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Modelling nuclear refuelling for power systems studies,

Assumptions and implementation in Posy2

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Korea Nuclear Society Autumn Conference – October 2026

Nuclear refuelling in practice

- Depends on reactor technology
  - PWR/BWR: off-load refuelling
  - PHWR: on-load refuelling
- Typical PWR/BWR refuelling cycle
  - **12–18 months** between refuellings
  - **4–8 weeks** of refuelling outage
- **More than fuel replacement**
  - Maintenance and inspection are also performed during the outage
- **Scheduling matters**
  - Planned outages are preferably aligned with seasonal off-peak periods

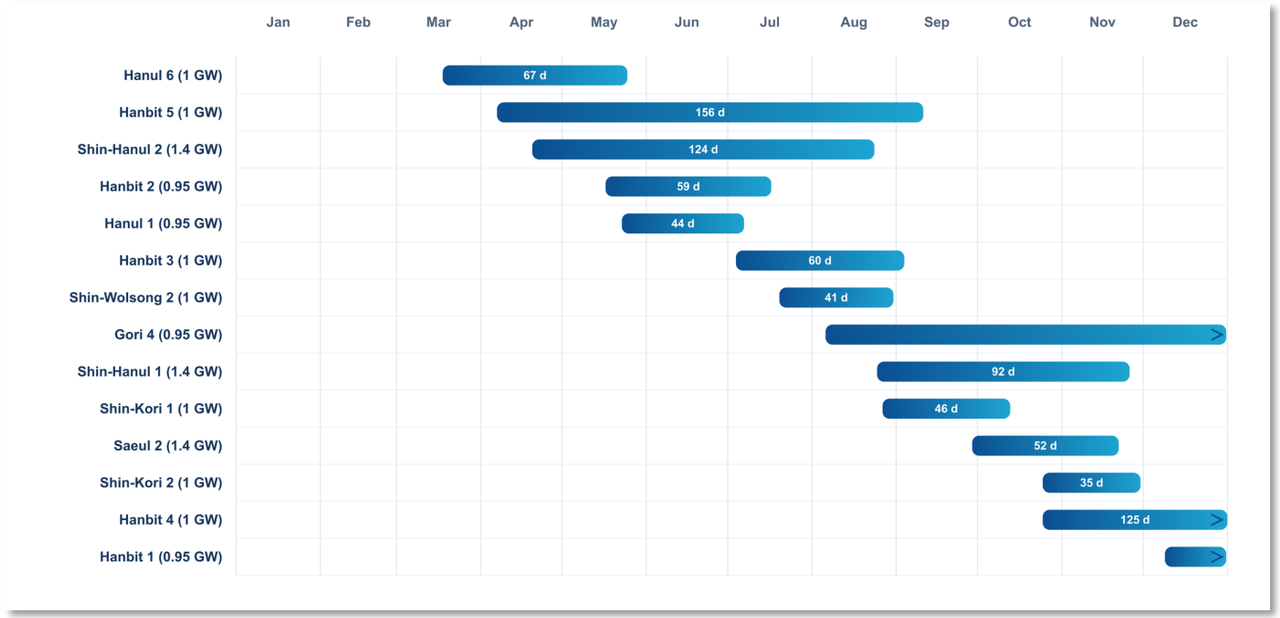


Figure 1. Historical planned maintenance outages of Korean nuclear units in 2025 (PWRs only)

[1] IAEA, Technical Reports Series No. 224
[2] Korea Hydro & Nuclear Power (KHNP), Planned Maintenance Status by Nuclear Unit (2011–2025), public data release, 9 June 2026.

Nuclear unit commitment in Posy2

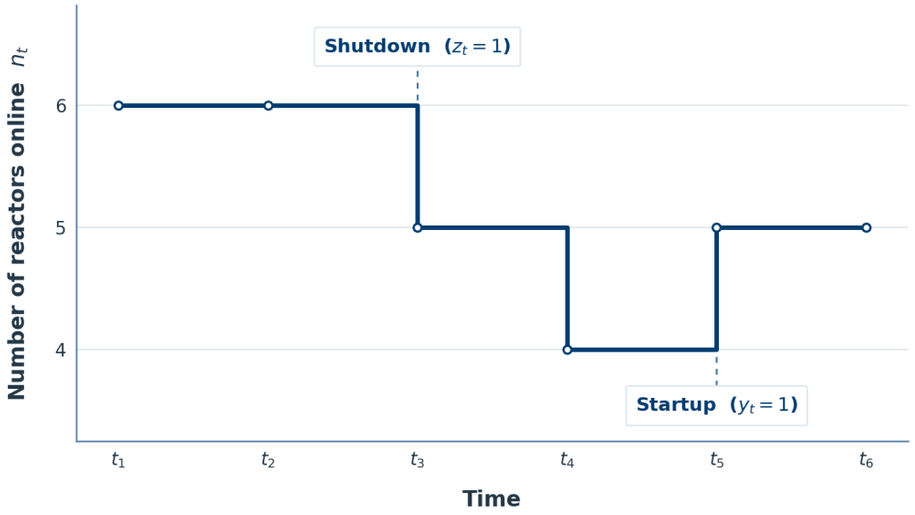
- **Unit commitment**
  - n_t: number of reactors online at hour t
- **Startup and shutdown decisions**
  - y_t : number of reactors starting up at hour t
  - z_t : number of reactors shutting down at hour t

$$n_t = n_{t-1} + y_t - z_t$$

- **Generation limited by committed reactors**

$$n_t P^{\min} \leq p_t \leq n_t P^{\max}$$

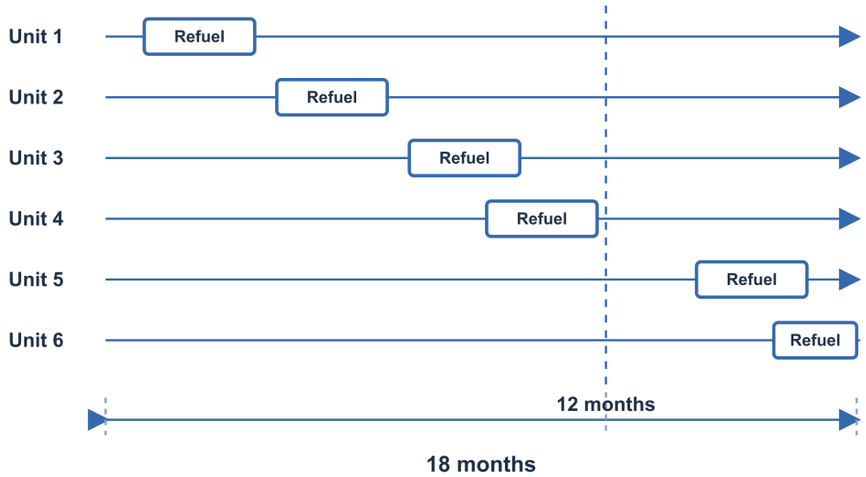
Time	t_1	t_2	t_3	t_4	t_5	t_6
n_t	6	6	5	4	5	5



Nuclear refuelling – assumptions

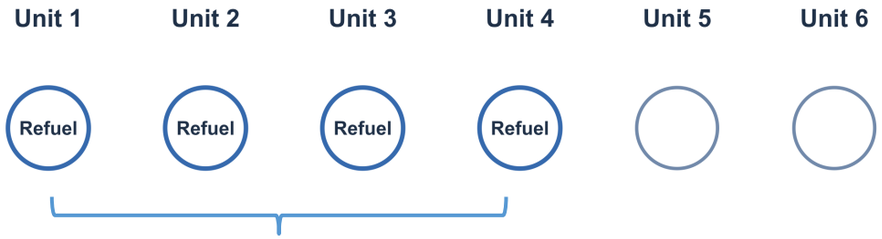
Physical interpretation	Posy2 representation
PWR refuelling cycle ≈ 18 months	≥ 2/3 of units/year
Multi-week refuelling outage	≥ 35-day outage
Refuelling requires shutdown	Unit commitment shutdown event
On – load refuelling	No refuelling shutdown constraint

Real operation (per reactor)



Each unit refuels about once every 1.5 years

Posy2 approximation (fleet level)



At least 4 refuelling shutdowns per year

N units → **≥ 2N/3 refuelling shutdowns per year**

Smoothed availability vs. Optimised refuelling schedule

- **Annual availability factor**
  - Smooth reduction in nuclear capacity throughout the year
- **Optimised refuelling**
  - Multi-week loss of capacity with optimised timing
- **At annual peak demand**
  - **1.83 GW more nuclear capacity available** with optimised scheduling
- **During low-demand refuelling periods**
  - **4.21 GW more nuclear capacity unavailable**

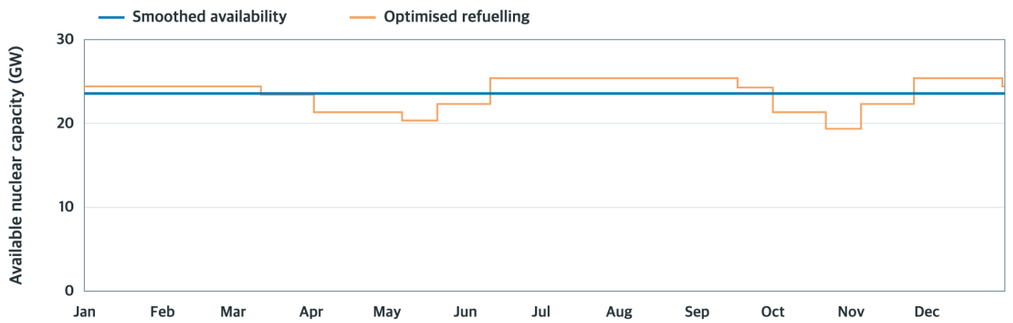


Figure 2. Available nuclear capacity over the year

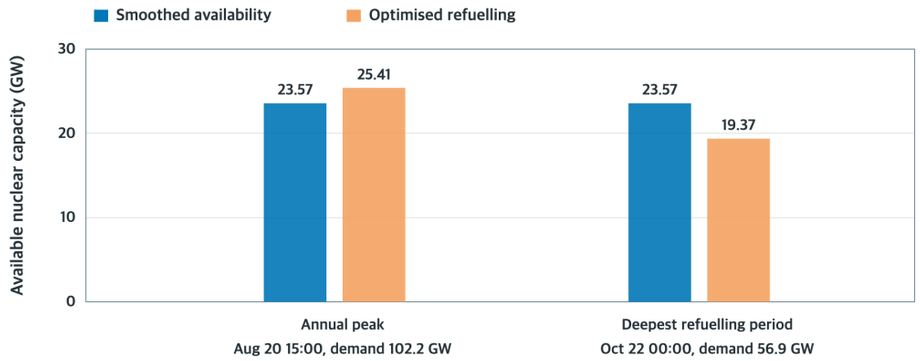


Figure 3. Available nuclear capacity at two critical hours

→ Same annual loss, different system impact over time

Fleet-wide refuelling scheduling

- **Optimisation of the refuelling schedule**
  - Scheduling follows the redidual demand profile
  - **Peak residual demand period**
    : 25.4 GW available
  - **Low residual demand period**
    : 19.4 GW available
  - Refuelling outages are shifted towards periods of lower residual demand

→ At fleet level, the timing of refuelling outages provides scheduling flexibility

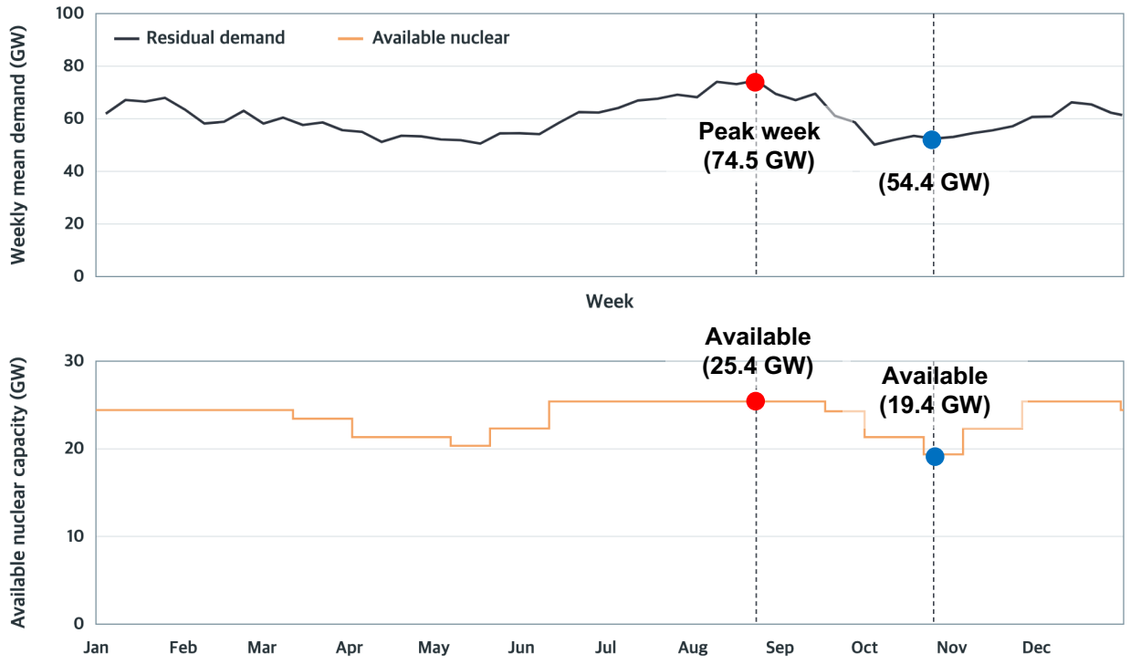


Figure 4. Weekly residual demand & optimised nuclear refuelling schedule (Korea, 2024)

Key takeaways

- Refuelling is a discrete, multi-week loss of nuclear capacity
- Annual availability factors do not capture the timing of these outages
- Optimised scheduling shifts refuelling towards lower-demand period

→ **Implemented in Posy2 and applied to the Korea system cost study**

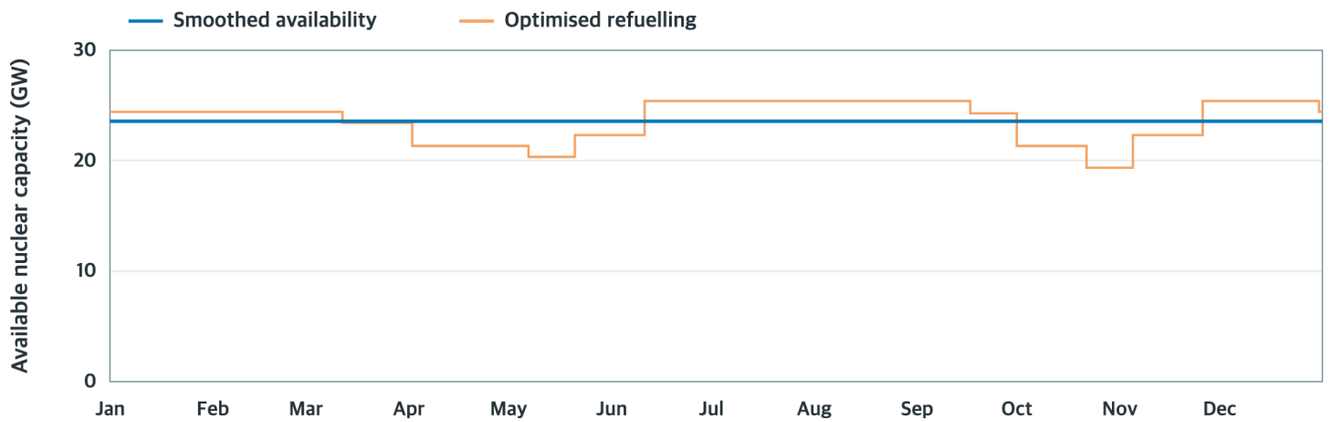


Figure 2. Available nuclear capacity over the year



Thank you