PWR SF Transportation Optimization: the Effect of Constraint Variation on the Interim Storage Plan

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1. Introduction

A short-term solution to the wet storage saturation problem of older nuclear power plants (NPPs) is to construct additional on-site dry storages or off-site interim storages [1]. Assumed a single on-site dry storage with the same capacity for each NPP site in Korea, this work studies the effect of the limited on-site storage capacity and PWR SF movement on the off-site interim storage plan by solving a dynamic optimization problem for the PWR SF transportation with the constraint variation

2. Korean Phase-out Scenario

Based on the present governmental policy on the nuclear energy, total 29 NPPs (25 PWRs and 4 PHWRs) are expected to be operated until their lifetime without life extension or addition of new fleets (Fig. 1) [2]. According to this, the accumulated SFs generated from PWRs are expected to reach about 27,000 tHM.

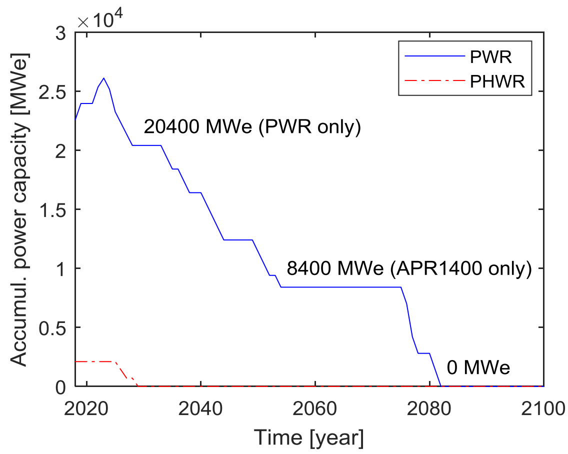

Fig. 1. Accumulated power capacity in the phase-out scenario.

In the Basic Plan on HLW Management (draft) [3], the expected time of wet storage saturation for each NPP site and the construction plan for the off-site interim storage is specified. But since the interim storage plan is based on the time required for siting the storage facility, it is necessary to validate the plan with the future predictions for the PWR SF generations and transportations between hypothetical storages under the nuclear phase-out scenario. In addition, the limitations of the on-site storage capacity and PWR SF movement should be considered in validating the interim storage plan.

3. Dynamic Optimization

Assumed a single dry storage per each NPP site, the required construction times for the on-site dry storages and off-site interim storage are obtained by solving a dynamic optimization problem for the PWR SF transportation. It is assumed that there is no additional installation of the compact rack for existing wet storages. And the on-site PWR SF transportation between wet storages is simplified by aggregating NPPs as a single fleet.

The first optimization problem is to maximize the delay of PWR SF transportation to a new on-site dry storage from the wet storage in each jth site, which can be formulated as follows,

$$\min_{m_{ds}(j,k),\forall k=t_0,\ldots,T} \sum_{k=t_0}^{T} |x_{ds}(j,k)| \tag{1}$$

subject to,

$$0 \le x_{ws}(j,k) \le x_{ws}^{u}(j,k) \tag{2}$$

$$0 \le m_{ds}(j,k) \le m_{ds}^{u}(j,k) \tag{3}$$

$$x_{ws}(j,k) = x_{ws}(j,k-1) - m_{ds}(j,k) + g(j,k) \tag{4}$$

$$g(j,k) = \frac{p(j,k)\times CF\times 365}{\varepsilon\times BU} \tag{5}$$

$$x_{ds}(j,k) = x_{ds}(j,k-1) + m_{ds}(j,k) \tag{6}$$

where $x_{ds}(j,k)$ is the accumulated SFs at time k in the jth site dry storage, $x_{ws}(j,k)$ is the accumulated SFs at time k in the jth site wet storage, $x_{ws}^{u}(j,k)$ is the upper boundary of $x_{ws}(j,k)$, $m_{ds}(j,k)$ is the amount of PWR SFs transported to the dry storage at time k in the jth site, $m_{ds}^{u}(j,k)$ is the upper boundary of $m_{ds}(j,k)$, $g(j,k)$ is the amount of PWR SFs generated at time k in the jth site, $p(j,k)$ is accumulated power capacity at time k in the jth site, CF is the capacity factor, ε is the efficiency, BU is the burn-up, t_0 is the current time, and T is the final time.

The second optimization problem is to maximize the delay of PWR SF transportation to a new off-site interim storage from the on-site storages, which can be formulated as follows,

$$\min_{m_{is}(j,k),\forall j=1,\ldots,N_s,\forall k=t_0,\ldots,T} \sum_{k=t_0}^{T} |x_{is}(k)| \tag{7}$$

subject to,

$$0 \le x_{ds}(j,k) \le x_{ds}^{u}(j,k), \forall j = 1,\ldots,N_s \tag{8}$$

$$0 \le \sum_{j=1}^{N_s} m_{is}(j,k) \le m_{is}^{u}(k) \tag{9}$$

$$x_{ds}(j,k) = x_{ds}(j,k-1) + m_{ds}(j,k) - m_{is}(j,k),$$
$$\forall j = 1,\ldots,N_s \tag{10}$$

$$x_{is}(k) = x_{is}(k-1) + \sum_{j=1}^{N_s} m_{is}(j,k) \tag{11}$$

where $x_{is}(k)$ is the accumulated SFs at time k in the interim storage, $x_{ds}^{u}(j,k)$ is the upper boundary of $x_{ds}(j,k)$, $m_{is}(j,k)$ is the amount of PWR SFs transported to the interim storage at time k from the jth site, $m_{is}^{u}(k)$ is the upper boundary of the sum of $m_{is}(j,k)$ for all sites N_s.

To see the effect of the constraint variations for the on-site dry storage capacity and PWR SF movement on the optimization result, we change $x_{ds}^{u}(j,k)$ in a range from 2000 tHM to 3000 tHM and $m_{ds}^{u}(j,k)$ in a range from 200 tHM/y to 1000 tHM/y. $m_{is}^{u}(k)$ is fixed with 1000 tHM/y because it doesn't affect the interim storage plan. Fig. 2 and Table 1 show representative results.

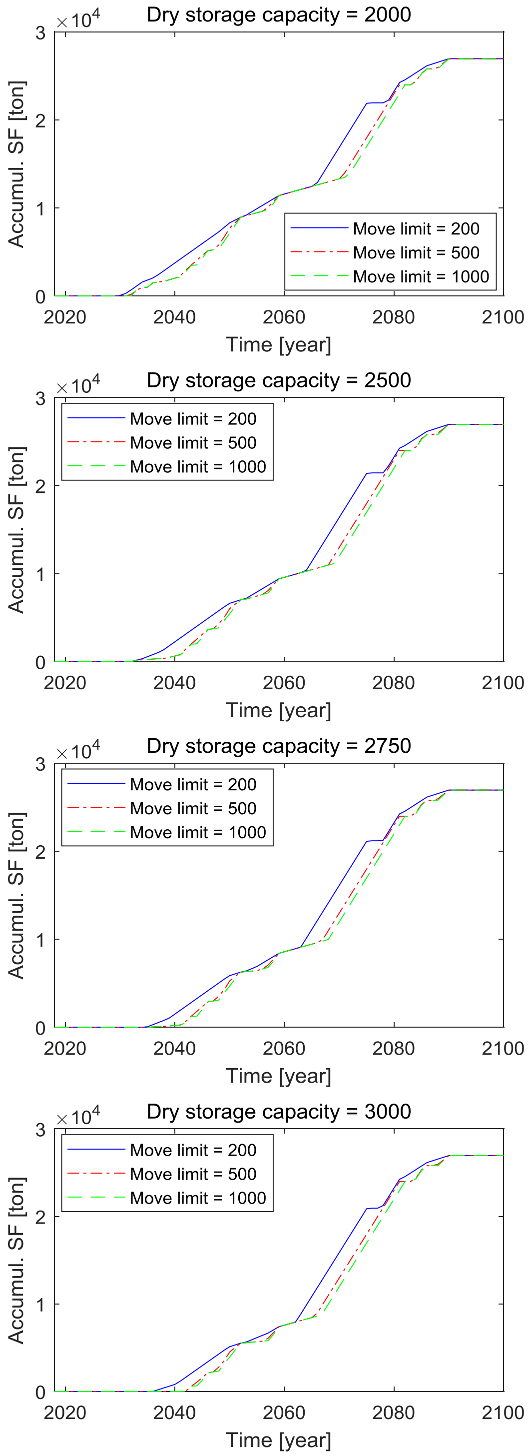

Fig. 2. Accumulated SF after the interim storage.

Table 1. Required construction time of the interim storage for different constraints for the on-site dry storage capacity $x_{ds}^{u}(j,k)$ and PWR SF movement $m_{ds}^{u}(j,k)$

$x_{ds}^{u}(j,k)$ [tHM]	$m_{ds}^{u}(j,k)$ [tHM/y]	Required time
2000	200	2030
	500	2032
	1000	2033
2500	200	2033
	500	2033
	1000	2033
2700	200	2034
	500	2034
	1000	2034
2750	200	2035
	500	2035
	1000	2035
2800	200	2035
	500	2037
	1000	2037
2900	200	2036
	500	2039
	1000	2039
3000	200	2036
	500	2042
	1000	2042

As shown in Fig. 2 and Table 1, the constraint variations for both on-site dry storage capacity and PWR SF movement affect the interim storage plan significantly. In particular, the constraint for the on-site dry storage capacity determines the latest construction time for the interim storage. And the impact of the constraint variation for the PWR SF movement higher than 500 tHM/y is negligible.

As a result, regardless of the PWR SF movement higher than 200 tHM/y, the on-site dry storage capacity should be more than 2750 tHM to follow the governmental interim storage plan (until 2035 [3]).

4. Conclusion

Under the Korean nuclear phase-out policy, the effect of the limitations of the on-site storage capacity and PWR SF movement on the interim storage plan was explored by solving a dynamic optimization problem of PWR SF transportation with the constraint variation. As a result, the constraint variation for the on-site storage capacity gave a significant impact on the interim storage plan. As a next step, the effect of the limitations of the interim storage capacity and PWR SF movement on the disposal plan will be studied.

REFERENCES

[1] MIT Nuclear Fuel Cycle Study Advisory Committee, The Future of the Nuclear Fuel Cycle: An Interdisciplinary Study, MIT, Boston, MA, US, 2011.

[2] MOTIE, The 8th Basic Plan on Electricity Demand and Supply (2017~2031), MOTIE, Seoul, Korea, 2017

[3] MOTIE, Basic Plan on High-level Radioactive Waste Management (Draft), MOTIE, Seoul, Korea, 2016.