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Process Improvement to Enhance Safeguardability of Pyroprocessing Facility

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1. Introduction

In order to enhance safeguardability of future pyroprocessing facilities, the efforts of development of safeguardability evaluation considering the facility design phase are required.

Korea Atomic Energy Research Institute (KAERI) studied possible diversion scenario for pyroprocessing facility [1]. The diversion scenarios were just developed for material balance area (MBA). However, diversion scenarios with respect to unit processes need more study.

In this study, processes were specified for pathways along mass flow through process analysis. Diversion pathways were discussed for specified process, assuming abnormal operation and operator missing.

2. Assessment of diversion scenario in pyroprocessing facility

The model facility in this study is based on 200 ton HM of KAPF [2]. The processes cover from spent fuel storage to RAR process, salt refining recycle, and disposal of wastes. The pathways of TRU and U were analyzed along the material flow and processes.

2.1. Diversion scenario in the previous study

KAERI suggests diversion possibility following 10 processes : 1) Transport of spent fuel, 2) Unloading fuel assemblies, 3) Decladding fuel rod, 4) Cutting fuel rod, 5) Spent fuel powder, 6) Electrolytic reduction metal, 7) Storage/Transport of U/TRU, 8) Product U, 9) Initial UCl_3 10) Wastes including TRU on the assumption of abnormal operation such as using of special crucible on purpose, manipulation of records and camera, surrogate unit, and manipulation of process concentration. Under normal operation, possibility of diversion is low due to small quantity of target materials.

2.2. Additional diversion scenario

Additional diversion scenarios of U and TRU were developed as shown in Table 1. The scenarios include processes of direct handling of materials and wastes and manipulating process conditions (concentration, recovery rate, and electrode) under abnormal operation such as using undeclared crucible, manipulation of records and monitoring camera.

Table 1. Process-based diversion scenarios

Process	Diversion scenario
Oxidation decladding	Manipulation of TRU recovery rate as process condistion of decladding
LiCl salt purification	Recovery at salt refining process after forcible dissolution of metal at electrolyte reduction (exchange of anode-cathode)
LiCl-KCl distillation	Pu formation in change of process condition of distillation (Require study of possibility of diversion)
Distilled salt storage	Diversion using surrogate salt and declaration of low recovery rate of salt
Electrowinning	Diversion using solid electrode
Cd distillation	Recovery TRU by distillation in disguise as metal waste after volatilization of TRU in change of distillation condition
U/TRU ingot fabrication	Recovery TRU as shipping out of quartz waste from ingot fabrication
LiCl-KCl salt purification	Pu recovery through solid cathode using intentionally enriched salt prior to salt refining

As shown in Table 2, in order to prevent diversion of the processes, safeguards measures are required at unit processes. Revision of material accountancy measures and containment/surveillance or monitoring of processes must be required since diversion for processes can be carried out under abnormal operation. Although safeguards implementation enhances safeguardability, the possibility of diversion can decrease through each process improvement.

Table 2. Safeguards measures for each diversion scenario

Process	Safeguards measure
Oxidation decladding	- Measurement of weights of powder and Zr hulls - Monitoring of temperature of decladding process, time, rotation - Serveillance of inflow external powder
LiCl salt purification	- Measurement of reduction and refining salt concentration - Monitoring of electrode of electrolyte reduction
LiCl-KCl distillation	- Monitoring of ingot concentrations - Monitoring of process temperature and degree vacuum
Distilled salt storage	- Measurement of weight of recovery salt - Serveillance of external salt
Electrowinnin g	- Measurement of cathode voltage - Serveillance of approach of solid electrode
Cd distillation	- Measurement of weight of Cd and HM - Monitoring of process temperature and time - Surveillance of Cd transport
U/TRU ingot fabrication	- Measurement of weight of TRU ingot - Material accountancy of wastes - Monitoring of transport of quartz wastes
LiCl-KCl salt purification	- Measurement of HM concentration in salts - Monitoring of process of salt refining

3. Process improvement for safeguardability

If there are possibility of diversion of special nuclear materials, safeguardability can be enhanced through improvement of unit processes. Three parts of processes is able to be proposed in total processes

The first proposition is continuous casting. Quartz tube as mold is applicable for fabrication of nuclear fuels using recovered U/TRU [3], but there is possible for ingot loss and diversion. In this case, TRU loss and wastes can decrease by U/TRU continuous casting in ingot fabrication process.

Scandia crucible decreases possibility of diversion. Ceramic crucible has pores which Li or liquid metal can penetrate [4]. Scandia has only a few pores at surface. To avoid loss of materials, Scandia is one of the candidate of the crucible materials.

The last improvement is use of fluoride at electrolyte reduction process. Alkali metal is not able to be reduced at LiCl-Li_2O electrolyte reduction processes [5]. As perfect reduction from oxide to metal, TRU loss can decrease. If fluoride electrolytes are applied at the process, reaction rate of solubility increases. Also, residue salt removal process is not required due to easiness of separation of molten metals and salts by difference of density.

Although additional experiments and effects of improved processes are required. However, safeguardability will enhance if improved processes as suggested above apply to the stage of the process design.

4. Conclusion

In this study, additional diversion scenarios were developed in pyroprocessing facility. As suggested improved process to avoid diversion, safeguardability will be able to be secured at the design phase.

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REFERENCES

[1] Korea Atomic Energy Research Institute, "IAEA 회원국지원프로그램을 통한 파이로시설의 안전조치 방안 개발" (2012).

[2] Ko, W. I. et al., "Preliminary conceptual design and cost estimation for Korea Advanced Pyroprocessing Facility Plus (KAPF)", Nuclear Engineering and Design, 277, 212-224 (2014).

[3] Inoue, T., An overview of CRIEPI Pyroprocessing Activities, Presentation at 9th OECD/NEA P&T IEM Nimes, France.

[4] Kim, D. et al. (2016). Controlling the leakage of liquid bismuth cathode elements in ceramic crucibles used for the electrowinning process in pyroprocessing. Journal of Nuclear Materials, 478, 91-96.

[5] Herrmann, S., Li, S., and Simpson, M. (2007). Electrolytic Reduction of Spent Light Water Reactor Fuel Bench-Scale Experiment Results. Journal of Nuclear Science and Technology, 44(3), 361-367.