Federal Office
for the Safety of
Nuclear Waste Management

From Energy System Pathways to Spent Fuel Inventories: Scenario-Based Assessment of High-Level Radioactive Waste and Disposal Capacity

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Research Question and Analytical Framework

Research Question

How do alternative long-term energy pathways of selected countries (with later extension to the EU and additional cases) affect future nuclear spent fuel inventories and the consistency of geological disposal capacities?

Approach

1. **Harmonized baseline SNF inventory:** Compilation and standardisation of national spent fuel data from Joint Convention reports, including treatment of aggregated waste categories.

2. **Scenario-based nuclear electricity trajectories:** Linking baseline inventories to long-term energy system scenarios to derive country-specific nuclear electricity trajectories.

3. **Conversion to spent fuel quantities:** Translation of nuclear generation pathways into cumulative spent fuel quantities using IAEA-based factors and operational methods, including uncertainty

4. **Comparison with repository capacities:** Comparison of projected spent fuel inventories with planned geological disposal capacities to identify potential saturation risks.

Harmonised Spent Nuclear Fuel Inventory

Country		HLW	Unit	Spent Fuel	Unit	Period	Publication Year
Finland	...	0	m^3	2,488	tHM	31.12.2023	2024
France		4,420	m^3	15,031.7	tHM	31.12.2023	2024
			...				
Germany		507	m^3	16,711	tHM	31.12.2023	2024
	...						
Switzerland		115	m^3	1,716.0	tHM	31.12.2023	2024

Source: IAEA, Joint Convention National Reports 8th Review Meeting cycle (2025)

Objective
Establish a consistent, cross-country baseline of spent nuclear fuel inventories.

Data Source
Joint Convention National Reports (8th Review Meeting cycle)

Principle
Construction of a research-oriented dataset enabling comparability across countries despite heterogeneous reporting structures

Output
Baseline inventory per country:

$$SNF\ i, 0$$

Scenario-Based Nuclear Electricity Trajectories

Scenario	Core System Logic	Role of Nuclear Energy	Implication for SNF
Fully Renewable (in development)	RES-dominated transition	Fast phase-out	Very low / declining SNF
Go RES	Accelerated decarbonisation	Strong nuclear phase-down	Low SNF growth
REPowerEU++	Energy independence focus	Shrinking but persistent nuclear	Low-moderate SNF growth
EU Trinity	Constrained transition	Prolonged reliance before decline	Moderate SNF growth
Expansion Pathway (in development)	Nuclear growth strategy	Systematic expansion	High SNF growth

Source: Barani et al. (2026)

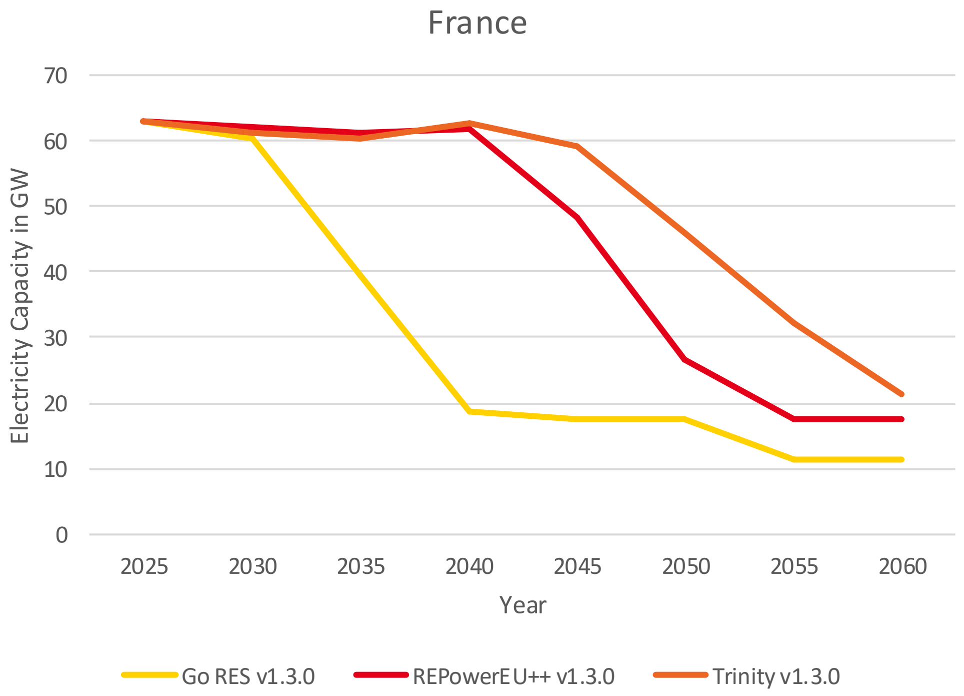
- Future nuclear electricity generation pathways were derived from long-term energy system scenarios reflecting alternative transition dynamics.
- For each country *i* and year *t*, nuclear electricity generation is represented as:

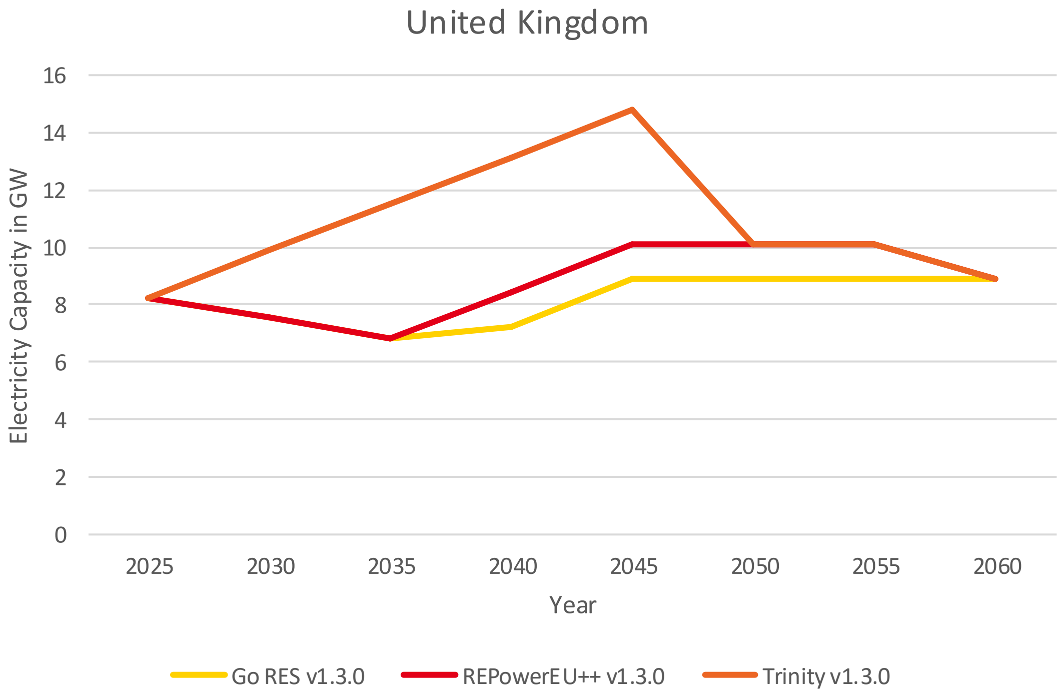
$$E_{i,t}^{nuc}$$

With:

$E_{i,t}^{nuc}$ is the annual nuclear electricity generation (TWh)

Scenario-Based Nuclear Electricity Trajectories





Source: Barani et al. (2026)

Conversion to Spent Fuel Quantities

Idea:
Spent fuel accumulation is derived from actual reactor operation, accounting for utilisation rates and installed capacities.

$$SNF = \sum_{r,y} \left(\frac{40}{0.75} \cdot LF_{r,y} \right) \cdot RFU_r$$

with:
$LF_{r,y}$: reactor load factor in year *y*
RFU_r: reference unit capacity of reactor *r*
Default load factor: 75% if unavailable

→ Captures empirical reactor performance and operational variability across countries and time.

Source: IAEA (2008)

Assumption:

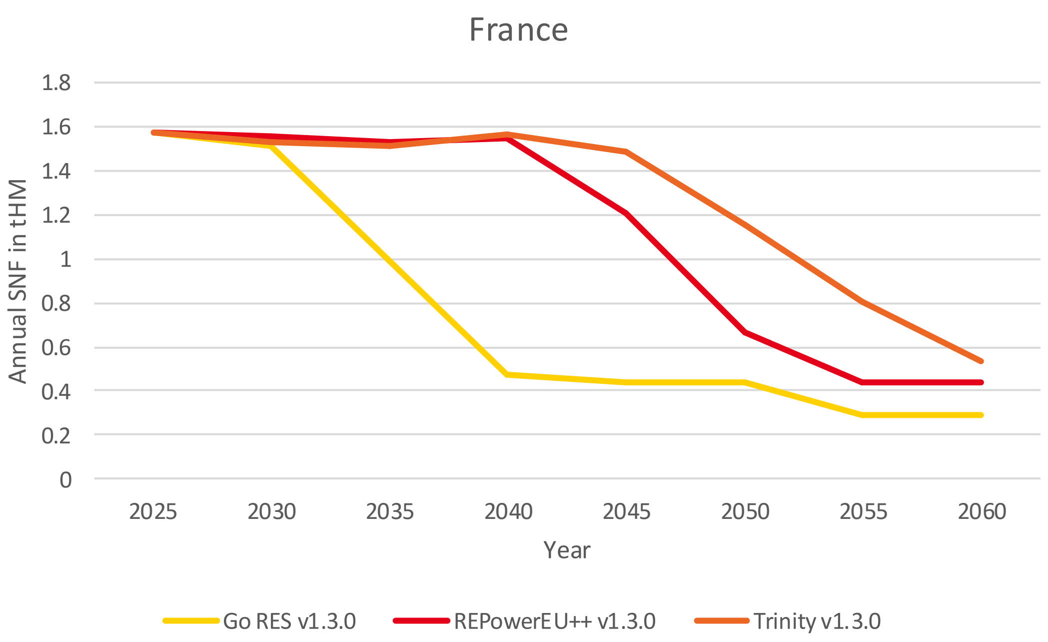
A reactor with a capacity of 1 GWe operating continuously produces:
1 GWe × 8760 h/year = 8760 GWh/year = 8.76 TWh/year

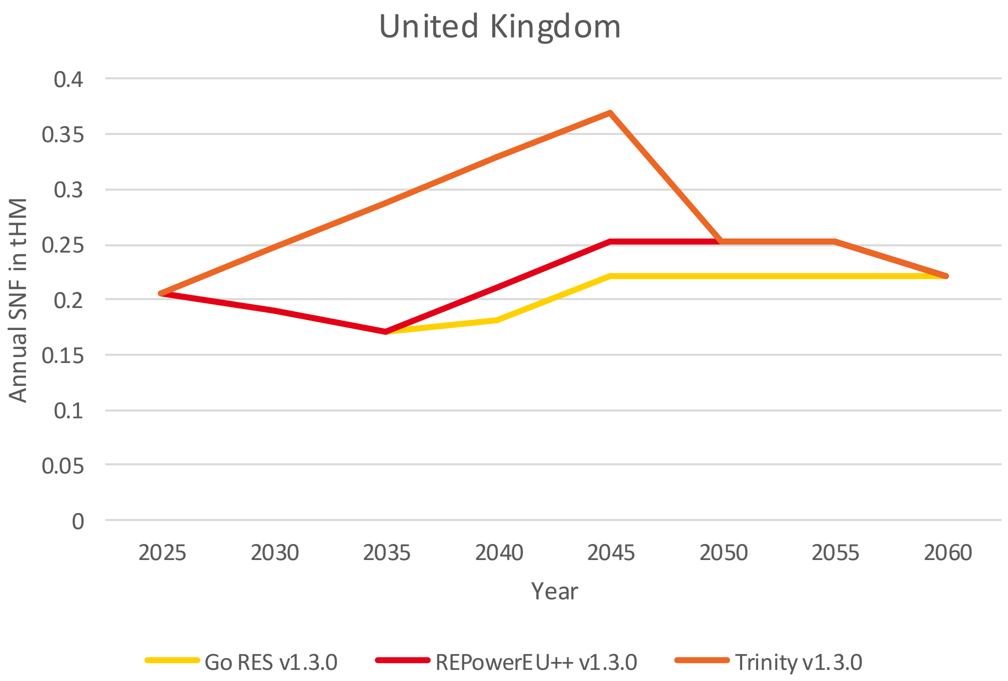
The IAEA reports a broad range of spent fuel arisings of approximately 30–50 tHM per GWe·year for light-water reactors, corresponding to 0.020–0.057 tHM/TWh.

For contemporary reactor fleets operating at higher burnup levels, a narrower range of 0.020–0.027 tHM/TWh is applied, with a central value of 0.025 tHM/TWh used for scenario projections in this work.

Preliminary Results of Selected Countries

Annual SNF in tHM





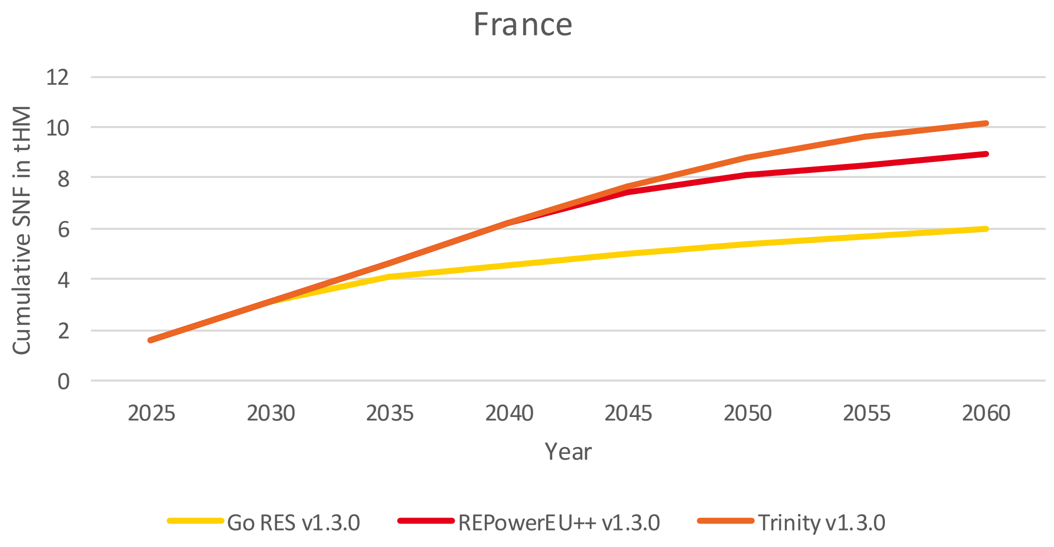
Source: IAEA (2008)

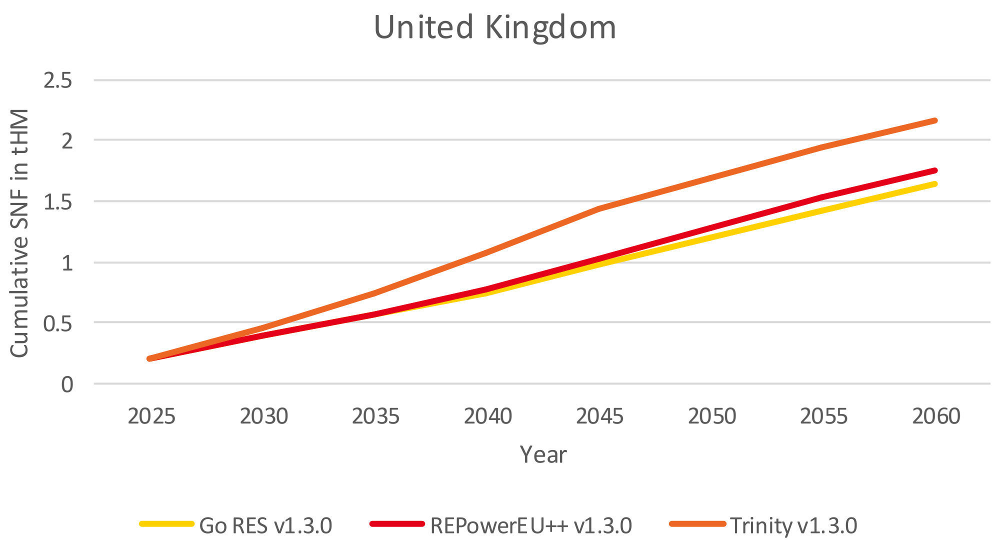
Preliminary Results of Selected Countries

Cumulative Spent Fuel Inventories

From annual generation to long-term waste inventories

$$SNF_{i,t} = SNF_{i,0} + \sum_{k=1}^{t} \Delta SNF_{i,k}$$





Source: IAEA (2008)

Repository Capacity Consistency

(work in progress)

Do projected spent fuel inventories remain consistent with existing and planned geological disposal capacities?

$$SNF_{i,t} \text{ vs. } C_i^{\text{repo}}$$

Source: IAEA (2008)

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Thank you!