Process Faults Analysis and Design Considerations for Pyroprocess Hot Cell Safety

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1. Introduction

KAERI (Korea Atomic Energy Research Institute) has been studied the pyroprocess since 1997 [1]. For demonstration of pyroprocess, KAERI developed two facilities, the ACPF (Advanced spent fuel Conditioning Process Facility) [2-5] and the PRIDE (PyRoprocess-Integrated inactive DEmonstration facility) [6]. From 2013 KAERI performs a pre-conceptual design of the ESPF (Engineering-Scale Pyroprocess Facility) [7].

In this paper, the process faults analysis and design considerations for pyroprocess hot cell safety are described.

2. Process Flow and Safety Analysis

2.1 Process Flow

The pyroprocess is composed of a disassembly and rod cutting of the spent fuel assembly, chopping and decladding, voloxidation, electro-reduction, electro-refining, electro-winning, salt purification and recovery, waste form fabrication, off-gas treatment, etc. Fig. 1 shows a typical flow diagram of the pyroprocess. The process throughput is the most important design parameter to determine each process equipment size and capacity, material handling requirements, and the waste and product requirements.

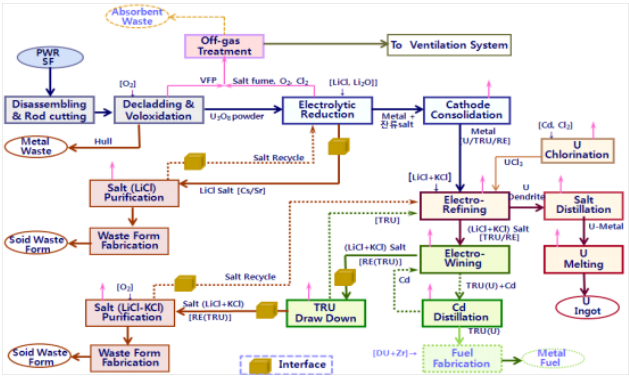

Fig. 1. Pyroprocess Flow Diagram

2.2 Process Faults Analysis and Design Considerations

Process safety was considered for safe operation. Process safety analyses were performed by fault analysis on each process. Table 1 shows the common results of the fault analyses and design considerations on the pyroprocess facilities. The analysis results show that the main fault types are pressure and temperature build-ups, failure to maintain an inert atmosphere, interruption of electric power, failure of the off-gas trapping system, and failure in molten salt transfer. The serious effects caused by these faults are a radioactive material release and a hot cell contamination. The solving methods to prevent these faults are to install an engineered safety system, for example a dual control system and an automatic shut-off system for emergency.

Table 1. Faults Analysis and Design Considerations of each Process.

Process	Fault Type	Design consideration
Disassembling & Chopping	-Assembly drop -Can drop	-Safe handling system -Manual control for emergency
Oxidative decladding	-Pressure build-up -Temperature build-up -SF powder spill	-Dual pressure control system -Back flushing system for filter -Manual control for emergency -Air shut-off in high pressure -Cell firefighting system
Homogenization	-SF powder spill	-Collection system of SF powder
Pretreatment of metal oxide	-SF powder spill -Temperature build-up -Pressure build-up -Cooling water leakage	-Dual pressure control system -Administrative and geometry controls of fuel material
Electro-reduction	-Pressure build-up	-Dual pressure control system -Manual control for emergency -Ar shut-off in high pressure
	-Temperature build-up or below melting temperature	-Dual temperature control system -Electric power shut-off in high temperatures -Cold trap for emergency -Easy replacement of heating element
Cathode processing	-Pressure build-up -Temperature build-up	-Dual pressure control system -Dual vacuum system
Electrolytic refining	-Pressure build-up -Temperature build-up -Feed metal drop	-Dual pressure control system -Electric power shut-off in high temperatures -Cold trap for emergency -Easy replacement of heating element
Salt distillation	-Pressure build-up -Temperature build-	-Dual pressure control system -Electric power shut-off in

	up -Feed material drop -Cold trap failure -Vacuum failure	high temperatures -Cold trap for emergency -Easy replacement of heating element
Ingot casting	-Pressure build-up -Temperature build-up -Feed material drop -Cold trap failure	-Dual pressure control system -Electric power shut-off in high temperatures -Cold trap for emergency -Easy replacement of heating element -Firefighting system
U chlorination	-Pressure build-up -Temperature build-up -Feed material drop -Cold trap failure	-Dual pressure control system -Electric power shut-off in high temperatures -Cold trap for emergency -Easy replacement of heating element -Cl_2 exhausting system for emergency
LCC electro-winning	-Pressure build-up -Temperature build-up -Feed material drop -Cold trap and salt transfer line failure	-Dual pressure control system -Electric power shut-off in high temperatures -Cold trap for emergency -Easy replacement of heating element -Cl_2 exhausting system for emergency
Cd distillation	-Pressure build-up -Temperature build-up -Feed material drop -Cold trap failure	-Dual pressure control system -Electric power shut-off in high temperatures -Cold trap for emergency -Easy replacement of heating element
Residual actinide recovery	-Pressure build-up -Temperature build-up -Feed material drop -Cold trap and salt transfer line failure	-Dual pressure control system -Electric power shut-off in high temperatures -Cold trap for emergency -Easy replacement of heating element
LiCl purification	-Pressure build-up -Temperature build-up -Feed material drop -Cold trap and salt transfer line failure	-Dual pressure control system -Manual control for emergency -Easy replacement of heating element -Electric power shut-off in high temperatures -Cold trap for emergency
LiCl+KCl purification	-Pressure build-up -Temperature build-up -Feed material drop -Cold trap and salt transfer line failure	-Dual pressure control system -Manual control for emergency -Easy replacement of heating element -Electric power shut-off in high temperatures -Cold trap for emergency
Waste form fabrication	-Pressure build-up -Temperature build-up -Feed material drop -O_2 control malfunction -Cl_2 exhaust system malfunction -Cold trap and salt transfer line failure	-Dual pressure control system -Manual control for emergency -Easy replacement of heating element -Electric power shut-off in high temperatures -Cold trap for emergency
Off-gas treatment	-Interruption of off-gas exhaust	-Dual vacuum system -Dual pressure control system -Differential pressure monitoring system -Easy replacement of heating element -Electric power shut-off in high temperatures -Firefighting system

3. Conclusions

KAERI has been developing a pyroprocess for conditioning and reutilization of PWR spent nuclear fuels. The safety evaluations of the pyroprocess facilities were performed to confirm the safe design. The process safety as one of the safety evaluations was analyzed by the faults tree method. The corresponding safe design considerations for each fault type were also considered.

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