Supplementary information for

First-of-a-Kind deployment prospects for small modular reactors

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Fig. S1. From heterogeneous SMR design-stage classifications to a harmonised five-phase development framework. The central portion of the figure shows SMR development phases and associated sub-phases based on International Atomic Energy Agency (IAEA) classification schemes, with colour shading indicating Conceptual, Basic and Detailed design phases (orange gradient) and post-design activities including licensing, construction and operation (blue gradient). The upper panel shows the sequential five-phase framework adopted in this study (Table S1) which distinguishes a design phase (Conceptual design, Basic design and Detailed design) from a post-design phase (licensing and construction). FOAK deployment is used here to denote the transition to First-of-a-Kind operation, capturing grid-connected commercial operation rather than demonstration milestones.

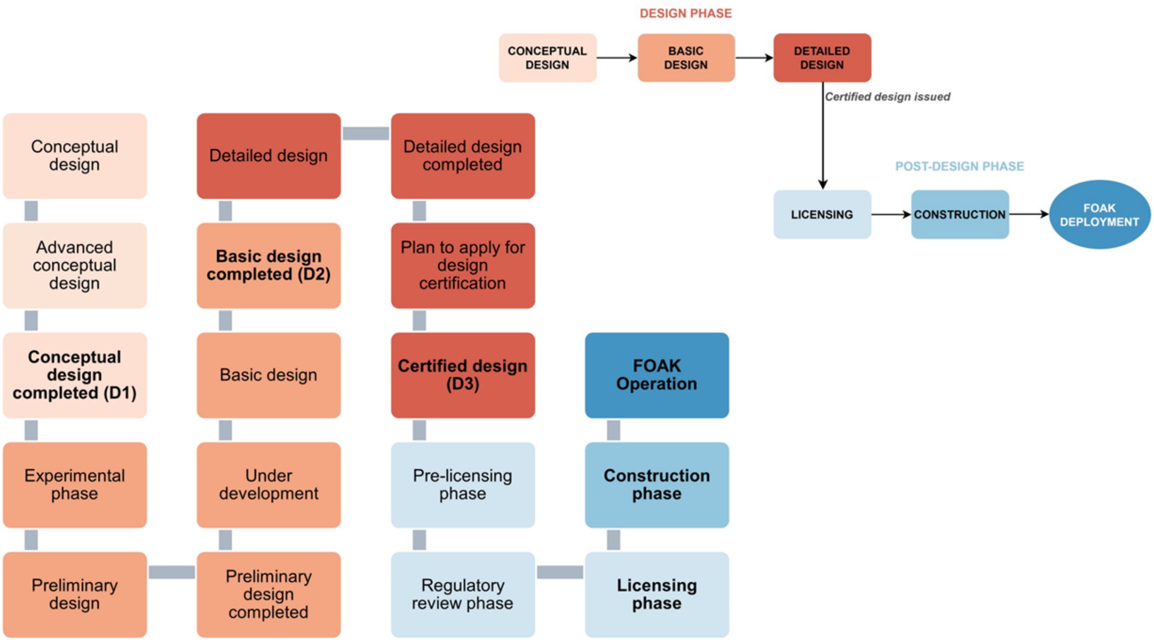


Fig. S2. Design-phase failure and stalled development across the SMR pipeline. Horizontal bars show observed progression of selected SMR designs through Conceptual, Basic and Detailed design phases between 1984 and 2025. Colour shading indicates development phase (Conceptual, Basic and Detailed design). Red crosses denote inactive designs, while grey triangles indicate stalled development, defined as designs that have not progressed beyond their most advanced recorded phase by the 2025 observation cutoff. Bars for inactive designs terminate within the phase in which failure occurred, whereas stalled designs extend to the observation boundary. Designs are ordered by Conceptual design start year.

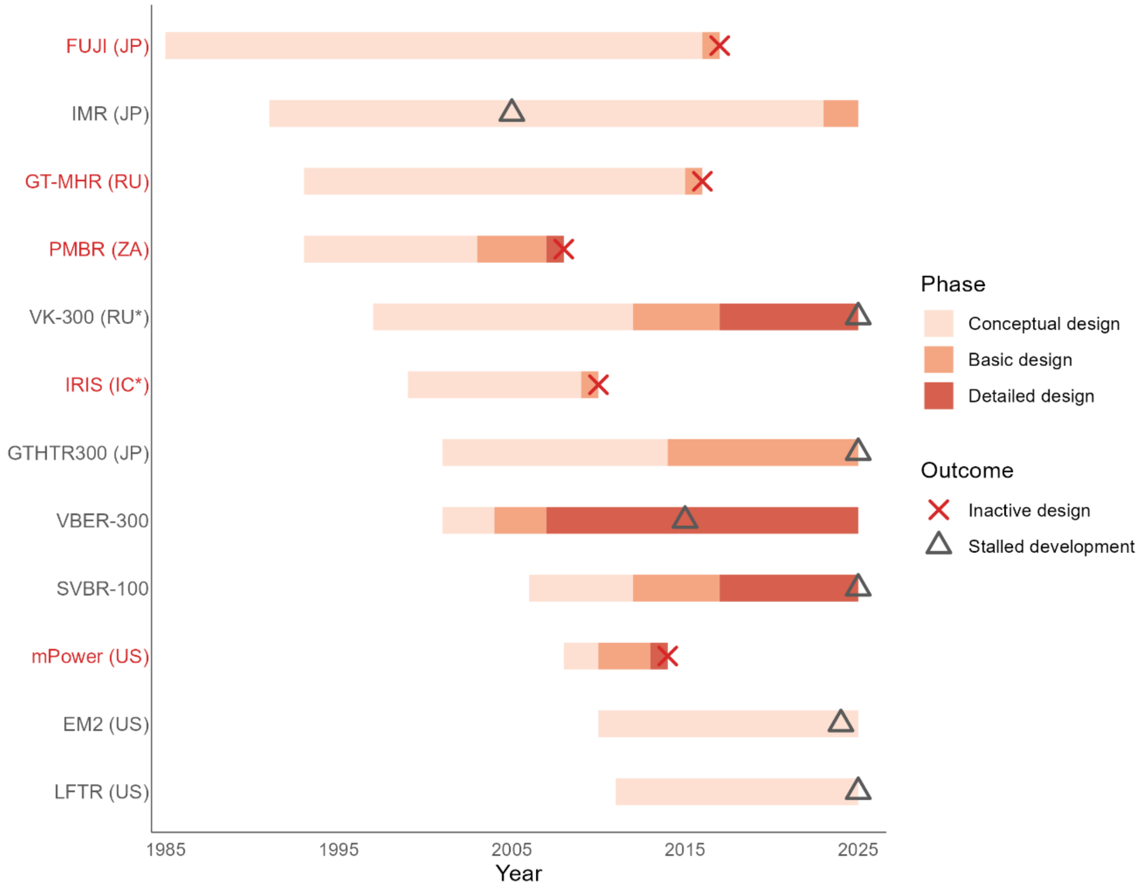


Fig. S3. SMR design portfolio by country and development phase. Distribution of active SMR designs across development phases by country. The portfolio spans twelve OECD countries, with one additional design (EAGLES-300) represented at the EU level, with FOAK deployment targeted for Belgium. Argentina is classified as OECD in line with its membership of the Nuclear Energy Agency since 2017. The remaining designs are located in four non-OECD countries—Russia, China, India and South Africa.

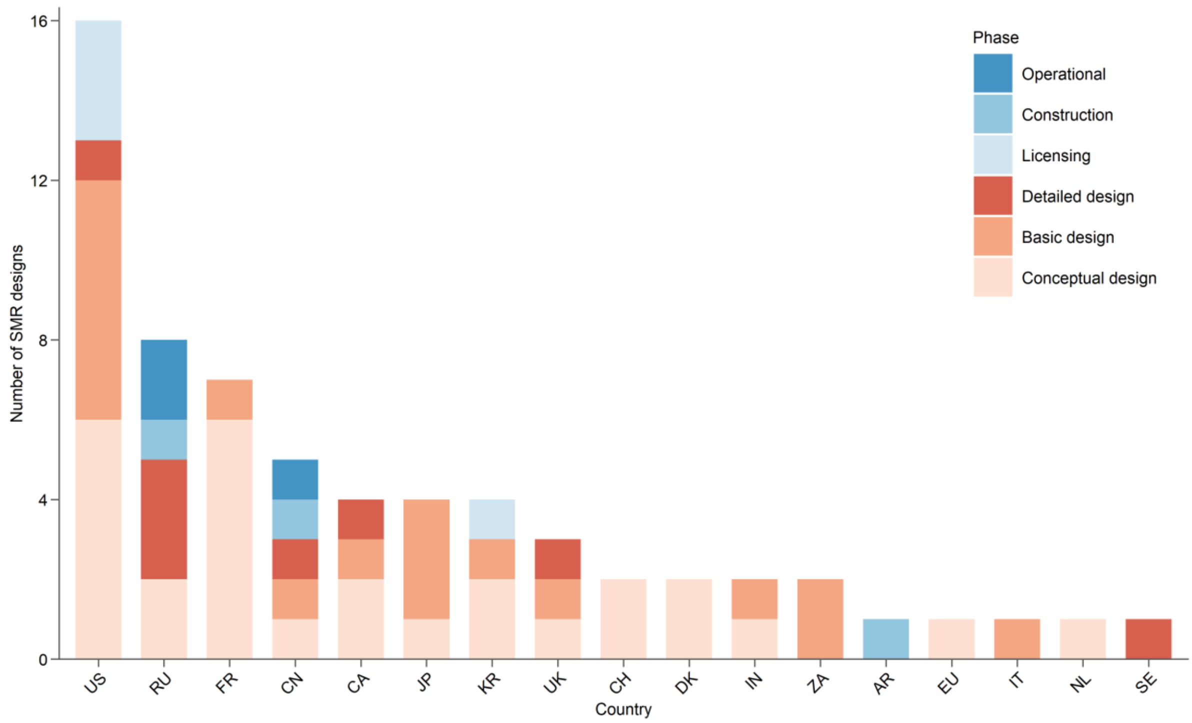


Fig. S4. Composition and characteristics of the global SMR design pipeline at end-2025. The figure summarises the full historical SMR design evidence base (n = 75) and the active SMR design sample used in the main FOAK projections (n = 64). **a,** Distribution of all SMR designs by development status, including failed designs (n = 11). **b,** Cumulative development-phase experience across the active 2025 design sample, expressed as a percentage of total observed phase durations. **c,** Distribution of active designs by cooling type (water-, metal-, salt- and gas-cooled). **d,** Distribution of active designs by power output range in megawatts electric (MWe). **e,** Distribution of active SMR designs across development phases, grouped by cooling type.

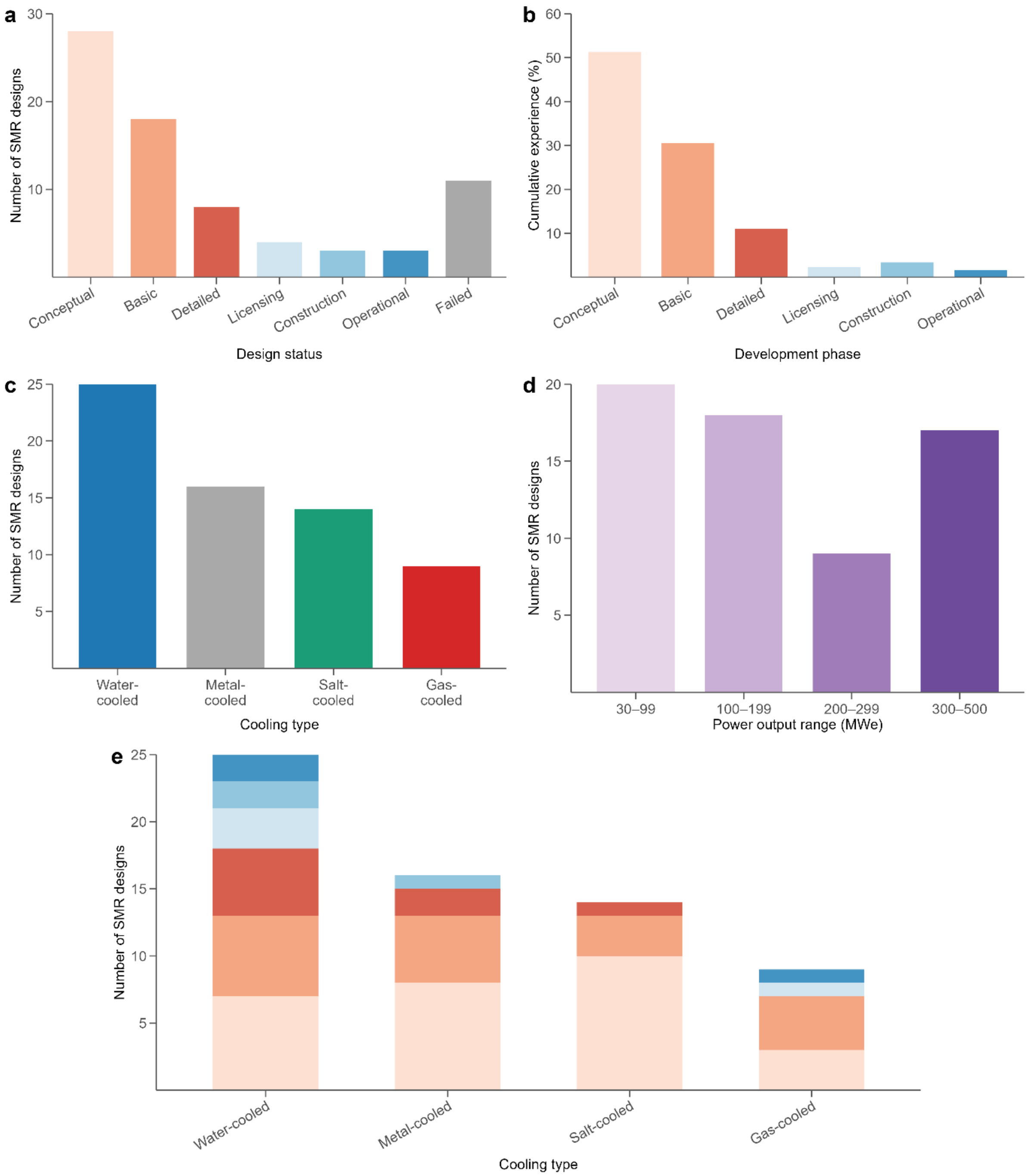


Fig. S5. Historical vendor-target and global SMR design pipelines, 1984–2025. a, Annual number of SMR designs in the vendor-target sample (n = 35), stacked by development phase. **b,** Annual number of SMR designs in the global pipeline (n = 64), stacked by development phase. The vendor-target sample includes only designs with vendor-stated FOAK deployment targets and contains no operational designs by 2025.

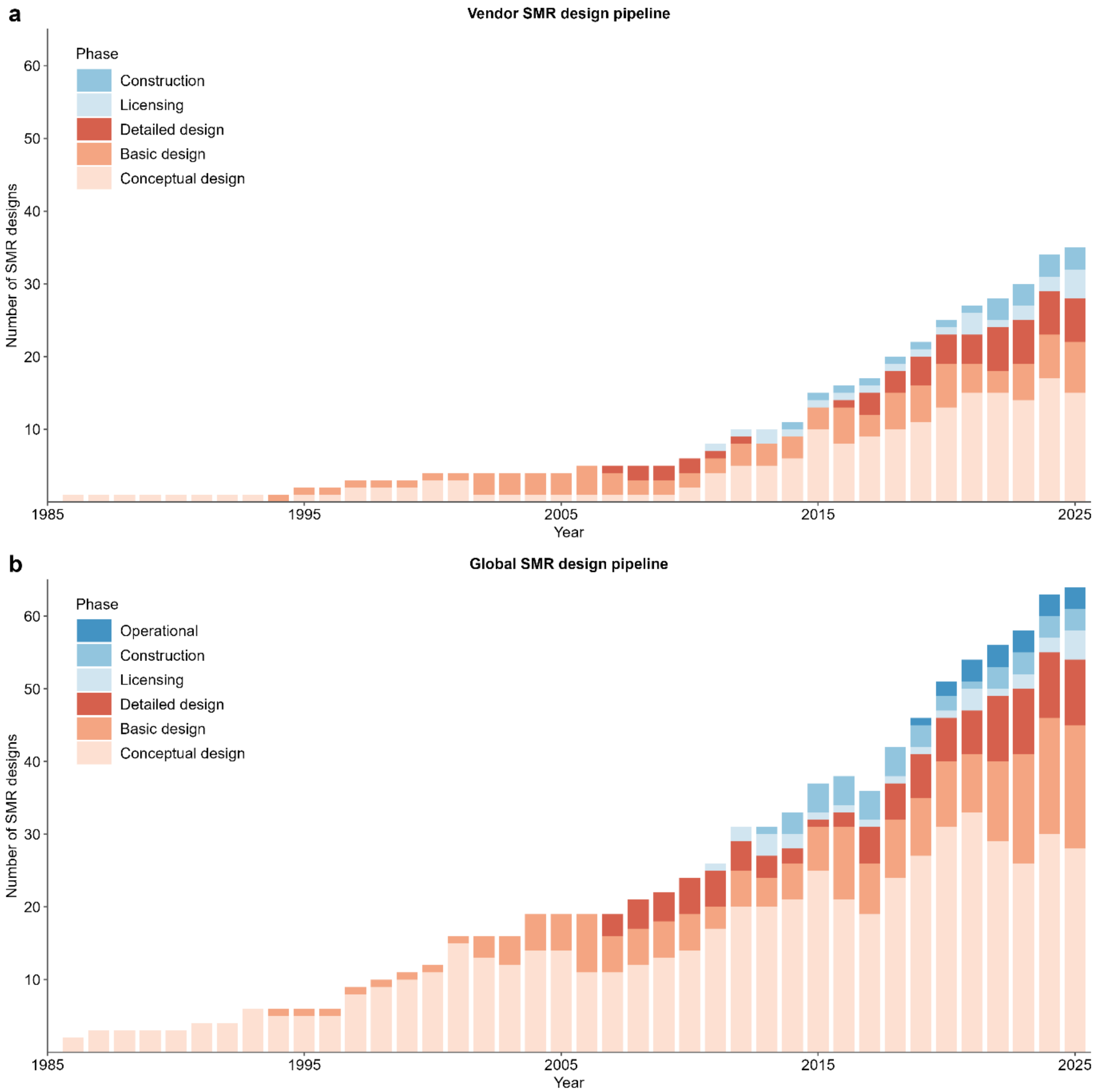


Fig. S6. Global FOAK SMR deployment across reference and sensitivity scenarios. a–c, Cumulative FOAK SMR deployment under the Baseline scenario at the P10, P50 and P90 levels, respectively. **d–f,** Cumulative FOAK SMR deployment under the Accelerated scenario at the P10, P50 and P90 levels, respectively. The reference trajectory is shown in black and compared with five scenario-based sensitivity analyses: Current-phase completion, ADVANCE-OECD licensing, Construction cascade, Late-stage risk and Stalled development.

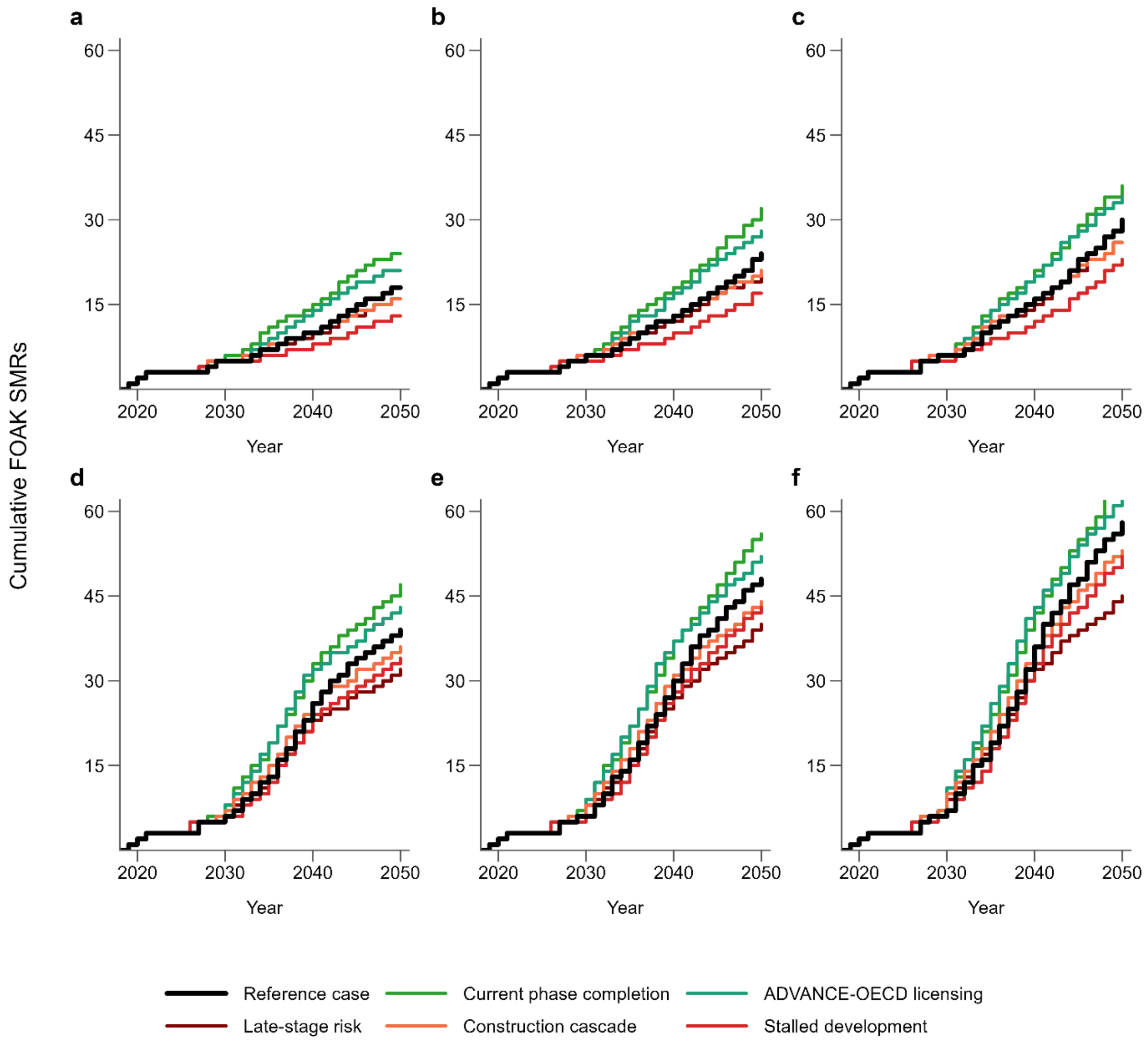


Fig. S7. Regional and national FOAK SMR deployment trajectories. a–f, Cumulative FOAK SMR deployment under the Baseline scenario for North America, Europe, OECD-Asia, Russia, China, and the Rest of the World (RoW). **g–l,** Cumulative FOAK SMR deployment under the **Accelerated** scenario for the same groupings. Solid lines show median trajectories, and shaded bands show the P10–P90 interval.

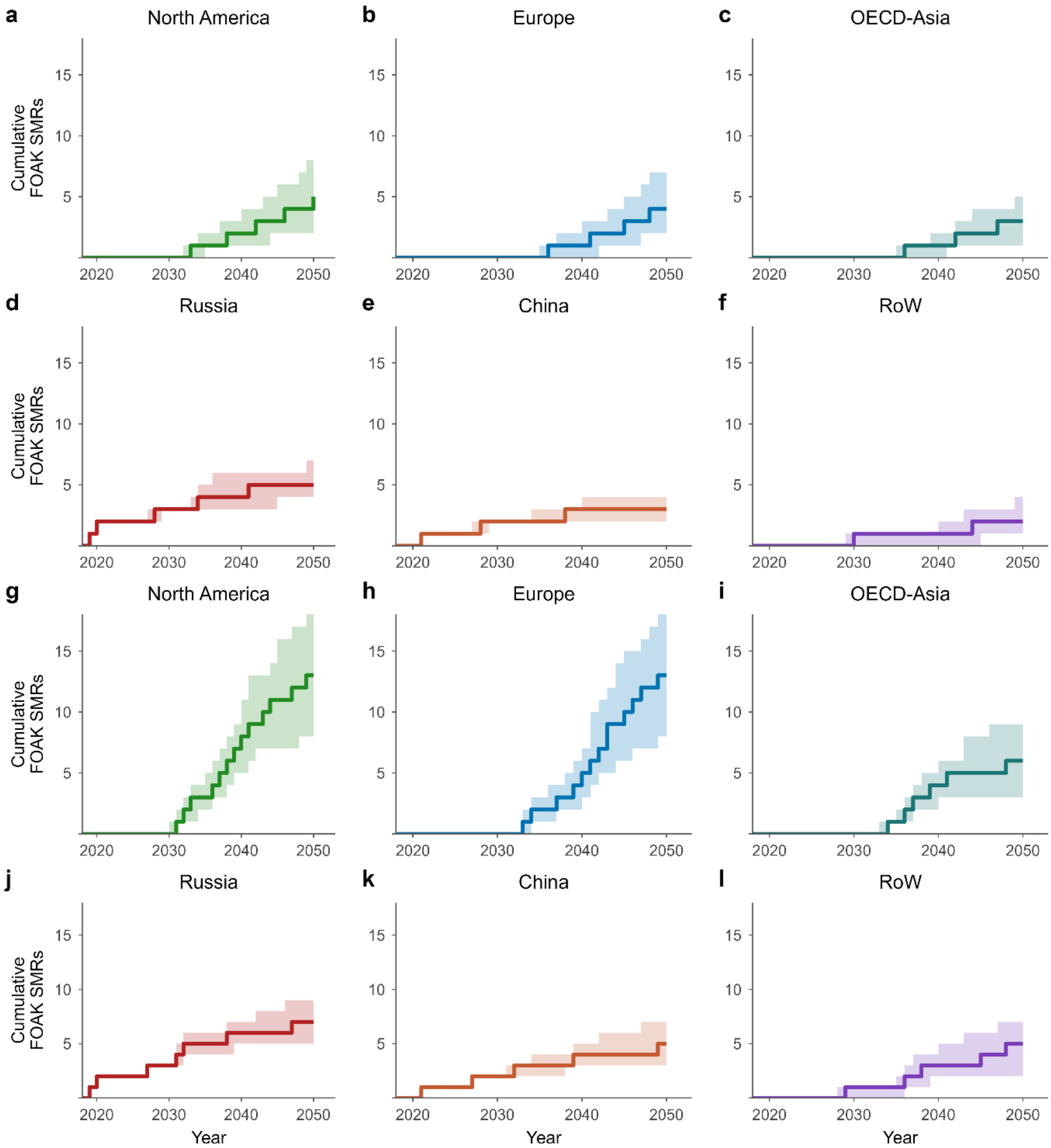


Fig. S8. Association between cumulative development duration and technology readiness level (TRL) across global, OECD and non-OECD SMR designs. a, Global sample. **b,** OECD sample. **c,** Non-OECD sample. Colours indicate current development phase. Cumulative development duration is positively associated with TRL at the global level ($R^2 = 0.248$, $p < 0.001$; $R^2 = 0.274$, $p < 0.001$ when the three operational designs are excluded). Positive associations are also observed in the OECD ($R^2 = 0.197$, $p = 0.002$) and non-OECD ($R^2 = 0.309$, $p = 0.021$) subsamples. In panel c, the solid line shows the fitted relationship for all non-OECD designs, whereas the dashed line shows the fitted relationship when the three operational designs are excluded ($R^2 = 0.462$, $p = 0.008$).

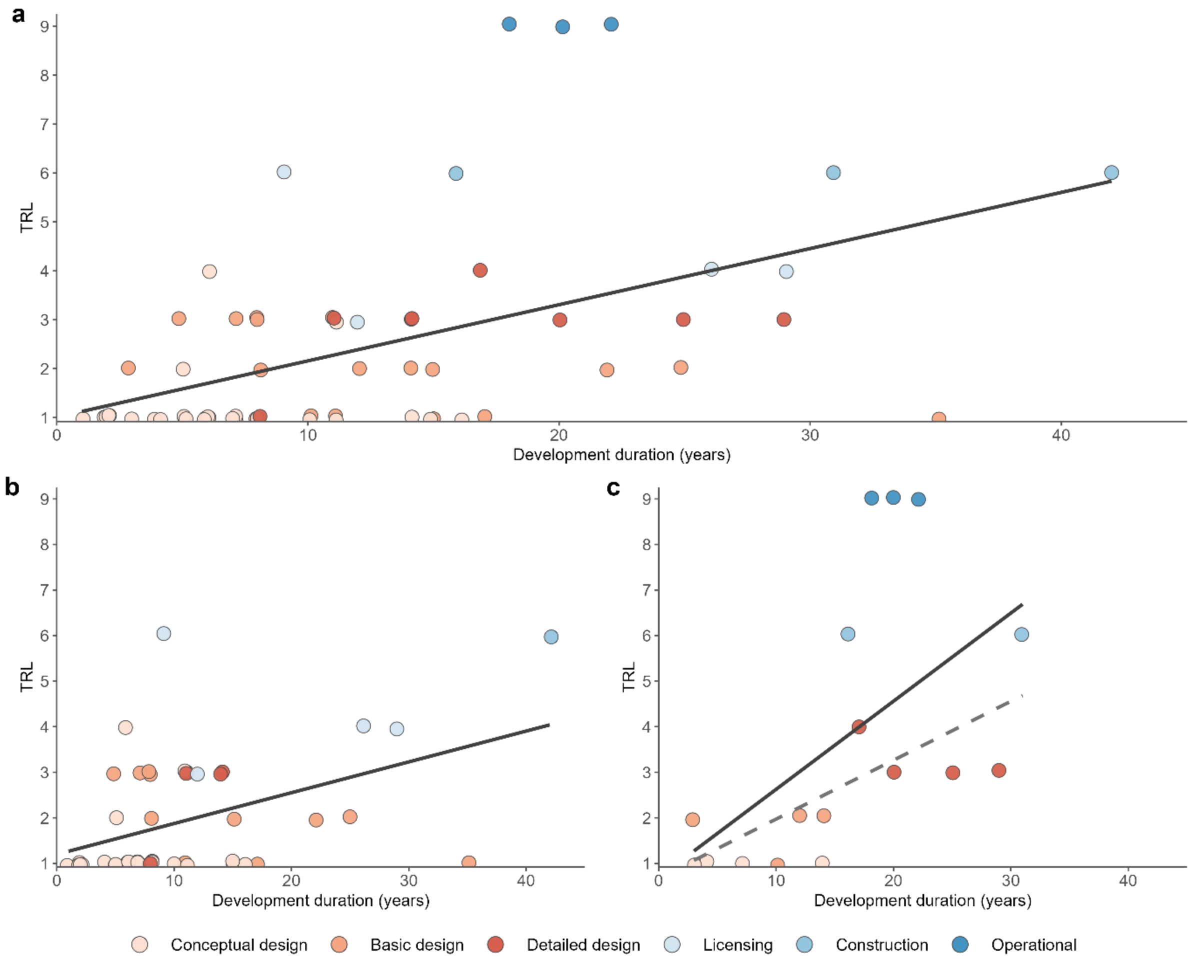


Fig. S9. AMR-specific late-stage risk sensitivity for the active design cohort. a, Accelerated scenario trajectories for active advanced modular reactor (AMR) designs in the OECD and non-OECD cohorts. **b,** Corresponding AMR-specific late-stage risk sensitivity, in which licensing and construction attrition risks are increased for AMRs while other Accelerated scenario assumptions are held fixed. The analysis excludes post-2025 design additions and instead focuses on active AMR designs already in the pipeline at end-2025 (OECD: n = 33; non-OECD: n = 6). The horizontal axis is therefore shown to 2045, the period over which the active-cohort sensitivity yields its FOAK outcomes. Lines show median cumulative FOAK deployments and shaded bands indicate P10–P90 ranges. See Methods and Supplementary Note 18 for the sensitivity specification.

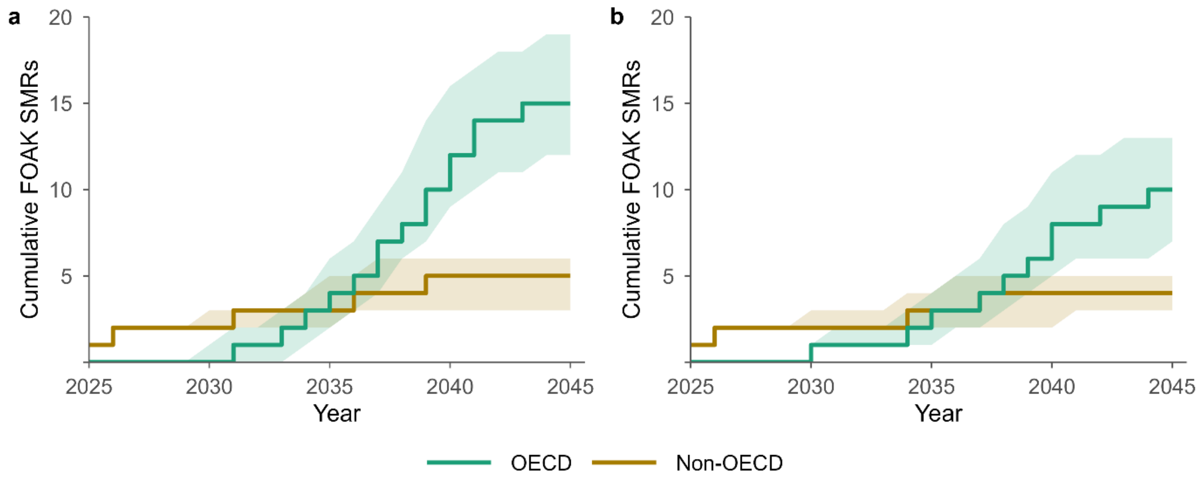


Fig. S10. Conceptual design duration versus start year of the conceptual design phase. The figure shows the relationship between Conceptual design (CD) start year and CD duration across three nested samples used for CD phase parameterisation. The black regression line represents the full empirical sample of designs that completed CD (n = 40). The grey line represents the Baseline sample (n = 35), which excludes designs that began CD before 1995. The green line represents the Accelerated sample (n = 27), derived by excluding the slowest-duration upper-tail designs from the Baseline sample. Points are coloured to show mutually exclusive nested groups: black points are empirical-only observations excluded from the post-1994 Baseline sample, grey points are retained in the Baseline sample but excluded from the Accelerated sample, and green points are the Accelerated subset, which is also contained within the Baseline and empirical samples. The shaded grey band shows the 95% confidence interval around the fitted regression for the full empirical sample. Regression results are reported in Table S4.

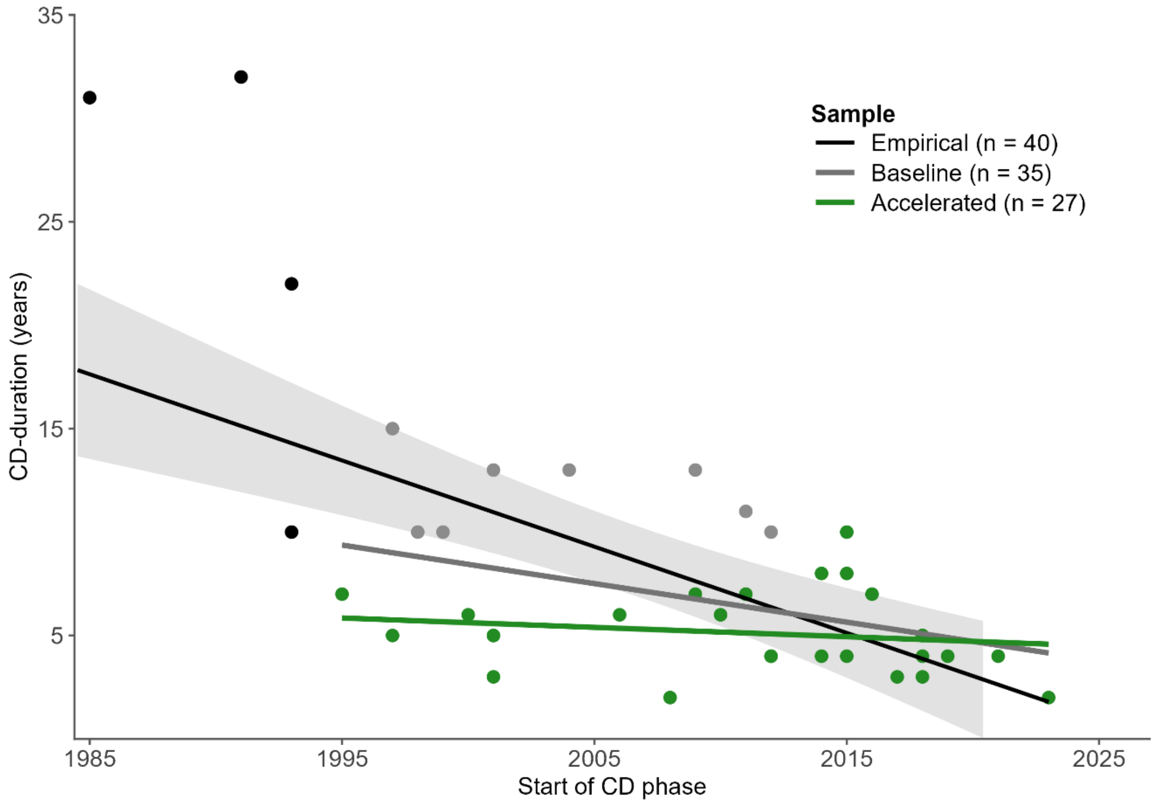


Fig. S11. Duration of SMR design phase versus project start year (n = 10). Design phase is defined as the interval from Conceptual design start to completion of Detailed design, marking entry into Licensing. The sample includes ten designs that transitioned into licensing between 2011 and 2025, split evenly between OECD and non-OECD countries and comprising seven water-cooled designs and three advanced modular reactors (AMRs). Circles denote OECD designs and triangles denote non-OECD designs. The fitted regression indicates an overall decline in design-phase duration with later project start year ($\beta = -0.59$ years per year, $p \approx 0.004$; adjusted $R^2 \approx 0.64$). However, when the sample is divided into early (1984–2000) and recent (2001–2017) cohorts, within-period slopes are not statistically significant (both $p > 0.23$), indicating that recent projects do not show a uniform continuation of timeline compression. A model including an interaction between start year and cohort likewise indicates no statistically significant difference in slopes between periods, despite a strong overall fit (adjusted $R^2 \approx 0.71$). Shorter design durations have accumulated over time, but recent projects vary around this broader trend rather than showing continuous improvement.

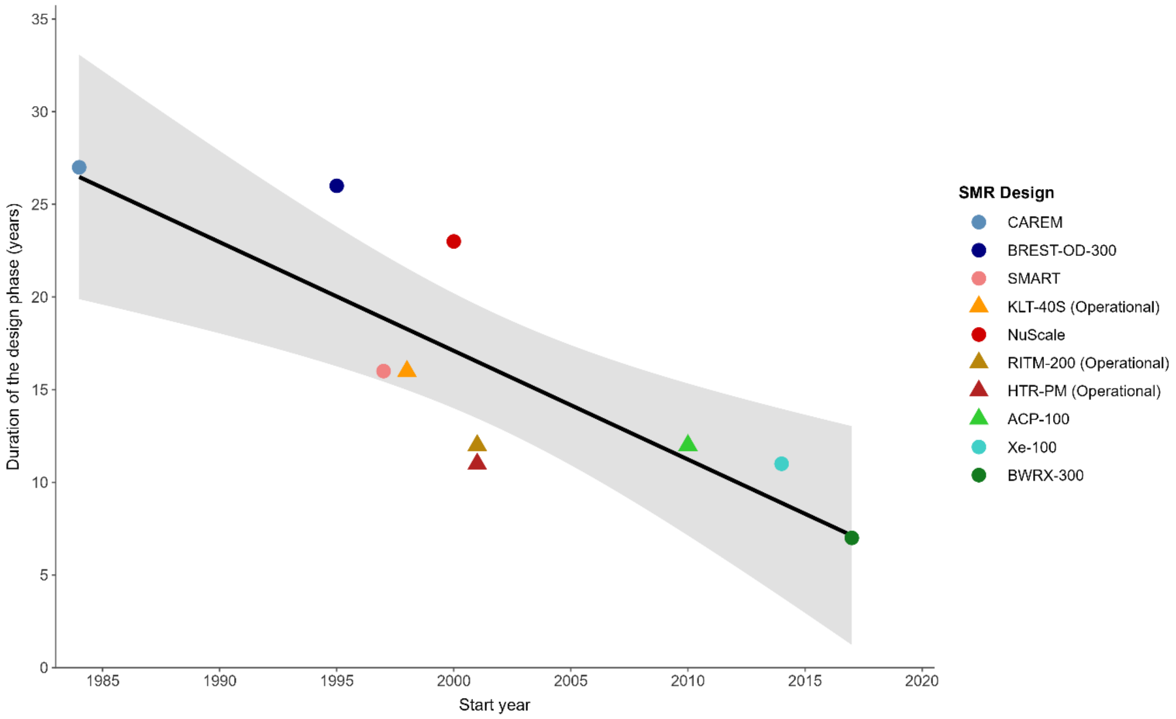


Fig. S12. Construction-duration distribution fits. a, Fitted distributions for SMR construction durations (n = 24). **b,** Fitted distributions for historical construction durations for 30–500 MW reactors (n = 100). Bars show the empirical distributions; fitted curves show candidate parametric distributions. The lognormal distribution provides the best statistical fit in both samples, based on the lowest AIC.

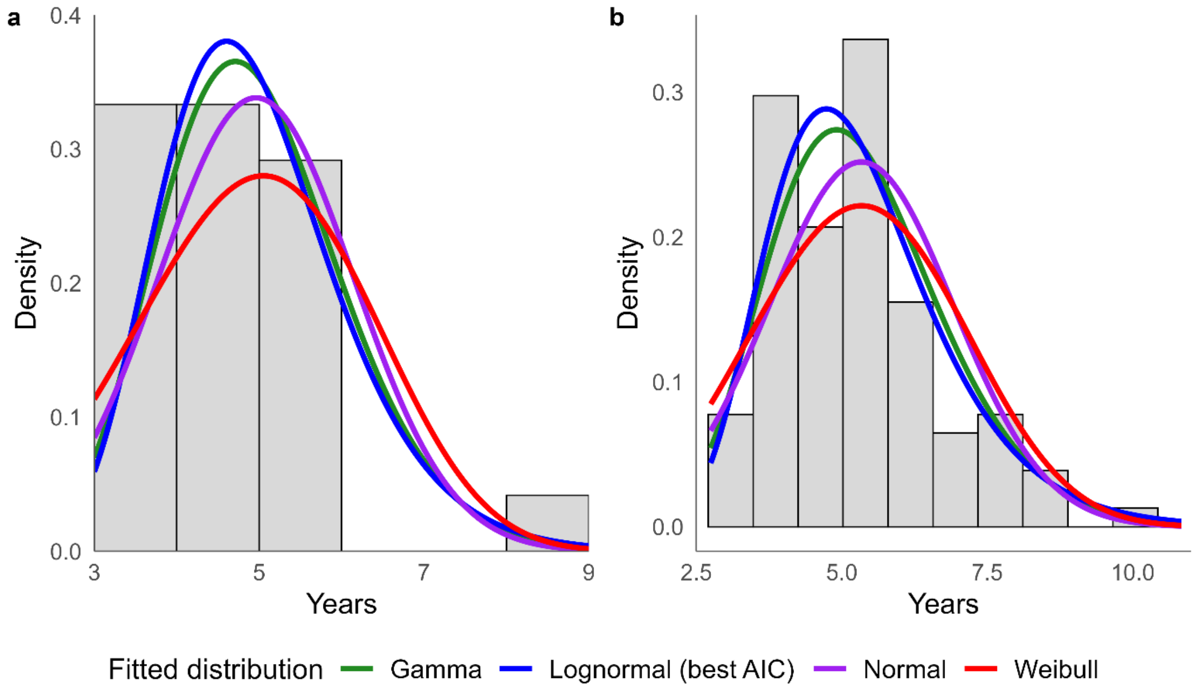


Fig. S13. Phase-specific posterior distributions of design-phase failure probabilities under Baseline (grey) and Accelerated (green) scenarios. Jeffreys posterior distributions are shown for **a**, Conceptual design, **b**, Basic design, and **c**, Detailed design; dashed lines indicate posterior medians. The figure illustrates phase-dependent convergence and divergence in failure risk, with greater separation between scenarios at later design stages.

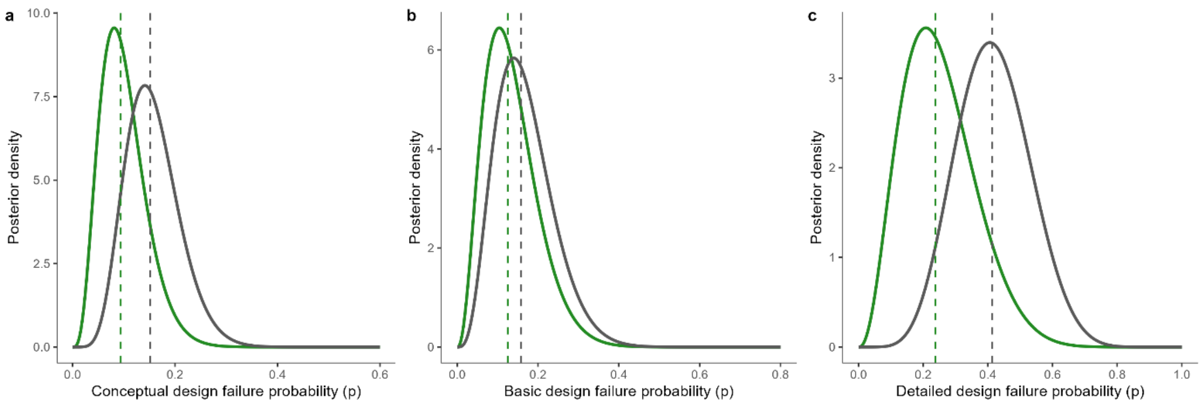


Fig. S14. Licensing- and construction-readiness across SMR development phases. **a**, Licensing-readiness scores across SMR development phases for the cross-check sample (n = 38). **b**, Construction-readiness scores across SMR development phases for the cross-check sample (n = 41). Colours indicate development phase, while marker shapes distinguish water-cooled and non-water-cooled designs. Licensing-readiness scores increase modestly with development phase, but the linear association is only marginal ($\beta = 0.273$, $R^2 = 0.097$, $p = 0.057$). Construction-readiness increases with development phase, with a strong linear association across the cross-check sample ($\beta = 0.628$, $R^2 = 0.540$, $p < 0.001$). In both panels, non-water-cooled designs are concentrated more heavily in earlier development phases, whereas water-cooled designs are more widely distributed across later stages.

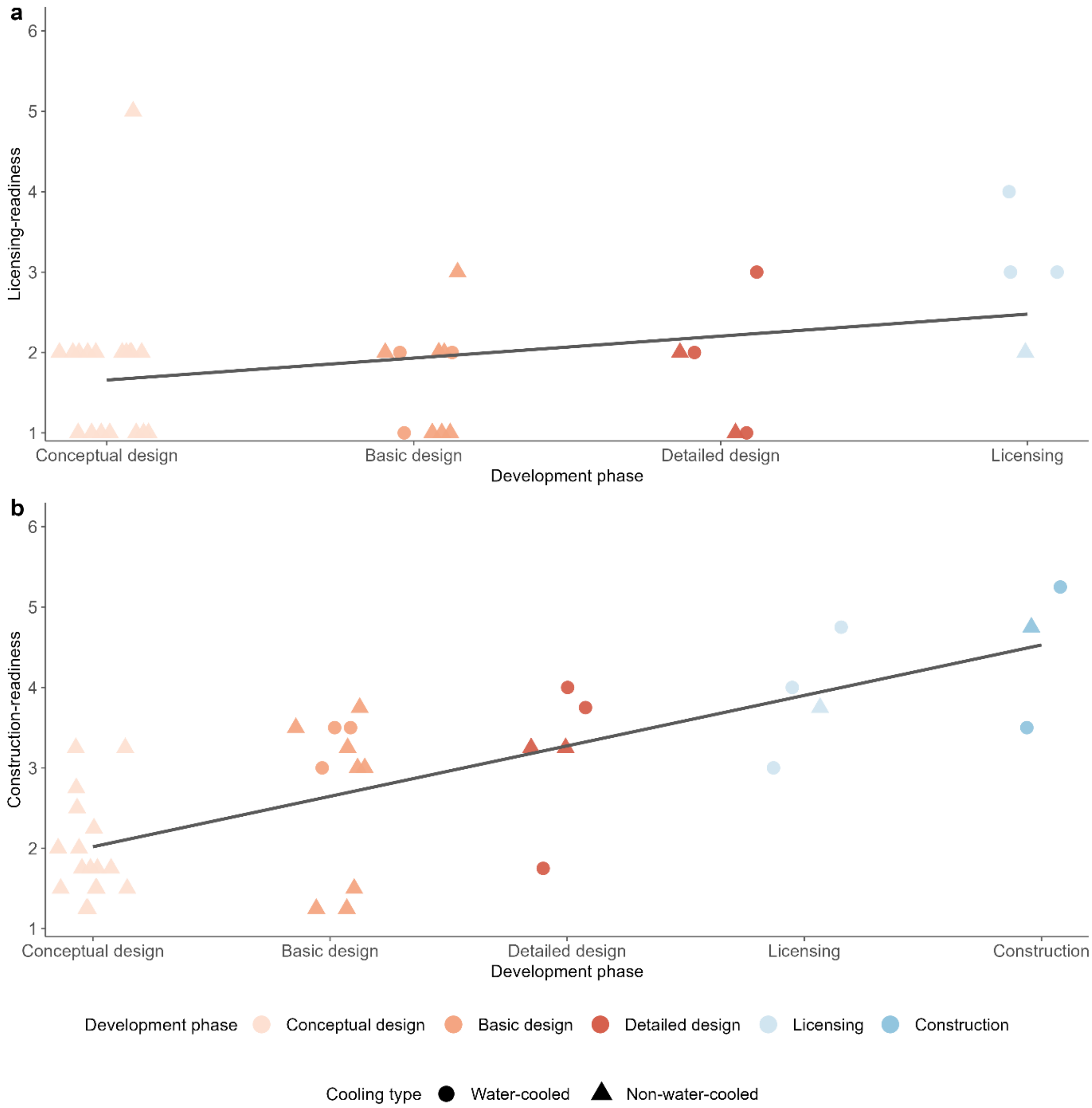
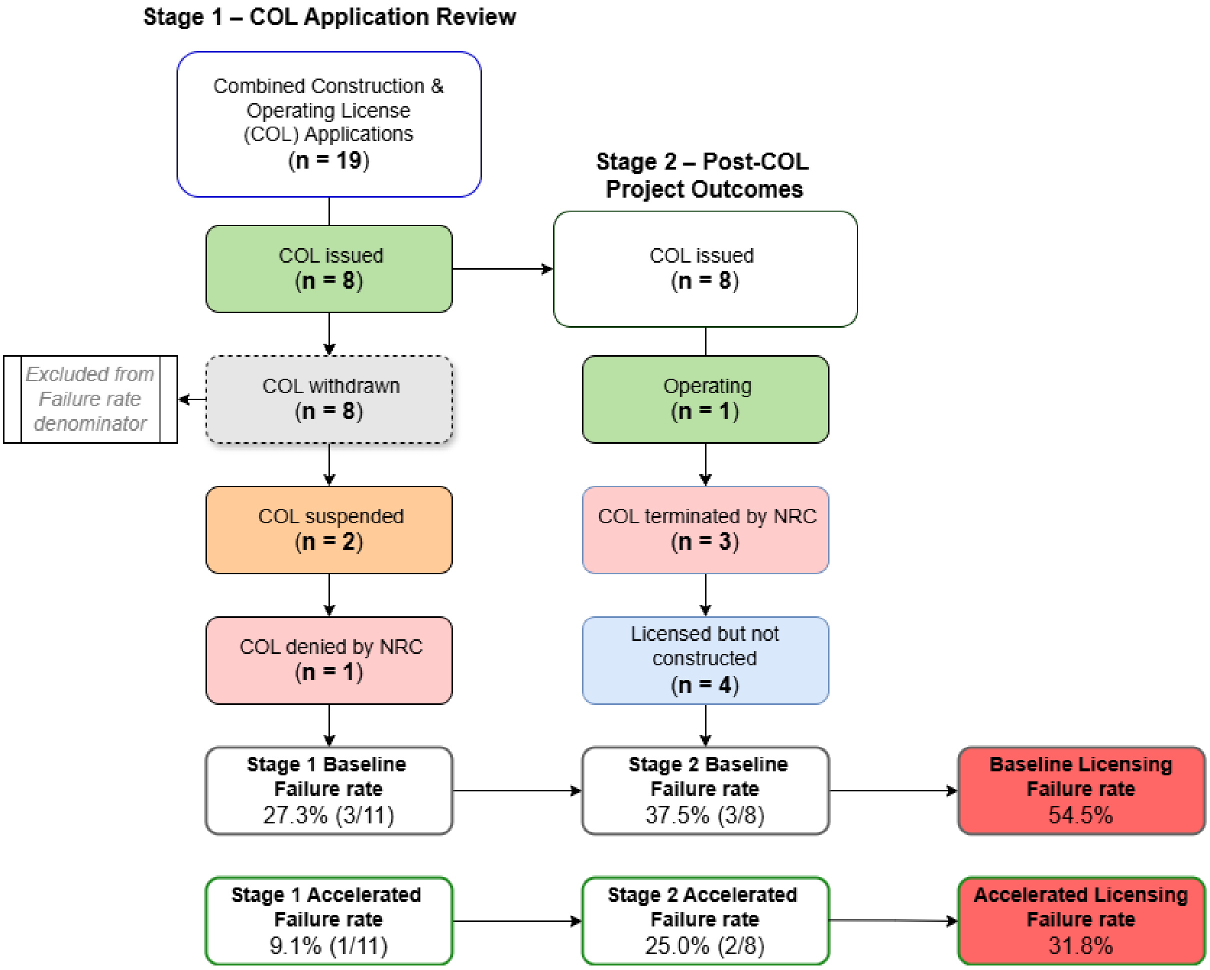


Fig. S15. Two-stage U.S. licensing outcomes for Combined Construction and Operating License (COL) applications, 2007–2025. Stage 1 covers COL application review and excludes application withdrawals from the failure-rate denominator. Stage 2 follows the subset of issued COLs, distinguishing operating, terminated and licensed-but-unbuilt outcomes. Outcomes are derived from the U.S. Nuclear Regulatory Commission's Combined License Applications for New Reactors record[1]. Under Baseline assumptions, the combined U.S. licensing failure rate is 54.5%; under Accelerated assumptions, it declines to 31.8%.



Supplementary Tables

Table S1. Operational definitions of the five phases of SMR development. Definitions are adapted from the International Atomic Energy Agency's mid-1990s design classification[2] and subsequent SMR development reviews undertaken by Pioro et al.[3,4]. Harmonisation is applied to support consistent cross-design phase measurement. As a supplementary maturity cross-check, these phases correspond indicatively to the TRL-based SMR development mapping in Kang et al.[5] : Conceptual design = TRL 1, Basic design = TRL 2, Detailed design = TRL 3, Licensing = TRL 4–5, and Construction = TRL 6–8. FOAK operation corresponds to TRL 9 but is treated as the endpoint of construction rather than a separate development phase in our model.

Phase	Definition
Conceptual design	The reactor concept and preliminary layout are formally established, with initial descriptions of major components, broad performance and safety objectives, and indicative project scope, but before Basic design specifications are completed.
Basic design	The scope of the overall plant has been defined, the major components, systems, and structures have been specified, and a formal framework of technical documentation, cost estimates, and project scheduling has been established. Where alternative taxonomies distinguish developmental or preliminary sub-stages within this interval, we treat these as part of a single Basic design phase for consistent cross-design measurement.
Detailed design	The reactor and plant configuration are brought to near-completion, culminating in a certified or otherwise finalised design basis supported by detailed engineering documentation, safety analyses, manufacturing and procurement specifications, and a complete implementation schedule.
Licensing	The reactor moves from a certified or otherwise finalised design basis into formal regulatory review and approval processes, spanning the period from completion of Detailed design until first nuclear-island concrete for the licensed reactor. This phase includes jurisdiction-specific activities such as pre-application review, formal application, regulatory assessment, and licence issuance, but is treated here as a single harmonised phase for cross-design comparison. Where a licence has been granted but formal construction has not yet begun, the project remains classified in the Licensing phase.
Construction	Begins with first nuclear-island concrete and formal on-site construction activity for the licensed reactor, and continues through component manufacture and delivery, plant assembly, system installation, commissioning, and start-up, until FOAK operation. FOAK operation is defined here as first grid connection for commercial rather than purely demonstration purposes. Where a reactor reaches technical demonstration or limited initial operation without entering commercial service, we do not treat this as completion of the Construction phase.

Table S2. Pre-2000 SMR designs subsequently cancelled or suspended indefinitely. Identifies early SMR concepts initiated before 2000 that were later cancelled or suspended, providing historical context for attrition in the early SMR design pipeline. These designs document the legacy pre-2000 cohort; their analytical treatment in the design-failure classification is reported in Table S3.

Design	Country	Region	MWe	Cooling type	CD start year
FUJI	JP	OECD-Asia	200	Salt	1985
PRISM	US	North America	311	Metal	1987
GT-MHR	IC[2]	*Russia*	288	Gas	1993
PMBR	ZA	South Africa	165	Gas	1993
LEADIR-PS[1]	CA	North America	36	Metal	1997
IRIS[1]	IC[2]	*North America*	335	Water	1999

[1]Designs that did not progress beyond the Conceptual design phase; [2]International Consortium: The Gas Turbine–Modular Helium Reactor (GT-MHR) design was proposed by General Atomics (US), OKBM Afrikantov (RU) and supported by Fuji Electric (JP), with OKBM later leading development; the International Reactor Innovative and Secure (IRIS) design was led by Westinghouse (US) with major contributions from Italian organisations and research institutions.

Table S3. SMR design failures by inactivity and stalled development by sample and classification. Inactive designs denote projects that were cancelled or suspended indefinitely. Stalled development denotes designs that remained in their most advanced recorded phase beyond an extended expected duration, indicating limited or absent observable progression. This table defines the classification used for design-phase failure-rate estimation; pre-2000 legacy designs listed in Table S2 are repeated only where they enter the corresponding failure or stalled-development classification. To maintain consistency with Extended Data Fig. 1, selected stalled licensing- and construction-phase cases are reported descriptively, but these are excluded from phase-specific failure-rate estimation.

In-sample design failures					
Design	**Country**	**Cooling type**	**Failed Phase**	**Start year of failed / stalled phase**	**Outcome classification**
FUJI	JP	Molten-salt	BD	1985	**Inactive design**
IMR	JP	Water	CD	1991	Stalled development (32 y)
GT-MHR	RU	Gas	BD	1993	**Inactive design**
PMBR	ZA	Gas	DD	1993	**Inactive design**
IRIS	IC[1]	Water	BD	1999	**Inactive design**
VBER-300	RU	Water	DD	2007	Stalled development (19 y)
mPower	US	Water	DD	2008	**Inactive design**
EM2	US	Gas	CD	2010	Stalled development (16 y)
LFTR	US	Molten salt	CD	2011	Stalled development (15 y)
GTHR-300	JP	Gas	BD	2014	Stalled development (12 y)
SVBR-100	RU	Metal	DD	2017	Stalled development (9 y)
VK-300	RU	Water	DD	2017	Stalled development (9 y)
SMART-100[2]	KR	Water	Lic.	2013	Stalled development (13 y)
CAREM[2]	AR	Water	Con.	2014	Stalled development (14 y)
Out-of-sample design failures					
Design	**Country**		**Failed Phase**	**Start Year of CD phase**	**Outcome classification**
FBNR[3]	BR	Water	CD	2003	**Inactive design**
PRISM[3]	US	Metal	DD	1984	**Inactive design**
WWER-300[4]	RU	Water	DD	2008	*Stalled development*
Flexblue	FR	Water	CD	2011	**Inactive design**
LEADIR-PS	CA	Meta	CD	2013	**Inactive design**
MSTW	DK	Molten salt	CD	2015	**Inactive design**

[1]IC denotes International Consortium; [2]SMART-100 and CAREM are reported as stalled-development cases for descriptive consistency with Extended Data Fig. 1. However, licensing- and construction-phase failure rates are estimated using a separate post-design-phase method rather than stalled-development classifications, so these cases are excluded from that analysis. SMART-100 should be interpreted cautiously because it follows the earlier SMART design lineage. [3]FBNR and PRISM share a single entry in the IAEA biennial reports in 2012; LEADIR-PS and MSTW share a single entry in 2016; WWER-300 recorded two entries (2012 and 2014); Flexblue recorded three entries (2012–2016); [4]WWER-300 is treated as a special case of inactive/suspended development rather than as a stalled design within the active pipeline. Although the design was last listed by the IAEA in 2014 as being under Detailed design, no subsequent activities or updates could be retrieved after the mid-2010s. It is therefore classified as inactive/suspended for the historical pipeline figure (Extended Data Fig. 1), but excluded from the active-pipeline set used to identify stalled development cases.

Table S4. Sampling approach and regression results for Conceptual design phase parameterisation. The table reports the nested samples used to assess temporal trends in Conceptual design duration and to define the Baseline and Accelerated parameterisation samples. β indicates the estimated change in Conceptual design duration associated with a one-year later CD start year; negative values indicate shorter durations for designs initiated later.

Sample	n	Sample period	Inclusion criteria	β per start year	β per decade	R^2, (Adj. R^2)	p-value
Empirical	40	1984–2025	All SMR designs that completed the Conceptual design phase	-0.417	-4.17 years	0.396 (0.380)	<0.001
Baseline	35	1995–2025	Empirical sample excluding designs that began Conceptual design before 1995	-0.186	-1.86 years	0.183 (0.158)	0.010
Accelerated	27	1995–2025	Baseline sample excluding the slowest-duration upper-tail designs	-0.045	-0.45 years	0.032 (-0.007)	0.372

Table S5. Summary statistics for design-phase durations (years) by phase, scenario and variant. Summary statistics used to compare alternative parameterisation samples for Conceptual design (CD), Basic design (BD) and Detailed design (DD) durations. Variants include empirical, projected, filtered or adjusted baseline samples, and accelerated samples derived using upper-quartile trimming. Bold text indicates the selected scenario parameters used in the Monte Carlo model.

Phase	Scenario	Variant	n	Md	M	SD	Min–Max	Q1–Q3	P10–P90
Conceptual design (CD)	Bas.	Empirical	40[1]	6.5	8.45	6.74	2.0–32.0	4.0–10.0	3.0–13.2
	Bas.	Projected	69	6.0	7.65	5.77	2.0–32.0	4.0–10.0	2.0–13.2
	Bas.	Filtered	35	6.0	6.66	3.46	2.0–15.0	4.0–9.0	3.0–12.2
	Accel.	Q3 cut	27	5.0	5.11	1.95	2.0–10.0	4.0–6.5	3.0–7.4
Basic design (BD)	Bas.	Empirical	21	4.0	5.10	3.43	2.0–14.0	3.0–5.0	2.0–11.0
	Accel.	Q3 cut	16	3.0	3.56	1.15	2.0–5.0	3.0–5.0	2.0–5.0
	Bas.	Projected	37	4.0	4.76	3.10	2.0–14.0	3.0–5.0	2.0–9.8
	Accel.	Q3 cut	28	3.0	3.39	1.03	2.0–5.0	3.0–4.0	2.0–5.0
Detailed design (DD)	Bas.	Empirical	10	3.0	3.60	1.35	2.0–6.0	3.0–4.8	2.0–5.6
	Accel.	Q3 cut	7	3.0	2.86	0.69	2.0–4.0	2.5–3.0	2.0–3.7
	Bas.	Projected	20	4.0	4.90	3.89	2.0–19.0	3.0–5.0	2.0–9.0
	Bas.	Adjusted[2]	19	4.0	4.16	2.09	2.0–9.0	3.0–5.0	2.0–6.9
	Accel.	Q3 cut	14	3.0	3.21	1.05	2.0–5.0	2.3–4.0	2.0–5.0

[1]Includes Aurora Powerhouse, which was added to the broader design inventory after the failure-rate parameterisation and was not used in calibrating design-phase failure rate. [2]VBER-300 removed from the Baseline sample due to stalled development (duration of 19 years in the DD phase, Fig. S2).

Table S6. Model-fit diagnostics for design-phase durations under Baseline and Accelerated scenarios. Bold text indicates the distribution retained for simulation. Asterisks (*) denote the lowest AIC or BIC among candidate distributions based on unrounded values, where this differs from the retained distribution.

		Baseline Scenario		**Accelerated Scenario**	
Phase	**Distribution**	**AIC**	**BIC**	**AIC**	**BIC**
Conceptual design (CD)	**Lognormal**	**175.958**	**179.010**	**114.571**	**117.163**
	Gamma	176.662	179.915	113.754*	116.346*
	Normal	184.642	187.695	115.612	118.203
	Weibull	178.776	181.829	114.592	117.183
Basic design (BD)	**Lognormal**	**165.368**	**168.590**	**83.841**	**86.506**
	Gamma	171.400	174.622	83.366*	86.030*
	Normal	191.892	195.024	83.841	86.506
	Weibull	177.394	180.616	84.131	86.795
Detailed design (DD)	**Lognormal**	**75.340**	**77.121**	**46.069**	**47.347**
	Gamma	76.343	78.124	45.954*	47.233*
	Normal	81.270	83.050	46.624	47.902
	Weibull	78.362	80.143	46.143	47.421

Table S7. Mean design-phase durations for OECD and non-OECD SMR designs. Compares mean durations across completed Conceptual design (CD), Basic design (BD) and Detailed design (DD) phases for OECD and non-OECD designs. Across the three design phases combined, cumulative mean duration is similar for OECD and non-OECD designs, at 17.6 and 16.4 years, respectively.

Phase	**OECD (n)**	**Mean**	**SD**	**Non-OECD (n)**	**Mean**	**SD**
Conceptual design	26	8.5	7.6	15	8.2	5.0
Basic design	11	5.1	3.8	10	5.0	3.3
Detailed design	5	4.0	1.6	5	3.2	1.1

Table S8. Mean design-phase durations (years) for water-cooled SMRs and advanced modular reactors (AMRs). Compares mean durations across completed Conceptual design (CD), Basic design (BD) and Detailed design (DD) phases for water-cooled and AMR designs. Median values are not reported for DD owing to the small sample size.

Phase	**Technology group**	**n**	**Mean**	**SD**	**Median**
Conceptual design	Water-cooled	20	8.0	6.8	6.0
Conceptual design	AMRs	20	8.9	6.9	7.0
Basic design	Water-cooled	13	5.2	3.3	4.0
Basic design	AMRs	9	5.0	3.6	5.0
Detailed design	Water-cooled	7	3.7	1.4	4.0
Detailed design	AMRs	3	3.3	1.5	3.0

Table S9. Design-level licensing durations: historical completions and projected end-of-year scenarios (2025–2028). Licensing duration is measured in years from the first accepted post-detailed-design filing to the authorisation enabling first nuclear-island concrete (FNIC). For completed non-OECD cases, observed licensing durations are reported. For OECD cases, projected durations are shown under alternative end-of-year completion assumptions (2025–2028), holding licensing start years fixed. OECD status reflects the primary regulatory context. For BWRX-300, the relevant licensing pathway is in Canada. Projections are scenario devices rather than forecasts; if FNIC does not occur, licensing remains open-ended by definition.

SMR design (country)	OECD Member	Licensing start	Construction start	Licensing duration (completed)	Licensing duration (Construction start 2026)
CAREM (AR)	No	2011	2014	3	—
HTR-PM (CN)	No	2012	2013	1	—
RITM-200 (RU)	No	2013	2014	1	—
SMART (KR)	Yes	2013	—	—	13
KLT-40S (RU)	No	2014	2015	1	—
ACP-100 (CN)	No	2021	2022	1	—
BREST-OD-300 (RU)	No	2021	2022	1	—
NuScale (US)	Yes	2023	—	—	3
BWRX-300 (US/JP)	Yes	2025	—	—	1
Xe-100 (US)	Yes	2025	—	—	1

Table S10. Summary statistics for licensing durations under historical and projected completion scenarios. Statistics are reported for the 10-design licensing panel under one historical case (completed non-OECD designs only; n = 6) and four projected completion scenarios (End-2025 to End-2028; n = 10). Owing to the small sample and discrete yearly durations, lower-tail percentiles can coincide with the minimum. The increase in the mean from End-2025 (2.6 years) to End-2028 (3.8 years) illustrates the approximately 0.4-year step-up generated by each additional year applied to the four active OECD cases.

Scenario	*n*	M	SD	Min	P5	Q1	Md	Q3	P95	Max
Historical only (completed non-OECD set)	6	1.33	0.82	1.0	1.0	1.0	1.0	1.50	2.50	3.0
End-2025 (add current cases finishing 2025)	10	2.60	3.75	1.0	1.0	1.0	1.0	3.00	8.50	13.0
End-2026	10	3.00	4.00	1.0	1.0	1.0	1.50	3.25	9.50	14.0
End-2027	10	3.40	4.30	1.0	1.0	1.0	2.00	3.50	10.50	15.0
End-2028	10	3.80	4.64	1.0	1.0	1.0	2.00	4.50	11.50	16.0

Table S11. Licensing and construction phase-duration parameters by scenario. Licensing and construction phase durations are parameterised as truncated lognormal distributions under Baseline and Accelerated scenarios. The table reports the imposed bounds, fitted log-space parameters, truncated mean and selected percentiles used in the Monte Carlo model (Supplementary Notes 8–10). Licensing parameters apply to OECD designs and to non-OECD designs outside Russia and China. For Russia and China, the Baseline scenario applies the Accelerated licensing range, while the Accelerated scenario applies a fixed one-year licensing rule. Construction parameters apply across all designs.

Scenario	Bounds (yrs)	μ (log)	σ (log)	Truncated mean (yrs)	P10	P50	P90
Licensing phase							
Baseline	2–8	1.469	0.287	4.50	3.02	4.33	6.14
Accelerated	1–3	0.805	0.143	2.25	1.85	2.23	2.65
Construction phase							
Baseline	3–7.5	1.615	0.206	5.07	3.87	5.00	6.39
Accelerated	3–5	1.377	0.124	3.97	3.40	3.95	4.57

Table S12. Distributional fits for licensing and construction durations. Lower AIC and BIC indicate better fit. Bold indicates the best-fitting distribution. For both licensing and construction durations, the lognormal distribution provides the best fit across the samples shown, with gamma as the next-best alternative.

Sample	*n*	Distribution	AIC	BIC
Licensing phase				
Licensing completions	6	Gamma	14.04	1.53
		Lognormal	**12.51**	**0.00**
		Normal	17.50	4.99
		Weibull	15.65	3.14
Licensing completions and projected completions by end-2025	10	Gamma	42.94	5.00
		Lognormal	**37.94**	**0.00**
		Normal	57.75	19.81
		Weibull	43.09	5.15
Licensing completions and projected completions by end-2025, excluding SMART	9	Gamma	21.72	1.89
		Lognormal	**19.83**	**0.00**
		Normal	26.22	6.39
		Weibull	23.48	3.65
Construction phase	***n***	**Distribution**	**AIC**	**BIC**
SMR design reference case	24	Gamma	76.54	78.89
		Lognormal	**75.57**	**77.93**
		Normal	80.02	82.38
		Weibull	83.31	85.66
Historical reference case	100	Gamma	364.27	365.68
		Lognormal	**360.47**	**365.68**
		Normal	379.750	384.961
		Weibull	383.925	389.135

Table S13. Sensitivity check excluding SMART (n = 9): best-versus-next-best AIC under slippage scenarios. Lower AIC indicates better fit. Across all slippage scenarios for the licensing phase sample excluding SMART (n = 9), the lognormal distribution remains the best fit, with gamma consistently the next-best alternative. Although the AIC gap narrows slightly over time, the preferred distribution remains unchanged, indicating a robust result.

Scenario	Best fit	AIC (best)	Next-best	AIC (next)	ΔAIC
Best Case 2025	Lognormal	19.830	Gamma	21.719	**1.889**
BC+1 (2026)	Lognormal	25.479	Gamma	26.581	**1.102**
BC+2 (2027)	Lognormal	30.947	Gamma	31.788	**0.841**
BC+3 (2028)	Lognormal	35.016	Gamma	35.896	**0.880**
BC+4 (2029)	Lognormal	38.137	Gamma	39.131	**0.994**

Table S14. Descriptive statistics for construction duration reference cases. The reference cases span empirical observations and projections for SMRs, expert estimates for SMRs and historical observations for conventional nuclear (small- to medium-sized reference class) (Supplementary Note 10).

Sample / source	*n*	M	SD	Min	P5	Q1	Md	Q3	P95	Max
Historical SMRs (2019–2021)	3	7.0	1.7	6.0	6.0	6.0	6.0	7.5	8.7	9.0
Historical and projected SMRs (2019–2025)	6	6.8	3.1	4.0	4.0	4.0	6.0	9.8	11.3	12.0
IAEA 2021–2024 estimates	24	5.0	1.2	3.0	3.6	4.0	4.0	5.5	6.0	9.0
Historical reactors (32–497 MWe, 1953-1979)	100	5.3	1.6	2.8	3.4	4.2	5.3	5.9	8.6	10.8

Table S15. Historical rates of design additions by region/group and cooling type. The table reports empirical design-entry rates used to calibrate post-2025 design additions in the pipeline-evolution module. For the Baseline scenario, rates are calculated from each region/group's first observed design start year to 2025. For the Accelerated scenario, rates are calculated over the post-Fukushima period, 2011–2025. Counts in parentheses indicate the number of designs used in the Baseline and Accelerated rate calculations, respectively. Regional and aggregate-group rates provide the main geographic allocation framework for future design additions; global cooling-type rates are reported for transparency and context (Methods, Supplementary Note 11).

Region / aggregate group (n)	**Historical rate (1991–2025)**	**Post-Fukushima rate (2011–2025)**
Europe (20, 18)	1.11	1.20
US (18, 15)	0.69	1.00
Russia (9, 2)	0.29	0.13
OECD Asia (9, 4)	0.26	0.27
China (5, 2)	0.20	0.13
RoW (6, 5)	0.18	0.33
Canada (5, 4)	0.17	0.27
OECD (52, 41)	1.49	2.73
Non-OECD (20, 9)	0.61	0.60
Global (72, 50)	2.06	3.33
Cooling type (n)		
Water (28, 16)	0.80	1.07
Metal (18, 14)	0.58	0.93
Salt (16, 15)	0.89	1.00
Gas (10, 5)	0.30	0.33

Table S16. Historical cooling-type shares of SMR design additions by region/group. The table disaggregates the regional/group design-addition rates reported in Table S15 by cooling type. Counts in parentheses indicate historical total designs and post-Fukushima designs, respectively. Baseline shares are measured over each region/group's observed historical period to 2025 and adjusted using a Jeffreys correction; Accelerated shares are measured over 2011–2025 and adjusted in the same way. These shares are used to assign cooling type probabilistically within each regional/group allocation (Methods, Supplementary Note 11).

Region/group	Cooling type (*n*)	Historical share (1991–2025); Jeffreys adjusted share	Post-Fukushima share (2011–2025); Jeffreys adjusted share
Europe	Salt (8, 7)	0.40; 0.39	0.39; 0.38
	Metal (7, 7)	0.35; 0.34	0.39; 0.38
	Water (4, 4)	0.20; 0.20	0.22; 0.23
	Gas (1, 0)	0.05; 0.07	0.00; 0.03
US	Salt (6, 6)	0.33; 0.33	0.40; 0.38
	Water (5, 3)	0.28; 0.28	0.20; 0.21
	Metal (4, 4)	0.22; 0.23	0.27; 0.26
	Gas (3, 2)	0.17; 0.18	0.13; 0.15
Russia	Water (7, 2)	0.78; 0.68	1.00; 0.63
	Metal (2, 0)	0.22; 0.23	0.00; 0.13
	Salt (0, 0)	0.00; 0.05	0.00; 0.13
	Gas (0, 0)	0.00; 0.05	0.00; 0.13
OECD Asia	Water (5, 2)	0.56; 0.50	0.50; 0.42
	Gas (2, 1)	0.22; 0.23	0.25; 0.25
	Metal (2, 1)	0.22; 0.23	0.25; 0.25
	Salt (0, 0)	0.00; 0.05	0.00; 0.08
China	Water (3, 1)	0.60; 0.50	0.50; 0.38
	Gas (1, 0)	0.20; 0.21	0.00; 0.13
	Salt (1, 1)	0.20; 0.21	0.50; 0.38
	Metal (0, 0)	0.00; 0.07	0.00; 0.13
Canada	Metal (3, 2)	0.60; 0.50	0.50; 0.42
	Salt (1, 1)	0.20; 0.21	0.25; 0.25
	Water (1, 1)	0.20; 0.21	0.25; 0.25
	Gas (0, 0)	0.00; 0.07	0.00; 0.08
Rest of the World (RoW)	Gas (3, 2)	0.50; 0.44	0.40; 0.36
	Water (3, 3)	0.50; 0.44	0.60; 0.50
	Salt (0, 0)	0.00; 0.06	0.00; 0.07
	Metal (0, 0)	0.00; 0.06	0.00; 0.07

Table S17. Right-censored designs under the design-phase failure-rate classification. The table lists designs that had entered Conceptual, Basic or Detailed design by the end of the observation window but had not yet completed their current phase. These designs were treated as right-censored observations and were therefore not counted as successful phase completions when estimating design-phase failure rates. Designs are ordered by phase start year, and countries are shown in brackets.

Phase	Censored time-period	Right-censored designs	Total (*n*)
Conceptual design	2012–2025	KARAT-45 (RU), LFR-W (US), CA Waste Burner (DK), BANDI-60 (KR), CMSR (DK), MCSFR (US), KARAT-100 (RU), NUWARD (FR), START (CH), CANDU SMR (CA), FMR (US), MSR-100, SSR-W (UK/CA), Thorizon (NL), DF300 (CA), SALUS-100 (KR), XAMR (FR), sm-TMSR-400 (CN), Blossom Energy (JP), BSR (IN), HEXANA (FR), MK-60 (CH), EAGLES-300 (EU/BE), OTRERA 300 (FR), Stellarium (FR), Blue Capsule (FR)	26
Basic design	2017–2025	GTHTR300 (JP), DMS (JP), ThorCon 500 (US/ID), SSR-U (UK/CA), AP300 (US), CAP200 (CN), HTMR-100 (ZA), KP-FHR (US), SC-HTGR (FR), SUPERSTAR (US), A-HTR-100 (ZA), ARC-100 (CA), Aurora Powerhouse (US), IMR (JP), LFR-AS-200 (FR), i-SMR (KR), BSMR-200 (IN)	17
Detailed design	2021–2025	SMR-300 (US), IMSR400 (CA), ACPR50S (CN), Rolls Royce-SMR (UK), ThorCon (US), NATRIUM (US), SEALER-55 (SE)	7

Table S18. Phase-specific design-failure rates estimated using Jeffreys posterior distributions. Posterior means are reported as descriptive summaries; Monte Carlo simulations draw from the full posterior distributions. Based on these posterior means, the implied cumulative probability of failure across the Conceptual, Basic, and Detailed design phases is **57.7%** under the Baseline scenario (1 - (0.851 x 0.846 x 0.588) = 0.577) and **38.5%** under the Accelerated scenario (1 - (0.909 x 0.880 x 0.769) = 0.385).

Phase	Scenario	Observed failures (n/N)	Failure rate (%)	Posterior (Jeffreys)	Posterior Mean	95% Crl (2.5–97.5%)
Conceptual design (CD)	Baseline	7/47	14.9	Beta (7.5, 40.5)	15.6	6.9–27.0
	Accelerated	4/44	9.1	Beta (4.5, 40.5)	10.0	3.2–20.2
Basic design (BD)	Baseline	4/26	15.4	Beta (4.5, 22.5)	16.7	5.4–32.5
	Accelerated	3/25	12.0	Beta (3.5, 22.5)	13.5	3.5–28.7
Detailed design (DD)	Baseline	7/17	41.2	Beta (6.5, 10.5)	38.2	17.4–61.7
	Accelerated	3/13	23.1	Beta (2.5, 10.5)	19.2	3.6–43.6

Table S19. Status summary for NEA SMR Dashboard Editions 2 (2024) and 3 (2025). Counts and shares of total designs classified as included in the assessed sample, active but not included, and inactive/cancelled/paused. The table also reports the total number of active designs in each edition and clarifies how the assessed subset relates to the broader dashboard (Supplementary Note 11).

Category	2024 (*n*)	2024 (%)	2025 (*n*)	2025 (%)
Included (assessed)	56	57.1	74	58.3
Active, not included	7	7.1	25	19.7
Inactive / cancelled / paused	35	35.7	28	22.0
Active total (incl. + not incl.)	63	64.3	99	78.0
Total designs	**98**	100	**127**	100

Table S20. Inactive cohort by reactor size and implied failure rate: SMRs 30–500 MWe vs microreactors <30 MWe. Active designs in the NEA SMR Dashboard are partitioned into SMRs (30–500 MWe) and microreactors (<30 MWe), and the inactive cohort is apportioned accordingly to derive an estimated number of inactive designs for each size class. This provides the basis for an implied inactive cohort for eligible SMR designs in Editions 2 (2024) and 3 (2025).

					Estimated number of inactive designs	
NEA Edition (year)	**Total active (*n*)**	**SMRs, 30–500 MWe (*n*, %)**	**Micro-reactors, <30 MWe (*n*, %)**	**Total inactive**	**SMRs (*n*)**	**Microreactors (*n*)**
Ed.2 (2024)	56	41 (73.2)	15 (26.8)	35	26	9
Ed.3 (2025)	74	51 (68.9)	23 (31.1)	28	19	9

Table S21. Triangulated failure-rate estimates for eligible SMR designs (30–500 MWe). Derived by combining the active SMR cohort with the estimated number of inactive SMR designs reported in Table S20. Wilson 95% confidence intervals are reported to indicate uncertainty around the estimated failure rates.

NEA Edition (year)	**Eligible SMR designs (30–500 MWe)**		**Estimated failure rate (%)**	**Wilson 95% CI**
	Active (*n*)	**Inactive (*n*)**		
Ed.2 (2024)	41	26	38.8 (26/67)	28.0–50.8
Ed.3 (2025)	51	19	27.1 (19/70)	18.1–38.5

Table S22. U.S. Nuclear Regulatory Commission (NRC) outcomes for Combined Construction and Operating License (COL) applications, 2007–2025. Stage-1 denominators exclude applications withdrawn by the licensee because these cases reflect mixed market-regulatory drivers rather than strict licensing failure. Wilson 95% confidence intervals are reported for all empirical failure-rate estimates. These two-stage NRC outcomes[1] are used to inform the empirical U.S. licensing benchmark applied in the calibration.

Outcome (Licensing Stage 1)	**Number**	**Share (%)**
Combined Construction & Operating License (COL) issued	8	72.7
Suspended	2	18.2
Denied	1	9.1
Baseline Failure Rate (Stage 1)	3	27.3 (9.7–56.6)
Accelerated Failure Rate (Stage 1)	1	9.1 (1.6–37.7)
Outcome (Licensing Phase 2)	**Number**	**Share (%)**
Operating	1	12.5
Terminated after COL received/passing Stage 1	3	37.5
Valid COL but yet to enter the construction phase	4	50.0
Baseline Failure Rate (Stage 2)	3	37.5 (13.7–69.4)
Accelerated Failure Rate (Stage 2)	2	25.0 (7.1–59.1)
Baseline Failure Rate	–	54.5
Accelerated Failure Rate	–	31.8

Table S23. Calibration of country-specific licensing failure rates. Baseline and Accelerated licensing failure rates are assigned by grouping countries into regulatory archetypes defined by licensing maturity, institutional continuity, and demonstrated follow-through from licensing to construction (Supplementary Note 13). The table reports the calibrated risk values and their rationale.

Category	Countries	Baseline Failure risk (%)	Accelerated Failure risk (%)	Rationale and characterisation
SMR Reference case: licensing success	AR (CAREM)	0	0	• Argentina's national champion SMR design – CAREM – has been under construction since the mid-2010s • Demonstrated SMR licensing success
China and Russian high-capacity licensing regimes	CN, RU	2	1	• State-directed programmes with strong follow-through • Residual failure risk associated with administrative and other non-technical factors
OECD mature licensing regimes	BE, CH, CA, FR, JP, KR SE, UK	4	2	• High-stability OECD regulators • Proven history, supported by strong interagency coordination
Non-OECD advanced licensing regimes	IN, ZA	6	3	• Mature but frictional systems. • Established nuclear legacy but institutional delays
Nuclear legacy transition case	NL, RO	8	4	• Limited but continuous nuclear legacy • Constrained contemporary licensing depth
Nuclear revival case	IT	10	5	• Nuclear legacy but decades of dormancy • Higher uncertainty relative to the Netherlands
Nuclear newcomer	DK, ID, RW	12	6	• Nuclear newcomer with no prior licensing experience • Highest baseline uncertainty excluding the United States
Empirical NRC licensing benchmark	US	54.5	31.8	• Empirical two-stage NRC data used directly to estimate failure risks • Excluded from ranking system

Table S24. Classification of national SMR design portfolios and associated licensing-penalty factors. Portfolio classifications reflect remaining pre-construction licensing burden rather than cumulative historical design activity. Designs already operational or under construction are excluded. Where anticipated FOAK deployment is expected to occur under a foreign licensing regime, designs are retained under their country of origin unless explicitly reassigned in the main licensing calibration. Portfolio penalties capture coordination burden, not intrinsic technical risk.

SMR design category	Number of designs	Countries	Number of active designs pre-construction[1]	Total designs[2]	Baseline penalty	Accelerated penalty
National champion[3]	1	BE, CH, IT, ID, NL, RO, RW, SE, UK	1	9	0	0
Small portfolio	2	IN, DK, ZA	2	6	2	1
Moderate portfolio	3–4	CN, KR, JP	3, 4, 4	11	4	2
Large portfolio	5–10	RU, CA, FR	5, 5, 7	17	6	3
Very large portfolio	≥10	US[4]	14	14	8	4

[1]Portfolio complexity is attributed to the jurisdiction expected to conduct the primary FOAK licensing review where this is explicitly defined. Where deployment jurisdiction remains uncertain or speculative, designs are attributed to the vendor's country of origin. [2]Total design counts (n = 57) exclude designs that are already operational or under construction and therefore do not contribute to future licensing burden. From the country count, this includes Argentina (CAREM), China (HTR-PM, ACP-100), Russia (RITM-200, KLT-40S, BREST-OD-300) and the United States (BWRX-300). [3] National-champion cases in the current pre-construction sample are EAGLES-300 (BE), START (CH), LFR-AS-200 (IT/FR), Thorizon (NL/FR), ThorCon 500 (US/ID), NuScale (US/RO), DF300 (CA/RW), SEALER-55 (SE) and Rolls-Royce SMR (UK). These designs constitute the primary focus of their country's near-term licensing effort and therefore receive no portfolio penalty. [4]For the United States, the large domestic design portfolio is represented in the table for completeness, but no additional U.S. portfolio penalty is applied in the main licensing specification because this burden is already embedded in the separate empirical U.S. licensing calibration. In the OECD ADVANCE sensitivity where the U.S. is assigned the national regulatory penalty of Canada, the associated design portfolio penalty (8% in the Baseline scenario and 4% in the Accelerated scenario) is applied.

Table S25. International licensing-readiness scores for SMR cooling technologies across selected countries. Scores are reported separately for the pre-licensing (Pre.) and licensing (Lic.) stages, where 1 = significant experience, 2 = limited experience, and 3 = no or very limited experience. Lower mean scores indicate greater overall licensing readiness across cooling technologies. For consistency with the coolant-type classification used in this study, metal-cooled designs include World Nuclear Association entries classified as fast-neutron reactors where these correspond to sodium- or lead-cooled fast reactors. Scoring and compilation: Authors' coding based on information reported by the World Nuclear Association.[6]

	Belgium		**Canada**		**China**		**South Korea**		**Russia**		**Ukraine**		**United States**	
SMR cooling type	**Pre**	**Lic**	**Pre**	**Lic**	**Pre**	**Lic**	**Pre**	**Lic**	**Pre**	**Lic**	**Pre**	**Lic**	**Pre**	**Lic**
Water-cooled	3	3	3	3	–	1	1	1	1	1	1	1	2	2
Gas-cooled	3	3	3	3	–	1	3	3	2	2	3	3	3	3
Metal-cooled[1]	3	3	3	3	–	–	3	3	2	2	3	3	3	3
Molten-salt-cooled	3	3	3	3	–	–	3	3	2	2	3	3	3	3
Mean	**3.00**		**3.00**		**1.00**		**2.63**		**1.75**		**2.63**		**2.75**	

[1]The WNA survey uses "fast-neutron reactor" (FNR) as a design category within its taxonomy. Because all identified FNR entries correspond to sodium- or lead-cooled fast reactors, we treat them as metal-cooled to maintain coolant-type consistency across our full SMR database.

Table S26. Cooling-type licensing-readiness benchmarks and penalty calibration. The NEA sample means provide the primary benchmark for each cooling type, while cross-check and full-sample estimates are reported as validation against broader active-pipeline coverage. Water-cooled designs show the strongest licensing-readiness performance and therefore receive no penalty, whereas metal-, gas-, and molten-salt-cooled designs receive downward penalty adjustments under the Baseline and Accelerated scenarios. Full-sample counts refer to the active design pipeline used in the modelling framework.

Cooling type	**NEA sample size (*n*)**	**NEA mean**	**Cross-check (*n*)**	**Sample mean (cross-check)**	**Full sample (*n*)**	**Baseline Penalty**	**Accelerated penalty**
Water-cooled	17	3.00	9	2.33	25	0	0
Metal-cooled	15	2.00	12	1.67	16	4	2
Gas-cooled	11	1.82	8	1.50	9	4	2
Molten-salt-cooled	9	1.89	9	2.11	14	4	2
All designs	52	2.25	38	1.89	64	—	—

Table S27. Historical distribution of reactor construction outcomes by region and design type (1954–2016). The table summarises construction outcomes for 554 reactors, disaggregated by region and by reactor design type, and reports the corresponding number of successes, failures, and implied failure rates. This evidence provides part of the empirical basis for the construction-failure assumptions used in the analysis. PWR = pressurised water reactor; BWR = boiling water reactor; Non-LWR = non-light-water reactor; LWGR = light-water gas reactor. RoW denotes the rest of the world and includes Africa (South Africa, n = 2) and South America (Argentina, n = 3).

Region	**Sample size (*n*)**	**Successes (*n*)**	**Failures (*n*)**	**Failure rate (%)**
North America	191	151	40	20.9
Asia	151	151	0	0.0
Europe	131	128	3	2.3
Russia	47	33	14	29.8
USSR (excl. RU)	29	24	5	17.2
RoW	5	5	0	0.0
Design Type	**Sample size (*n*)**	**Successes (*n*)**	**Failures (*n*)**	**Failure rate (%)**
PWR	314	281	33	10.5
BWR	103	83	20	19.4
Non-LWR	112	109	3	2.7
LWGR	25	19	6	24.0
Total	**554**	**492**	**62**	**11.2**

Table S28. Definition and application of country-level indicators for deriving construction-phase failure rates. The table defines the six country-level indicators used to calibrate construction-phase failure risk and shows how each enters the model. The first two indicators capture early post-FOAK deployment capability, the next two capture deployment scale and accumulated construction experience, and the final two act as standalone modifiers. The 32-year reference period corresponds to 2019–2050, matching the interval from the first full year after initial historical SMR FOAK operation in Russia (RITM-200) to the study horizon under the tripling global nuclear target. FOAK denotes the first grid-connected/commissioned nuclear unit in a country; the 5th unit corresponds to FOAK+4. The reference-case rule for formative indicators is defined as countries with rapid early replication/scale-up in the historical record (score = 0). Each reference case serves as the benchmark historical performance and received no penalty with then failure-rates framework. For SMR designs located in China and Russia, formative penalties are capped at zero to avoid penalising systems with demonstrated operational SMR experience and ongoing SMR construction activity. For cumulative nuclear experience, the U.S. is the benchmark with >100 GWe commissioned capacity in the FOAK reference window and a peak 3-year average deployment rate of 8.2 GWe yr^{-1}. *Failure* denotes cancellation or long-term suspension prior to operation (events coded consistently across reactor types). Reference cases for the historical construction failure indicator are China (CN), France (FR), Japan (JP), and the United Kingdom (UK); these counties have zero failure events and the lowest Wilson-score upper bounds relative to other countries with 0% failure. This indicator enters the model as an additive modifier rather than a performance composite. Classification of construction activities at the end of the observation period follows coding in the IAEA Power Reactor Information System (PRIS) database[7] (SMRs are included in the construction count). The recent construction activity indicator enters the model as an additive modifier rather than a performance composite.

Indicator	Definition	Model application
Early deployment duration (T_5)	Years from FOAK commissioning to commissioning of the 5th unit (FOAK+4): $T_5 = Y_{5th} - Y_{FOAK}$.	Relative proxy for early post-FOAK replication capability; longer durations imply weaker formative performance. Reference cases are assigned no penalty (score = 0).
Early upscaling duration (≥1.5 GWe)	Years from FOAK commissioning to the first year in which cumulative commissioned capacity reaches ≥1.5 GWe: $T_{1.5} = Y_{\geq 1.5} - Y_{FOAK}$.	Relative proxy for early post-FOAK scale-up capability; longer durations imply weaker formative performance. China and South Africa are the reference cases.
Cumulative nuclear experience (GWe commissioned)	Total commissioned national capacity within the first 32 years after FOAK (SMR reference period, 2019–2050).	Proxy for industrial and supply-chain maturity. Absolute measure (not normalised by reactor size or country size). The U.S. is the reference case.
Peak annual deployment (3-year rolling average)	Maximum 3-year rolling average of annual national commissioning capacity (GWe yr^{-1}) within the first 32 years after FOAK.	Relative proxy for construction learning and deployment intensity. The U.S. is the reference case.
Historical construction failure rate[4]	Frequency of construction cancellation or long-term suspension events within the first 32 years after FOAK commissioning.	Absolute measure applied uniformly across countries and reactor sizes. Countries are ranked using Wilson score intervals for the construction-failure proportion; reference cases have zero events and the lowest Wilson upper bound.
Recent construction activity (including SMRs)	Commissioned units and units under construction after the 32-year FOAK reference period (including SMRs).	Relative measure distinguishing sustained/renewed construction activity from prolonged construction hiatuses. China and Russia are reference cases (score = 0).

Table S29. Early post-FOAK deployment and upscaling metrics. The table reports the country-level milestones used to construct the early deployment and early upscaling indicators. Specifically, it records the commissioning year of the first reactor unit (FOAK), the commissioning year of the fifth unit (FOAK+4), the duration between these milestones, the year in which cumulative national nuclear capacity first reached ≥1.5 GWe, the duration required to reach that threshold, and the corresponding number of units. These metrics provide the empirical basis for the early deployment and early upscaling indicators used in the construction-phase calibration. The Soviet Union (USSR) excludes reactors commissioned in Russia

Country	FOAK comm. year	$FOAK_{+4}$ comm. year	Duration for T_5 (yrs)	Year of ≥1.5 Gwe capacity	Duration for ≥1.5 Gwe	No. of units (≥1.5 Gwe)
AR	1974	N/A	N/A	2016	43	3
BE	1975	1985	11	1975	1	3
CA	1968	1972	5	1972	5	5
CH*	1969	1984	16	1979	11	4
CN	1994	2002	9	1994	1	3
FR	1959	1966	8	1969	11	8
IN	1969	1984	16	1992	24	8
IT	1964	N/A	N/A	N/A	N/A	N/A
JP	1966	1972	7	1972	7	5
KR	1978	1986	9	1983	6	3
NL	1963	N/A	N/A	N/A	N/A	N/A
RO	1983	N/A	N/A	N/A	N/A	N/A
RU	1964	1972	9	1973	10	6
SE	1972	1976	5	1975	4	4
UK	1956	1959	4	1965	10	17
US	1958	1963	6	1968	11	11
USSR	1973	1980	8	1979	7	4
ZA	1984	N/A	N/A	1985	2	2

Table S30. Country-level historical reactor construction records and associated failure rates. For each country, the table reports the historical construction and commissioning periods used in the reference sample, together with cumulative installed capacity, peak annual deployment capacity, total number of units, the number of units in the 30–500 MWe range, the implied historical construction failure rate, and Wilson confidence intervals. Construction and commissioning periods are shown in the same column to summarise the span from first to last construction start and from first to last unit commissioning within the observation window. The USSR is represented by Armenia (AM), Kazakhstan (KZ), Lithuania (LT), Ukraine (UA). The USSR total combines Russia with the four Soviet satellite countries (AM, KZ, LT, and UA).

Country	Con. period / Comm. period (first-last start / first-last unit	Total capacity (GWe)	Peak annual capacity (GWe yr⁻¹)	Total no. of units (no. of units, 30–500 MWe)	Failure rate (*n*)	Wilson CI
AR	1968–1981 1974–2016	1.6	0.5 (1974–1976)	3 (1)	0.0% (0/3)	0.0–56.1%
BE	1969–1978 1975–1985	5.5	0.63 (1983–1985)	7 (2)	0.0% (0/7)	0.0–35.4%
CA	1960–1985 1968–1993	15.6	1.5 (1983–1985)	24 (2)	0.0% (0/24)	0.0–13.8%
CH	1965–1974 1969–1984	2.9	0.32 (1983–1985)	5 (3)	0.0% (0/5)	0.0–43.5%
CN	1985–2016 1994–2024	53.9	5.8 (2014–2016	56 (2)	0.0% (0/56)	0.0–6.4%
FR	1955–1985 1959–2000	64.0	5.9 (1985–1987)	68 (9)	0.0% (0/68)	0.0–5.3%
IN	1964–1990 1969–2000	2.0	0.4 (1993–1995)	14 (14)	0.0% (0/14)	0.0–21.5 %
IT	1958–1982 1964–1981	1.4	0.5 (1964–1966)	4 (3)	42.9% (3/7)	15.8–75.0%
JP	1961–1992 1966–1997	42.3	3.4 (1984–1986)	53 (9)	0.0% (0/53)	0.0–6.8%
KR	1972–2000 1978–2005	17.1	1.7 (1998–2000)	28 (0)	0.0% (0/20)	0.0–16.1%
NL	1965–1969 1963–1973	0.5	N/A	2 (2)	0.0% (0/2)	0.0–65.8%
RO	1983–1987 1996–2007	1.3	N/A	2 (0)	60% (3/5)	0.0–65.8%
SE	1966–1980 1972–1985	9.6	1.6 (1981–1983)	12 (1)	0.0 % (0/12)	0.0–24.3%
UK	1953–1980 1956–1989	13.4	1.8 (1985–1987)	42 (27)	0.0% (0/42)	0.0–8.4%
US	1954–1978 1958–2016	108.8	8.2 (1984–1986)	127 (17)	24.0% (40/167)	18.1–31.0%
RU	1957–1988 1964–2012	24.4	1.7 (1984–1986)	33 (10)	29.8% (14/47)	18.7–44.0%
USSR	1964–1987 1973–2006	20.6	2.6 (1985–1987)	24 (5)	17.2% (5/29)	7.6–34.5%
USSR (total)	1957–1987 1964–2006	45.0	4.2 (1985–1987)	62 (15)	25.0% (19/76)	16.6–35.8%
ZA	1976 (both) 1984–1985	1.8	N/A	2 (0)	0.0% (0/2)	0.0–65.8%
Total/ cumulative	1953–2016 1956–2024	387.0	24.4 (1985–1987)	492 (102)	11.2% (62/554)	9.7–15.5%

Table S31. National nuclear construction activity within the 32-year post-FOAK reference period, including SMRs. For each country, the table reports the span from the first to the last construction start within the 32-year post-FOAK window (2019–2050), together with the total number of units and the maximum installed capacity achieved during that period. Construction outcomes are disaggregated into operational, under construction, suspended operation, cancelled construction, suspended construction, and permanent shutdown. These indicators are used to capture recent national construction activity in the construction-phase calibration. Maximum targeted capacity excludes cancellations and suspensions.

Country	Period (1st to last constr. start)	Total no. of units	Max. targeted capacity (GWe)	Oper.	Under constr.	Susp. Oper.	Canc. Constr.	Susp. constr.	Perm. Shut.
AR	2014	1	0.03	0	0	0	0	0	0
BE	N/A	0	0	0	0	0	0	0	0
CA	N/A	0	0.0	0	0	0	0	0	0
CH	N/A	0	0.0	0	0	0	0	0	0
CN	2017-2024	30	30.7	2	28	0	0	0	0
FR	1998-2007	3	4.5	3	0	0	0	0	0
IN	2000-2021	17	10.3	10	7	0	0	0	0
IT	N/A	0	0.0	0	0	0	0	0	0
JP	1986-2010	19	20.8	6	2	11	0	0	1
KR	2006-2018	10	11.9	8	2	0	0	0	0
NL	N/A	0	0.0	0	0	0	0	0	0
RO	N/A	0	0.0	0	0	0	0	0	0
RU	2006-2024	14	12.1	9	4	0	0	1	0
SE	N/A	0	0.0	0	0	0	0	0	0
UK	1988-2019	3	4.5	1	2	0	0	0	0
US	2013	4	4.5	2	0	0	2	0	0
ZA	N/A	0	0.0	0	0	0	0	0	0
Total	**1986–2024**	**101**	**129.3**	**41**	**45**	**11**	**2**	**1**	**1**

Table S32. Country-level construction-phase penalty assignments by indicator. The table reports the indicator-specific country groupings and penalty values used to calibrate construction-phase failure risk prior to the addition of the technology-level SMR construction-readiness modifier. The first two indicators capture formative construction capability, while the next two capture deployment scale and accumulated construction experience; in the model, these two pairs are combined as averaged component scores before the standalone modifiers for historical construction failure rates and recent construction activity are applied (Supplementary Note 14). Bas. and Acc. denote the Baseline and Accelerated scenarios, respectively.

Construction phase failure-rate indicator	Category (Best to worst performance)	Country	Bas. scenario penalty	Acc. scenario penalty
Time to 5th reactor commissioned after FOAK (T_5)	> 5 years	UK, CA, SE	0	0
	6–7 years	US, JP	2	1
	8–9 years	BE, FR, CN, KR, RU	4	2
	> 9 years	CH, IN	6	3
	< 5 units commissioned	AR, IT, NL, RO, ZA	8	4
Time to 1.5 GWe cumulative capacity ($T_{1.5}$GWe)	< 2 years	BE, CN, ZA	0	0
	2–5 years	SE, CA	2	1
	6–7 years	KR, JP	4	2
	7–11 years	CH, RU, UK, FR, US	6	3
	> 11 years	IN, AR	8	4
	< 1.5 GWe capacity	IT, NL, RO	10	5
Cumulative nuclear experience (GWe deployed)	Largest construction experience	US	0	0
	Large-scale	FR, CN, RU, JP	2	1
	Medium-high	KR, CA	4	2
	Medium	UK, SE, BE	6	3
	Low	CH, IN, ZA, AR, IT, NL, RO	8	4
	None	DK, ID, RW	10	5
Peak annual capacity (GWe yr^{-1}) over 3 years	Highest peak deployment rate	US	0	0
	High	FR, CN	2	1
	Medium-high	RU, JP	4	2
	Medium	UK, KR, SE, CA	6	3
	Low	AR, BE, ZA, IT, IN, NL, RO	8	4
Historical failure rates	Zero with lowest uncertainty	FR, CN, JP, UK	0	0
	Zero with low-moderate uncertainty	CA, KR, IN, SE, BE	2	1
	Zero with moderate uncertainty	AR, CH, NL, ZA	4	2
	High	US, RU	6	3
	Highest	IT, RO	8	4
Recent construction activity	Highest construction activity	CN, RU	0	0
	Large-scale	KR, IN	2	1
	Large-scale but suspended capacity	JP	4	2
	Medium	FR, UK, US	6	3
	Low or none	AR, BE, CA, IT, NL, SE, RO, ZA	8	4

Table S33. Reference-set imputation of country-level penalties for nuclear newcomer and export-led SMR deployment contexts. For target deployment markets lacking directly observable construction records, country-level penalties are derived by combining observable national indicators with imputed values for unobserved construction metrics. The Asia and Europe rows are reported as illustrative regional reference checks for the Danish design case, while the global row provides the benchmark imputation used in the model. This approach allows construction risk to be assigned consistently in newcomer and export-led deployment settings without relying on arbitrary assumptions about unobserved national capabilities.

Region	**Ref. target market**	**Formative replication duration, T_5 (years)**	**Formative upscaling duration, $T_{1.5}$ (GWe)**	**Formative phase composite, FPC (c)**	**Historical construction failure rate, F_{32} (c)**	**Imputed national penalty (unobserved metrics)**	**Total country-level penalty[1]**
Asia	Thailand	1.5	2.0	1.8	0.5	2.3	11.3
Europe	Norway or Denmark	2	3.4	2.7	1.4	4.1	13.1
Global	N/A	1.8	2.4	2.1	1.3	3.4	**12.4**

[1]The total penalty combines the imputed national penalty with the Deployment Capacity Intensity and Recent Construction Activity deductions applied to the illustrative Danish design case.

Table S34. Cooling-type construction-readiness benchmarks and penalty calibration. NEA sample means provide the primary benchmark for each cooling type, while cross-check and full-sample estimates are reported as validation against broader pipeline coverage. Water-cooled designs show the strongest construction-readiness performance and therefore receive no penalty, whereas metal-, gas-, and molten-salt-cooled designs receive downward penalty adjustments under the Baseline and Accelerated scenarios. Full-sample counts refer to the active design pipeline used in the modelling framework.

Cooling type	**Full sample (*n*)**	**NEA sample size (*n*)[1]**	**NEA mean**	**Cross-check sample (*n*)**	**Cross-check mean**	**Baseline Penalty**	**Accelerated penalty**
Water-cooled	25	17	3.94	11	3.64	0	0
Metal-cooled	16	15	2.58	13	2.54	4	2
Gas-cooled	9	11	2.20	8	1.94	4	2
Molten-salt-cooled	14	9	2.36	9	2.50	4	2
All designs	64	52	2.90	40	2.70	N/A	N/A

[1]Includes operational designs represented in the NEA Dashboard for comparative benchmarking purposes.

Table S35. Summary of regional and national-specific failure rates. The table reports the regional and country-level licensing and construction failure-rate estimates used to parameterise post-2025 design additions in the simulation framework, together with corresponding Jeffreys confidence intervals. OECD and non-OECD aggregates are included as supplementary benchmarks to show how these national and regional estimates map onto broader deployment groupings.

Phase	Scenario	SMR sample population	*n*	Failure rate	Jeffreys CI
Licensing	Baseline	Europe	16	11.4%	2.7–34.4%
	Accelerated	Europe	16	5.7%	0.7–25.7%
	Baseline	United States	14	57.6%	31.9–79.7%
	Accelerated	United States	14	33.4%	15.1–61.5%
	Baseline	OECD-Asia	8	9.5%	1.4–45.4%
	Accelerated	OECD-Asia	8	4.8%	0.0–26.2%
	Baseline	Canada	6	11.0%	1.9–55.8%
	Accelerated	Canada	6	5.5%	0.0–33.3%
	Baseline	Russia	8	5.5%	0.0–26.2%
	Accelerated	Russia	8	2.8%	0.0–26.2%
	Baseline	China	5	4.4%	0.0–37.9%
	Accelerated	China	5	2.2%	0.0–37.9%
	Baseline	Rest of the World	7	11.1%	1.6–50.1%
	Accelerated	Rest of the World	7	5.6%	0.0–29.2%
	Baseline	OECD	45	25.1%	13. 7–38.3%
	Accelerated	OECD	45	14.0%	5.8–25.4%
	Baseline	Non-OECD	19	7.6%	0.6–22.1%
	Accelerated	Non-OECD	19	3.8%	0.6–22.1%
	Baseline	Global	64	19.9%	11.9–31.3%
	Accelerated	Global	64	11.0%	5.0–20.3%
Construction	Baseline	Europe	16	20.5%	5.6–42.1%
	Accelerated	Europe	16	10.3%	2.7–34.4%
	Baseline	United States	14	19.1%	6.4–46.9%
	Accelerated	United States	14	9.6%	0.8–28.8%
	Baseline	OECD-Asia	8	13.0%	1.4–45.4%
	Accelerated	OECD-Asia	8	6.5%	1.4–45.4%
	Baseline	Canada	6	18.7%	1.9–55.8%
	Accelerated	Canada	6	9.3%	1.9–55.8%
	Baseline	Russia	8	6.4%	1.4–45.4%
	Accelerated	Russia	8	3.2%	0.0–26.2%
	Baseline	China	5	2.0%	0.0 –37.9%
	Accelerated	China	5	1.2%	0.0–37.9%
	Baseline	Rest of the World	7	25.8%	6.5–64.8%
	Accelerated	Rest of the World	7	12.9%	1.6–50.1%
	Baseline	OECD	45	18.7%	8.8–30.8%
	Accelerated	OECD	45	9.4%	3.1–19.8%
	Baseline	Non-OECD	19	11.2%	2.3–29.7%
	Accelerated	Non-OECD	19	5.6%	0.6–22.1%
	Baseline	Global	64	16.5%	9.5–27.8%
	Accelerated	Global	64	8.3%	3.0–16.3%

Table S36. Vendor-announced FOAK target years by region and reactor cooling type. The table reports the distribution of vendor-stated FOAK target years for the 35 designs with announced deployment targets, summarised by lower quartile, median and upper quartile. These values are used to contextualise the vendor-ambition gap and the limited differentiation of announced timelines by geography and reactor cooling type.

Sample group	Sample	n	Vendor FOAK target year	Baseline gap	Accelerated gap
Global / regional / reactor class	Global	35	2032.5 (2028.0–2035.0)	10.5 (7.0–16.4)	4.8 (3.3–6.4)
	OECD designs	28	2032.8 (2028.7–2035.0)	11.8 (7.8–17.1)	4.8 (3.3–6.6)
	Non-OECD designs	7	2032.0 (2026.0–2033.8)	9.7 (6.2–13.5)	3.5 (2.2–4.8)
	Water-cooled designs	13	2033.0 (2028.4–2033.9)	6.9 (4.7–9.4)	2.3 (1.4–3.0)
	Advanced modular reactors	22	2032.0 (2028.1–2035.0)	13.5 (9.3–18.4)	6.6 (4.7–8.5)
Development phase	Conceptual design	15	2034.0 (2029.4–2035.0)	14.8 (10.0–20.9)	7.6 (5.3–10.5)
	Basic design	7	2032.0 (2028.6–2033.2)	10.5 (7.0–15.4)	4.8 (3.3–6.4)
	Detailed design	6	2030.9 (2029.5–2032.8)	5.7 (3.8–8.4)	2.1 (1.5–2.8)
	Licensing	4	2030.5 (2029.9–2032.4)	2.7 (1.5–4.1)	0.5 (-0.1–1.1)
	Construction	3	2026.0 (2026.0–2027.6)	1.3 (0.3–2.6)	0.3 (0.1–0.8)
Aggregated development stage	Design phase	28	2033.0 (2029.0–2035.0)	12.1 (8.2–17.5)	5.4 (3.8–7.2)
	Post-design phase	7	2029.9 (2026.0–2031.8)	2.7 (1.5–4.1)	0.5 (0.1–1.1)

Table S37. Reference and scenario-based sensitivity outcomes for cumulative FOAK SMR deployment at selected time points. Cumulative number of SMR designs reaching FOAK operation under the reference Baseline and Accelerated scenarios and five scenario-based sensitivity analyses in 2035, 2040, 2045 and 2050. Values report the median and P10–P90 interval for each model case. The sensitivity cases correspond to the P50 trajectories shown in Extended Data Fig. 5 and the P10, P50 and P90 trajectories shown in Supplementary Fig. 6.

Year	Model case	Baseline median	Baseline P10–P90	Accelerated median	Accelerated P10–P90
2035	Current phase completion	13	11–14	22	19–24
2035	ADVANCE-OECD licensing	12	9–14	22	19–26
2035	**Reference scenario**	9	7–11	16	13–19
2035	Construction cascade	10	8–12	18	15–21
2035	Late-stage risk	9	7–11	16	13–19
2035	Stalled development	7	6–9	15	12–18
2040	Current phase completion	18	15–21	37	33–42
2040	ADVANCE-OECD licensing	17	14–20	37	32–43
2040	**Reference scenario**	13	10–16	30	26–36
2040	Construction cascade	13	10–16	31	26–36
2040	Late-stage risk	12	10–15	27	23–32
2040	Stalled development	10	8–12	28	24–33
2045	Current phase completion	25	21–29	47	40–55
2045	ADVANCE-OECD licensing	23	19–28	45	37–54
2045	**Reference scenario**	18	15–23	41	34–48
2045	Construction cascade	17	14–22	38	32–46
2045	Late-stage risk	17	13–21	34	28–39
2045	Stalled development	13	11–17	36	29–43
2050	Current phase completion	32	24–36	56	47–65
2050	ADVANCE-OECD licensing	28	21–34	52	43–62
2050	**Reference scenario**	24	18–30	48	39–58
2050	Construction cascade	21	16–26	44	36–53
2050	Late-stage risk	21	16–26	40	32–45
2050	Stalled development	17	13–23	43	34–52

Table S38. SMR capacity projections for 2035–2050.

Source and scenario	Year of publication	2035 target (GW)
NNL UK (low)	2014	65.0
NNL UK (high)	2014	85.0
NEA (high)	2016	21.0
NEA (low)	2016	0.9
NuScale (low)	2017	55.0
NuScale (high)	2017	75.0
McKinsey & Company (Tripling nuclear target)	2018	35.0
Idaho National Laboratory	2021	6.0
NEA (Tripling nuclear target)	2022	35.0
NNWI (base-case)	2023	7.4
IAEA (high)	2024	49.3
IAEA (low)	2024	4.8
Source and scenario	**Year of publication**	**2050 target (GW)**
NEA (1160 GW***)	2022	375
NNWI High case	2023	300
NNWI Base-case	2023	155
NNWI Low case	2023	28
IAEA High case	2024	139
IAEA Low case	2024	9
Wood Mackenzie NZS	2024	345
Wood Mackenzie BCS	2024	230
IEA NZE	2025	200
IEA APS	2025	118
IEA STEPS	2025	39

NNL = National Nuclear Laboratory; NEA = Nuclear Energy Agency; NNWI = New Nuclear Watch Institute; IAEA = International Atomic Energy Agency; NZS = Net Zero Scenario; BCS = Base case scenario; NZE = Net Zero Emissions; APS = Announced Pledges Scenario; STEPS = Stated Policies Scenario

Supplementary Notes

Supplementary Note 1. The five phases of SMR development

Three decades ago, the IAEA cautioned that inconsistent use of design and licensing terms obscures the "real development status" of reactor projects, impeding comparison across designs and jurisdictions[2]. To counter this, it proposed three sequential design milestones—Conceptual design completed (D=1), Basic design completed (D=2), and Detailed design completed (D=3)—as common reference points (hereafter CD, BD and DD).

Under this framework, progression from CD to BD to DD is illustrated as a shift from extended description to several binders to thousands of files, reflecting the increasing completeness and documentation intensity of reactor design. However, these reference markers have not been applied consistently in the IAEA's SMR catalogues from 2012 to 2024, which instead enumerate up to 13 design sub-stages (e.g., advanced conceptual, preliminary design completed, Basic design completed, Detailed design completed, plan to apply for design certification and certified design) (Fig. S1).

Vinoya et al.[8] adopt this terminology in their state-of-the-art review. Related literature has broadened the IAEA's early guidance, but often at the cost of clarity: Pioro[3,4] sets out seven stages (pre-conceptual, conceptual, basic, developmental, preliminary, final/certified and construction); the World Nuclear Association (WNA)[6] frames work packages as reactor concept → plant-level → system-level → component-level design; and Ernst & Young[9] segments national programmes into initiation (years 1–2), development (≈7 years) and construction (≈7 years). While descriptively useful, these schemes mix engineering, regulatory and programmatic lenses, complicating duration measurement and cross-country comparisons. Consequently, the IAEA's earlier caution remains current.

Kang et al.[5] likewise note that SMR development terminology is applied inconsistently and observe that, although the IAEA has proposed a broader general design-classification model, only five stages are sufficiently clear and consistently interpretable across designs: Pre-conceptual/Conceptual design, Basic design, Detailed design, Under Construction and Operational. We concur with their broader diagnosis that existing classifications remain difficult to apply consistently but depart from their formulation in two important respects. First, the pre-conceptual stage is rarely documented consistently, can linger for years and, if included, inflates design durations unevenly. We therefore acknowledge but omit pre-conceptual work from our metrics. Second, rather than treating construction and operation as the only clearly usable post-design stages, we explicitly distinguish licensing and construction as separate measurable phases.

Guided by the 1996 IAEA milestones and the subsequent critique advanced by Kang et al.[5], we therefore adopt a five-phase development sequence for modelling FOAK deployment timelines: Conceptual design (CD), Basic design (BD), Detailed design (DD), Licensing and Construction (Table S1). This framework is designed for phase-duration measurement and

FOAK deployment modelling rather than Technology Readiness Level (TRL) assignment, as implemented by Kang et al.[5].

Phases may overlap (for example, through early licensing interactions during late DD), but for duration measurement we assign one start and one finish to each phase using the earliest formal, documented milestone (Methods). Phase hand-offs are treated as contiguous in the timeline. Where jurisdictions lack explicit "design completed" announcements, we use documentary proxies such as tender-package release or a regulator-accepted safety case. This five-phase structure preserves the IAEA's clean D=1/D=2/D=3 markers while responding to concerns that many intermediate development labels are not consistently usable. Specifically, we integrate a measurable **Licensing phase** anchored to formal filings or permits enabling first nuclear-island concrete. Additionally, we define Construction through FOAK operation as grid connection for commercial rather than demonstration use, thereby enabling transparent cross-jurisdictional duration statistics.

Supplementary Note 2. Early failure patterns in the SMR design pipeline

Our historical analysis shows that the early uptake of SMR development was accompanied by substantial attrition risks. Between 1984 and 1999, 12 designs entered the global SMR pipeline, comprising six water-cooled designs and six advanced modular reactors (three metal-cooled, two gas-cooled and one salt-cooled). The cohort included four Russian designs, three from OECD-Asia, two from North America, and one each from Argentina, Canada and South Africa. Six of these designs were later cancelled or suspended indefinitely, with failures spanning all represented regions and all cooling types present in the cohort (Table S2).

Supplementary Note 3. Stalled development in the SMR pipeline

The active SMR pipeline is reduced by removing designs that have exceeded the scenario-specific P95 elapsed-time threshold for their current development phase (Fig. S2 and Table S3). This sensitivity provides a direct counterpoint to the reference treatment, in which retained long-duration designs are forced to enter their next phase in 2026 and then proceed through standard project-progression and failure-risk rules. Under the Baseline case, thresholds are set at 13.0, 12.2, 9.0, 6.7 and 6.8 years for Conceptual design, Basic design, Detailed design, licensing and construction, respectively. Under the Accelerated case, the corresponding thresholds are 8.0, 5.0, 5.0, 2.8 and 4.7 years. Relative to the reference case, this reduces median cumulative FOAK deployment by 2050 by 7 under Baseline assumptions and 5 under Accelerated assumptions (Baseline: P10 −5, P90 −7; Accelerated: P10 −5, P90 −6).

To test sensitivity to the treatment of long-stalled designs, we constructed two scenario-specific active-pipeline inclusion filters. The Baseline stalled-development filter retains 46 of the 64 active designs, including the three designs already operational by 2025. The Accelerated stalled-development filter retains 56 active designs, also including the three operational designs. These filters bound the extent to which long-duration designs remain analytically viable within the active 2025 pipeline under the corresponding scenario assumptions. Unlike the current-phase completion sensitivity, which temporarily protects retained designs from failure in the phase they occupy at the end of 2025 before reintroducing phase-specific failure risks from the subsequent phase onward, the stalled-development sensitivity changes the composition of the active starting pipeline itself. It therefore tests how projected FOAK deployment changes when designs with limited observable progression are removed before standard project-progression, failure-risk and post-2025 pipeline-evolution assumptions are applied.

Notably, VK-300 (RU) provides the clearest illustration of stalled development under our framework. Although VK-300 completed Conceptual design after 15 years, exceeding the Baseline Conceptual design P95 threshold of 13 years, it then progressed through Basic design within a typical timeframe. However, it has remained in Detailed design since 2017 and has reached/exceeded the Baseline Detailed design P95 threshold of 9 years. Its cumulative design-phase exposure now exceeds 29 years, surpassing the P95 threshold for cumulative Conceptual design–to–Detailed design duration of 26.6 years. A comparable pattern is observed for VBER-300 (RU), which entered Conceptual design in 2001 and progressed efficiently through Conceptual and Basic design, but has remained in Detailed design since 2007, amounting to nearly two decades of Detailed design stalling. These cases demonstrate that prolonged stalling can emerge at later design stages independently of early-phase performance.

Evidence of downstream spillover is provided by **CAREM**, which required approximately 27 years to progress from CD entry (1984) to licensing (2011) in Argentina. Since entering licensing, the project has experienced extended post-design delays, with combined licensing and construction durations now approaching or exceeding the upper bounds applied in our modelling framework (licensing + construction ≈ 15 years). While CAREM itself reflects a historically specific development pathway, mapping an equivalent trajectory onto designs entering the pipeline in later decades would similarly imply deployment timelines extending well beyond FOAK-relevant horizons. This further illustrates how exceptionally prolonged design-phase development can propagate into subsequent stages and constrain deployment feasibility, without implying formal project failure.

The relevance of stalled development is further underscored by contrasting control cases within the same jurisdiction. Mirroring VBER-300, **RITM-200** (RU) entered CD in 2001 but progressed to FOAK commissioning within approximately 18 years—well within the range represented by the Accelerated scenario. Similarly, **KLT-40S** (RU) progressed from CD to operation in roughly 22 years. These trajectories demonstrate that FOAK deployment within two decades has been achievable under comparable institutional conditions within Russia, reinforcing that the prolonged stalling observed for VK-300 and VBER-300 likely reflects design- and project-specific development trajectories rather than jurisdiction-wide constraints.

While prolonged design-phase durations tend to amplify exposure to project attrition, the **mPower** case illustrates a parallel risk: failure can also occur under comparatively streamlined development trajectories in the OECD (Fig. S2). Poised in the early 2010s to become the leading U.S. SMR design, mPower advanced rapidly through Conceptual and Basic design phases and secured early institutional and contractual support. Nevertheless, the project was effectively mothballed in the mid-2010s following the withdrawal of investors and customers[10].

This outcome highlights that accelerated progression through early design phases does not immunise SMR projects against cancellation, underscoring how non-technical factors such as financing and market commitment shape design survival alongside temporal dynamics. Taken together, these dynamics underscore the importance of multiple factors in shaping prospects for reaching certified design and subsequent FOAK deployment.

Finally, the observed concentration of stalled development cases within the Russian cohort reflects data availability rather than selective case inclusion: Russia constitutes one of the largest and most active SMR design pipelines globally and therefore provides the clearest empirical record of long-horizon design progression. Importantly, Russia is generally regarded as a high-performing nuclear jurisdiction with demonstrated FOAK delivery capability. The observation of prolonged detailed-design stalling within this context therefore provides a conservative signal that stalled development can arise even under comparatively favourable institutional and industrial conditions. Additional detailed-design failures observed outside Russia, which span both OECD and non-OECD countries—mPower and PRISM (U.S) and PBMR (ZA)—further indicate that late-stage attrition is not jurisdiction-specific. Collectively, these cases support the treatment of extended DD-phase stalling as a generalisable execution risk rather than an artefact of any single national programme.

Supplementary Note 4. Framework overview and modelling approach

This note further documents the modelling architecture and case-specific project-progression rules used to generate First-of-a-Kind (FOAK) deployment projections for small modular reactors (SMRs). It complements the Methods by making explicit how observed phase histories, scenario assumptions, phase-specific failure risks and design-specific implementation rules interact within the Monte Carlo simulation framework.

The framework represents SMR development as a sequential five-phase process: Conceptual design, Basic design, Detailed design, Licensing and Construction. FOAK operation is treated as the endpoint of construction and marks the transition from development to first grid-connected operation. Phase durations are defined at annual resolution as intervals between recorded phase-start years. For completed phase transitions, each phase begins in its recorded start year and ends at the recorded start year of the next phase; construction ends at FOAK operation. This allows heterogeneous design histories to be represented within a consistent sequential framework.

The model consists of two coupled modules. The **project-progression module** estimates remaining time to FOAK operation for designs already present in the active SMR pipeline at the end of 2025, conditional on each design's observed phase and elapsed time in that phase. The **pipeline-evolution module** simulates post-2025 design additions and passes future entrants through the same phase-duration and attrition structure. Together, these modules estimate cumulative FOAK deployment through 2050 under Baseline and Accelerated assumptions. The Baseline scenario represents empirically grounded continuation of current development conditions, while the Accelerated scenario represents a favourable empirical bounding case based on faster observed development, higher design-entry rates and lower calibrated attrition risks.

The vendor-target comparison and full global deployment model use this architecture for different purposes. In the vendor-target comparison, the project-progression module is first applied without phase-specific failure risks to isolate timing divergence between vendor-announced FOAK dates and modelled development timelines. In the full global deployment model, phase-specific failure risks are applied to both active designs and simulated post-2025 additions, so the results capture both schedule constraints and attrition. Several deterministic project-progression rules are applied ex ante to selected active designs where generic phase-duration sampling would misrepresent design-specific evidence. Although some of these rules concern licensing or construction, their function is to define how specific designs transition through the five-phase project-progression framework; they do not override subsequent failure-risk treatment or the remaining simulation structure.

Rule 1: Forced next-phase starts for retained long-duration designs. Some active designs had already spent longer in their observed 2025 phase than the maximum duration implied by the relevant empirical phase-duration distribution. For these retained long-duration designs, the model assigns completion of the current phase in the following simulation year, rather than drawing a fresh full phase duration and thereby double-counting elapsed development time. This rule prevents active designs from being indefinitely held in their observed phase while also avoiding an artificial reset of projects that have already accumulated substantial development time. It does not guarantee FOAK operation: once the forced next-phase start is assigned, each design re-enters the standard project-progression sequence and remains subject to subsequent phase-duration sampling, licensing and construction requirements, and phase-specific failure risks.

Under the Baseline scenario, this rule affects **six designs**. Progression from Conceptual design to Basic design is enforced for EM2 (US), LFTR (US) and KARAT-45 (RU). Progression from Detailed design to Licensing is enforced for three Russian designs: VBER-300, SVBR-100 and VK-300. Under the Accelerated scenario, tighter phase-duration bounds mean that an additional nine designs are affected. In addition to the Baseline cases, Conceptual-design to Basic-design enforcement also applies to BANDI-60 (KR), CA Waste Burner (DK) and LFR-W (US); basic-design to detailed-design enforcement applies to DMS (JP), GTHTR300 (JP), SSR-U (UK/CA) and ThorCon500 (US/ID); and Detailed-design to Licensing enforcement applies to SMR-300 (US) and IMSR-400 (CA). These rules retain analytically relevant active designs while limiting optimism through the subsequent progression and failure-risk structure.

Rule 2: Compressed licensing treatment for Russian and Chinese designs. Russian and Chinese SMR licensing pathways are treated separately from the broader licensing assumptions applied to other jurisdictions. Observed SMR licensing in these countries has often functioned as a shorter formal approval checkpoint, closely coupled to construction authorisation and state-led deployment decisions, rather than as a longer, more open-ended pre-construction licensing process. For this reason, relevant Russian and Chinese designs are assigned compressed licensing treatment. Under the Baseline scenario, they draw from the standard licensing-duration range of 1–3 years. Under the Accelerated scenario, licensing is implemented as a fixed one-year transition. This rule applies to relevant active Chinese designs—ACPR50S, CAP200 and smTMSR-400—and Russian designs — KARAT-100, KARAT-45, SVBR-100, VBER-300 and VK-300—and, where applicable, to simulated future designs assigned to these jurisdictions.

Rule 3: Anchored construction-start years for selected licensing-stage designs. For a small group of active designs already in licensing in 2025, the model anchors the transition from licensing to construction using design-specific project evidence rather than drawing a full unresolved licensing duration from the generic distribution. This rule applies to BWRX-300, Xe-100, NuScale and SMART100. The anchor years represent the modelled construction-start year under the Accelerated scenario, with the Baseline scenario assigned one additional year to reflect slower progression without introducing bespoke delay assumptions. Accordingly, BWRX-300 is assigned construction start in 2026 under Accelerated and 2027 under Baseline; Xe-100 in 2027 and 2028; and NuScale and SMART100 in 2029 and 2030, respectively.

These anchors are intended to reflect identifiable late-stage project pathways while remaining broadly consistent with the scenario-specific licensing assumptions: the Accelerated licensing range is 1–3 years, whereas the Baseline range is 2–8 years. NuScale is treated more conservatively because its earlier US pathway did not proceed to construction and its current FOAK pathway is anchored instead to the Romania deployment timetable. SMART100 is assigned the same later anchor because, despite its long elapsed licensing history, no stronger near-term construction-start signal is used. This rule affects timing only; designs remain subject to the relevant phase-specific failure risks and, once construction begins, to the scenario-specific construction-duration assumptions.

Rule 4: CAREM construction-progress adjustment. CAREM is handled using a design-specific construction-progress rule because it had already entered construction before the 2025 model baseline. The simulation therefore does not redraw a full construction phase from the generic construction-duration distribution. Instead, it samples only the remaining construction duration conditional on assumed 2026 construction progress: 30–40% complete under Baseline assumptions and 40–50% complete under Accelerated assumptions. The remaining construction time is derived from the scenario-specific construction-duration distribution and added from the 2026 reference point to estimate CAREM's probabilistic FOAK operation date. This adjustment affects construction speed only; CAREM remains subject to the relevant national-level failure-risk treatment.

Treatment of post-2025 design additions and deployment interpretation. Post-2025 design additions are handled separately from the active-pipeline implementation rules. The active-pipeline filters and deterministic project-progression rules determine how observed designs present at the end of 2025 enter the simulation. The pipeline-evolution module then adds future designs stochastically according to scenario-specific entry rates. We do not apply an additional sensitivity analysis to the post-2025 design-entry rates themselves, because these rates define the Baseline and Accelerated pipeline-expansion scenarios rather than an independently identifiable uncertainty distribution; uncertainty in future additions is instead represented through Poisson sampling around the scenario-specific, time-varying entry rates. These future entrants are assigned regional and technological characteristics and then progress through the same sequential phase-duration and phase-specific attrition framework as active designs. As a result, increasing post-2025 design entry does not translate directly into near-term FOAK deployment, because new entrants must still pass through Conceptual design, Basic design, Detailed design, Licensing and Construction before reaching FOAK operation.

This timing constraint is central to the interpretation of the results. The model separates four analytically distinct quantities: *announced ambition*, *active-pipeline inclusion*, *development speed* and *survival probability*. Vendor-announced timelines describe ambition. Active-pipeline filters and implementation rules determine which observed designs are treated as analytically viable starting points and how their current phase status is represented. Phase-duration assumptions determine how quickly retained and future designs can progress. Failure-rate assumptions determine how many survive to FOAK operation. Combining these components in a Monte Carlo framework allows the analysis to estimate median deployment outcomes, uncertainty intervals and sensitivity-based feasibility spaces.

The framework is therefore not a deterministic forecast of which specific SMR designs will succeed. Nor is it a structural model of policy reform, financing conditions or supply-chain mobilisation. Rather, it defines a **probabilistic feasibility space** for FOAK deployment by combining observed development histories, scenario-specific progression assumptions, pipeline-entry dynamics, phase-specific attrition and explicit project-progression rules for designs whose status requires treatment outside generic sampling. This approach allows the analysis to distinguish vendor ambition from empirically constrained deployment prospects and to show how near-term FOAK deployment remains limited by the structure and maturity of the active SMR pipeline.

Supplementary Note 5. Design-phase duration parameterisation and sample construction

To assess whether Conceptual design (CD) durations have shortened over time, we regressed CD duration against CD start year across three nested samples of designs that completed the CD phase. In the full empirical sample ($n = 40$), CD duration declined significantly with later start year ($\beta = -0.417$ years per calendar year; adjusted $R^2 = 0.380$; $p < 0.001$), equivalent to a reduction of around 4.2 years per decade. However, this relationship is partly shaped by older designs with long CD durations. After excluding designs that began CD before 1995, the Baseline sample ($n = 35$) still shows a statistically significant but weaker decline ($\beta = -0.186$; adjusted $R^2 = 0.158$; $p = 0.010$), equivalent to around 1.9 years per decade. This indicates some historical compression in CD durations, but also shows that the trend weakens substantially once early long-duration cases are removed.

We therefore use the post-1994 filtered sample to parameterise CD duration under the Baseline scenario. This sample has a median duration of 6.0 years, mean duration of 6.66 years and standard deviation of 3.46 years, compared with 6.5, 8.45 and 6.74 years in the full empirical sample. The filtered sample also reduces the maximum observed CD duration from 32.0 to 15.0 years, providing a more representative basis for contemporary SMR development conditions. For the Accelerated scenario, we further exclude the slowest-duration upper-tail designs from the Baseline sample, retaining 27 designs. This produces a tighter and faster distribution, with a median of 5.0 years, mean of 5.11 years, standard deviation of 1.95 years and P10–P90 range of 3.0–7.4 years. In this Accelerated sample, the temporal trend disappears: the slope falls to −0.045 years per calendar year and is not statistically significant (adjusted $R^2 = -0.007$; $p = 0.372$). These results provide limited evidence that CD durations have continued to compress in recent decades (Table S4). Rather than supporting open-ended acceleration in early-stage SMR development, they suggest that CD durations are subject to a practical lower bound once historically slow and less representative cases are removed.

Table S5 reports summary statistics for the alternative samples used to parameterise CD, Basic design (BD) and Detailed design (DD) durations. For CD, we also report a projected sample that assumes completion of designs currently in CD by 2025. This projected sample contains 69 designs and has the same median as the filtered Baseline sample (6.0 years), but retains greater dispersion and a longer upper tail (M = 7.65 years; SD = 5.77; max = 32.0). Using this sample for parameterisation would therefore overstate CD duration uncertainty. We retain it for validation and context, while using the filtered Baseline sample (n = 35) and its Accelerated derivative (n = 27) for simulation and scenario construction.

To date, 21 designs have completed the Basic design (BD) phase, including two that later failed, while 16 remain in BD. We first estimate BD duration using the full set of projects that progressed to DD. We then expand this evidence with projected durations for designs currently in BD, assuming completion by the end of 2025 and transition to DD in 2026. This subgroup (n = 16) has already accumulated substantial time in BD, with a median duration of 4 years per design (IQR = 3–4), indicating relatively tight clustering among contemporary projects. The resulting projected sample therefore reflects a realistic, data-anchored best-case progression.

To avoid over-optimism, we impose a minimum BD duration of 2 years for the three cases beginning BD in 2025 (BSMR-200, i-SMR and LFR-AS-200), consistent with the fastest observed completions (ACP100, BWRX-300 and Natrium = 2 years). This adjustment mitigates right-censoring while preserving the empirical distribution under Baseline assumptions (M = 4.8; SD = 3.1; IQR = 3.0–5.0). The Accelerated BD sample is then derived by trimming the Baseline sample at the third quartile (Q3), yielding 28 observations and a more compressed but still plausible duration profile.

To parameterise Detailed design (DD), we first identified 10 historical SMR projects that progressed to licensing (Fig. S11). Because this precedented set is small, we expanded the evidence base by projecting all active DD designs to complete by the end of 2025 and enter licensing in 2026, increasing the sample to 20 designs. Two adjustments were then applied to improve realism and internal consistency, yielding an adjusted Baseline DD sample of 19 designs. First, we imposed a 2-year floor (DD ≥ 2 years), aligned with the fastest empirical cases (ACP100 and Xe-100); for SEALER-55, which entered DD in 2025, this sets the earliest feasible licensing transition to 2027. Second, we excluded VBER-300, whose approximately 19-year DD duration would disproportionately inflate the sample mean (4.9 versus 4.2 years) and SD (3.9 versus 2.1). Because this case appears to reflect project-specific delay rather than DD-phase structure, it was excluded from parameter estimation.

From this adjusted Baseline DD sample, we derived an Accelerated subset by trimming at Q3 and retaining the fastest 75% of observations (n = 14). The resulting 19- and 14-design samples preserve realistic tails, reflect heterogeneity in modern SMR programmes and avoid distortion from extreme outliers, whereas the smaller historical subsets alone would understate likely DD durations by omitting stalled or delayed projects. Together, these parameterisations provide coherent inputs for Monte Carlo simulation of downstream project progression.

Supplementary Note 6. Model fit diagnostics for design phases

Across the three design phases (Conceptual, Basic, and Detailed design), we evaluated distributional fit under both Baseline and Accelerated scenarios using four candidate families: lognormal, gamma, Weibull, and normal (Table S6). Baseline samples consistently favoured a lognormal specification, with lower AIC and BIC values than the alternative families in all three phases.

This provides strong internal support for retaining lognormal distributions under baseline conditions and is consistent with the broader phase-duration evidence presented elsewhere in the study. Under the Accelerated scenario, the best-performing family varies slightly across phases: gamma yields the lowest information criteria in Conceptual and Detailed design, whereas Weibull performs marginally best in Basic design. However, these differences are uniformly small (all ΔAIC < 1 relative to lognormal), indicating that accelerated-phase fits are only weakly sensitive to the specific distributional form selected.

We therefore retain a lognormal specification across all design phases in both scenarios. This choice is supported by the clear Baseline evidence, the minimal fit differences observed under acceleration, and the analytical advantage of applying a single parametric family throughout the modelling framework. Substantively, this suggests that acceleration primarily compresses variance and truncates the upper tail of phase durations rather than fundamentally altering their underlying distributional form. The near-equivalence of accelerated fits further indicates that downstream Monte Carlo results are unlikely to be materially affected by selecting gamma or Weibull instead of lognormal, while a unified lognormal specification improves consistency, interpretability, and reproducibility across phases.

Supplementary Note 7. Design-phase robustness checks

As a robustness check, we benchmark the combined design-phase duration (CD, BD and DD) using the 10 historical designs that completed all three phases between 2010 and 2024 (Argentina = 1; China = 2; South Korea = 1; Russia = 3; United States = 3). The sum of phase means implied by our parameterisation—approximately 15.5 years under Baseline assumptions and 11.4 years under Accelerated assumptions—closely matches the empirical cohort. The 10-design sample completed the full design phase in 16.1 years on average, while trimming the upper quartile (Q3; n = 7) yields 12.1 years, aligning with the Accelerated aggregate. This correspondence supports the internal consistency of the Baseline and Accelerated parameterisations for downstream simulation.

We further assess whether design-phase durations exhibit systematic changes over time and find that reductions in design-phase duration have accumulated over time, but have not continued to decline uniformly in recent projects (Fig. S11). While further acceleration remains possible, it is unlikely to arise from simple extrapolation of past trends and will instead depend on structural changes in design, licensing and delivery processes[11–15]. Next, we compare completed design-phase durations across key subgroupings to assess whether meaningful differences emerge by regulatory context or reactor type.

First, we compare mean durations across completed design phases for OECD and non-OECD SMR designs, finding only small differences between the two groups. Phase-specific gaps were modest throughout, amounting to 0.3 years in Conceptual design, 0.1 years in Basic design and 0.8 years in Detailed design (Table S7). Summing mean durations across the three completed design phases yields a cumulative average of 17.6 years for OECD designs, compared with 16.4 years for non-OECD designs. Overall, this indicates only a marginal non-OECD advantage of 1.2 years across designs that successfully completed these phases. Second, we compare mean durations at the technology level, observing only limited differences between water-cooled designs and advanced modular reactors (AMRs): mean phase-duration gaps of 0.9 years in Conceptual design, 0.2 years in Basic design and 0.4 years in Detailed design (Table S8). These findings complement Extended Data Fig. 2 by showing that the marked differences in cumulative design entry by OECD membership and reactor cooling type are not matched by large systematic differences in completed design-phase durations.

Finally, we examine the association between cumulative development duration and technology readiness level (TRL) across the global SMR sample and across OECD and non-OECD subsamples based on the study of Kang et al.[5] (Extended Data Fig. 7). Development duration was positively associated with TRL at the global level ($R^2 = 0.248$, $P < 0.001$), and this relationship remained statistically significant when the three operational designs were excluded ($R^2 = 0.274$, $P < 0.001$). Similar positive associations were observed in both the OECD ($R^2 = 0.197$, $P = 0.002$) and non-OECD ($R^2 = 0.309$, $P = 0.021$) subsamples, although the fitted relationship was steeper in the non-OECD case. This difference was accentuated when the three operational non-OECD designs were included, reflecting the fact that the only SMRs to complete the full development cycle to date are located in Russia and China. Even when these operational designs were excluded, the non-OECD relationship remained statistically significant and comparatively steeper ($R^2 = 0.462$, $P = 0.008$).

We therefore interpret the TRL regressions primarily as a relative indicator of maturity progression rather than as a direct phase-equivalent duration metric, since published TRL classifications do not map cleanly onto the five development phases used in our framework. Even so, the results remain directionally consistent with the phase-duration evidence reported above, which indicates only a modest non-OECD advantage across completed design phases.

Supplementary Note 8. Defining the scope of the SMR licensing phase

We define First-of-a-Kind (FOAK) licensing duration as the elapsed time from completion of Detailed design—culminating in a certified design—to First Concrete Pour (FCP). This demarcation subsumes pre-licensing maturation activities (e.g. vendor design reviews, generic design assessments, gap analyses and closure of research, development and innovation items) within the design phase, so that the licensing clock captures the site-specific pathway to construction.

Pre-licensing activities can span several years and strongly condition subsequent review timelines[16]. In practice, these activities often involve iterative regulator engagement, technology qualification and evidence generation prior to formal application[17–19]. For advanced reactors, particularly non–light-water reactor (non-LWR) designs, this phase may extend over multiple years due to limited experimental data, evolving codes and standards, and the need to establish novel safety cases[20]. We therefore treat pre-application maturation as part of Detailed design rather than licensing.

Cross-national experience indicates that regulators expect high design maturity at the point of application, including stable design configurations, closed R&D items and a coherent safety case. Designs that enter licensing prematurely tend to incur additional Requests for Additional Information (RAIs) and, in some cases, are forced back into Detailed design to establish a revised certified baseline. This pattern is consistent with evidence from both the historical reactor fleet and the emerging SMR pipeline[6,21], and reinforces the importance of clearly separating design maturation from site-specific licensing.

Licensing regimes broadly span prescriptive (deterministic) and goal-setting (performance-based) approaches[22]. Prescriptive systems benefit from established codes and standards but are less flexible for novel designs, while goal-setting systems enable innovation but introduce greater interpretive uncertainty for applicants[23]. In practice, most jurisdictions operate hybrid systems, and the resulting institutional variation contributes to both the mean and dispersion of licensing durations.

Our FOAK licensing duration therefore includes site-specific application and review, regulator technical assessment and RAIs, environmental and statutory approvals, public-hearing processes, issuance of a construction permit (or equivalent), and a short mobilisation period prior to first concrete. Empirically, licensing is a multi-stage, resource-intensive process. As a benchmark, United States Nuclear Regulatory Commission (U.S. NRC) design certification (treated here as part of Detailed design) requires on the order of ~179,000 staff-hours, while site-specific licensing stages such as Early Site Permits and Combined Licences require tens of thousands of staff-hours each[24]. These magnitudes help explain why licensing timelines are typically right-skewed rather than completed within a narrow time window.

Licensing frameworks were developed around large light-water reactors (LWRs), allowing LWR-based SMRs to draw on established precedents. By contrast, non-LWR technologies—including molten salt reactors (MSRs), sodium- and lead-cooled fast reactors, and high-temperature gas-cooled reactors—face additional evidence requirements related to fuels, coolants, materials behaviour, source terms and emergency planning. They may also raise challenges in digital instrumentation and control, human factors engineering and, in some cases, licensing of transportable or modular configurations. In OECD contexts, these factors tend to extend FOAK licensing timelines and increase their variance[20,21]. These features—high design maturity requirements, iterative regulatory review, and technology-specific evidence gaps—motivate the use of right-skewed (**lognormal**) distributions to represent FOAK licensing durations in the model.

Supplementary Note 9. Licensing phase parameterisation

We parameterised FOAK licensing duration using available empirical evidence together with targeted literature review. Building on our scope definition (Supplementary Note 8), we treat licensing duration as jurisdiction-sensitive rather than as a single globally transferable process. We first compiled licensing durations measured from the first accepted post-detailed-design filing to the authorisation enabling first nuclear-island concrete. The completed historical sample is small and entirely non-OECD, so it is informative for plausible lower-bound performance but not representative of likely OECD licensing conditions (Table S9 and Table S10). These observations therefore inform the Accelerated licensing range for OECD designs and non-OECD designs outside China and Russia, and the Baseline licensing range for China and Russia. Under Accelerated assumptions, China and Russia are assigned a **fixed one-year** licensing rule to reflect licensing as a shorter formal checkpoint coupled to construction approval. Broader institutional and regulatory evidence is then used to calibrate the scenario-level parameters.

A systematic review by Sam et al.[22] provides a useful benchmark for interpreting licensing delays, distinguishing shorter-horizon licensing challenges from longer-duration barriers that are likely to affect SMR deployment for over a decade and require coordination across multiple organisations. We use this distinction as a guiding benchmark rather than a mechanical threshold. Outside China and Russia, the available evidence suggests that FOAK licensing is a resource-intensive, iterative process in which most projects conclude within a few years, but a minority experience prolonged delay. We therefore set **8 years** as the upper bound of the Baseline licensing-duration window: long enough to accommodate extended FOAK review, but conservative relative to the decade-scale boundary at which licensing delay begins to resemble a structural barrier rather than an ordinary project challenge.

The SMART programme illustrates this risk. The original SMART design received Korean Standard Design Approval (SDA) in 2012 but did not proceed directly to FOAK deployment; SMART100 was subsequently developed as an updated version, with a new SDA application submitted in December 2019, regulatory review beginning in August 2021, and approval granted in September 2024[25,26]. Licensing durations above 8 years are therefore treated as a signal of stalled development, with clear downstream implications for FOAK viability.

Recent expert and institutional assessments reinforce this interpretation. IAEA expert polling identified licensing reform as a top-tier enabler of SMR deployment[27], while the NEA SMR Dashboard[28] continues to identify licensing as one of the most important comparative bottlenecks in market readiness. In our cross-check sample, licensing-readiness scores increase only modestly across development phases, indicating that regulatory preparedness does not automatically follow technical maturation (Fig. S14a). Alongside the substantial effort required for major regulatory reviews, this supports treating licensing as a bounded but right-tailed phase whose duration is highly sensitive to institutional context, technology type and design maturity.

Several quantitative benchmarks inform the licensing-duration bounds. For large light-water reactors (LWRs), combined licensing sequences are commonly reported in the 4–5-year range[29], while SMRs may require additional technology-specific review and evidence generation, especially where novel module designs or non-water-cooled systems are involved[30].

Ambitious recent OECD targets still tend to cluster around approximately two years from construction-permit application to first concrete[31], which is consistent with our Accelerated range but generally presumes strong regulatory coordination, early public engagement and high design maturity at application[6]. Vendor information for VBER-300 (RU), indicating roughly 36 months to a licensable package[32], is consistent with the upper end of an accelerated licensing window. These benchmarks support the scenario bounds adopted here for jurisdictions outside China and Russia: 2–8 years under Baseline assumptions and 1–3 years under Accelerated assumptions. The Baseline range accommodates extended FOAK review and possible delay, while the Accelerated range reflects highly coordinated pathways in which pre-application work has already resolved most major issues (

Table **S11**).

China and Russia are treated separately because licensing there has more often functioned as a short formal checkpoint closely coupled to construction approval. As stated, we therefore model China and Russia on 1–3-year timelines under the Baseline scenario and apply a flat 1-year rule under the Accelerated scenario, consistent with observed experience for ACP-100, BREST-OD-300, HTR-PM, KLT-40S and RITM-200.

Accordingly, FOAK licensing durations are represented using truncated lognormal distributions. Under Baseline assumptions outside China and Russia, licensing spans 2–8 years with a truncated mean of **4.50 years**. Under Accelerated assumptions outside China and Russia, licensing spans 1–3 years with a truncated mean of **2.25 years**. Exploratory distributional fits identify the lognormal distribution as the best-fitting specification for licensing durations, with gamma as the nearest alternative (Table S12). Additional sensitivity checks under alternative slippage assumptions yielded the same conclusion (Table S13), confirming that this choice is robust to plausible variation in unresolved cases.

Supplementary Note 10. Construction phase parameterisation

Given the scarcity of SMRs that have reached First-of-a-Kind (FOAK) operation (n = 3), we parameterise construction duration using a layered evidence base. We first combine realised FOAK outcomes, projected near-term SMR completions and IAEA schedule estimates to define the primary SMR construction-duration anchor (Table S14). We then compare this anchor against a historical benchmark of small- to medium-sized reactor construction and published FOAK SMR construction estimates before setting the final scenario bounds.

Three SMRs have entered operation to date: HTR-PM (China, ~5–6 years), KLT-40S / floating power unit (Russia, 5–6 years) and RITM-200 (Russia, ~8–9 years). These realised durations provide a conservative empirical anchor for FOAK construction time. For symmetry with other development phases, we also test a best-case projection in which ACP100 (4 years), BREST-OD-300 (4 years) and CAREM (12 years) complete by end-2025. This adjustment has little effect on central tendency but increases dispersion, reinforcing the need to treat projected completions cautiously.

To position these realised outcomes, we compile expert-judged construction durations for seven flagship SMR designs from the IAEA Technology Roadmap[33], spanning Q3-2026 (ACP100, CN) to Q4-2030 (SMART-100, KR). This set, dominated by OECD designs, yields an initial mean close to 5 years. We then widen coverage with additional schedule estimates from recent IAEA sources, excluding CAREM (AR) as a clear long-duration outlier. Combined with the three realised projects and earlier IAEA estimates, this produces a consolidated 24-observation SMR reference case for parameterisation. The resulting distribution has a mean of approximately **5.0 years** and is best described by a lognormal distribution among the candidate families considered (Table S12).

To broaden the empirical basis further, we construct a historical reference case from 100 small- to medium-sized reactors (32–497 MW) drawn from the IAEA PRIS database[34], aligned with the power range used in our SMR design sample. These reactors were commissioned between 1953 and 1972, with a median commissioning year of 1962 (IQR = 1957.8–1967.0). This benchmark therefore captures early nuclear construction experience for reactors in a comparable power range and provides a historical upper-tail check against the more optimistic contemporary SMR schedule estimates. Table S14 reports descriptive statistics for these construction-duration reference cases, with the IAEA 2021–2024 estimates (n = 24) serving as the primary empirical anchor for scenario design.

Independent studies broadly support this parameterisation. Asuega et al.[35] report a mean FOAK construction duration of 52 months (4.3 years), with a 90% range of 40.8–72 months (3.4–6.0 years), represented by a lognormal form. Abou-Jaoude et al.[36] likewise characterise construction using a lognormal distribution in the U.S. context. For BWRX-300, Stewart and Shirvan[37] estimate 44–54 months (3.7–4.5 years) under favourable assumptions, rising to roughly 60–70 months (5.0–5.8 years) under median schedule risk, with more severe upper-tail outcomes also possible. Other published estimates are broadly consistent with this range, typically placing FOAK SMR construction in the 4–6-year range, with some optimistic cases nearer 3–4 years and more difficult cases extending beyond 6 years[38–41].

The construction-duration parameters reported in

Table **S11** therefore bracket two plausible FOAK pathways. Under Baseline assumptions, construction spans **3–7.5 years** with a mean of 5.1 years, remaining close to the 5.0-year IAEA-based anchor while allowing for a broader upper tail informed by realised FOAK outcomes, projected long-duration cases and the historical benchmark. Under Accelerated assumptions, construction spans **3–5 years** with a mean of 4.0 years, representing a faster but still plausible pathway consistent with optimistic published estimates. In both cases, lognormal specifications are retained to capture right-skewed construction risk (Table S12). This treatment is also consistent with the construction-readiness cross-check, where readiness scores increase strongly across development phases, indicating that construction preparedness is closely tied to technical maturation and proximity to site delivery (Fig. S14b).

Overall, these sources support the two bracketing scenarios and the use of a lognormal FOAK construction model. They also suggest that subsequent NOAK construction could plausibly compress by around 1–2 years, converging towards roughly 3–4 years as standardisation, spillovers and siting efficiencies accumulate.

Supplementary Note 11. Post-2025 Conceptual design entrants and additions to the SMR pipeline

Across 42 years of SMR development activity, we identify 75 distinct designs initiated between 1984 and 2025. The sample includes 11 designs that were ultimately cancelled or entered indefinite suspension (Extended Data Fig. 1), including projects placed in "care and maintenance" following technical or other setbacks. Across the full sample, three designs were launched during the 1980s: CAREM (AR) in 1984, FUJI (JP) in 1985 and PRISM (US) in 1987. However, FUJI and PRISM both failed during early development (Table S2).

To derive a more representative calibration for future design additions, we exclude these pioneering concepts from the additions model, given the very high attrition rate within this small early cohort and the increasingly uncertain status of CAREM, which has experienced repeated suspensions during its prolonged construction phase. We therefore anchor the modern phase of global SMR development to the launch of Japan's water-cooled Integrated Modular Reactor (IMR) in 1991. This was followed shortly thereafter by South Africa's Pebble Bed Modular Reactor (PBMR) in 1993, marking the beginning of non-OECD and non-water-cooled SMR additions in the modern sample. Future pipeline expansion beyond the observed 2025 cut-off was calibrated using the Conceptual design start year of each SMR in the additions dataset.

Two global reference rates were derived (Table S15). The Baseline rate reflects the full modern period from 1991 to 2025, during which 72 designs entered the pipeline, yielding an average entry rate of 2.1 designs per year. The Accelerated rate reflects the post-Fukushima period from 2011 to 2025, during which 50 designs entered the pipeline over 15 years, yielding an average entry rate of 3.3 designs per year. These rates define the starting intensities for future post-2025 design additions (Fig. 2c).

For the future trajectory, each scenario was modelled in two stages. First, the observed annual global entry rate was held constant during an initial formative phase to the scenario-specific pivot year. Under the Baseline scenario, the 2.1-designs-per-year rate was maintained until 2035. This cut-off broadly corresponds to the period over which early FOAK deployment and initial fleet-level replication could plausibly begin to reveal which designs advance beyond demonstration, as illustrated by the planned four-unit BWRX-300 deployment at the Darlington site in Canada. Under the Accelerated scenario, the higher 3.3-designs-per-year rate was maintained until 2030, representing a more compressed formative phase in which Russian and Chinese FOAK projects, alongside early OECD designs, begin to clarify the emerging design landscape.

Second, after the relevant pivot year, annual entry rates were assumed to decline smoothly towards 2050 using an exponential decay function. This mechanism serves as a saturation constraint rather than a direct extrapolation from conventional reactor deployment history, much of which occurred between the 1960s and 1980s. It prevents the model from indefinitely extending the recent high rate of SMR design entry, while still allowing substantial future pipeline expansion. These assumptions reflect the expectation that, as FOAK projects move into licensing, construction and early operation, the global pipeline is more likely to gradually consolidate around fewer viable vendor and technology pathways than to continue adding new FOAK designs at the same rate. This is consistent with historical evidence that nuclear reactor supply markets have tended to consolidate around a limited number of major vendors, reactor types and designs[42].

The exponential decline reduces SMR design additions by 2050 to 40% of the initial entry rate in the Baseline scenario, yielding **0.8 designs per year**, and to 20% of the initial entry rate in the Accelerated scenario, yielding **0.7 designs per year**. Although the terminal rate is slightly lower under the Accelerated scenario, the distinction between scenarios lies primarily in the timing of moderation: the decline begins in 2030 under Accelerated assumptions, compared with 2035 under Baseline assumptions. This represents an earlier closure of the formative SMR design-entry phase under the Accelerated scenario, rather than a simple assumption of uniformly lower design activity. By 2050, both scenarios converge to fewer than one additional design per year, but they do so through different pathways from the 2030s onward. This specification avoids both premature closure of the SMR innovation space and implausible indefinite expansion in the number of distinct FOAK designs.

Annual additions between 2026 and 2050 were then simulated using Poisson draws around these time-varying global rates across 10,000 Monte Carlo iterations per design. In each future year, the model first determines the total number of new SMR designs entering the global pipeline, and then distributes these additions across Canada, the United States, Europe, OECD Asia, Russia, China and the Rest of World (RoW). Allocation probabilities were derived from scenario-specific historical design-entry patterns at the country or regional-bucket level (Table S16). For the Baseline scenario, geographic entry rates were calculated from the first observed modern SMR design start year in each bucket to 2025 inclusive. For the Accelerated scenario, rates were recalculated uniformly over 2011–2025.

Within each geographic bucket, cooling type was assigned probabilistically across four cooling classes—water, metal, salt and gas—using observed historical shares. To avoid zero-probability outcomes in buckets with sparse or absent representation of particular cooling types, these shares were adjusted using a Jeffreys correction before normalisation. This preserves the empirical cooling profile of each bucket while ensuring that all cooling categories retain a non-zero probability of appearing in future synthetic additions. Global, OECD, non-OECD and cooling-specific rates were retained as descriptive checks, but allocation in the model was conducted at the geographic-bucket level.

Under this specification, the model yields a median of 40 cumulative new designs entering the pipeline by 2050 under Baseline conditions (P10–P90: 32–49) and 48 under Accelerated conditions (40–57). Averaged across 2026–2050, this corresponds to mean annual addition rates of 1.61 and 1.94 designs per year, respectively. These trajectories therefore represent a gradual moderation in annual design-entry intensity over time, while preserving a clear separation between Baseline and Accelerated expansion pathways (Fig. 2c).

Supplementary Note 12. Design-phase failure parameters

To quantify phase-specific failure rates, we catalogued design-phase transitions for 69 SMRs initiated between 1984 and 2025, including five documented project failures with verified phase-duration data for at least the Conceptual design (CD) phase. Because our FOAK modelling requires designs to be under active development and supported by verified phase-duration evidence, the core sample would otherwise omit projects that failed during CD. Within this observed record, we identify three cancellations during Basic design (BD) and two during Detailed design (DD), implying comparatively limited directly observable attrition across the design phase.

This record is likely to understate early-stage attrition because many designs remain under development, especially in CD, where discontinuations are least visible and are seldom documented systematically in available sources. To reduce this bias, we extended the evidence base by incorporating six additional failed designs reported in IAEA biennial sources (2012–2024) but lacking verified phase-duration data: FBNR, PRISM, WWER-300, Flexblue, LEADIR-PS and MSTW (Table S3). This yields a consolidated failure-rate sample of 75 designs for parameterising the modelling framework (Extended Data Fig. 1).

PRISM is particularly important in this respect, as it was one of the pioneering SMR concepts launched in the mid-to-late 1980s but subsequently entered a prolonged period of suspension and inactivity following developmental and licensing barriers in the mid-1990s. A later inventory update also added Aurora Powerhouse as an active CD-stage design after its planned FOAK deployment pathway was confirmed for a 75 MWe configuration rather than a sub-30 MWe design. Because this case is an active design rather than a verified cancellation, it affects only descriptive CD denominators and does not alter the model calibration or results.

Designs that had entered Conceptual design, Basic design or Detailed design but had not completed that phase by the end of 2025 were excluded from phase-specific failure-rate estimation, since these cases cannot be counted as successful phase completions. This exclusion removes 26, 17 and 7 ongoing observations from the CD, BD and DD completed-outcome cohorts (Table S17), thereby ensuring that incomplete phase observations are not treated as evidence of successful project progression.

Conceptual design-phase failures. Alongside the 40 SMRs that completed Conceptual design (CD) within the extended calibration dataset, we identify four verified CD-stage cancellations, yielding a conservative lower-bound CD failure rate of **9.1%** (4/44). Including the later Aurora Powerhouse inventory update changes the descriptive rate only marginally to 8.9% (4/45), without materially affecting model calibration or results. Accordingly, to represent a more optimistic development pathway, the Accelerated scenario is anchored to empirically verified cancellations only, reflecting cases in which progression or termination was actively resolved rather than allowed to persist under prolonged uncertainty. To parameterise the Baseline scenario, reflecting slower progress and higher failure risks, we additionally account for **stalled development** (Fig. S2), capturing designs that remain in a phase for durations inconsistent with continued project progression.

This treatment of prolonged phase stalling as a source of attrition is conceptually analogous to survival and related pharmacometric studies in clinical medicine, where delayed or absent response to treatment is associated with an elevated downstream hazard of disease progression or death, even in the absence of an immediately observed failure event. In these settings, time to response itself becomes prognostic: prolonged persistence in an intermediate state is interpreted as evidence of reduced underlying viability, increasing the probability of ultimate treatment failure[43,44].

We identify stalled-development cases using distribution-based thresholds derived from observed historical phase-duration data, rather than assumptions about formal cancellation status. Under this definition, CD stalled-development cases are designs that have reached or exceeded the 95th percentile of the Baseline CD duration distribution (15 years), with no subsequent evidence of transition to the Basic design (BD) phase. We attribute stalled development to the most recent phase reached by a design, defined as the latest phase that the design has entered but not subsequently completed with the exception of Japan's IMR, which is retained as a CD stalled-development outlier because its observed CD duration exceeded the 95th-percentile threshold before its later transition to BD in 2023. This ensures that earlier phase durations are not counted separately and avoids double counting. Where a design has completed an earlier phase after prolonged delay, stalled-development attribution is therefore evaluated only at the subsequent phase if progression has since stalled, even if that later phase has not formally failed (for example, VK-300 in Russia).

The most extreme outlier for CD stagnation is Japan's IMR design[45,46], which required more than three decades to complete CD before entering BD in 2023. In technical terms, this case shows that even exceptionally prolonged delays do not necessarily preclude eventual phase completion. However, if an equivalent trajectory were to apply to a design entering the pipeline in 2026, progression beyond CD would not be expected until around 2058, implying that prospects for FOAK deployment, even under accelerated conditions, would be deferred until the mid-2060s. Such timelines fall well outside policy-relevant SMR deployment horizons, motivating the treatment of extreme phase stalling as stalled development rather than relying solely on formal cancellation status.

Prolonged CD durations are also associated with elevated downstream risk. Two of the three BD-phase failures in our main dataset exceeded the CD P95 threshold: FUJI (JP) required 31 years to complete CD and GT-MHR (RU) required 22 years. These cases provide further evidence that extreme early-stage stalling can signal deteriorating competitiveness and heightened attrition risk in subsequent development phases.

Alongside IMR, we identify two additional U.S. designs that exceed 15 years in the CD phase but have yet to transition to BD: EM2 and LFTR. Although these projects remain listed as active in IAEA reports, their extended CD durations imply the same FOAK-relevant consequences as more extreme outliers, albeit in attenuated form. For a new design entering the pipeline, exceeding 15 years in CD would delay entry into BD until the early 2040s, leaving only a narrow and increasingly implausible window for FOAK deployment by 2050, even under accelerated assumptions. Such cases therefore remain formally active but exhibit materially elevated risks of horizon infeasibility and downstream attrition.

Accordingly, we include these designs as stalled-development cases in the Baseline CD attrition parameterisation, yielding an implied CD failure rate of **14.9%** (7/47); this changes only marginally, to 14.6%, when the later Aurora Powerhouse inventory update is included. By contrast, the Accelerated scenario retains the documented lower-bound CD failure rate (**9.1%),** reflecting reduced stalling-related attrition under more favourable conditions (Table 1 and Table S5).

These CD attrition estimates should be interpreted as calibration parameters derived from the observable historical record, rather than as definitive claims about future early-stage attrition. The CD phase is particularly exposed to incomplete observability because it sits closest to the boundary between exploratory concept development, dormant design activity and formal project progression. The evidence base is strongest where cancellations or phase transitions are documented, and weaker where long-running early concepts remain nominally active but lack consistent updates. Additional early-stage bottlenecks may therefore remain unobserved, including multi-decadal exploratory development and prolonged CD-phase stagnation in advanced SMR jurisdictions such as China[47,48] and South Korea[49,50]. Under the present Baseline threshold, KARAT-45 (RU) is retained as an ongoing observation rather than coded as stalled development, because it remains below the 15-year CD threshold as of 2025. Future updates to this framework can revise CD attrition estimates as additional evidence emerges through documented cancellations, phase transitions or continued progression beyond stalled-development thresholds.

Basic design-phase failures. We apply the same failure-parameterisation framework to subsequent design phases, distinguishing between Baseline and Accelerated conditions using identical attribution rules. As in the CD phase, observed failures are combined with stalled development cases under the Baseline scenario, while only confirmed failures are retained under Accelerated conditions. This allows phase-specific failure risks to be assessed consistently across the design pipeline, while avoiding double counting and preserving comparability across phases.

Within the Basic design (BD) phase, we identify three documented failures (IRIS, International Consortium; GT-MHR, RU; FUJI, JP) while stalled development is limited. Only one design (GTHR300, JP) has remained in BD for a duration comparable to the upper bound of the Baseline BD distribution (≈12 years), reinforcing the broader interpretation of BD as a **consolidation phase** rather than a dominant attrition point. This yields a BD-phase failure rate of **15.4 %** (4/26) and **12.0 %** (3/25) under Baseline and Accelerated assumptions, respectively (Table 1 and Table S5).

Detailed design-phase failures. In the Detailed design (DD) phase, we identify two documented failures in the phase-duration dataset (PMBR, ZA; mPower, US), alongside two inactive designs recorded in IAEA sources but lacking definitive phase-duration data (PRISM, US; WWER-300, RU). In addition, three cases of stalled development are identified (VBER-300, SVBR-100, VK-300). Together, these observations yield DD-phase failure rates of **41.2%** (7/17) under Baseline conditions and **23.1%** (3/13) in the Accelerated scenario (PMBR, mPower, PRISM) (Table 1 and Table S5).

PRISM is treated as an edge case, having entered pre-licensing review in 1994 after more than a decade of development, indicating progression beyond early conceptual work. **WWER-300** (300 MWe), by contrast, was categorised in IAEA records as having reached the Detailed design phase, consistent with the classification of the related **VBER-300** (325 MWe). On this basis, both designs are conservatively included in the DD-phase sample for estimating failure risk, while recognising some ambiguity in the historical record. However, because WWER-300 is already treated separately as representative of stalled development, only PRISM is counted within the accelerated DD-failure subset.

Aggregated design-phase failure outcomes. Aggregating across the three design phases, the Baseline scenario yields a total design-phase failure rate of **57.7%,** while the Accelerated scenario yields **38.5%** (Table S18). These results identify the DD phase as a pronounced bottleneck, with licensing readiness generating a pronounced risk of project failure or prolonged delay, thereby diminishing prospects for progression towards certified design. By contrast, the BD phase appears comparatively less restrictive—subject to small denominators—while CD-phase failure rates range from approximately 9% to 15% under Accelerated versus Baseline assumptions. This pattern is consistent with BD functioning as a consolidation stage, in which designs that progress conceptually typically advance onward. Attrition then re-emerges at DD, where licensing and delivery requirements impose renewed technical, organisational and financial constraints, alongside heightened uncertainty and risk.

We quantify uncertainty around phase-specific design-failure rates using Bayesian posterior distributions under Jeffreys priors (Table S18)[51]. This provides a weakly informative treatment of uncertainty for binomial proportions and remains stable under small sample sizes or extreme observed probabilities[52–54]. Posterior means are reported as descriptive summaries, while the Monte Carlo simulations draw from the full posterior distributions, allowing uncertainty in phase-specific attrition risks to propagate coherently across phases and scenarios[55,56].

This approach avoids overconfidence at the boundaries, accommodates skewed uncertainty arising from sparse data, and ensures internal consistency between reported intervals and downstream stochastic modelling[57]. Consistent with recent Bayesian reliability studies, weakly informative or objective priors are particularly well suited to sparse binomial settings where posterior and predictive behaviour must be propagated through simulation-based decision models[58]. Overall, Bayesian intervals such as Jeffreys priors exhibit favourable average coverage properties relative to alternative interval constructions[59].

Jeffreys posterior distributions are shown in Fig. S13 for Conceptual Design (a), Basic Design (b), and Detailed Design (c), with dashed lines indicating posterior medians. The figure illustrates phase-dependent convergence and divergence in failure risk, with increasing separation between scenarios at later design stages. The resulting design-phase failure posteriors are visualised in Fig. 3d, illustrating divergence in FOAK SMR design survivorship across CD, BD, and DD under Baseline and Accelerated conditions.

External triangulation using the Nuclear Energy Agency SMR Dashboard. We triangulate our design-phase failure-rate parameters using recent evidence from the Nuclear Energy Agency (NEA) SMR Dashboard. Edition 2 (2024) catalogued 56 active SMR designs, of which 41 met our sampling criterion (≥ 30 MWe), while Edition 3 (2025) listed 51 designs above this size threshold (total = 74), with 43 of these entering our final sample (Table S19).

We draw on the 51 designs from the NEA dataset in subsequent procedures for licensing- and construction-readiness metrics to approximate design-level FOAK deployment risks (e.g. water-cooled versus non-water-cooled designs). Designs which were excluded consist primarily of early-stage variants, prototypes, or non-electric concepts, which do not meet our strict criteria for phase-transition modelling, yet still provide valuable contextual evidence of the emerging global SMR pipeline.

Wilson score intervals are used for this external benchmark and diagnostic exercise to characterise uncertainty around empirically observed binomial proportions without imposing a distributional model. In this context, the objective is not probabilistic propagation but transparent comparison of observed rates across phases and scenarios. Wilson intervals provide well-behaved frequentist coverage for small samples and probabilities near zero or one, outperforming Wald intervals and avoiding the excessive conservatism of exact Clopper–Pearson limits, as demonstrated in extensive comparative and simulation studies[60–65]. Unlike the Jeffreys posteriors used elsewhere for generative modelling and Monte Carlo propagation, Wilson intervals here serve a descriptive role, offering a model-agnostic benchmark against which inferred failure-rate behaviour can be externally assessed.

Applying a proportional allocation of inactive designs between microreactors (< 30 MWe) and larger SMRs (30–500 MWe), we estimate 26 and 19 inactive or cancelled SMR designs above the 30 MWe cut-off in Editions 2 and 3, respectively. However, the NEA SMR Dashboard reports aggregate design inactivity without specifying the development phase at which individual designs stalled (Table S19 and Table S20). Designs that have progressed into Detailed design may be less likely to appear as simply inactive, as later-stage projects more often transition into formal cancellation, prolonged suspension, or licensing-related delay. Accordingly, the NEA inactive-design pool is expected to reflect predominantly **early-phase attrition** (that is, CD/BD), while remaining only an approximate external benchmark for our phase-specific estimates.

Using the 2024 and 2025 NEA editions, we estimate overall inactivity rates of **38.8%** (95% Wilson CI: 28.0–50.8%) and **27.1%** (95% Wilson CI: 18.1–38.5%), respectively, for eligible SMR designs above the 30 MWe threshold (Table S21). For comparison, our model implies cumulative failure probabilities of approximately 28% under the Baseline scenario and 20%

under the Accelerated scenario up to the end of the **BD phase**, derived from the sequential survival of Conceptual and Basic design phases.

These values are broadly comparable to the NEA inactivity rates, which is consistent with—though not sufficient on its own to prove—the interpretation that NEA-recorded inactivity predominantly reflects early-phase design attrition rather than failures arising during Detailed design. Differences between the NEA estimates and the modelled early-phase failure probabilities are therefore expected, reflecting variation in classification, censoring and phase aggregation, rather than inconsistency in the inferred design-phase dynamics.

Supplementary Note 13. Licensing-phase failure risks and parameterisation

International reviews have long stressed that licensing risks for SMRs vary by both design type and country regulatory profile[6,30,66]. Existing nuclear licensing frameworks were originally developed for large light-water reactors (LWRs) and still impose sequential, non-harmonised regulatory steps that create structural bottlenecks for SMR deployment[23,29,67,68]. As a result, SMRs must navigate the same multi-stage pathway of pre-licensing engagement, design certification, construction licensing and operating approval, but—unlike large reactors—often require module-specific certification, extending overall timelines[20,69]. The absence of internationally harmonised review processes further forces vendors to pursue repeated licensing across jurisdictions, adding delay and regulatory burden[66,70].

Compounding these institutional frictions is the limited regulatory experience with many advanced, non-LWR SMR designs, most of which are yet to be built or operated anywhere[71,72]. This lack of operational precedent constrains the capacity of national regulators to assess novel safety cases, particularly for technologies using alternative coolants or moderators, and can lead to longer review processes compared to established LWR-based designs[73]. These challenges are evident even in countries with relatively advanced SMR programmes, such as the U.S., UK and Canada[10], underscoring the global nature of SMR licensing constraints.

Quantifying uncertainty in the licensing phase. For the licensing phase, historical SMR project progression remains limited to a small number of designs. To date, six SMRs have achieved FOAK licensing—KLT-40S, RITM-200 and BREST-OD-300 in Russia; HTR-PM and ACP-100 in China; and CAREM in Argentina—with BWRX-300 treated separately through its Canadian pathway (Table S13). However, these directly observable cases are few in number, entirely non-OECD, and therefore only partially informative for estimating broader licensing-phase performance.

We therefore treat the current SMR record as an empirical reference point rather than a sufficient statistical basis for design-level licensing failure rates. Instead, licensing risks are derived from a structured calibration framework combining (**1**) national regulatory performance, (**2**) national SMR portfolio size and (**3**) technology-level licensing readiness. This provides a more generalisable and internally consistent basis for parameterising licensing attrition across heterogeneous institutional settings.

The framework produces three additive components for non-U.S. designs: a country-level regulatory penalty, a national portfolio-size modifier and a technology-level licensing-readiness modifier. The country-level penalty captures the general licensing environment, including nuclear-programme maturity, regulator capability, institutional stability and documented SMR licensing or construction experience. The portfolio-size modifier captures the additional coordination burden created by multiple parallel FOAK licensing pathways. The technology-level modifier captures differences in regulatory familiarity across cooling classes. The United States is treated separately using empirical NRC licensing outcome data for large reactors, because these data provide a direct benchmark for the conversion of licensing progress into construction outcomes.

In contrast to earlier design phases, licensing failure risks are best interpreted as bounded optimistic and pessimistic post-design outcomes rather than as direct extensions of upstream technical uncertainty. We therefore calibrate the Accelerated scenario first as an optimistic bound grounded in historical nuclear and contemporary SMR experience. We then derive Baseline values by doubling the corresponding Accelerated penalties. This preserves relative differences across countries and technologies while avoiding pseudo-precision in a data-sparse setting.

For non-U.S. jurisdictions, we assign a single country-level licensing penalty per scenario using a ranked regulatory-capacity scale calibrated against historical nuclear-programme maturity, regulator capability, institutional stability and, where available, demonstrated SMR licensing or construction outcomes. The resulting six-tier structure yields bounded licensing-failure additions from 0–6% in the Accelerated scenario and 0–12% in the Baseline scenario. The United States is treated as a separate empirical case due to the availability of detailed licensing outcome data (Fig. S15 and Table S22).

Country-level calibration of regulatory performance and licensing penalties. Argentina serves as the reference case and is assigned a zero-licensing penalty, reflecting the clearest documented example of a national-champion SMR, defined here as a single domestically prioritised design progressing through a concentrated national licensing pathway, moving through licensing into construction. The remaining countries are ordered follows:

- China and Russia form a separate high-capacity group with residual penalties of 1% in Accelerated and 2% in Baseline, reflecting strong state-backed programmes and demonstrated SMR licensing and construction activity.
- Canada, France, Japan, South Korea, Sweden and the United Kingdom form the advanced OECD licensing group and receive penalties of 2% and 4%, respectively, reflecting mature regulatory institutions and comparatively predictable review conditions.
- India and South Africa are grouped as non-OECD advanced regimes and assigned 3% and 6%.
- The Netherlands and Romania form a nuclear-legacy transition group at 4% and 8%.

- Italy is treated as a nuclear revival case at 5% and 10%, and nuclear newcomers including Denmark, Indonesia and Rwanda are assigned the highest (non-U.S.) penalties of 6% and 12%.

Table S23 summarises the resulting country groups and their rationale. The U.S. calibration completes the regulatory-performance component of the licensing framework before the portfolio-size and technology-level modifiers are introduced below.

United States calibration of regulatory performance and licensing failure rates. The United States is treated as a separate empirical case rather than being assigned a penalty through the cross-national ranking framework. This reflects the unusually detailed Nuclear Regulatory Commission (NRC) evidence base for large-reactor Combined Construction and Operating Licence outcomes and the fact that U.S. licensing failure is better understood not simply as formal regulatory rejection, but more broadly as failure to translate licensing progress into the start of construction. In this sense, the U.S. benchmark captures projects that are denied, suspended, terminated after licence issuance, or licensed but remain unbuilt. Because this empirical benchmark already reflects the frictions associated with a large, heterogeneous and institutionally complex development environment, we do not apply an additional U.S. portfolio penalty in the main specification.

To calibrate U.S.-specific licensing failure risks, we draw on the NRC record for Combined Construction and Operating Licences (COLs)[1]. The NRC provides both a highly relevant reference case and an unusually rich public licensing record for empirical calibration. Our sample comprises 19 COL applications submitted since 2007, with all but one case corresponding to large light-water reactors. Although this record may overstate attrition risks for modern SMRs, it remains the most comprehensive evidence base available for modelling the conversion of licensing progress into construction outcomes.

Following the NRC evidence base, we model U.S. licensing as a two-stage process (Fig. S15 and Table S22). **Stage 1** covers COL application review. We exclude applicant withdrawals from the failure-rate denominator because these cases reflect mixed market-regulatory drivers rather than strict licensing failures. U.S. licensing failures at this stage are therefore defined as applications categorised as denied or suspended. This leaves 11 eligible cases: under Baseline assumptions, two suspended applications and the Aurora denial are treated as failures, yielding a Stage-1 failure rate of **27.3%** (3/11); under Accelerated assumptions, only the Aurora case is treated as a hard failure, reducing the Stage-1 rate to **9.1%** (1/11).

Stage 2 evaluates post-COL project outcomes for the eight projects that received stage-1 approval. Three projects were later terminated, one proceeded to construction and operation, and four remain licensed but unbuilt. Treating the licensed-but-unbuilt cases as right-censored survivors yields a Baseline Stage-2 failure rate of **37.5%** (3/8). In the Accelerated scenario, one of the three terminated projects is assumed instead to proceed, reducing the Stage-2 failure rate to **25.0%** (2/8). Combined across both stages, the overall U.S. licensing failure rate falls from **54.5%** in the Baseline scenario to **31.8%** in the Accelerated scenario.

For integration into the SMR dataset, these U.S. licensing risks are applied as two sequential filters to designs that remain in the pre-licensing phases. For designs already in licensing, we apply case-specific rules to preserve consistency with observed project maturity. BWRX-300 is exempt from both Stage-1 and Stage-2 U.S. licensing attrition because its relevant FOAK licensing pathway is in Canada and it is already close to construction. NuScale's current 77 MWe design is treated as having cleared Stage 1, however, it remains exposed to Stage-2 risk because no construction licence has yet been exercised for the updated module design under its current FOAK deployment pathway in Romania. Xe-100 remains exposed to both Stage-1 and Stage-2 licensing risks.

This treatment preserves the conservative integrity of the Baseline case without double-penalising the U.S. pipeline. It is also consistent with wider evidence that NRC licensing throughput is likely to remain a binding constraint on near-term U.S. nuclear expansion, even under more supportive reform scenarios[74]. Our licensing-filtered U.S. SMR totals therefore sit between the historical NRC record and more concentrated forward-looking scenarios in which only a small number of designs progress through licensing to FOAK deployment[75].

Portfolio-size modifier for country-level licensing risk. Countries differ not only in regulatory capacity but also in the breadth of SMR design portfolios they actively pursue towards FOAK deployment. A wider portfolio increases coordination demands on national regulators, raises the volume of parallel safety assessments, and introduces additional interfaces with vendors, utilities and research organisations. As a result, larger portfolios face greater procedural complexity and a higher likelihood that at least one active design experiences delay or attrition, even where underlying regulatory capability remains strong. By contrast, countries centred on a single national-champion design typically face a simpler licensing burden, clearer institutional focus and lower coordination overhead.

To capture these effects, we classify countries into portfolio categories based on the number of FOAK licensing pathways they actively support. This classification is explicitly forward-looking and reflects remaining licensing burden rather than cumulative historical design activity. Designs that are already operational or under construction are therefore excluded, as they no longer contribute to future licensing coordination demands.

The classification is derived from the design database but adjusted to reflect licensing-specific realities, including cross-border development pathways. National-champion designs are retained under their country of origin even where anticipated FOAK deployment is expected to occur under a foreign licensing regime, as in the cases of Italy's LFR-AS-200 and the Netherlands' Thorizon design, both of which are expected to follow French licensing pathways. These designs are therefore not treated as equivalent to domestic French projects, given their distinct national ownership and cross-country coordination requirements.

Each portfolio category carries an additive penalty that increases proportionally across scenarios while preserving the same ordinal structure under Baseline and Accelerated conditions (Table S24). This portfolio-based adjustment complements the country-level regulatory calibration by capturing design-specific coordination burdens rather than intrinsic technical risk. The classification is intentionally schematic and comparative, and is not intended to imply uniform licensing outcomes within a given portfolio tier.

Technology-level licensing readiness across SMR cooling classes. Third, we complement the national regulatory and portfolio-level components of the licensing framework with a technology-level licensing-readiness modifier across SMR cooling classes. As an initial benchmark, we draw on the 2021 World Nuclear Association (WNA)[6] design-maturity survey, which compares pre-licensing and licensing experience across seven countries using a three-point ordinal scale. Although the WNA survey reflects a fixed point in time, it provides a harmonised international comparison of licensing readiness across reactor cooling types and regulatory contexts. The WNA evidence indicates that water-cooled SMRs exhibit the highest overall licensing readiness, while gas-, metal- and molten-salt-cooled designs display systematically lower and broadly comparable readiness levels. Cross-country variation further indicates that China and Russia occupy the most advanced licensing positions, with OECD countries generally intermediate and other jurisdictions more limited in experience (Table S25).

To develop a more recent and design-specific basis for this component, we then draw on the NEA SMR Dashboard[28], which reports licensing readiness on a six-point ordinal scale across individual SMR designs. This provides the primary basis for our cooling-type adjustment. Across this evidence base, water-cooled designs again exhibit the highest licensing readiness, while non-water-cooled categories score lower on average. However, the internal ordering among gas-, metal- and molten-salt-cooled designs is not sufficiently robust to justify finer separation, given their smaller sample sizes and broadly overlapping readiness profiles.

We therefore treat water-cooled designs as the reference class and all non-water-cooled designs as a single lower-readiness category, assigning a common penalty of 2 percentage points in the Accelerated scenario and 4 percentage points in the Baseline scenario under the general penalty-scaling rule (Table S26). The NEA dashboard is not used here as a deterministic predictor of project-level licensing success. Rather, it serves as an aggregated indicator of relative licensing readiness across broad technology classes, reflecting differences in regulatory familiarity, institutional precedent and cumulative learning.

Combined licensing failure-rate assignment. Final design-level licensing failure rates were assigned differently for non-U.S. and U.S. designs. For non-U.S. designs, licensing failure rates were obtained by adding three components: (1) the country-level regulatory penalty, (2) the national SMR portfolio-size modifier, and (3) the cooling-type readiness penalty. Licensing attrition therefore varied systematically across the dataset according to host-country regulatory conditions, the number of concurrent domestic SMR licensing pathways, and whether the design was water-cooled or an advanced modular reactor (AMR). This framework reflects expected licensing risk conditional on jurisdictional and technological context, rather than unconditional historical frequencies alone.

For U.S. designs, the country-level regulatory and portfolio-size components are replaced by the separate NRC-based empirical calibration described above. U.S. designs therefore retain their case-specific treatment for BWRX-300, NuScale and Xe-100, while remaining subject to the broader phase-specific progression framework used elsewhere in the model.

Licensing failure rates for post-2025 design additions. For post-2025 design additions, licensing failure rates were assigned using the same three-component framework applied to the main SMR sample. Designs were first mapped to a set of regional licensing environments comprising four national-level cases—China, Russia, Canada and the United States—and three aggregated regional cohorts: Europe, OECD Asia, and Rest of World. This structure preserves key institutional distinctions while allowing future entrants to be modelled consistently at the regional level.

Within this framework, national-level penalties were applied directly for China, Russia, Canada and the United States, reflecting their distinct regulatory environments and empirically grounded calibration. For the aggregated regions, licensing parameters were derived from representative national programmes: Europe was assigned the OECD mature licensing-regime penalty and treated as a mixed cohort; OECD Asia was parameterised using the average of Japan and South Korea; and Rest of World was derived from India and South Africa, excluding Argentina as a national-champion reference case.

All regional licensing parameters were held constant at their observed contemporary levels. This avoids imposing speculative assumptions about future institutional change while preserving relative differences in regulatory performance across regions. Final licensing failure rates for each simulated design were then obtained by combining the assigned regional regulatory penalty, the corresponding portfolio penalty, and the cooling-type readiness adjustment, consistent with the main licensing framework.

Supplementary Note 14. Construction-phase failure risks and parameterisation

Construction-phase failure risks were calibrated using the historical nuclear construction record rather than by trying to estimate a separate FOAK-specific construction failure rate. This is necessary because FOAK status is often difficult to define consistently across reactor projects, whereas the IAEA PRIS database records whether construction projects were completed, cancelled or suspended. We therefore treat observed historical construction-phase failures as an empirical lower-bound benchmark for SMR construction risk, recognising that early-deployment attrition extends beyond the first completed unit and that nuclear markets have historically remained moderately concentrated[42].

To convert this historical benchmark into design-specific SMR construction failure parameters, we combine it with country-level indicators of construction capability. These indicators capture the national project-delivery environment in which FOAK SMR construction would occur, including early deployment performance, deployment scale, historical construction reliability and recent construction activity. All indicators are assigned according to the target deployment jurisdiction rather than vendor nationality.

Historical construction failure benchmarks. Historical construction-phase failure risk was benchmarked using the IAEA PRIS database. After excluding projects still under construction at the end of 2025, units below 30 MWe and the three operational SMRs, the analytical sample comprised 722 reactor projects, of which 91 failed during construction, corresponding to an observed global failure rate of 12.6%. A smaller 30–500 MWe cohort yielded a lower observed failure rate of 7.9%. These descriptive benchmarks contextualise the construction-phase calibration, while the final country- and design-level parameters are derived from the multi-indicator framework described below.

Table S27 summarises historical construction outcomes by region and reactor design class using the curated historical sample. These tables are descriptive rather than determinative: they provide the empirical context for subsequent penalty assignment, but the final construction-phase parameters are derived from the indicator framework below.

National construction capability indicators and formulation. To derive design-specific construction failure parameters, we translate the historical construction benchmark into country-level indicators that proxy the delivery environment in which FOAK SMR construction would occur. This treats success and failure symmetrically as outcomes of the same underlying project-survival process[76]. The indicators are selected to capture four mechanisms that plausibly shape construction survival: early post-FOAK learning and replication capability, the ability to scale construction activity beyond isolated projects, the historical propensity for cancellation or suspension, and the persistence of construction institutions into the contemporary period (Table S28).

These dimensions are relevant to SMR FOAK construction because early projects depend not only on reactor design maturity, but also on national construction routines, supply-chain coordination, regulatory inspection capacity, site delivery experience and continuity of nuclear project execution. All indicators are evaluated for the target deployment jurisdiction, independent of vendor nationality, so that construction risk is attributed to the environment in which the project would actually be built.

Formative phase construction capability. Early system learning and institutional capacity development following national FOAK entry are captured through two time-to-deployment measures. The first, $T_5(c)$, records the number of years from FOAK commissioning to completion of the fifth reactor unit (FOAK + 4). The second, $T_{1.5}(c)$, measures the number of years from FOAK commissioning to deployment of 1.5 GWe of cumulative installed capacity. These two indicators are positively associated (Pearson's $r = 0.68$), and are therefore averaged to form the Formative Phase Construction Index (Table S29):

$$\mathrm{FPC}(c) = \frac{T_5(c) + T_{1.5}(c)}{2}.$$

This index isolates early execution capability and learning-by-doing effects, preceding cumulative fleet measures and avoiding contamination by mature deployment dynamics.

Deployment capacity intensity. Sustained national delivery capability is quantified over a fixed 32-year post-FOAK reference window (i.e. 2019–2050) using two complementary measures. Cumulative installed capacity, $C_{32}(c)$, captures total delivery experience, while peak annual deployment intensity, $P_3(c)$, is defined as the maximum three-year rolling average of commissioned capacity within the same window. These two indicators exhibit near one-to-one correspondence ($r = 0.98$), justifying their treatment as an equally weighted construction-capability composite rather than as independent drivers. Accordingly, we combine them into a Deployment Capacity Intensity score (Table S29):

$$\mathrm{DC}(c) = \frac{C_{32}(c) + P_3(c)}{2}.$$

This formulation balances long-run scale with demonstrated peak execution capacity, distinguishing sustained delivery regimes from those characterised by sporadic or one-off construction episodes.

Historical construction failure experience. National construction reliability is measured through the observed proportion of failed or abandoned reactor construction projects within the same 32-year reference window (Table S30). The Historical Construction Failure Rate is defined as

$$\mathrm{HCFR}_{32}(c) = \frac{\text{failed starts}}{\text{total starts}},$$

and enters the framework directly, without smoothing or normalisation. This preserves empirical differentiation between consistently successful construction regimes and those exhibiting elevated cancellation or suspension rates.

Recent construction activity. To capture institutional continuity and the persistence of construction capability into the contemporary period, a Recent Construction Activity indicator, $RCA(c)$, is included. This reflects reactor starts and/or completions after the end of the 32-year FOAK reference window, including operational SMRs and units under construction (Table S31). This term distinguishes dormant or moratorium regimes from those in which construction capability has been sustained or renewed.

Composite national construction capability. Taken together, the four indicators triangulate national construction capability across distinct temporal episodes of nuclear deployment (Table S28). The formative phase index captures early post-FOAK learning and replication capacity, the deployment capacity composite reflects subsequent scale-up and acceleration dynamics, the historical failure rate anchors long-run reliability across the same reference window, and the recent construction activity indicator identifies whether delivery capability has been sustained, renewed, or allowed to decay in the contemporary period.

In summary, the framework integrates both historical and contemporary national construction experience. Given heterogeneity in historical failure rates across reactor technologies and established differences between SMR cooling types, we also carry forward the approach applied in the licensing phase. The construction capability index is completed by incorporating a technology-specific indicator to capture design-level SMR heterogeneity within countries (Table S34). Excluding cooling type, national construction capability for FOAK deployment is therefore defined as a composite function of the following four indicators:

$$\mathrm{NCC}(c) = f(\mathrm{FPC}(c), \mathrm{DC}(c), HCFR_{32}(c), RCA(c)).$$

In implementation, FPC(c) and DC(c) are treated as equally weighted performance composites capturing formative and mature delivery capability, while F_{32}(c) and R(c) enter as additive modifiers reflecting observed failure propensity and institutional continuity. Definitions, data sources, and model application for each indicator are summarised in Table S28.

Formative phase completion index. The Formative Phase Construction (FPC) Index distinguishes a small group of high-performing countries (notably Canada and Sweden), followed by Japan and the UK, which exhibit relatively rapid formative progression across both dimensions. By contrast, Italy, the Netherlands, Argentina and South Africa consistently occupy the lower end of the distribution, reflecting limited fleet expansion and incomplete progression beyond early deployment stages.

We identify the UK, Canada and Sweden as the reference cases across the **first indicator** ($T_5(c)$ or 'FOAK + 4'), while China and South Africa receive no point deductions under the **second indicator** ($T_{1.5}(c)$). South Africa's position reflects its historical construction performance at the Koeberg site in Cape Town where two large Framatome reactors (921 MWe each) were commissioned in rapid succession between 1984 and 1985. Although no new nuclear construction activity has occurred in the intervening decades, these reactors have recently received 20-year licensing extensions, while the government remains committed to pursuing an SMR-deployment pathway to support its national energy plans.

Given China and Russia's lead performance in global SMR construction activity, both countries serve as the reference case under the FPC index (i.e. alongside UK, CA and SE in Indicator 1, and alongside ZA in Indicator 2). Accordingly, China and Russia receive no adjustment to their construction failure risk under the first composite measure. FPC metrics are subsequently carried forward into the construction capability assessment, where they contribute to the composite national FOAK construction failure rate.

Historical construction failure rates. Across the 14 sampled countries (counting the Soviet Union as a single bloc), total installed capacity amounts to 387.0 GWe, drawn from an estimated 450.1 GWe of initiated projects—equivalent to a 14.0% construction failure rate at the capacity level. In reactor-count terms, we identify 62 cancellations or suspensions out of 554 construction starts (11.7% failure rate), showing broadly consistent results between capacity- and unit-based metrics. The slightly higher failure rate by capacity indicates that cancelled (n = 53) or suspended projects (n = 9) were on average larger than completed ones (Table S27).

Of the 492 reactors that reached operation, 102 units (20.7%) fall within the 30–500 MWe small-to-medium class. Within this group, 3 reactors were cancelled and two were suspended during construction, resulting in a 4.9% failure rate for this cohort. Extending the dataset to include all Soviet exports (n = 55) —an increase of 26 reactors to the USSR-count—increases the failure rate to 8.5% (10/118) following failures in Cuba (n = 2) and East Germany (n = 3), alongside Russia (n = 3), Italy (n = 1) and the United States (n = 1). When restricted to countries with at least one recorded construction failure, the mean historical construction-phase failure rate rises to **24.8%** (62 of 250 units), compared with **11.2%** across the full 14-country sample. Alongside the USSR, failures are primarily concentrated in the United States (40/167 units) while Italy represents the highest level of national failure at 42.9% (3/7 units).

Accordingly, this expanded record captures the upper envelope of historically observed construction-phase failure rates for SMR-sized reactors when calibrated to the current global SMR portfolio. By contrast, both the analysis of failure rates across the historical fleet (n = 722) and across all reactor classes within the construction-phase sub-sample (n = 554) yield more conservative central estimates. This implies that the 4.9% failure rate identified for the SMR-sized cohort represents a comparatively optimistic lower-bound benchmark, particularly at the FOAK level.

Historical construction failure rates are grouped using Wilson 95% confidence intervals to account for heterogeneous sample sizes:

- France, China, Japan and the UK form the reference cohort (adjustment = 0), as their intervals overlap near zero and are statistically indistinguishable at the 95 % level.
- Canada, South Korea, India and Sweden also share a 100% construction record but broader uncertainty ranges, receiving a 1-point deduction under the Accelerated scenario. Argentina, the Netherlands and South Africa are assigned 2-point deduction due to very small sample sizes and wider uncertainty (i.e. up to 3 reactors commissioned and no failures).
- The U.S. and Russia (including USSR exports) receive a 3-point deduction, reflecting moderate historical failure rates despite extensive construction experience.
- Finally, Italy receives the maximum penalty (4-point deduction) among countries with nuclear experience due to a high observed failure rate and limited reactor base.
- For completeness, we assign Denmark an incremental deduction, corresponding to 5 points) to reflect the ranking of nuclear newcomers under this measurable category (i.e. no nuclear experience = 5 points deduction under the Accelerated scenario and 10 points deduction under the Baseline scenario).

Recent construction experience. To capture the temporal persistence of construction capability beyond the 32-year FOAK reference window, we apply a recent construction activity adjustment based on PRIS outcomes after the reference period for each national case. This indicator distinguishes countries with sustained or renewed commissioning and active build pipelines from those with prolonged construction hiatuses, which are not fully reflected in cumulative capacity or peak-deployment metrics.

We operationalise recent construction activity using PRIS records of units commissioned and units under construction in the post-reference period (including SMRs), reporting targeted capacity (GWe) as a scale proxy for context. Countries are grouped into the following categories (Table S31):

- Highest construction activity (CN, RU; reference cases, score = 0)
- Large-scale (KR, IN)
- Large-scale but suspended capacity (JP)
- Medium (FR, UK, US)
- Low or none (AR, CA, IT, NL, SE, ZA).

Three features of the recent record are noteworthy. First, Japan would otherwise have ranked among the highest-activity cases in this period on the basis of its pre-2011 construction trajectory, with substantial additional capacity that was planned or initiated but ultimately not realised. Its classification as **large-scale but suspended capacity** therefore captures a distinct, system-level discontinuity associated with the post-Fukushima construction hiatus, which materially altered Japan's realised deployment pathway over the subsequent decade. This discontinuity plausibly also constrained the national institutional momentum and industrial continuity relevant to contemporary SMR development, even if its downstream effects are not directly observed in PRIS.

Second, the U.S. renewal is concentrated in a single cohort (2013), with four starts and two subsequent cancellations, illustrating that contemporary construction activity can coexist with programme fragility. However, cancellation propensity is captured primarily by the historical construction failure indicator rather than by the recency adjustment, which is designed to reflect continuity of build activity. Third, Argentina's recent record is dominated by a single long-running SMR project (CAREM, 30 MWe), which remains under construction after more than a decade. Accordingly, we classify Argentina in the low-activity group without presuming eventual failure. Alongside Argentina, countries with no post-reference construction activity are assigned the maximum penalty in this indicator (8 points deduction under Baseline assumptions; 4 points deduction under Accelerated assumptions).

Metric-based penalty calibration at the country level. Country-level construction penalties are assigned to the target deployment market, defined as the national setting in which project delivery would occur and whose regulatory, construction, labour, inspection and supply-chain conditions would therefore shape construction outcomes. This ensures that construction risk is attributed to the institutional environment governing project execution, while FOAK, design and technology-specific risks are handled separately through explicit design-level modifiers.

Penalties are derived by ranking countries across the construction indicators described above, with the best-performing case assigned zero penalty and weaker performance translated into discrete deductions. In the Accelerated scenario, each step corresponds to a one-point deduction, while Baseline penalties are doubled to reflect slower learning and weaker institutional adaptation. Table S35 summarises the resulting country- and regional-level construction penalties, independent of SMR cooling type, by integrating the evidence from Table S29–Table S34.

Country-specific adjustments. The country-level penalties reported in Table S32 retain their historically derived category placements, with limited design-level adjustments applied where contemporary deployment conditions materially alter the relevance of baseline national indicators. Russia and China receive no penalty for formative phase completion or recent construction activity, reflecting demonstrated SMR-scale deployment and ongoing construction in both countries. For designs that have entered construction and carry no remaining country- or design-specific penalties, a residual construction-phase failure risk floor of 1% under the Accelerated scenario and 2% under the Baseline scenario is retained to avoid zero-risk outcomes. In addition, where a design's most credible near-term FOAK pathway lies outside the developer's home jurisdiction, country assignment is based on the target deployment market. Accordingly, BWRX-300 is modelled using Canadian rather than U.S. construction conditions.

For nuclear newcomer and export-led SMR deployment contexts, some country-level construction indicators cannot be assigned directly because they presuppose an operating nuclear programme and corresponding historical deployment record. In such cases, these unobserved indicators are imputed using reference distributions drawn from plausible deployment-market groupings, while directly observable indicators are retained for the relevant national case. This ensures that country-level penalties can still be derived in a consistent manner for designs targeting newcomer or export-led markets, without imposing arbitrary assumptions about institutional strength or weakness.

Table **S33** reports the reference-set imputation procedure and resulting penalty assignments for representative cases.

Nuclear Energy Agency Construction-readiness index. Next, we compute a construction-readiness index as the mean of four Nuclear Energy Agency (NEA) indicators—siting, financing, supply chain and fuel. Benchmark values by cooling type are derived from the NEA Dashboard sample (n = 52) and cross-checked against NEA-listed designs in our own dataset (n = 40). Both samples consistently rank water-cooled designs highest. Among non-water-cooled designs, the cross-check yields relatively small differences in mean readiness scores, which remain within category-level standard deviations and are based on limited sample sizes. We therefore treat all non-water-cooled SMR designs as a single lower-readiness class.

Water-cooled designs serve as the reference case (0), while a uniform penalty of 2 percentage points is applied to non-water-cooled designs in the Accelerated scenario and doubled to 4 percentage points in the Baseline scenario. Russia's BREST-OD-300 is treated as an exception: given its advanced construction status and demonstrated fabrication maturity, its construction-readiness penalty is set to zero, while all country-level penalties remain unchanged. Table S34 summarises the cooling-type benchmarks and final penalty calibration applied in the construction-readiness module.

Supplementary Note 15. Construction-failure parameterisation for post-2025 additions

Regional construction failure parameters were derived from representative national programmes. Canada and the United States were treated separately due to differences in licensing environments, although their historical construction performance converged at identical values (Accelerated = 8, Baseline = 16), providing an internal validation. European parameters were calculated as the mean of France, Sweden, the United Kingdom and Belgium, which again converged to the same values as North America (Accelerated = 8, Baseline = 16). OECD Asia was derived from Japan and South Korea (Accelerated = 5.75, Baseline = 11.5). China and Russia were treated as standalone cases due to their distinct state-directed nuclear programmes (China: Accelerated = 1, Baseline = 2; Russia: Accelerated = 4.5, Baseline = 9). The Rest-of-World category was estimated from India and South Africa, excluding Argentina as a national champion SMR case (Accelerated = 10.75, Baseline = 21.5).

The resulting ordering of construction reliability therefore runs: China → Russia → OECD Asia → North America/Europe → Rest of World, consistent with historically stronger state-coordinated nuclear deployment and weaker performance across emerging programmes.

For the future regional failure module, national licensing and construction penalty factors were held constant at their observed contemporary levels. This avoids imposing speculative assumptions about how national portfolios may expand, contract or translate into institutional learning by 2050. The model therefore treats these factors as relative indicators of present regional advantage or disadvantage, while allowing future divergence to emerge through differential design additions, cooling-type composition and phase-specific failure risks. Europe was assigned a small-portfolio licensing penalty as an intermediate case reflecting its mixed cohort structure.

Supplementary Note 16. Technology readiness levels and vendor-announced FOAK timelines

Technology readiness level assessments for SMRs. Following its development by NASA in the 1970s[80], the technology readiness level (TRL) approach is well established in the energy technology literature, including assessments of advanced nuclear reactors and their components[81–83]. However, the TRL scale is best understood as an indicative guide to technological maturity rather than a definitive measure of development progress. Its interpretation is highly context-specific, and attainment of a higher TRL does not guarantee continued progression, commercial viability or timely deployment[81–83]. We therefore use TRL as a supplementary cross-check rather than as a substitute for the observed five-phase development pathway.

Although several adaptations of the nine-tier TRL structure have been developed across multiple domains[84,85], they typically retain the same underlying logic: technologies progress from early research and development, through demonstration, to operation in a relevant or real-world environment. For nuclear reactors, however, TRL 9 denotes technical operation rather than full market readiness. This distinction is important because reaching FOAK operation does not ensure a pathway to successful NOAK deployment or large-scale rollout[86,87]. More fundamentally, SMRs cannot plausibly be expected to traverse the full TRL sequence faster than less complex, less capital-intensive and less risk-embedded energy technologies such as solar photovoltaics[88], lithium-ion batteries[89], offshore wind[90]or hydrogen electrolysers[91,92], all of which required multi-decadal maturation before widespread commercial uptake.

Here, we integrate the recent TRL assessment by Kang et al.[5] to triangulate our findings on SMR development timelines and the temporal dynamics of FOAK deployment. Kang and colleagues assessed the full spectrum of SMR designs catalogued to date, including micro-reactors and inactive designs. Their final sample comprised 141 designs, of which 55% were classified as TRL 1, 15% as TRL 2, 19% as TRL 3, 1.6% as TRL 4, 6% as TRL 6 and 3% as TRL 9. Only a small minority had therefore progressed beyond the early maturity range, with relatively few entering the transitional stages between research and engineering development.

For triangulation, these TRL categories can be mapped approximately onto our five-phase SMR development pathway: TRL 1 to pre-conceptual or Conceptual design, TRL 2 to Basic or preliminary design, TRL 3 to Detailed design, TRL 4–5 to regulatory review and licensing, TRL 6–8 to construction and commissioning, and TRL 9 to operational status. Although approximate, this correspondence reinforces the central finding that most SMR designs remain far from operational maturity.

We find that all but six designs in our main sample (n = 64) are represented in the study of Kang et al.[5]. The missing designs comprise three in Conceptual design (BSR, EAGLES-300 and MK60) and three in Basic design (BSMR-200, DMS and SSR-U). We assign these designs to TRL 1 and TRL 2, respectively, based on their observed development phase, thereby completing the cross-check. This yields approximately 50% of designs at TRL 1 (n = 32), 13% at TRL 2 (n = 8), 20% at TRL 3 (n = 13), 6% at TRL 4 (n = 4), 6% at TRL 6 (n = 4) and 5% at TRL 9 (n = 3). Excluding operational SMRs, only 13% of designs have reached TRL 4 or above.

The TRL cross-check also supports our interpretation of vendor-announced FOAK timelines. For the subsample with vendor targets, we retain 32 of 35 designs directly from Kang et al.[5], while three designs not included in their assessment are assigned TRLs from their observed development phase (BSMR-200, BSR and EAGLES-300). This provides full coverage of the vendor-target cohort and enables a design-level comparison between TRL, phase progression and FOAK timing across the SMR pipeline. Despite this variation in maturity, many target-bearing designs remain at early stages of development, indicating that vendor-announced timelines are only weakly differentiated by observed technological readiness.

Vendor-announced FOAK timelines and maturity-adjusted deployment gaps. We identify vendor-stated FOAK deployment targets for 35 designs in our dataset. Applying our five-phase framework, supported by the TRL cross-mapping, shows that many target-bearing designs remain at early stages of maturity: 15 are in Conceptual design or equivalent TRL 1, eight are in Basic design or equivalent TRL 2, and five are in Detailed design or equivalent TRL 3, while four are under Licensing or equivalent TRL 4–5 and three are under Construction or equivalent TRL 6–8. Despite this wide variation in observed maturity, the median vendor target year is 2032.5 (IQR = 2030.0–2033.3; P10–P90: 2028.0–2035.0), indicating that announced timelines vary little with observed development status.

Water-cooled designs exhibit narrower vendor-ambition gaps than advanced modular reactors (AMRs) (Extended Data Fig. 4a), with median gaps of around 7 years under Baseline assumptions and 2 years under Accelerated assumptions, compared with around 14 years and 6 years, respectively, for AMRs. This disparity is consistent with the earlier development profile of AMRs: 14 of 22 AMR designs with vendor targets have yet to enter Detailed design, including 11 still in Conceptual design.

Divergence is also stronger in the OECD than in the non-OECD. Non-OECD vendors remain comparatively closer to modelled timelines, with median gaps of 9.7 years (P10–P90: 6.2–13.5) under Baseline and 6.6 years (4.7–8.5) under Accelerated assumptions. By contrast, OECD vendors overshoot modelled FOAK timelines by around 12 years (7.8–17.1) and 5 years

(3.3–6.6), respectively, with greater uncertainty around these estimates (Extended Data Fig. 4b and Table S36). Under the ADVANCE-OECD licensing sensitivity, the OECD median gap narrows only modestly, to 9.5 years (6.0–14.8) under Baseline and 3.5 (2.1–5.2) years under Accelerated assumptions. Even under this optimistic regulatory pathway, faster OECD licensing alone does little to close the broader mismatch between vendor targets and modelled FOAK deployment timing.

This pattern is consistent with earlier assessments of vendor optimism in SMR development. The UK government's 2016 techno-economic assessment found that vendor-reported TRLs were tightly clustered between 6 and 8, whereas evidence-based revisions widened markedly to 2–8 for integral pressurised water reactors, 2–6 for high-temperature gas-cooled reactors, and 2 for lead-cooled, molten-salt and sodium-cooled concepts[93]. Rubio and Tricot[93] concluded that some vendors had not provided substantiating evidence for their claimed TRLs, which may reflect optimism bias or misinterpretation of the TRL scale. The same assessment also applied optimism-bias uplifts of 54–66% to vendor cost estimates and noted that costs could rise further during technical development and generic design assessment[93].

More recent European analysis reaches a related conclusion from a different angle: TRL assignments vary substantially within SMR categories, while limited public design detail and evolving regulatory processes make readiness difficult to score consistently[94]. Light-water SMRs appear relatively more mature because of their similarity to large reactors, whereas advanced concepts still require substantial validation before commercial readiness[94]. Against this background, our five-phase development framework offers a more transparent basis for assessing SMR progress, because it anchors readiness in observable project milestones rather than vendor self-assessments of technological maturity.

The contrast between Rolls-Royce SMR, Natrium and NUWARD illustrates why design-level phase status matters. Rolls-Royce SMR and Natrium are OECD frontrunner designs that have advanced into later development stages, so their vendor-ambition gaps are smaller than those observed for earlier-stage designs, even though neither gap disappears under Baseline assumptions. By contrast, NUWARD is France's flagship water-cooled SMR design, but its development trajectory has been reset. Earlier assessments, including the New Nuclear Watch Institute's (NNWI) 2023 outlook[95], placed NUWARD on an ambitious deployment path broadly comparable to Rolls-Royce SMR, with a first French unit expected around the early 2030s. The International Energy Agency (2025 report)[96] and earlier UK 2016 assessment[93] likewise cite a 2030 FOAK deployment timeline for NUWARD. However, the latest EU Joint Research Centre (JRC) review notes that EDF reset the design in 2024, shifting from the earlier twin-unit concept to an updated 400 MWe design, with Conceptual design expected to be finalised only by mid-2026 and a market-ready product targeted for the 2030s[94].

NUWARD therefore provides a concrete example of how design resets can materially alter FOAK timelines, pushing a prominent water-cooled SMR back into an earlier development phase despite earlier vendor and policy-facing expectations of deployment around 2030.

Supplementary Note 17. Scenario-based sensitivity analyses

To assess how projected global FOAK deployment changes under alternative assumptions, we implement five scenario-based sensitivity analyses that modify specific constraints within the Baseline and Accelerated reference cases (Extended Data Fig. 5, Fig. S6 and Table S37). These analyses are used to bound the broader feasibility space of the global reference trajectories (Fig. 4b), whereas the reference trajectories themselves are retained for regional and technology-specific analyses (Fig. 5, Fig. 6a,b).

Current-phase completion. All designs currently occupying an active development phase are assumed to complete that phase successfully before returning to the model's standard progression and failure dynamics. This sensitivity analysis provides an upper-bound test of near-term FOAK deployment from the existing active pipeline. For post-2025 design additions, Conceptual design failure is set to zero at entry under the Baseline scenario, while both Conceptual and Basic design failure are set to zero under the Accelerated scenario. Designs then proceed under the standard phase-specific progression and failure rules. Relative to the reference case, this increases median cumulative FOAK deployment by 2050 by 8 under both Baseline and Accelerated assumptions (Baseline: P10 and P90 both +6; Accelerated: P10 +8, P90 +7).

ADVANCE-OECD licensing. We define a sensitivity in which OECD jurisdictions (North America, Europe and OECD Asia) are assigned licensing timelines comparable to those observed in Russia and China. This assignment is intended to test whether faster regulatory processing alone could materially narrow projected FOAK deployment delays in OECD settings. Under this assumption, licensing durations are reduced to a fixed one-year period under the Accelerated scenario and remain one to three years under the Baseline scenario.

To align this specification more closely with faster OECD licensing, the licensing failure rate applied to the United States is also reduced to the level used for Canada and other mature OECD nuclear systems, while the corresponding US portfolio penalty is reinstated to avoid overcompensation. No equivalent failure-rate adjustments are applied to Canadian, European, Japanese or South Korean designs, allowing the scenario to isolate the effects of accelerated licensing more clearly outside the United States.

This calibration is motivated by ongoing regulatory reforms aimed at facilitating advanced reactor deployment, particularly in the United States, where the Accelerating Deployment of Versatile, Advanced Nuclear for Clean Energy Act of 2024 (ADVANCE Act) was signed into law in July 2024[77]. More broadly, recent reforms in the United Kingdom[78] and new EU-level SMR initiatives[79] suggest a wider political push to reduce procedural bottlenecks and improve regulatory coordination across OECD jurisdictions. Relative to the reference case, this increases median cumulative FOAK deployment by 2050 by 4 under both Baseline and Accelerated assumptions (Baseline: P10 +3, P90 +4; Accelerated: P10 and P90 both +4).

Construction cascade. Construction failure risks are increased according to each design's current development phase, reflecting its distance from site delivery. No additional construction-cascade penalty is applied to designs already under construction. For active designs in Licensing, Detailed design, Basic design and Conceptual design, construction failure risk is increased stepwise by +5, +10, +15 and +20 percentage points under Baseline assumptions, respectively. Under Accelerated assumptions, these surcharges are halved to +2.5, +5, +7.5 and +10 percentage points. Post-2025 additions enter the model at Conceptual design and therefore receive the maximum construction-cascade surcharge: +20 percentage points under Baseline assumptions and +10 percentage points under Accelerated assumptions. This sensitivity analysis captures the possibility that early FOAK construction setbacks propagate upstream through investor confidence, contractor availability, regulatory stringency and supply-chain constraints. Relative to the reference case, it reduces median cumulative FOAK deployment by 2050 by 3 under Baseline assumptions and 4 under Accelerated assumptions (Baseline: P10 −2, P90 −4; Accelerated: P10 −3, P90 −5).

Late-stage risk. Licensing and construction failure risks are increased uniformly across the active pipeline while all other scenario parameters are held constant. Relative to the reference cases, this sensitivity analysis adds 10 percentage points to licensing and construction failure rates under Baseline assumptions and 5 percentage points under Accelerated assumptions. It is intended to capture a generalised deterioration in late-stage project conditions, including tighter financing, weaker public or political support, and more adverse regulatory or delivery environments. Relative to the reference case, this reduces median cumulative FOAK deployment by 2050 by 3 under Baseline assumptions and 8 under Accelerated assumptions (Baseline: P10 −2, P90 −4; Accelerated: P10 −7, P90 −13).

Stalled development. The active SMR pipeline is reduced by removing designs that have exceeded the scenario-specific P95 elapsed-time threshold for their current development phase. This sensitivity provides a direct counterpoint to the reference treatment, in which retained long-duration designs are forced to enter their next phase in 2026 and then proceed through standard project-progression and failure-risk rules. Under the Baseline scenario, thresholds are set at 13.0, 12.2, 9.0, 6.7 and 6.8 years for Conceptual design, Basic design, Detailed design, Licensing and Construction, respectively. Under the Accelerated scenario, the corresponding thresholds are 8.0, 5.0, 5.0, 2.8 and 4.7 years (Supplementary Note 4). Relative to the reference case, this reduces median cumulative FOAK deployment by 2050 by 7 under Baseline assumptions and 5 under Accelerated assumptions (Baseline: P10 −5, P90 −7; Accelerated: P10 −5, P90 −6).

To test sensitivity to the treatment of long-stalled designs, we constructed two scenario-specific active-pipeline inclusion filters. The Baseline stalled-development filter retains 46 of the 64 active designs, including the three designs already operational by 2025. The Accelerated stalled-development filter retains 56 active designs, also including the three operational designs. These filters bound the extent to which long-duration designs remain analytically viable within the active 2025 pipeline under the corresponding scenario assumptions. Unlike the current-phase completion sensitivity, which temporarily protects retained designs from failure in the phase they occupy at the end of 2025 before reintroducing phase-specific failure risks from the subsequent phase onward, the stalled-development sensitivity changes the composition of the active starting pipeline itself. It therefore tests how projected FOAK deployment changes when designs with limited observable progression are removed before standard project-progression, failure-risk and post-2025 pipeline-evolution assumptions are applied.

Supplementary Note 18. AMR-specific late-stage risk sensitivity

As a technology-specific sensitivity analysis, we test whether AMR deployment remains robust when two optimistic assumptions are relaxed: simulated post-2025 AMR design additions are excluded, and licensing and construction attrition are increased for active AMRs under Accelerated assumptions. The active pipeline comprises 39 AMRs, including one operational unit in China (Fig. 1 and Extended Data Fig. 2b). In this specification, AMR licensing and construction failure penalties are increased from 2% to 10% per phase, while all other parameters are held constant. Because the adjustment is intended to isolate technology-specific late-stage risk within the existing portfolio, rather than uncertainty associated with future pipeline expansion, the analysis is restricted to the active AMR pipeline (Fig. S9).

Relative to the Accelerated active-pipeline reference case (Md = 20; P10–P90: 16–24), this sensitivity reduces median cumulative AMR FOAK deployment by 2050 by 6 globally, 5 in the OECD and 1 in the non-OECD group. Global AMR deployment therefore falls to **14 FOAK units** by 2050 (P10–P90: 10–17). Compared with the 28 AMR FOAK deployments projected in the main Accelerated analysis when post-2025 pipeline evolution is included (P10–P90: 20–35; Fig. 5d and Fig. 6d), this combined restriction halves the projected AMR contribution by mid-century, underscoring the extent to which AMR expansion remains contingent on both future design additions and survival through late-stage licensing and construction.

Supplementary Note 19. Regional and technological variation in post-FOAK scaling potential

To assess the time available for post-FOAK scaling before 2050, we focus on surviving designs from the pre-2025 active pipeline (n = 61), as most post-2025 design additions reach FOAK only in the mid-to-late 2040s (Extended Data Fig. 4). The non-OECD, led by Russia and China, retains a substantial FOAK-to-NOAK (N^{th}-of-a-kind) scaling advantage, with a median window of 20.6 years under Baseline assumptions (16.7–22.8), compared with just 8.3 years in the OECD (6.0–11.0). Under Accelerated assumptions, the non-OECD window remains close to two decades (P10–P90: 18.5–21.3), whereas the OECD horizon expands by around 50%, to a median of 12.4 years (11.3–13.6). Europe remains the region with the shortest time horizon available for scaling its FOAK SMR portfolio (Extended Data Fig. 9a), reflecting the entry of several French metal- and molten-salt-cooled designs into the active pipeline since 2020 (Extended Data Fig. 2b and Extended Data Fig. 3).

These regional differences are mirrored at the cooling-type level. In the Baseline scenario, water-cooled FOAK SMRs have a median scale-up window of 15.5 years, compared with 8.5 years for AMRs (Extended Data Fig. 9). Under Accelerated assumptions, water-cooled designs extend this median window to 17.1 years (P10–P90: 16.0–18.0), while AMRs improve but still lag, with a median of 12.5 years (11.2–13.8).

Supplementary Note 20. SMR capacity projections for 2035–2050: range, uncertainty and implied deployment requirements

Early projections of SMR capacity to 2035, especially those published between 2014 and 2018, often anticipated substantial deployment, with estimates typically in the tens of gigawatts (Extended Data Fig. 10 and Table S38). Across published projections over the last decade (n = 8), the median estimate for global SMR capacity in 2035 is 35 GW (IQR: 7–58 GW). Earlier studies from 2014–2017 (n = 3) were markedly more optimistic, with a median of 60 GW (IQR: 30–78 GW), whereas later estimates were more conservative, with a median of 21 GW (IQR: 6–35 GW). One notable linkage within the dataset is that McKinsey & Company's 2018 tripling-global-nuclear pathway reported 35 GW by 2035, a value later adopted by the Nuclear Energy Agency (NEA) in its 2022 tripling scenario.

Projections to 2050 (n = 5) are substantially higher, with a full-sample median of 155 GW (IQR: 79–265 GW). However, excluding the four tripling-aligned scenarios lowers this to 118 GW (IQR: 34–147 GW), indicating that the highest mid-century values are concentrated in explicitly normative expansion pathways. The NEA's 2022 tripling scenario, for example, paired its 35 GW projection for 2035 with a 2050 estimate of roughly 375 GW. Set against our results, these more ambitious projections imply that a limited number of SMR designs would need to scale from pilot deployment to multi-gigawatt capacity within only a few years, particularly under tripling-aligned pathways.

Consistent with this, across the 61 non-operational designs in the active pipeline, the median design-level post-FOAK scaling window to 2050 is only 6.6 years under Baseline assumptions and 12.2 years under Accelerated assumptions. Only 17 of 61 non-operational active designs (27.9%) have a median post-FOAK scaling window of at least 10 years under Baseline assumptions; under Accelerated assumptions, this rises to 37 designs (60.7%). Among designs meeting this threshold, the mean scaling window is 15.7 years in both cases, indicating that acceleration primarily broadens the set of designs with a meaningful post-FOAK scale-up horizon rather than substantially lengthening the window available to the earliest movers.

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