Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2018

Critical Assessment of Transuranic Element Storage Facility with Wet Conditions: Monte Carlo Study.

Kilyoung Ko [a], Jinwhan Kim [a], Wooseub Kim [a], Seongkyu Ahn [b], Sehwan Park [b], Gyusung Cho [a*]
[a] *Dept of Nuclear & Quantum Engineering, Korea Advanced Institute of Science and Technology., Daejeon 291*
[b] *Korea Atomic Energy Reserch Institute, KAERI ., Daejeon 34057*
[*] *Corresponding author: gscho@kaist.ac.kr*

1. Introduction

As part of Reference Engineering-scale Pyroprocess Facility (REPF) project of Korea Atomic Energy Research Institute (KAERI), we are investigating transuranic element storage in a pyroprocess facility. There are variety methods to reprocess Spent Fuel (SF). Among them, the idea of pyroprocessing was suggested in order to prevent risk of nuclear proliferation, relevant to Plutonium by extracting Plutonium and Uranium together.

The production of pyroprocessing is metal fuels for the sodium cooled fast reactor (SFRs) while keeping intrinsic proliferation resistance [1]. KAERI is currently revising REPF with the goal of realizing a facility on a larger scale capable of treating 30 ten tons of heavy metal (tHM) per year. As of now a lot of issues related to the safety of pyroprocessing have been studied but safety issue in relation to TRU storage has not yet been studied a lot [2-5]. Furthermore, Study of SFs in a reform state i.e., TRU ingots generated from pyroprocessing does not conduct in depth [6].

In the present paper, we report on the potential effect of low-density water on transuranic element storage related to nuclear criticality. Such wet conditions could occur due to deluge, flood, tsunami and preferential flooding events et cetera. Typical water densities for various forms are presented in Table I. Previous study was focused on criticality safety issue in relation to geometry such as the number of stacked canister, arrangement and TRU H/R ratio in TRU storage. We assumed simulation conditions from previous study. Details pertaining to configurations and methods of the simulations are described in the following sections.

Table I: Density of Various Water Forms

Water Form	Density of Water (g/cm^3)	
	Range	Typical
Direct stream	4×10^{-3} to 1.0	---
Overhead sprinkler	8×10^{-4} to 1.0	---
Flood	---	1.0
Falling Rain	3×10^{-8} to 3×10^{-3}	3×10^{-5}
Natural Fog	1×10^{-11} to 2.5×10^{-3}	1×10^{-6}
Fog nozzle	8×10^{-4} to 2.5×10^{-3}	---

2. Material and Methods

2.1 Criticality Calculation

In this study, the criticality analysis for a storage facility is performed with Monte Carlo simulation. MCNP6 1.0 was used for Monte Carlo simulation to evaluate criticality. MCNP has been widely used for many years now in nuclear engineering to perform complex criticality studies and calculations. The nuclear cross-section libraries. ENDF/B-VII.1 are utilized in simulations and $S(\alpha,\beta)$ thermal neutron cross-sections were applied to hydrogen in a water molecule.

All criticality calculations employed 10,000 neutrons per cycle. Moreover, the initial 1000 cycles were discarded for convergence before the k_{eff} tallies, and 500 active cycles were run to prevent bias in the k_{eff} calculations. [7-8]

2.2 Simulation Conditions

A TRU ingot is the metal-form product generated from the spent fuel assemblies used in the pyroprocess. The TRU ingot was assumed to be placed within a stainless steel (STS304) canister, and the canisters were stacked vertically inside a stainless steel (STS304) container, as shown in Fig. 1 (a). It was assumed that the number of stacked is three. The array of containers was assumed to have a square lattice pattern, as shown in Fig 1 (b). The thicknesses of the canister and the container were assumed to be 10 mm and the container dimensions are just large enough to hold the canisters. The total production of TRU ingots per year is 250 pieces based on an annual throughput of 30 tHM. For the purposes of this work, the inventory was assumed to accumulate for up to three years. Vault for storage is 300 cm x 300 cm x 50 cm. Material composition of TRU ingot is presented in Table II.

Table II: Primary radionuclides of the TRU ingot

Radionuclide	W/O (%)
^{238}U	18.4
^{237}Np	4.0
^{239}Pu	29.6
^{240}Pu	14.0
^{241}Pu	5.5
^{242}Pu	4.8
^{241}Am	3.7

2.3 Simulation Scenario

Three scenarios are postulated for TRU storage facility. In the first scenario, water is introduced uniformly into storage until height of highest stacked TRU ingot. In the second scenario, water is introduced into storage until it is in a fully flooded condition, while the inside of canister remain dry. Final scenario considers the simultaneous introduction of water into storage and canister inside.

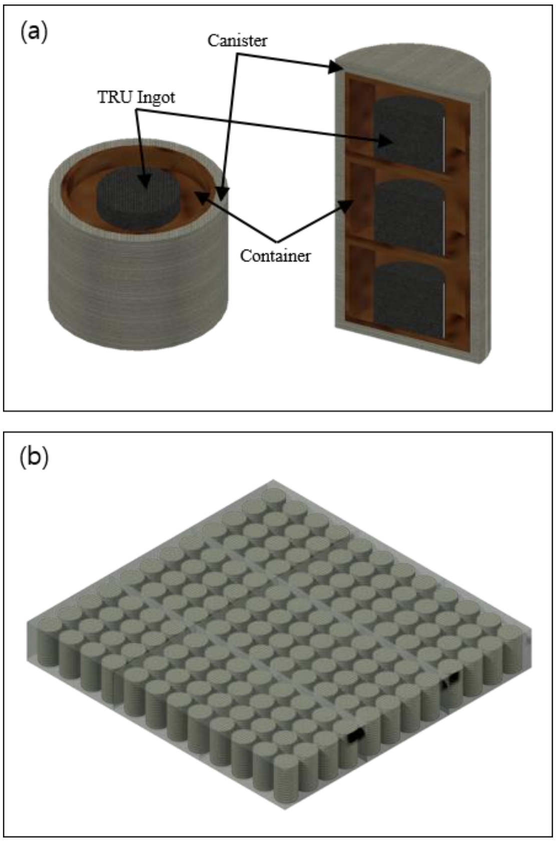

Fig. 1. (a) Canister filled with TRU Ingot horizontal and vertical cross-sectional view. (b) Canisters array view in the storage facility.

3. Result and discussion

3.1 Criticality

The result of this series of calculations are shown graphically in Fig 2 (a) and the result of commercial PWR fuel with 3 % concentration is shown in Fig 2 (b). The K_{eff} of all scenarios for TRU storage reached their peak with low density water. In contrast, K_{eff} of commercial fuel increased as water density increases typically. Depending on the scenario, the water density could be the same but make a difference of nearly 10 %. In addition, depending on the density of the water, it is possible to make a difference of around 15 % in the same scenario.

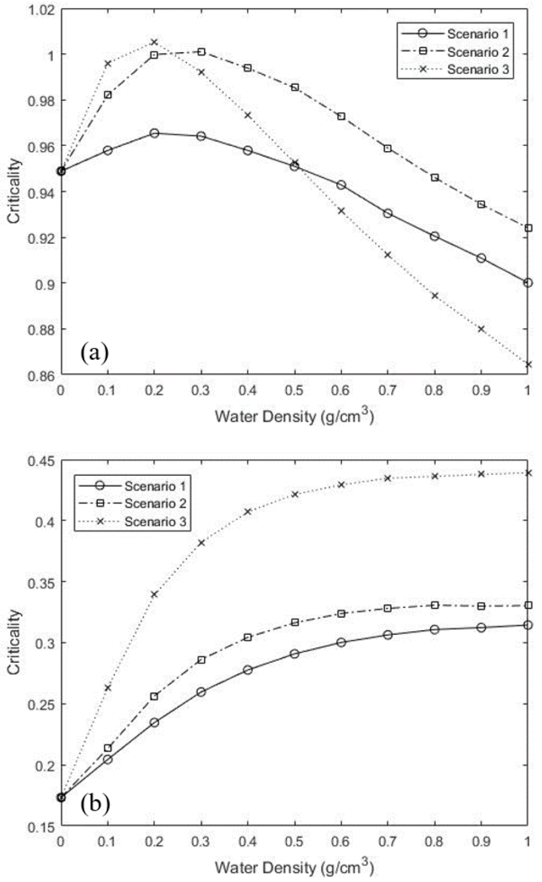

Fig. 2. (a) K_{eff} of scenarios with TRU ingot in TRU storage. (b) K_{eff} with 3% concentrated PWR fresh fuel in TRU storage,

3.2 Neutron Spectrum analysis

We conducted spectrum analysis to identify critical increase in low-density water. Neutron spectrums were calculated in TRU ingot using MCNP F4 tally with the third scenario. The neutron group structure is the 199-group SCALE CODE structure with one extra group added to bring the upper group boundary to 20 MeV. Neutron spectrums are shown in Fig. 3

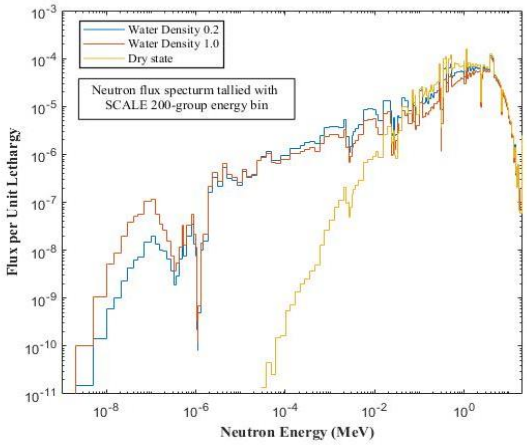

Fig. 3. Neutron spectra in the second scenario

In the Figure 3, Lethargy is defined as the natural logarithm of ratio of maximum energy that a neutron might have in a nuclear reactor to the neutron energy.

One may observe from Figure 3, that the spectrums with water density 0.2 g/cm^3 and 1.0 g/cm^3 are shifted to low energy due to moderation effect of water. To compare probability of distribution of neutron and ratio in the neutron spectrum, we conducted normalization of probability and divided into three energy ranges, thermal neutron (~ 1 eV), epi-thermal neutron (~ 100 keV) and fast neutron (~ 20 MeV), the results were presented in Table 3.

Table 3: Normalized probability of neutron distribution and distribution ratio of each range.

States	Thermal	Epi-thermal	Fast
	Normalized probability of neutron distribution		
	Distribution ratio		
Wet state with water density 0.2	*5.00E-08*	*2.59E-05*	*1.17E-04*
	0.035 %	*18.083 %*	*81.868 %*
Wet state with water density 1.0	*1.19E-07*	*1.06E-05*	*5.86E-05*
	0.172 %	*15.274 %*	*84.554 %*
Dry state with Ar gas	*0.00E+00*	*1.35E-05*	*1.80E-04*
	0.000 %	*6.938 %*	*93.062 %*

Despite wet state with water density 0.2 g/cm^3 shows higher criticality than dry state one in Fig. 2, probability of fast neutron distribution in dry state is higher than wet state. That is, fast neutron are not only factor to determine criticality. We tried to analyze the cause that affect criticality increase with low-density water in TRU storage facility. Pu-239 is good fissile material in thermal region also because of its high cross section. For this reason, firstly we focused on thermal region neutron.

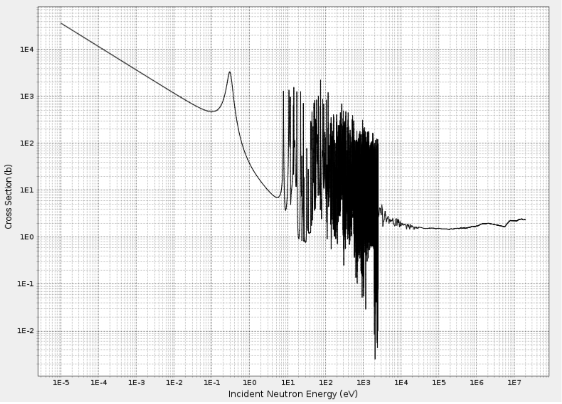

Fig. 4. Fission Cross Section of Pu-239 from http://atom.kaeri.re.kr (ENDF/B-VII. 1)

3.3 Neutron energy cut-off

MCNP KCODE cannot determine the energy spectra of emitted neutrons so we conducted simulation with energy cutoff card. Energy cutoff card is method to terminate particle that below the energy cutoff. We set up cutoff level to 1 eV for ignoring effect of thermal region neutrons. As a result of above simulation are shown in Fig. 5.

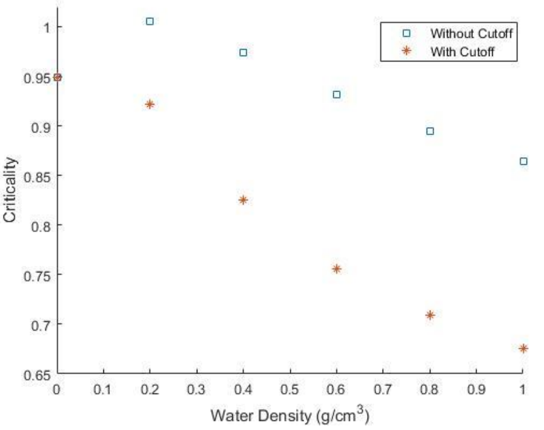

Fig. 5. Critical change with cutoff card

Although the portion of thermal region neutrons are tiny, 0.035 %, it affects criticality enormously, over 8 %. Furthermore, the variation of criticality grows larger as the density of water increase due moderated neutron portion is getting higher.

4. Conclusion

We are investigating a criticality issue with low density water in transuranic element storage of a pyroprocess facility. One of the reason of criticality increase with low density water is related to thermal neutron. But in this study, it could not explain overall process of neutron behavior and reason why criticality decrease in high density water region. So in the future study, we will conduct simulation study to find factors, being made trend of criticality.

ACKNOWLEDGEMENT

This work was partly supported by a National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIP) (NRF-2017M2A8A50 15084).

REFERENCES

[1] H.D. Kim, H.S. Shin, D.Y. Song, T.H. Lee, B.Y. Han, S.K. Ahn, S.H. Park, Application of Safeguards-By-Design for the Pyroprocessing Facilities in ROK, XL (2012) 24–31.

[2] R.A. Borrelli, Use of curium spontaneous fission neutrons for safeguardability of remotely-handled nuclear facilities: Fuel fabrication in pyroprocessing, Nucl. Eng. Des. 260 (2013) 64–77. doi:10.1016/j.nucengdes.2013.03.025..

[3] R.A. Borrelli, Use of curium neutron flux from head-end pyroprocessing subsystems for the High Reliability Safeguards methodology, Nucl. Eng. Des. 277 (2014) 166–172. doi:10.1016/j.nucengdes.2014.06.028..

[4] R.A. Borrelli, Functional components for a design strategy: Hot cell shielding in the high reliability safeguards methodology, Nucl. Eng. Des. 305 (2016) 18–27. doi:10.1016/j.nucengdes.2016.05.010.

[5] S.I. Moon, S.J. Seo, W.M. Chong, G.S. You, J.H. Ku, H.D. Kim, Identification of safety controls for engineering-scale pyroprocess facility, Nucl. Eng. Technol. 47 (2015) 915–923. doi:10.1016/j.net.2015.08.005.

[6] S.I. Moon, W.M. Chong, G.S. You, J.H. Ku, H.D. Kim, Y.K. Lim, H.S. Chang, Preliminary safety study of engineering-scale pyroprocess facility, Nucl. Eng. Technol. 46 (2014) 63–72. doi:10.5516/NET.06.2013.018.

[7] F. Brown, F.B. Brown, A Review of Best Practices for Monte Carlo Criticality Calculations, 836 (2009).

[8] R. Brewer, Criticality Calculations with MCNP5 TM : A Primer, World Wide Web Internet Web Inf. Syst. 836 (2009) 0–192.