Preliminary Safety Evaluation of Nuclear Criticality in a Large-scale Pyroprocess Facility

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1. Introduction

Korea Atomic Energy Research Institute (KAERI) has been developing a pyroprocess technology to reduce the waste volume and recycle some elements in a spent nuclear fuel. Because the operation with some fissionable materials such as pyroprocess operations may cause very high risks of criticality accident resulting in high radiation doses for facility worker or collocated worker, the safety evaluation of nuclear criticality is prerequisite to pyroprocess facility design. However, there are few published studies on the criticality evaluation for the pyroprocess facility due to lack of the facility information. KAERI conducted the preliminary conceptual (pre-conceptual) design of the large-scale pyroprocess facility. Preliminary safety assessment of nuclear criticality was evaluated using the pre-conceptual design data and SCALE/KENO code [1].

2. Nuclear criticality requirements

In Korea, article 90, 91, and 99 of enforcement regulations of Nuclear Safety Act require that the fuel storage, handling, and operation systems must be designed to be maintained subcritical [2]. NRC regulation also demand that the risk of criticality accidents must be limited by assuring that under normal and credible abnormal conditions, all nuclear processes are subcritical, including use of an approved margin of subcriticality for safety [3]. The table 1 shows the application of regulation for nuclear criticality safety.

Table 1. Application of regulation for nuclear criticality safety

Application	
Regulation	• Article 90, 91, 99 of the Enforcement regulations of Nuclear Safety Act • Article 5(7) of the Enforcement rule of the Radiation Safety Criteria • 10CFR Part 70 subpart H
Guide	• NUREG-1520 (Rev.2), • REG. Guide 3.4, 3.71 • IAEA Safety Standard No. NS-R-5 • DOE-STD-3007 • ANSI/ANS-8.1, 8.3, 8.15, 8.19, 8.20, 8.22, 8.23, 8.26

3. Validation of calculation method

For use in safety related analysis, the ability of a calculational methodology to accurately predict the subcriticality of a system must be well understood. The understanding of a calculational methodology's bias in predicting subcritical systems is obtained through the validation process. Validation includes identification of the difference between calculated and experimental results. This difference, called the bias, and the uncertainty associated with the bias are used in combination with additional subcritical margin to establish an upper safety limit (USL) [4]. In this study, the USL was set by following equation:

$$\mathrm{USL} = 1.0 + \mathrm{Bias} - \sigma_{bias} - \Delta_{SM} - \Delta_{AOA} \qquad (1)$$

Where the critical experiments are assumed to have a k_{eff} of unity, the bias is calculated as the difference between the calculated k_{eff} and the critical experiment modeled. The statistical uncertainty in the bias is represented by σ_{bias} and the subcritical margin is represented by Δ_{SM}. The term Δ_{AOA} is an additional subcritical margin to account for extensions in the area of applicability. The following condition must be demonstrated for all normal and credible abnormal operating conditions:

$$k_{calc} + 2\sigma_{calc} < USL \qquad (2)$$

Where k_{calc} is the calculated k_{eff} returned by the method and σ_{calc} is the uncertainty. In this study, SCALE/KENO Monte Carlo code was used for calculation of k_{eff} and uncertainty. Critical experiments from the International Handbook of

Evaluated Criticality Safety Benchmark Experiments (IHECSBE) are used for validation of calculation [5]. Over 350 cases are used in validation of KENO code and USL was determined. As a result of validation process, k_{eff} should be satisfied the following condition for being subcritical:

$$k_{eff} = k_{calc} + 2\sigma_{calc} < 0.9419 \qquad (3)$$

4. Evaluation objects

According to the general arrangement of large-scale pyroprocess facility which was developed from pre-conceptual design, temporary spent nuclear fuel assembly (SFA) storage vault and product (U ingot and U/TRU ingot) storage cell which has a high priority for the nuclear criticality safety were evaluated. The capacity of temporary SFA storage vault is up to 48 SFAs corresponding to 20 tHM. For the storage of product such as U ingot and U/TRU ingot, KAERI developed the vessel consists of inner-canister and container. Design requirements of product storage cell demand that 1 year of production for U ingot and 1 quarter for U/TRU ingot should be temporary stored. Thus, the amount of containers produced by designed storage container is 180 and 13, respectively. Source term were calculated by material flow sheet of pyroprocessing and ORIGEN code. Normal condition and abnormal condition which means flooding were evaluated respectively.

5. Results

Table 2 and 3 shows the results of k_{eff} of temporary SFA storage vault and product storage cell, respectively. All area indicates being subcritical under the normal and abnormal condition by calculated k_{eff} and equation (3).

Table 2. Calculated k_{eff} of temporary SFA storage vault

	Standard SFA (PLUS7, 10 years cooling)	Fresh fuel(PLUS7)
Normal	0.126056 ± 0.000093	0.15717 ± 0.00012
External flooding	0.34487 ± 0.00024	0.51832 ± 0.00027
Internal and external flooding	0.58022 ± 0.00033	0.91645 ± 0.00036

Table 3. Calculated k_{eff} of product storage cell

	U ingot container	U/TRU ingot container (1 quarter)	U/TRU ingot container (1 year)
Normal	0.26472 ± 0.00014	0.59457 ± 0.00033	0.62865 ± 0.00031
External flooding	0.33472 ± 0.00023	0.64929 ± 0.00033	0.67895 ± 0.00039
Internal and external flooding	0.35154 ± 0.00023	0.69687 ± 0.00034	0.70626 ± 0.00036

6. Conclusion

Criticality evaluation concerning the high priority area of large-scale pyroprocess facility was performed by pre-conceptual design data and Monte Carlo codes. The results indicate that there are no criticality risks corresponding to temporary SFA storage vault and product storage cell under any condition. However, the nuclear criticality safety of a storage arrangement requires a very careful contingency analysis as well as k_{eff} calculation. To reach a criticality safety conclusion requires a detailed nuclear criticality safety evaluation where credible contingencies are evaluated.

REFERENCES

[1] ORNL/RSICC, SCLAE 6.1.2, 2013.

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[4] USNRC, Guide for validation of nuclear criticality safety calculational methodology, NUREG/CR-6698, 2001.

[5] W.J. Marshall and B.T. Rearden, Criticality Safety Validation of SCALE 6.1, ORNL/TM-2011/450, 2011.