Risk Assessment of Co-Siting Small Modular and Microreactors with Nuclear Fuel Cycle Facilities

Establishing the first empirical NFC risk baseline for co-siting decisions

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Co-siting is imminent — but its risk baseline is missing

- **SMRs / MMRs nearing deployment**

NuScale, Oklo, Kairos, Westinghouse, and others

- **NFC facilities are prime hosts**

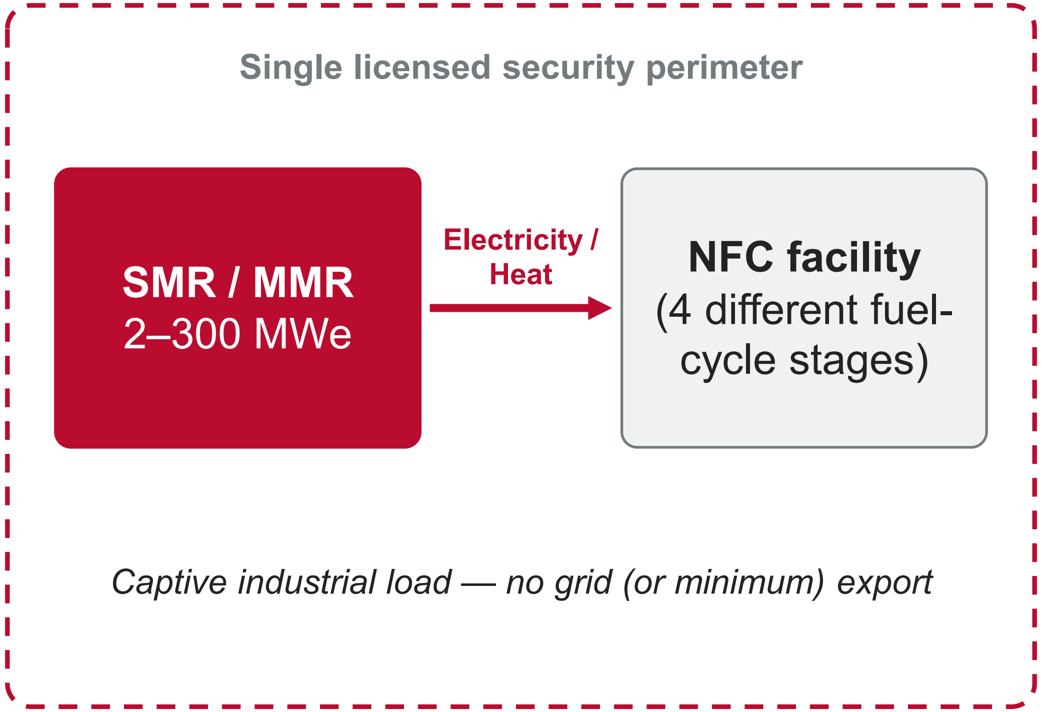
Electricity-intensive; already inside a licensed perimeter

- **Co-siting PSA needs the facility's risk profile first**

Yet no systematic global NFC risk database exists

- **This work builds that baseline**

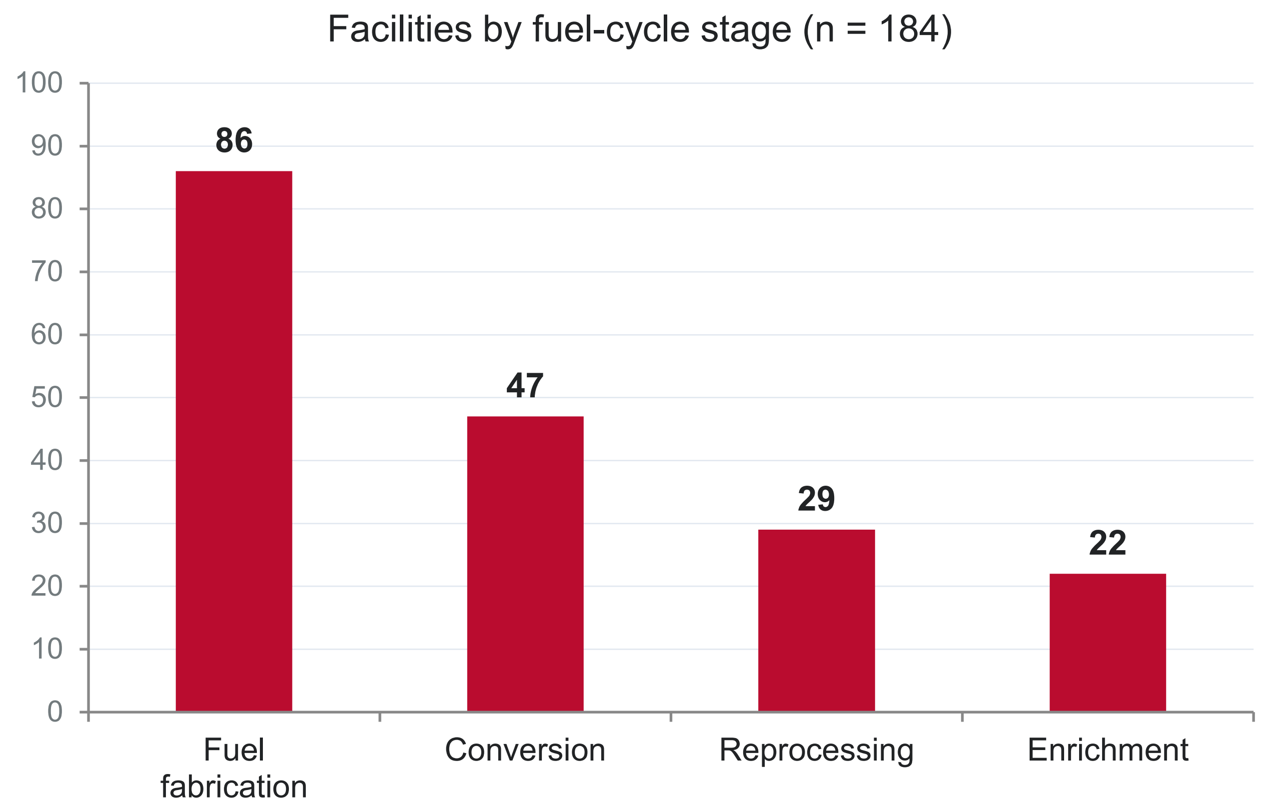
A precursor to a bidirectional reactor–facility PSA



Precedents: Bruce, Tricastin, Paducah

We built the first global NFC risk database

184 facilities · 16 countries · 80+ years of operating history



Database summary, 2024 reference year (Table 1)

- **Sources:** IAEA INFCIS, U.S. NRC, OECD/NEA, general literature
- **35 accidents · 101 fatalities** (1940s–2020s)
- **Two exposure metrics:** 3,881 status-based FY; 25,836 capacity-weighted FY
- **Monte Carlo UQ** (1,000 iter.) absorbs 58.7% missing end-dates → 90% CIs

Two facility-year denominators and Monte Carlo bound every risk metric

Exposure (facility-years)

- **M1 status-weighted** → 3,881 FY
- **M2 capacity-weighted** → 25,836 FY (6.66×)
- **Monte Carlo (1,000 iter.)** over 58.7% missing end-dates → 90% CIs

Status factors

In Operation 1.0 · Decommissioning 0.5 · Refurbishment 0.3 · Standby 0.25 · Shutdown / UC / Other 0.1 · Decommissioned 0.0

Risk metrics

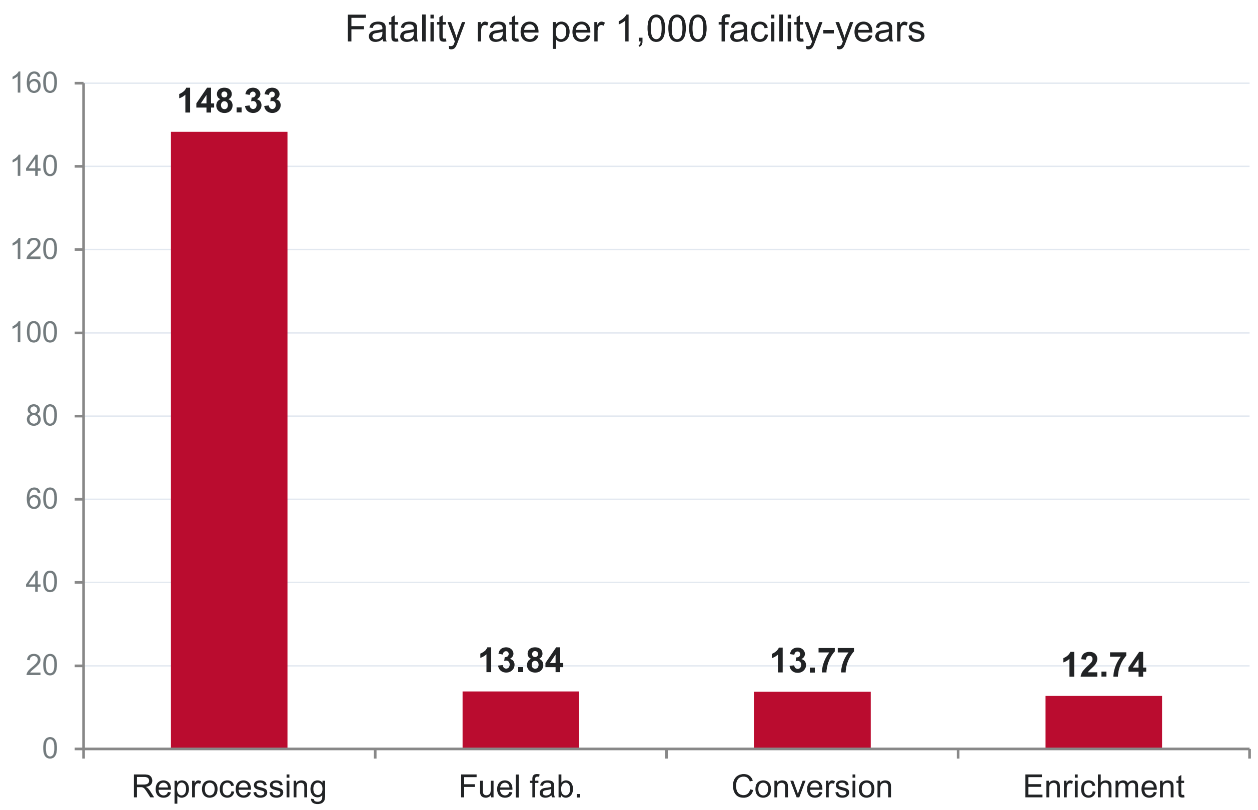
- Accident rate = accidents / 1,000 FY
- Fatality rate = accident rate × severity index
- Severity index = mean fatalities / accident = 2.89
- Accidents modeled as independent Poisson arrivals

Accident ↔ fatality r = 0.9958

frequency reliably tracks fatality risk

Reprocessing dominates NFC risk

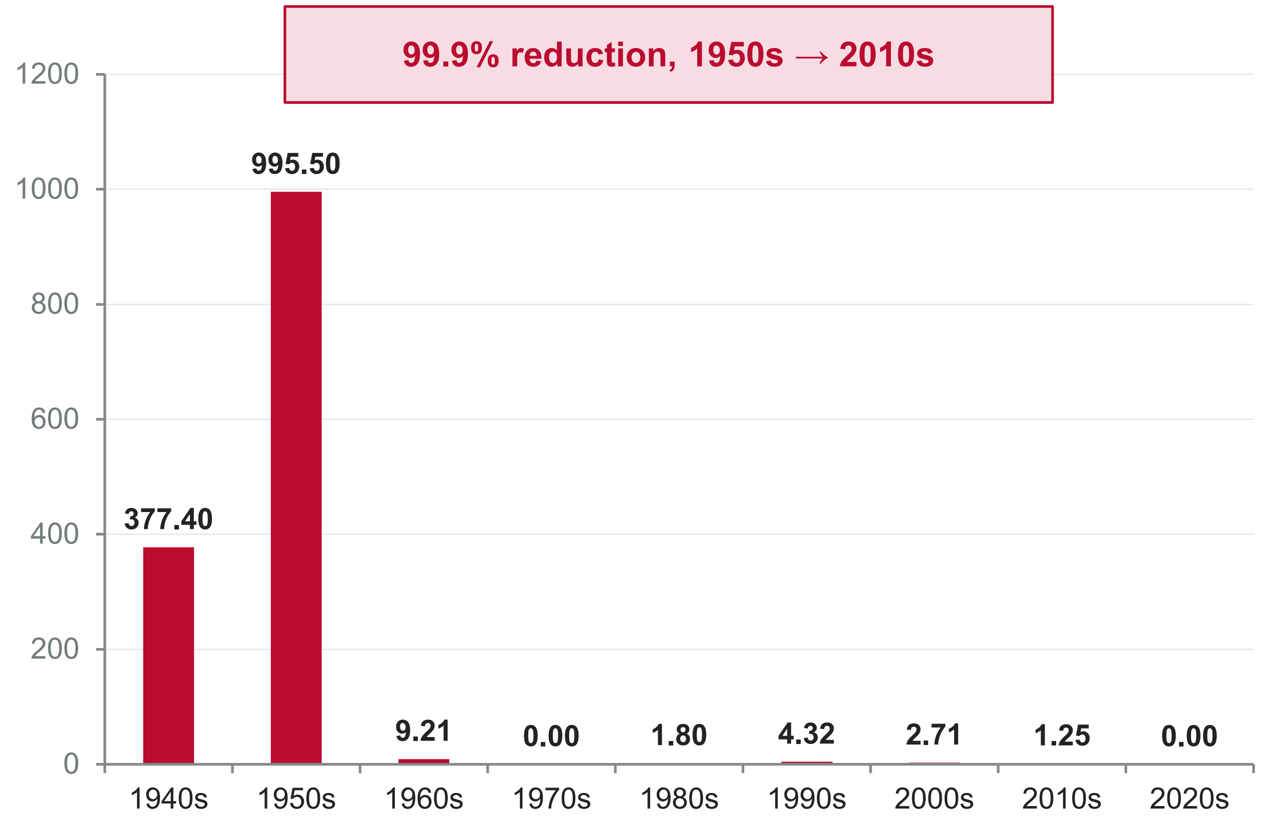
~148 fatalities per 1,000 facility-years — 10.7× any other stage



Risk metrics by stage, 2024 reference year (Table 2)

- **Other three stages statistically equivalent** (~13 / 1,000 FY)
- **Driver: PUREX chemistry + high-level liquid waste** (Cs / Sr source term)
- **Mayak 1957** dominates the reprocessing aggregate
- **Accident ↔ fatality r = 0.9958 →** frequency drives risk

NFC safety has matured 99.9% since the 1950s



Decade & regional fatality rates, 2024 ref. year (Figs. 2–3).

- **Two 1957 events** (UK Windscale and Mayak) = 87.1% of all fatalities

Risk tracks regulatory maturity

- **U.S. 14.56 / 1,000 FY** (upper bound); post-1990 zero fatal accidents
- **Japan 7.98 / 1,000 FY**
- **France 4.56 / 1,000 FY**
- **Others 1.39 /1,000 FY** — modern regimes lowest

A risk matrix ranks the four stages for co-siting

Stage	Fatality rate /1,000 FY	Primary hazard	Min. separation	Co-siting viability
Fuel fabrication	13.84	Criticality; UO_2 dust	Brownfield viable	**1 — entry point**
Enrichment	12.74	UF_6 pressurized inventory	≥ 400 m from UF_6	2 — strong
Conversion	13.77	HF toxic plume	400–1,700 m	3 — + HF screening
Reprocessing	**148.33**	PUREX HLW; Cs/Sr	Site-specific	**4 — full PSA required**

Fuel fabrication = the entry point; reprocessing requires a full site-specific PSA before co-siting.

Each stage maps to a defined regulatory pathway

Regulatory action by stage

- **Fuel fab. → ISA update** (NUREG-1520)
- **Enrichment → 10 CFR 70.64(b)** + pipeline freq.
- **Conversion → HF dispersion** + filtered intake
- **Reprocessing → full PSA** (10 CFR 70.61, $\leq 10^{-6}$ /yr)

Quantitative screening

- **Off-site dose ≤ 1 rem** per credible accident
- **HF IDLH 30 ppm at 1–2 km** → intakes outside plume
- **Overpressure < 0.01–0.02 bar** → no explicit analysis
- **Gas pipeline at 545 m** → $< 10^{-6}$/yr (NUREG-1827)

10 CFR 70.22(i) / 70.61; NUREG-1520 / 1827; IAEA SSR-4, SSG-35

Conclusions

Modern NFC sites are co-siting-ready — reprocessing excepted

1. **First global NFC risk baseline** — 184 facilities; the missing precursor to co-siting PSA
2. **Reprocessing is the singular high-risk stage** — 10.7× the others (historical data)
3. **99.9% maturation; risk tracks regulatory maturity** — modern sites suitable
4. **Co-siting risk matrix + regulatory pathways** — next: bidirectional reactor–NFC PSA
5. **Next:** Account for demonstrated industry learning and estimate current NFC risk from recent operating experience and plant-specific safety assessments (PSA/ISA)

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