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Fire Safety Consideration in the Pre-conceptual Design State of Pyro-Facillity

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1. Introduction

Nuclear power generation inevitably leads to the production of spent fuel which includes fission products and the importance of safely managing nuclear waste is becoming an increasingly important issue in the international society. As of 2014, the 23 domestic nuclear plants recorded 750 tons of spent fuel and an accumulated amount of about 13,000 tons is currently being stored on-site. In the near future, the on-site storage capacity for spent fuel is expected to reach their limit beginning with the Gori Nuclear Power Plant. The government, in order to solve this problem, has organized a public engagement committee and is searching for a solution. To use sustainable nuclear energy, our country is also pursuing research and development of fast breeder reactor and pyroprocessing technology in accordance with the international movement of spent fuel recycling and efforts towards nuclear non-proliferation which is centered on the development and demonstration of recycling spent fuel and fast breeder reactors. In December of 2008, the Korea Atomic Energy Commission, in response to this trend, has confirmed and announced its “Long-term Future Nuclear Energy Systems Plan” which includes the construction of the KAPF(Korea Advanced Pyroprocess Facility) by 2025 and the SFR(Sodium-cooled Fast Reactor) proven reactor by 2028. According to this plan, the Korea Atomic Energy Commission is actively engaging in R&D activities to substantiate pyroprocessing technology.

Pyro-facility has different features with nuclear power plant. In the pyroprocess, chemical and electrochemical separation were took place in the hot cells and material at risk (MAR) is distributed in many working areas. In this paper, we conducted the fire modeling of hot cells to see the stability of pyrophoric materials which is considered as one of the potential hazardous materials in the main process cell. Based on modeling results, consideration of fire safety pyro-facility will be discussed.

2. Methods and Results

2.1 Fire Hazard

A preliminary Hazards Analysis is performed that identifies and assesses fire risk. Although many process details will not be available during the pre-conceptual design phase, high-level events such as fire should be evaluated commensurate with the available process definition of MAR locations. From these evaluations, reasonably conservative prevention and mitigation strategies should be developed.

Table 1 lists potential fire hazardous events and initiator which were selected from preliminary hazard analysis of pyro-facility. Most significant risk in the main process cell (Ar hot cell) is pyrophoric material fire due to introduction of air. Uranium (U) and transuranic (TRU) ingots which are the final products of pyro-process is representative pyrophoric in the Ar cell. Their ignition and combustion behavior are significantly dependent on temperature and particle size [1-3]. Increase in particle size decreases ignition temperature of U and TRU. In the case of bulk U, ignition temperature is higher than 400°C. Therefore, it is importance to see whether the cell temperature under fire is above this temperature or not.

Table 1: Summary of potential fire events and causes at pyro-facility

Hazardous Event	Initiator/Cause
Air cell	
Localized fire in air cell resulting in localized contamination	Electrical sparks ignite transient combustibles Hot work ignites nearby combustibles
Localized fire in air cell resulting in damage to stored fuel elements and release of radioactive material	Electrical sparks ignite transient combustibles Hot work ignites nearby combustibles
Ar cell	
Air enters argon cell via transfer lock resulting in exposure of pyrophoric materials to air and release of radioactive material	Active penetration (transfer lock) is inadvertently open to air
	Damage occurs to transfer lock penetration while companion door is open (e.g., load drop)
	Load drops onto platen during loading/unloading the equipment transfer lock
	Damage occurs to transfer lock lid
	Equipment malfunction Inadvertent damage to passive penetration
Loss of argon cell confinement resulting in pyrophoric fire and release of radioactive material	Catastrophic equipment failure causing damage to argon cell confinement
	In-cell crane bridge or EMM bridge failure
	Multiple equipment failures Human error
Outside cells	
Discovery of exposed pyrophoric material outside of argon cell	Human error
Diesel fuel release and ignition of the DG fuel tank resulting in localized contamination	Diesel fuel leaks and ignites
Hydrogen release and subsequent explosion resulting in localized contamination	Hydrogen releases and accumulates to concentrations within explosive limits
Localized fire in cask handling resulting in cask breach and radioactive material release	Electrical sparks ignite transient combustibles Hot work ignites nearby combustibles
Localized fire outside cells resulting in localized contamination from outside cells	
Waste container fire outside cells resulting in a release of radioactive material	
Localized fire outside cells impacts cell windows resulting in localized contamination	

2.2 Fire modeling of main process hot cell

Main process hot cell is the place at which electrochemical and chemical separations of radionuclides were performed. Various equipment was operated at high temperature (above 400ºC) and the final product was fabricated. We conducted fire modeling of main process hot cell caused by cable tray fire to check the temperature. Fire modeling in hot cell was conducted Fire Dynamic Simulator (FDS, NIST). Technical information of the modeling was listed in table 2.

Table 2: Technical description of main process hot cell

Dimension	41 m(L) × 8 m(W) × 10 m(H)
Flow rate	> 18 m^3/s
Temperature	40ºC
Heat release rate	2,000 kW/m^2

Figure 1(a) shows the temperature profile of main process cell during the cable tray fire under HVAC operation. Temperature of the main process by fire was increased continuously during 600s, because we assumed that main process cell is insulated. After that reduction in remaining cables and introduction of oxygen reduces temperature of the cell. Figure 1(b) shows the temperature profile of main process cell under cable tray fire without HVAC operation. Limitation of oxygen significantly reduces the maximum cell temperature, but the cell temperature is stably maintained after finishing combustion.

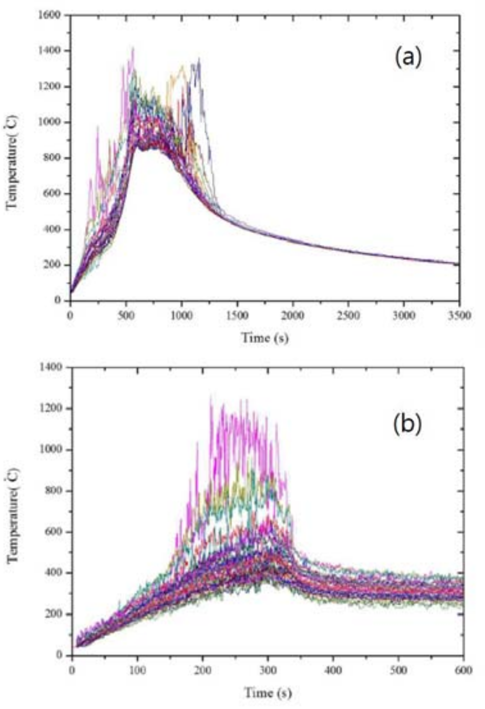

Fig. 1. Main process cell temperature profile (a) with HVAC operation and (b) without HVAC operation.

From this results, it is clear that pyrophoric U and TRU metals in the cell have a high possibility to be combusted by other fire event. Therefore great care is required in fire protection measures for U and TRU production.

3. Conclusions

We performed preliminary hazard analysis for pyro-facility and summarized potential fire hazard. Pyrophoric material fire is the dominant hazard in the main process hot cell and fire modeling of cable tray in the cell was analyzed to see the stability of pyrophoric materials. Analysis results clearly shows that pyrophoric materials are prone to be affected. Therefore much efforts should be given for fire protection of main process hot cell.

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