Proliferation Resistance Analysis of Autonomous Small Modular Reactor Design Optimization

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1. Introduction

ATOM (Autonomous, Transportable, On-demand, Modular) reactor is a conceptual Small Modular Reactor (SMR), based on the Pressurized Water Reactor (PWR), which is currently advocated for further development by Korea Advanced Institute of Science and Technology (KAIST). When developing the design requirements of ATOM, Security/ Safeguards-by-design (SSBD) should be considered at the earliest stage of the design process to optimize the system. This paper evaluates the characteristics of various design options, in terms of cost, proliferation resistance and safeguardability. This paper evaluates the cost and proliferation resistance for selected scenarios for core design options.

2. Top-tier Core Requirements Development

Various core performance scenario were assumed to analyze the proliferation resistance and estimated cost for ATOM reactor. Table 1 shows the basic core performance of ATOM, which is based on Pressurized Water Reactor (PWR).

Table 1. Assumed Core Performance of ATOM for Calculation

Enrichment	4.95%
Capacity factor	85%
Power conversion rate	35.15%
Reactor life	60

Table 2 shows the core performance scenario for optimizing proliferation resistance and cost of ATOM.

Table 2. Core Performance Scenario of ATOM

Power (MWe)	100,150,200,250,300
Power density (KW/l)	60, 70, 80
Burnup (GWd/MTU)	33(1batch), 44(2batch), 49.5(3batch)
Cycle length (yr)	Dependent

3. Proliferation Resistance Evaluation based on TOPS Method

TOPS task force suggested the framework for evaluating proliferation resistance of various fuel cycle systems [2]. The evaluation criteria consist of 3 main categories (material barriers, technical barriers, institutional barriers) and 15 subcategories. Table 3 summarizes the difference of proliferation resistance by evaluating each subcategory.

Table 3. Proliferation Resistance Evaluation Results based on Core Design Scenario

Barriers	Evaluation Result
Radiological	Self-protection characteristics is maintained when core characteristics changes, since the spent fuel has similar constituent compared to PWR SF.
Mass and Bulk	The attractiveness of SF decreases when burnup increases. However, no significant change occurs in 5% enrichment/33~49.5 GWd/MTU range.
Isotopic	Pu-239 fraction decreases when burnup increases.

Facility Access	Proliferation resistance increases when autonomous level and cycle length increases.
Available Mass	The amount of nuclear material increases when power increases. However, the amount per unit electricity will remain same. If burnup increases, PR increases since the amount of nuclear material decreases.

For different core characteristics, mass and bulk and isotopic barrier changed significantly. Table 4 summarizes the value of mass and bulk barrier and isotopic barrier for different burnup scenarios.

Table 4. The Difference of Isotopic Barrier Value based on Burnup

Average Burnup	Isotopic Barrier			
	Critical Mass	Isotope Enrichment	Neutron Emission	Heat
MWd/MTU	Pu	Pu-239/Pu	(Pu-240+ Pu-242) / Pu	Pu-238/Pu
33000	Same	56.6	27.9	1.3
43000		52.5	30.3	2.0
53000		50.4	31.2	2.7

4. Conclusion

For SMRs, modular design concept is widely considered as viable option. However, security and safeguards aspects should be carefully considered for modular design concept. Fuel burnup and cycle length should be maximized to reduce cost and achieve high proliferation resistance. Cycle length is dependent to fuel burnup, and no trade-off has been found in terms of cost and proliferation resistance. Finally, when autonomous operation level is increased, the facility access level is decreased so that the proliferation resistance is increased and security cost (which is included in O&M cost) can be decreased. During the design process of ATOM reactor, refueling method of modular reactors and spent fuel monitoring should be deeply considered to achieve security/safeguards-by-design, while the rest of requirements are similar with other PWRs.

Acknowledgments

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT & Future Planning (No. NRF-2016R1A5A1013919).

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