Dynamic Optimization of the PWR SF Transportation With Constraints on Storage Capacity and SF Movement

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1. Introduction

Most countries including Korea where the national policy for the spent fuel (SF) is “wait and see” are now faced with a big problem in wet storage capacity of the nuclear power plant (NPP). One temporary solution for this situation is to construct additional on- or off-site dry storages [1]. Assumed a single dry storage with a fixed capacity per each site in Korea, this work estimates the required construction times of on- and off-site dry storages from dynamic optimization of the PWR SF transportation.

2. Korean Phase-out Scenario

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

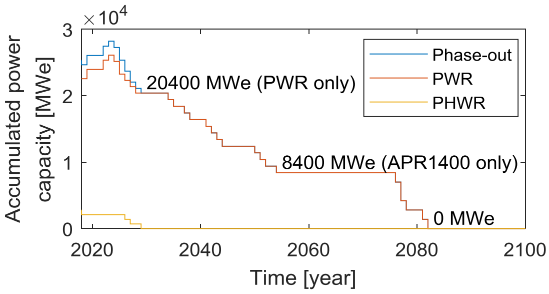

Fig. 1. Accumulated power capacity in phase-out scenario.

In the Basic Plan on High-level Radioactive Waste Management (draft) [2], the saturation times of wet storages in all sites and the plan for establishing an off-site dry storage (until 2035) are specified. But since the plan is based on the 7th Basic Plan on Electricity Demand and Supply [3], it is necessary to re-establish a construction plan for additional dry storages under the phase-out scenario (that is consistent with the 8th Basic Plan on Electricity Demand and Supply (draft) [4]). In addition, realistic limitations on the storage capacity and SF movement should be considered in the estimation of the required construction times for on- and off-site dry storages.

3. Dynamic Optimization

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

The optimization problem is to minimize the SF transportation to a new storage, which can be formulated as follows,

$$\min_{m_k \forall k=t_0,\ldots,T} \sum_{k=t_0}^{T} \left| x_{s,k} \right| \quad (1)$$

subject to,

$$0 \le x_{r,k} \le x_{r,k}^{u} \quad (2)$$

$$0 \le m_k \le m_k^{u} \quad (3)$$

$$x_{r,k} = x_{r,k-1} - m_k + g_k,\ g_k = \frac{p_k \times CF \times 365}{\varepsilon \times BU} \quad (4)$$

$$x_{s,k} = x_{s,k-1} + m_k \quad (5)$$

where $x_{s,k}$ is accumulated SFs at time k in the new storage s, $x_{r,k}$ is accumulated SFs at time k in the existing storage r, $x_{r,k}^{u}$ is the upper boundary of $x_{r,k}$, m_k is the amount of SF transportation at time k, m_k^{u} is the upper boundary of m_k, g_k is the amount of SFs generated by PWR at time k in the site, p_k is accumulated power capacity at time k in the 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. Limitations on the storage capacity and SF movement are set by $x_{r,k}^{u}$ and m_k^{u}.

All constraints are included in the on-site SF transportation problem (from wet storages to new dry storages) with 500 tHM/yr for m_k^{u} in the constraint (3). But the constraint (3) is excluded in the off-site SF transportation problem (from on-site storages to an off-site dry storage) because it doesn’t affect the estimated construction time of the off-site dry storage. Time-varying upper boundaries, $x_{r,k}^{u}$, in the constraint (2) are described in Fig. 3 with red lines.

As shown in Fig. 2, the required construction time of the off-site dry storage is expected to 2032. And the required construction times for the on-site dry storages are indicated in Fig. 3. It can be seen from the result that, tight constraints on the on-site dry storage capacity and SF movement could pull the required construction time for the off-site dry storage.

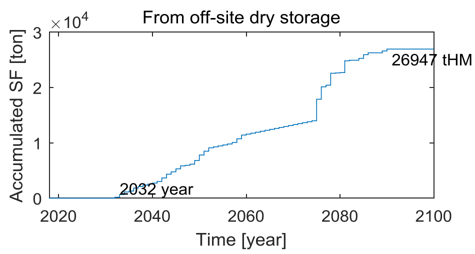

Fig. 2. Accumulated SF from the off-site dry storage.

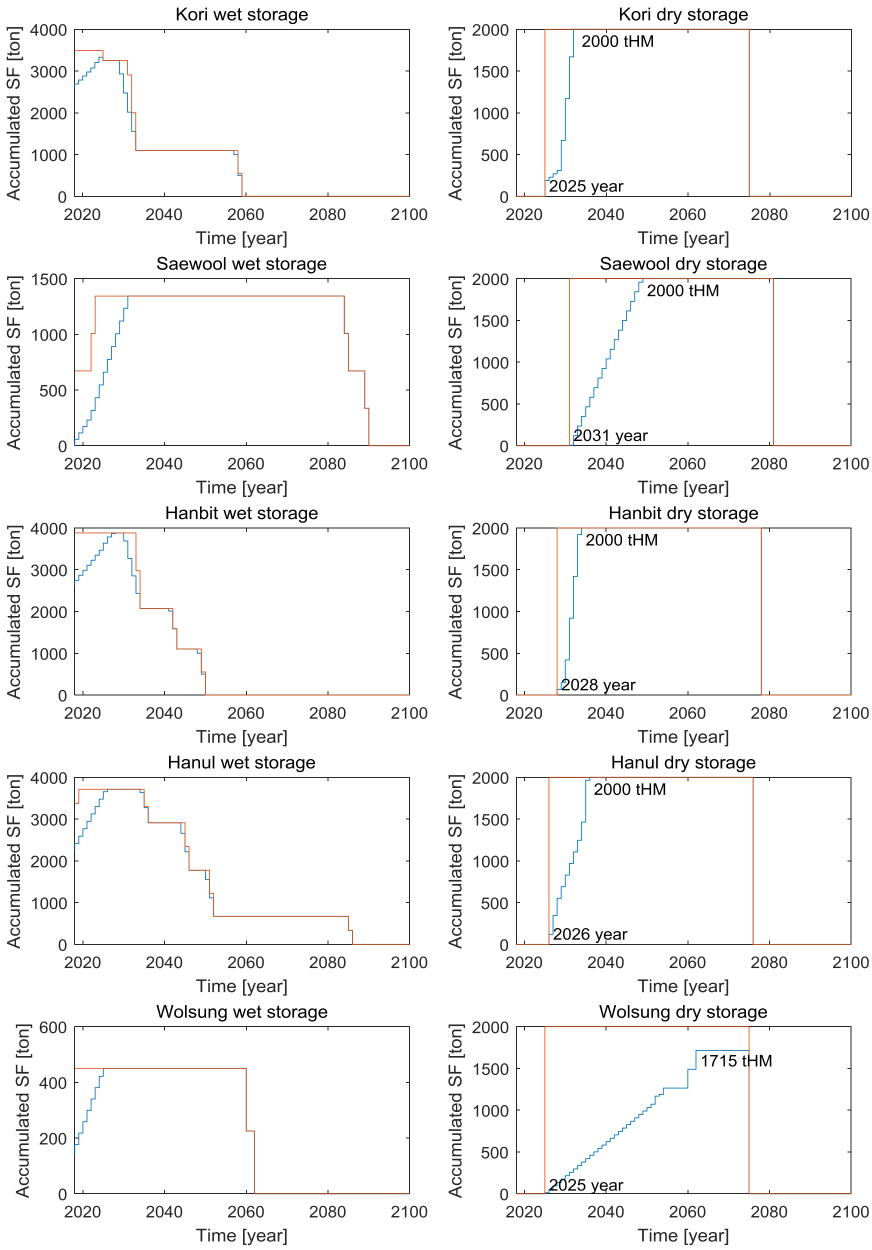

Fig. 3. Accumulated SFs of on-site wet and dry storages (blue line: accumulated SFs, red line: upper boundary).

4. Conclusion

Under the national nuclear phase-out policy, the required construction times of on- and off-site dry storages for PWR SFs were estimated by solving a dynamic optimization problem. In particular, tight constraints on the storage capacity and SF movement were applied to see the effect on the estimated construction times of the dry storages. As a next step, the effect of various limitations on the storage capacity and SF movement will be analyzed.

REFERENCES

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[4] MOTIE, The 8th Basic Plan on Electricity Demand and Supply (Draft), MOTIE, Seoul, Korea, 2017.