Insight from a Critical Review on the Safety Analysis of Nuclear Fuel Cycle Facility for Domestic Regulatory System

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1. Introduction

Korea has 20 nuclear power plants in operation, and 10,761 ton of spent fuel deposited in plant sites. The capacity of reservoir for spent fuel in plant sites is to begin to be full in 2016. The light water reactors of 16 units generate around 320 ton/year and the heavy water reactors of 4 units around 380 ton/year in Korea. And the electricity generated by nuclear power plants is planned to increase up to 59% share by 2030. Spent fuel classified as high level radioactive waste in law is characterized by high level radiation, high heat generation, and high radiological toxicity. In the contrary, it is also a very useful domestic energy source. Thus, the safe management of spent fuel is very important confronting job in nuclear industry. Advanced fuel cycle (AFC) using pyro-process is an innovative technology, by which environmental load is drastically relieved because the extracted long-lived fission products are burn in fast breeder reactors [1].

Domestic nuclear industry also has a perspective road map for the construction of AFC facilities as shown in Table I [1]. However, there is not a sufficiently detailed licensing regulatory system yet. Moreover, there is no systematic frame for the safety evaluation.

This paper reviews the safety analysis system of foreign fuel cycle facilities. Critical review leads to the insight for setting-up safety analysis system of domestic AFC facilities.

Table I: AFC Facility Plan

Year	Facility	Capacity	Comments
~ 2011	PRIDE	10 t/yr	Mock-up
~ 2016	ESPF	10 t HM/yr	Engineering Scale
~ 2025	KAPF	100 t HM/yr	

2. Features of Nuclear Fuel Cycle Facility in Safety

Nuclear fuel cycle is, not inclusively, composed of

- Uranium/ thorium mining and milling;
- Uranium refining and conversion;
- Uranium enrichment;
- Fuel fabrication;
- Transportation;
- Spent fuel storage;
- Spent fuel reprocessing;
- Re-fabrication;
- Radioactive waste management;
- Waste disposal;
- Decommissioning

And the features of nuclear fuel cycle facility in safety, compared with chemical plant and nuclear reactor, can be summarized;

- Variety of physical and chemical treatments applied to a wide range of radioactive materials in the form of liquids, gas and solids.

Table II: Safety Aspect for Fuel Cycle Facilities

SAFETY ASPECTS FOR FUEL CYCLE FACILITIES										
	Criticality	Radiation	Chemical Toxicity	Fire/ Explosion	Product/ Residue Storage	Waste Storage	Ageing Facilities	Decommis-sioning	Effluents	Maintenance
Mining/ Milling		◎	◎	O	◎	◎	◎	◎	◎	
Conversion	O	◎	◎	◎	O	◎	◎	O		
Enrichment	O	◎	◎	◎	◎		O	◎		
Fuel Fabrication	◎	◎	◎	◎	◎	◎	O	◎	◎	O
Reactors	◎	◎		◎		◎	◎	◎	◎	◎
Interim Storage	◎	◎				◎	◎	O		
Reprocessing	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
MOX fuel fabrication	◎	◎		◎	◎	◎	◎	◎	◎	◎
Waste disposal	O	◎		◎			◎	O	◎	
Transportation	O	◎	O	◎				O		
Vitrification	O	◎		◎		◎		◎	◎	◎

O - may be a concern depending on specific conditions (enrichments, composition, etc.)
◎ - concern at most facilities

Table III: Event Categorization in IAEA

Category	Description	Frequency	Examples
A	Very unlikely	$< 10^{-6}$/y	Large scale leakage of radioactivity into environment and criticality
B	Unlikely	10^{-6}/y ~ 10^{-4} /y	Fire, loss of cooling water, loss of ventilation
C	Not unlikely	10^{-4} ~ 10^{-2} /y	Process malfunctions, temporary loss of power

Table IV: Event Categorization in 10CFR70.61

Category	Description	Frequency	Acceptance Criteria
Intermediate-consequence event	Unlikely	$< 10^{-4}$/event/year	0.25 ~ 1.0 Sv, and so on
High-consequence event	Highly Unlikely	$<10^{-5}$/event/year	1Sv, and so on

- It is necessary to provide correspondingly a wide range of specific safety measures as inherent parts of these activities.
- Radiation protection requirement of the personnel is more demanding especially in view of the many human interventions required for the operation and maintenance of fuel cycle facilities.

Safety aspect for the fuel cycle facility and its relation for each process are listed in Table II.

3. Review of the Event Categorization and Safety Analysis System

In general it is obvious that in well designed nuclear fuel cycle facilities, the safety related events that have a high hazard potential will also have low frequency of occurrence and vice versa. Thus the categorization is very important element for the safety analysis system. IAEA TECDOC-1575 and 10CFR70.61 provide following event categorizations: Table III and Table IV.

U.S. NRC proposed an integrated safety analysis (ISA) in 10CFR70 Subpart H and NUREG 1520. The compositions of these two methods are inter-corresponding and similar. The procedure of ISA is as followings;

1. Choosing An ISA Method
2. Choosing A Team
3. Conducting The ISA
   - ① Scope of Analysis
   - ② Process Safety Information
   - ③ Hazard Identification
   - ④ Performing the Hazard Analysis
   - ⑤ Results of the Analysis
   - ⑥ Documenting the ISA Results

ISA method in above procedure has 12 alternatives, and each alternative has different applicability range from broad identification to in-depth analysis. And it also has different capability for quantitative risk assessment (QRA), difference in single failure applicability, and difference in multiple failure applicability.

4. Insight from the Review

IAEA method provides the quantitative frequency for the event categorization but just a qualitative statement for the acceptance criteria. This is a consistent policy for the safety analysis guide of IAEA. Just providing the qualitative statement for the acceptance criteria is to set up country specific ones according to its public acceptance. ISA method is also mentioned in IAEA guide, even though this paper does not explain here, but the systematic and detailed guides are not provided.

U.S. NRC's method seems largely dependent on the team member composition. Acceptance criteria are suggested only for each event but not for overall facility system. So in complicated system there may be limitation for safety assurance.

Defense-in-depth (DID) was just briefly discussed in NUREG 1520, but it should be noted that DID has played a successful role in safety assurance of nuclear power plant and it is a good compensation for the uncertainty. Concurrence occurrence also has played a similar role for the conservatism.

5. Conclusions

In this study, several safety systems for nuclear fuel cycle facilities were reviewed and insights were obtained. Such insights will help to develop the specific safety framework for the advanced fuel cycle using pyro-process in Korea.

REFERENCES

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