as Hazard Category 3 from a conservative point of view. However, this classification should be reconfirmed through a detailed hazard

Table 6
Frequency category [10].

Category	Characteristic Word	Frequency per Year (F)	Description
I	Normal	$1 \leq F$	Normal Operations
II	Likely or Anticipated	$10^{-2} \leq F < 1$	Incidents that may occur several times during the lifetime of the facility. Incidents that commonly occur
III	Unlikely	$10^{-4} \leq F < 10^{-2}$	Accidents that are not anticipated to occur during the lifetime of the facility. Natural phenomena in this frequency category include: Uniform Building Code earthquake, 100-year flood, maximum strong wind, etc.
IV	Very Unlikely	$10^{-6} \leq F < 10^{-4}$	Accidents that will probably not occur during the life cycle of the facility. This category includes the DBAs.
V	Extremely Unlikely	$F < 10^{-6}$	Al1 other accidents. Accidents too unlikely to be considered in the design basis. Some accidents in this frequency category may be evaluated as beyond DBAs.

Table 7
Risk ranking matrix [10].

Consequence severity category	Frequency category				
	I	**II**	**III**	**IV**	**V**
A	1	1	2	2	3
B	1	1	2	3	4
C	2	2	3	3	4
D	3	3	4	4	4

analysis at the basic design stage.

According to Table 3, the HCF structure corresponds to RW-IIb based on the NRC standard. Thus, the structure of the facility is designed by applying the RW-IIb requirements of US NRC Reg. Guide 1.143, and classified as non-nuclear safety class. Another standard, ANSI/ANS-2.26, corresponds to the SDC (Seismic Design Category)-2 of the facility [12]. In this case, the seismic design is designed by applying the risk category IV of IBC-2015 and ASCE/SEI 7-10 [13], and these requirements are the same as the RW-IIb requirements of US NRC Reg. Guide 1.143.

4.2. Preliminary hazard analysis in the conceptual design phase

4.2.1. Identification of potential hazards

General potential hazards list is derived by reviewing the Hot Cell Facility Safety Analysis Report (SAND2000-2355) of the Sandia National Laboratory [14] in the HCF as follows.

F09F Direct radiation exposure
F09F Nuclear fission criticality
F09F Release through leakage of radioactive liquid (on-site, off-site)
F09F Gaseous radioactive material leakage (on-site, off-site)
F09F Radioactive contamination
F09F Leakage of hazardous substances
F09F Radiation release due to fire
F09F Radiation release due to explosion

Table 8
Energy and material sources to accident categories.

Potential accident category	Energy and material sources
Fire	Electrical, Thermal, Flammables, Chemical Reaction
Explosion	Potential (Pressure), Explosive Material, Chemical Reaction
Loss of Confinement	Radioactive Material, Toxic Chemical
Direct Radiation Exposure	Ionizing Radiation Sources
Nuclear Criticality	Fissile Material
Man-made External Hazard	Non-Facility Events (e.g., aircraft crash), Cranes
Natural Phenomena Hazards (NPH)	Seismic, Extreme Wind, Flood, Lightning, and others

Because the HCF mainly performs repeated intermediate-level waste characterization activities, the specific risks associated with these activities can be easily identified. The possibility and severity of the explosion are limited to the administrative control of amounts of volatiles in the facility and the air circulation and dilution provided by the ventilation system. In addition, if compressed gas is required at the facility, compressed air packaged in standard industrial containers will be used. Therefore, the possibility of spontaneous damage in these industrial compressed gas containers is extremely low. The possibility of gas build-up to explosive levels in the facility is very limited by the operation of the ventilation system. Therefore, considering the operation of the ventilation system and administrative controls such as limiting the total amount of compressed gas located in the facility, the possibility of radioactive material leakage due to an explosion in the facility is determined to be negligible. Therefore, considering the characteristics of the facility and the radioactive materials handled, the following exclusion criteria can be applied when selecting the potential hazard type.

F09F The facility does not handle fissile material.
F09F The facility does not handle hazardous chemicals.
F09F Explosive chemicals are not handled in the facility.
F09F Radioactive materials are handled remotely only inside the facility.

If the types of potential hazards that can occur at the facility are selected by applying the above exclusion criteria, they are as follows.

F09F Direct radiation exposure (including direct radiation exposure to workers due to radioactive contamination)
F09F Radioactive material release through leakage of radioactive liquid (on-site, off-site)
F09F Gaseous radioactive material release (on-site, off-site)
F09F Radioactive materials release due to fire

The above derived major types of potential hazard are finalized by several subject matter experts which are participated in this research (KETEP No. 20201520300090) from research institute, engineering companies, and other university.

Administrative controls are used to limit the inventory of radioactive materials located at each identified location. Radiation protection procedures are used to control and mitigate radiation hazards by restricting workers' access to radioactive materials.

4.2.2. External events to be considered

External events should also be considered as one of the underlying hazards affecting the safety of this facility. In this study, a prescreening evaluation was performed on all possible external events and external events that may affect the facility were identified.

Table 9
Total radioactivity inventory in the Hot Cell Facility.

Nuclide	Radioactivity measurement in point Beach 1 (μCi/gm)	Total radioactive inventory (Ci) in the facility
Mn-54	876	8.78E-1
Fe-53	20,800	2.08E+1
Ni-63	25	2.508E-2
Co-60	8310	8.31E+0
Ni-63	1290	1.29E+0
Mo-93	0.15	1.50E-4
Nb-94	0.40	4.00E-4
Tc-99	-	-
Eu-152	0.05	5.00E-5
Eu-154	0.79	7.90E-4
Eu-155	0.50	5.00E-4

Table 11 shows possible external events that may occur in the facility and the results of the review. The "Results of screening process" column of Table 11 shows how each event was classified in the screening process. The four (4) criteria used in the screening process are:

F09F Group 1 – unlikely or very unlikely events
F09F Group 2 - Low severity of results events
F09F Group 3 - Events with no negative consequences
F09F Group 4 - Events requiring a certain level of qualitative or quantitative analysis

Summarizing the results of the external event screening process, it can be seen that there are two (2) types of external events, namely, loss of off-site power and design base earthquake to be considered as DBAs for the HCF.

The above screened potential external events are finalized by several subject matter experts which are participated in this research (KETEP No. 20201520300090) from research institute, engineering companies, and other university.

4.2.3. PHA for potential hazards and external events

The evaluation of potential hazards and external events is systematically performed, consequences (impact) and defenses functions are identified via PHA. Potential mitigation features available under normal, abnormal and accident conditions, which are reflected in the HCF are then reviewed and their contributions to public and worker safety are evaluated.

Qualitative evaluation of each potential hazard scenario was performed via PHA. Based on the PHA results, for each hazard scenario, the engineer qualitatively assigns frequency categories, consequence severity categories and risk ranking according to Tables 5–7. Based on a conservative assumption, it is considered that the release of radioactive materials by each hazard and the resulting radiation exposure are mitigated only by the physical form of radioactive materials, physical shielding, ventilation systems, and other factors. Table 12 and 13 summarize the public and worker hazard analysis results, respectively.

The main PHA results are summarized as follows.

F09F The impact of potential hazards on the public is very slight at most.
F09F In case of potential hazards other than "Ignition from combustible materials inside the facility," they pose a minor risk to workers, and facility managers should take mid-to long-term measures to reduce these potential consequences or possibilities. However, further analysis is considered unnecessary. These potential hazards are closely related to the radioactive inventory of samples handled in the restricted area (cell).

4.2.4. Selection of design base accidents (DBAs)

According to the PHA results, the impact of potential hazards on the public was negligible as shown in Table 12. However, in the case of the impact on the worker, the degree of danger due to direct exposure or leakage of radioactive materials to the outside was evaluated to be insignificant (minor), as shown in Table 13. As there are no unique incidents that are evaluated as high-risk, typical DBAs combine a number of similar accidents and select them as a complete set of associated accidents.

For each accident type, we select at least one bounded accident, which is a combination of accidents with very minor impact. That is, operational events inside the facility (e.g., direct exposure, spillage, and fire), natural hazard events that may affect the facility (e.g., earthquakes), and man-made events that originate outside the facility (e.g., aircraft crashes).

Most of the accidents that occur inside the facility can be characterized by the release of radioactive material to the outside. Several DBAs are selected because they are representative accidents that require further analysis. Therefore, the selected DBAs are the combination of several minor accidents that are most dangerous and most likely to affect workers. Table 14 shows the DBAs that should be quantitatively evaluated as linked accident scenarios for this facility.

Table 10
Inventory comparison for hazard categorization.

Nuclide	Radioactivity thresholds (Ci)		Total radioactivity in the facility	Ratio total radioactivity in the facility to the radioactivity thresholds	
	HC 2	HC 3		HC 2	HC 3
Mn-54	4.30E+05	8.80E+02	8.78E-1	0	0.001
Fe-53	4.30E+05	1.00E+04	2.08E+1	0	0.002
Ni-63	4.50E+06	5.40E+03	2.508E-2	0	0
Co-60	1.90E+05	2.80E+02	8.31E+0	0	0.03
Ni-63	4.50E+06	5.40E+03	1.29E+0	0	0
Mo-93	4.30E+05	2.20E+03	1.50E-4	0	0
Nb-94	8.60E+04	2.00E+02	4.00E-4	0	0
Tc-99	3.80E+06	1.70E+03	-	0	0
Eu-152	1.30E+05	2.00E+02	5.00E-5	0	0
Eu-154	1.10E+05	2.00E+02	7.90E-4	0	0
Eu-155	7.30E+05	9.40E+02	5.00E-4	0	0
Sum				0	0.033

Table 11
Potential external events.

Types of external event	Group	Result of the screening process
Coastal Erosion	1	Not likely to happen
Avalanches/Landslides	1	Not likely to happen
Missile	1	Not likely to happen
Chemical/Toxic Gas Releases	1	Not likely to happen
Tsunami	1	Not likely to happen
Industrial or Military Facility Accident	1	Not likely to happen
Volcanic Activity	1	Not likely to happen
Transportation Accidents	1	Not likely to happen
External Explosions	1	Not likely to happen
External Floods	1	Not likely to happen
Snow	1	Not likely to happen
Typhoon	2	Low severity of results
External Fires	3	No negative consequences
Aircraft Impacts	3	No negative consequences
Loss of Off- Site Power	4	Qualitative/quantitative analysis required (Worker)
Design Base Earthquakes	4	Qualitative/quantitative analysis required (Worker)

Table 12
Risk evaluation results for the public.

Hazard type	Hazard scenario	Frequency category	Consequence severity category	Risk ranking
Direct Radiation Exposure	F09F Damage to protective clothing when entering the radiation area and/or ignoring work procedures such as entering the radiation area before decontamination	III	D	4
	F09F Direct exposure of workers due to the fall of radioactive materials	III	D	4
Release of Radioactive Liquid	F09F Leakage of cooling water from cutting tools and possible leakage of radioactive contaminated water during decontamination process	III	D	4
	F09F Leakage of radioactive gas in the air due to the failure of the air conditioning system	III	D	4
Release of Radioactive Materials to the Air	F09F Suspended particles generated during the cutting process leak into the compartment area due to failure of compartment penetration or of the air conditioning system	III	D	4
	F09F During the chemical pretreatment process, radioactive gas leaks into the air due to damage to the air conditioning system.	III	D	4
Release of Radioactive and Toxic Materials due to Fire	F09F Ignition from combustible materials inside the compartment such as processing oil and cable sheathing	IV	D	4
	F09F Evaporation of radioactive solution / occurrence of fire	III	D	4

4.3. Classification of the hot cell facility

As a result of analyzing the relationship between safety class, quality class, seismic category, and electrical class applied to domestic nuclear power plants, the correlation is generally shown in Table 15.

Therefore, using the preliminary hazard analysis results presented in Section 4.1 and Table 15, the hot cell facility is classified as shown in Table 16.

5. Discussion and conclusion

In this paper, related domestic and international technical standards were reviewed to present the classification criteria of NRNFs in Korea. Classification of an HCF, a type of NRNF, was performed using the presented classification criteria.

For the safety classification of NRNFs in Korea, the hazard categorization method suggested by the US DOE was applied. Accordingly, the hazard category was determined first and safety class and seismic category were assigned based the defined hazard category. It is desirable to perform hazard analysis using a graded

Table 13
Risk evaluation results for workers.

Hazard type	Hazard scenario	Frequency category	Consequence severity category	Risk ranking
Direct Radiation Exposure	F09F Damage to protective clothing when entering the radiation area and/or ignoring work procedures such as entering the radiation area before decontamination	III	C	3
	F09F Direct exposure of workers due to the fall of radioactive materials	III	C	3
Release of Radioactive Liquid	F09F Leakage of cooling water from cutting tools and possible leakage of radioactive contaminated water during decontamination process	II	D	3
	F09F Leakage of radioactive gas in the air due to the failure of the air conditioning system	II	D	3
Release of Radioactive Materials to the Air	F09F Suspended particles generated during the cutting process leak into the compartment area due to failure of the compartment penetration or of the air conditioning system	III	C	3
	F09F During the chemical pretreatment process, radioactive gas leaks into the air due to failure of the air conditioning system.	III	C	3
Release of Radioactive and Toxic Materials due to Fire	F09F Ignition from combustible materials inside the compartment such as processing oil and cable sheathing	IV	D	4
	F09F Evaporation of radioactive solution / occurrence of fire	III	C	3

Table 14
Type of design basis accidents.

No.	DBA description	Hazard type
1	Direct radiation exposure of workers by entering the cell without compliance with work procedures and regulations	Direct exposure
2	A fall accident occurred while handling radioactive materials. Direct exposure of workers due to workers entering cells to clean it up.	Direct exposure
3	Operation of the ventilation system is stopped due to loss of external power and non-operation of the emergency generator. This causes contaminated air inside the cell to leak into the operator's living space due to the violation of negative pressure inside the cell	Release of contaminated air due to loss of external power
4	Due to design-based earthquake, the ventilation system is shut down, and contaminated air inside the cell leaks into the worker's living space due to damage to the cell penetration	Release of contaminated air due to earthquake
5	Evaporation of the sample radioactive solution due to overheating in an electric furnace, etc. At the same time, a fire occurs and the function of the ventilation system is lost. As a result, the contaminated air inside the cell leaks into the worker's living space.	Release of contaminated air due to fire

Table 15
General correlation between safety class and other design categories in NPPs.

Safety class	Quality class	Electrical class	Seismic category
Safety Class 1,2,3	Q	Class 1E	Seismic Cat. I
Non-Nuclear Safety	A	Non-Class 1E	RW-IIa
Non-Nuclear Safety	S	Non-Class 1E	RW-IIb

Table 16
Classification of the hot cell facility.

Safety class	Quality class	Electrical class	Seismic category
Non-Nuclear Safety	S	Non-Class 1E	RW-IIb

approach in the same manner as the US DOE because the relevant design data are insufficient at the initial stage of NRNF design in Korea. In this paper, a PHA was performed in a qualitative manner, focusing on the conceptual design phase, and classified into hazard category. As a result of the classification, the HCF was classified as Hazard Category 3; accordingly, its safety class was classified as Non-Nuclear Safety, seismic category as Non-Seismic (RW-IIb), and quality class as Manufacturers' Standards (S).

The application of graded approaches up to the conceptual design phase is based on the engineer's judgment and experience, and on the ability of the analyst to secure design and operation data for similar facilities to efficiently perform hazard analysis. Therefore, the potential hazard and external event lists derived in this paper should be justified through the quantitative analysis to be performed after the conceptual design phase. As the classification is finalized in the basic design phase, it is judged that it is appropriate to prepare input data from a conservative perspective and perform hazard categorization until the conceptual design phase.

Based on the findings of this paper, it is necessary to properly set the classification criteria of NRNFs in Korea as soon as possible.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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