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Identification of Safety SSCs and ACs for Pyroprocess Facility

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1. Introduction

Pyroprocess technology has been considered as a fuel cycle option to solve the spent fuel accumulation problems in Korea. The Korea Atomic Energy Research Institute has been studying pyroprocess technology, and the conceptual design of an engineering-scale pyroprocess facility, called the Engineering-Scale Pyroprocss Facility (ESPF) [1,2], has been performed on the basis of a 10 tHM throughput per year. In this paper, safety requirements of the ESPF for the protection of facility workers, collocated workers, the off-site public, and the environment were introduced. For the identification of safety SSCs (Structures, Systems, and Components) and/or ACs (Administrative Controls), the following activities were conducted: 1) identifying hazards associated with operations, 2) determining hazard category, 3) identifying potential events associated with these hazards, and 4) identifying the potential preventive and/or mitigative controls that reduce the risk associated with these accident events.

2. IDENTIFICATION OF POTENTIAL ACCIDENT SCENARIOS

2.1. Hazard Identification

A hazard is defined as a source of danger (i.e., material, energy source, or operation) with the potential to cause illness, injury, or death to personnel or damage to an operation or the environment (without regard for the likelihood or credibility of accident scenarios or consequence mitigation) [3]. The fundamental hazards affecting the ESPF can be categorized into process-related hazards, natural hazards, and manmade external hazards. Among the hazards, spent fuel, radioactive materials, toxic materials, and combustibles are included in process-related hazard materials. Hazard identification activities were conducted, and some process-related hazards and natural hazards were identified. However, manmade external events were not considered as a unique hazard in this study, and that could be dealt with after establishing security design policies.

In this study, a preliminary hazard checklist (PHC) evaluation was used to identify potential facility hazards. Materials and energy hazard sources that have the potential to lead to an uncontrolled release of radioactive or hazardous materials from the ESPF were investigated. An SF cask area, active material storage area, transfer tunnel area, air cell area, argon cell area, and operating area were considered to determine the preliminary initial events. As a result of a PHC evaluation for the ESPF, a total of 41 candidate initial events were determined.

2.2. Hazard Categorization

Facility hazard categorization is necessary since the facility category provides the regulatory basis for the amount of required accident analysis and selection of safety SSCs and ACs. Determining the correct facility hazard category involves comparing the facility radioactive material content to threshold values of radioactive material, which is specified in DOE-STD-1027 [4]. Hazard category 3 nuclear facilities have the potential for localized consequences, and have sufficiently low quantities of radioactive material that no potential exists for an accidental criticality. Hazard category 2 nuclear facilities have the potential for on-site consequences, and have sufficient quantities of fissionable material leading to an accidental criticality. Hazard category 1 nuclear facilities are reserved for reactor facilities having a steady-state power level greater than 20 MWt.

Depletion calculations are used to determine the hazard category of the ESPF. Using the SCALE 6.0 code package, an ORIGEN-ARP depletion calculation for 10 tHM of PWR spent fuel with burnup of 55,000 MWD/MTU and 10 years of cooling was performed. The depletion and decay calculations show that the quantity of both important actinide isotopes such as Sr-90, Cs-134, Cs-137, Pu-239, and Pu-241 each individually and the sum of the isotopes easily exceed their isotopic threshold of hazard category 2. According to this result, it is clear that the ESPF that uses PWR spent fuels as feeding material should be categorized as a hazard category 2 nuclear facility.

Table 1. Hazard category sum-of-the-fractions determination

Isotope	Threshold of Hazard Category 2 (g)	10 tHM of PWR spent fuel (g)	Fraction
Sr-90	1.6×10^2	7.877×10^2	4.92
Cs-134	4.6×10^1	7.850×10^1	1.71
Cs-137	1.0×10^3	1.586×10^4	15.86
Pu-239	9.0×10^2	6.113×10^4	67.92
Pu-241	2.8×10^1	1.131×10^4	403.92
		Total	494.33

2.3. Hazard Evaluation

A qualitative hazard evaluation was performed to select the potential hazardous events and causes at the

ESPF. Internal events happen as a result of operator error and equipment failure during process or facility operation. An analysis of postulated accidents caused by malevolent acts is not within the scope of this study.

In this study, a hazard evaluation of the ESPF and associated operations was conducted using a preliminary hazard analysis (PHA). The results of the PHA serve as the basis for hazard ranking so that bounding accident scenarios can be selected. Hazard ranking is determined by qualitatively assigning frequency and consequence estimates to each hazard or accident scenario developed by the PHA. The hazard frequency, which is based on available data, operating experience, and engineering judgment, is categorized into four grades: (A) Anticipated or Likely, (U) Unlikely, (V) Extremely Unlikely, and (E) Beyond Extremely Unlikely, and the hazard consequence severity is classified into four grades: (H) High, (M) Moderate, (L) Low, and (N) Negligible [5]. A risk ranking matrix is used to compare all hazards and accident scenarios identified in the PHA.

The facility hazards may result in an uncontrolled release of radioactive or hazardous material and a direct radiation exposure, and were evaluated using the PHA; preliminary bounding accidents were then selected. As a result of a PHA for the 41 candidate initial events, ten initial events falling into hazard ranking 1 or 2 were determined as bounding initial events. The first column of Table 1 shows an example of a PHA for initial events selected as bounding events.

2.4. Preventive and Mitigative Features

From the analysis in accordance with the PHA, the controls for ESPF were derived, which are shown in bold/italic text in Table 1. Some additional features are also listed for hazard events not requiring formal derived controls.

The hazard evaluation results described in Table 1 show that the ESPF is designed and operated using a defense-in-depth approach that protects the off-site public, collocated workers, facility workers, and environment from the associated hazard events. Based on the estimated risk, some safety-significant SSCs and ACs were identified for the facility and the collocated worker, and one safety-class SSC for the radioactive material release accident was identified for protection of the off-site public. The identified SSCs for each event will be credited for preventing or mitigating the events through accident analyses in ongoing study.

3. SUMMARY

A hazard evaluation for the Engineering-Scale Pyroprocss Facility (ESPF) was performed for identification of the safety SSCs (Structures, Systems, and Components) and ACs (Administrative Controls). As a result of the hazard evaluation, some safety-significant SSCs and ACs were then identified for the facility and the collocated workers, and one safety-class SSC was identified for protection of the off-site public. This study will be used to perform a safety evaluation for accidents involving any of the hazards identified, and to establish safety design policies and advance a more definite safety design.

Table 2. Summary of accident scenario and identified controls

Hazardous Event	Preventive and Mitigative Features	
	Design	Administrative
Fire and Explosions: Air enters argon cell via open, active penetration (transfer lock) resulting in exposure of pyrophoric materials to air and release of radioactive material	***Transfer lock dual door airlocks*** Argon cell atmosphere monitoring Transfer lock door positions monitored Hot cell exhaust system Building exhaust system Building structure	***AC(s) on transfer lock operation*** ***AC on quantity of exposed pyrophoric material inside argon cell*** ***AC on transfer lock leak rate*** Operator training Approved procedures
Radioactive Material Release: Damage and meltdown of spent fuel assembly resulting in release of radioactive material	***Storage vault design*** to prevent damage of spent fuel Storage cooling system Building exhaust system Safety exhaust system	Radiation protection program
Direct Radiation Exposure: Loss of air or argon cell shielding resulting in direct radiation exposure to facility workers	***Air and argon cell structure*** ***Air and argon cell shielding***	***AC on direct radiation exposure restrictions*** Radiation protection program Operator training
Inadvertent nuclear criticality: Inadvertent nuclear criticality in argon cell or waste storage cell	***Argon cell shielding*** ***Waste storage cell shielding*** Building structure	***AC on personnel access restrictions***
Nonradioactive Hazardous Material Release: Chlorine gas release	***Evacuation System*** Chlorine gas monitoring system and alarms	Operator training Approved procedures
Natural Phenomena Hazards: Earthquake results in severe building structural damage/collapse and results in radioactive material release	***Cell structure*** Building structure	***AC on quantity of pyrophoric material inside argon cell*** ***Ac on AFC radioactive material inventory*** ***Emergency management program***

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