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A Nested Monte Carlo Discrete-Event Framework for Multi-Module SMR Availability and Project Economics

From component reliability and repair logistics to distributional generation-economics outcomes

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Availability is often assumed, not explained

Installed capacity → **Availability** → Delivered output

Availability depends on:

Failures · shared systems · refueling · repair logistics · operating policy

Techno-economic models

Fixed capacity factor
Assumed operating performance

PRA / reliability models

Failures and dependencies
Technical or safety endpoints

Missing link: plant operation → economic outcome distributions

Framework: from plant behavior to economic outcomes

Reliability inputs

Failure rates · CCF · repair times

→

Discrete-event simulation

Failures · dependencies · operating policy · finite-crew repair

→

Capacity trace

Site output over time

→

Outcome distributions

CF · forced outages · repair spend · revenue risk

Nested Monte Carlo: outer = parameter uncertainty · inner = stochastic operating histories

A single run produces a capacity trace

NuScale-inspired 12-module SMR · illustrative 10-year trace · Policy M · Balanced repair bundle

Plant configuration

NuScale-inspired SMR site

12 modules × 77 MWe = 924 MWe

375 modeled elements

Shared systems can affect multiple modules

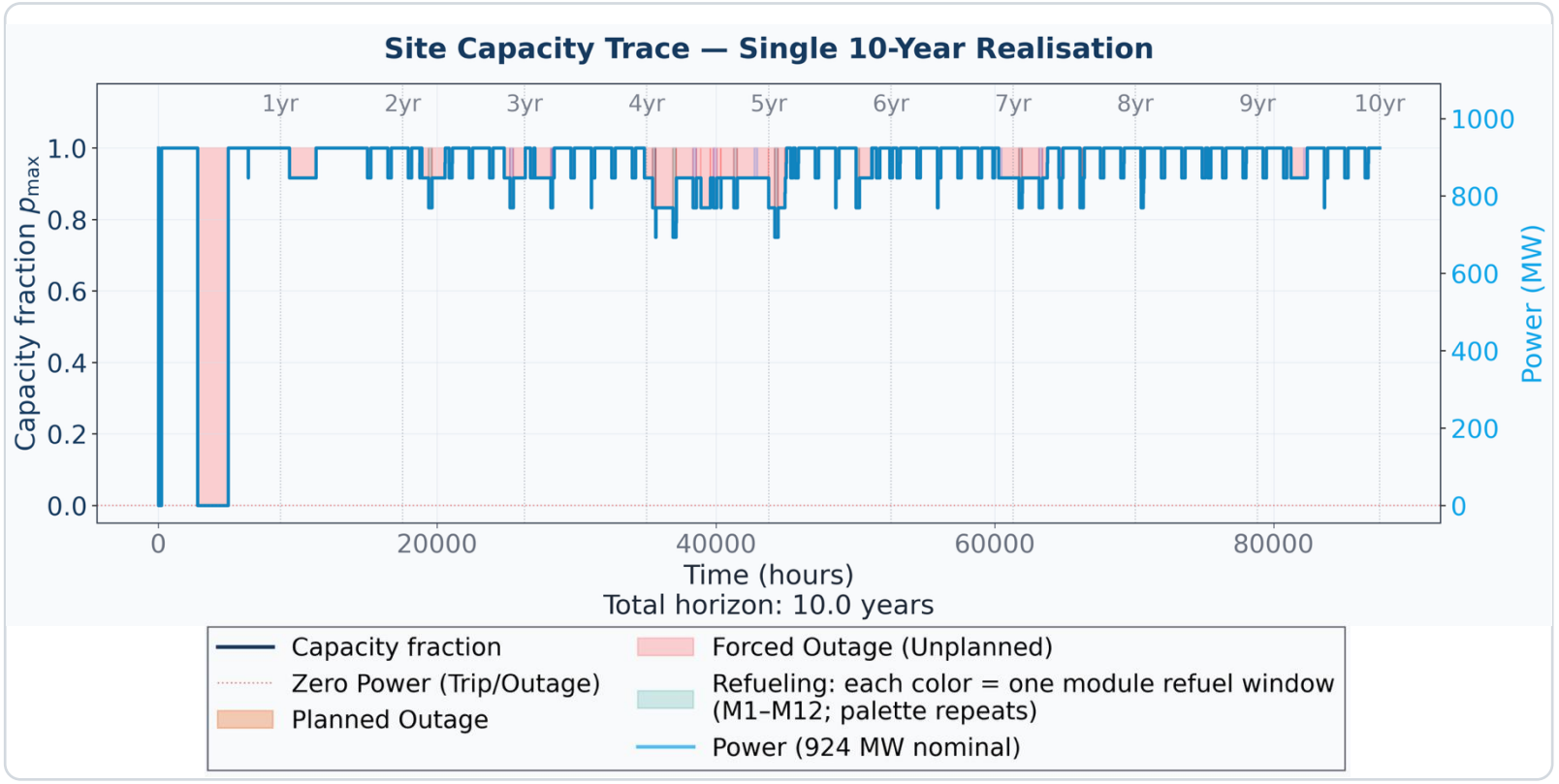
Baseline ensemble

60-year economic life

10 epistemic × 20 aleatory = 200 runs

Policy M + Balanced repair bundle

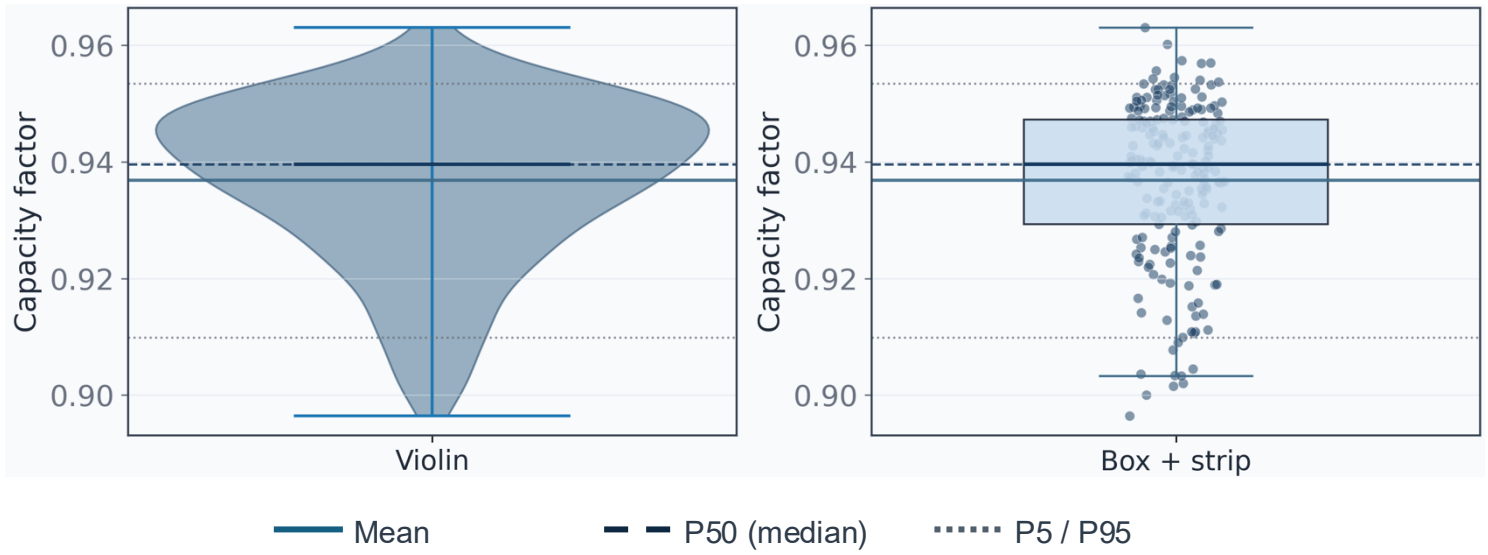
Scope: public / generic data; framework demonstration, not a vendor-specific forecast



The trace is the bridge between operational events and technical and economic metrics.

Availability becomes a distribution, not a point estimate

60-year baseline · Policy M · Balanced repair bundle · 200 runs



Baseline results

Median lifetime CF

94.0%

P5–P95 range

91.0–95.3%

P5–P95 width

4.3 pp

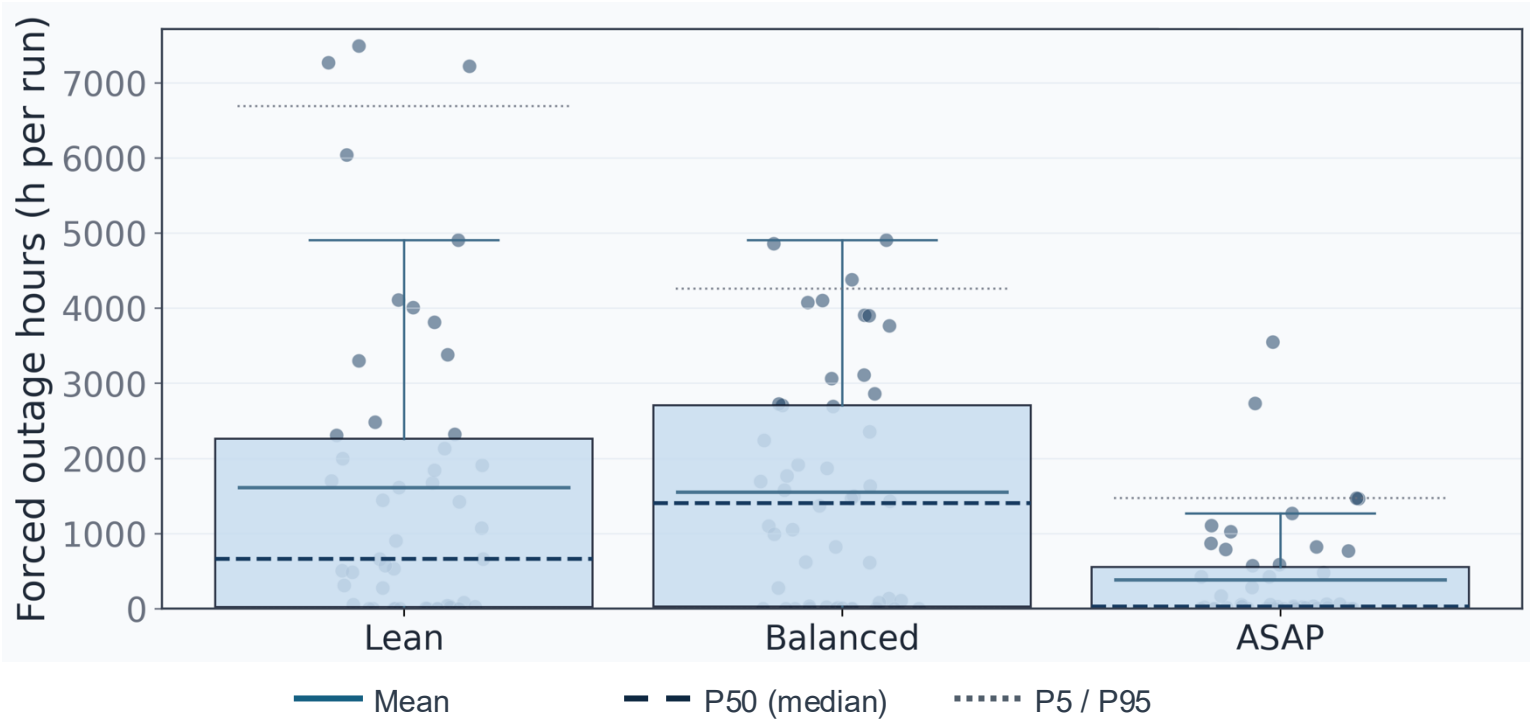
Forced outages drive the lower tail.

Availability is **generated from simulated plant histories**, not imposed as a fixed input.

The framework turns availability uncertainty into decision metrics

Repair logistics, reliability upgrades, and revenue exposure — evaluated with the same simulation framework

Repair-resource sensitivity: forced-outage tail



Repair logistics

P95 forced-outage hours

Lean: **6,691 h**

Balanced: **4,258 h**

ASAP: **1,469 h**

Reliability levers

λ/5 sensitivity

TGT: median-throughput lever

PCS: tail-risk lever

Economic scale

$RaR_5 \approx \$754M$

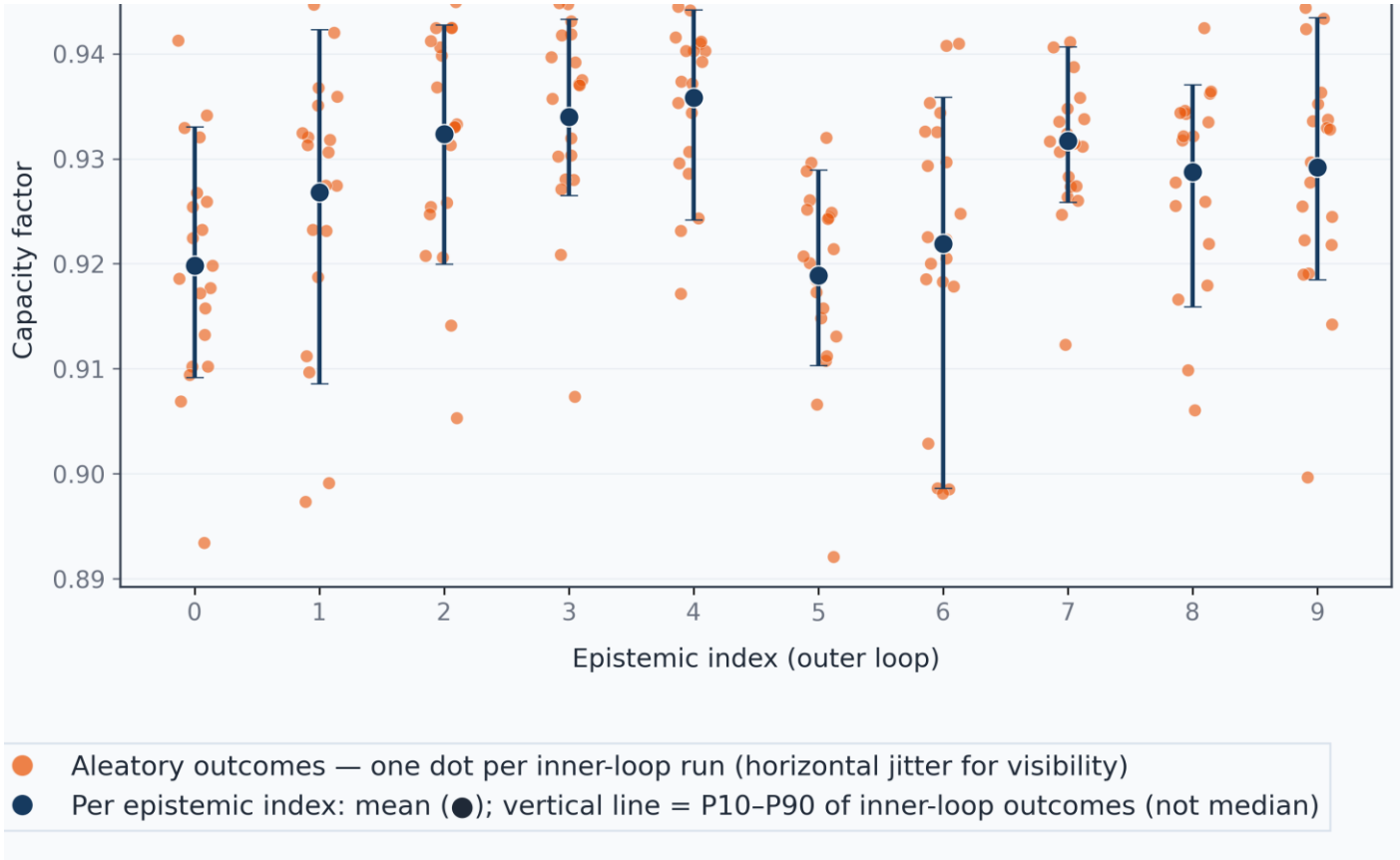
60-year baseline downside revenue shortfall

Same plant, different decisions reshape different parts of the availability and revenue-risk distributions.

Values are illustrative; the contribution is the framework linking reliability, repair logistics, and revenue risk.

BACKUP · Q&A

Nested Monte Carlo: two uncertainty layers



Outer loop
uncertain failure rates and CCF β

Inner loop
stochastic plant histories at fixed parameters

Design
10 epistemic × 20 aleatory = 200 runs

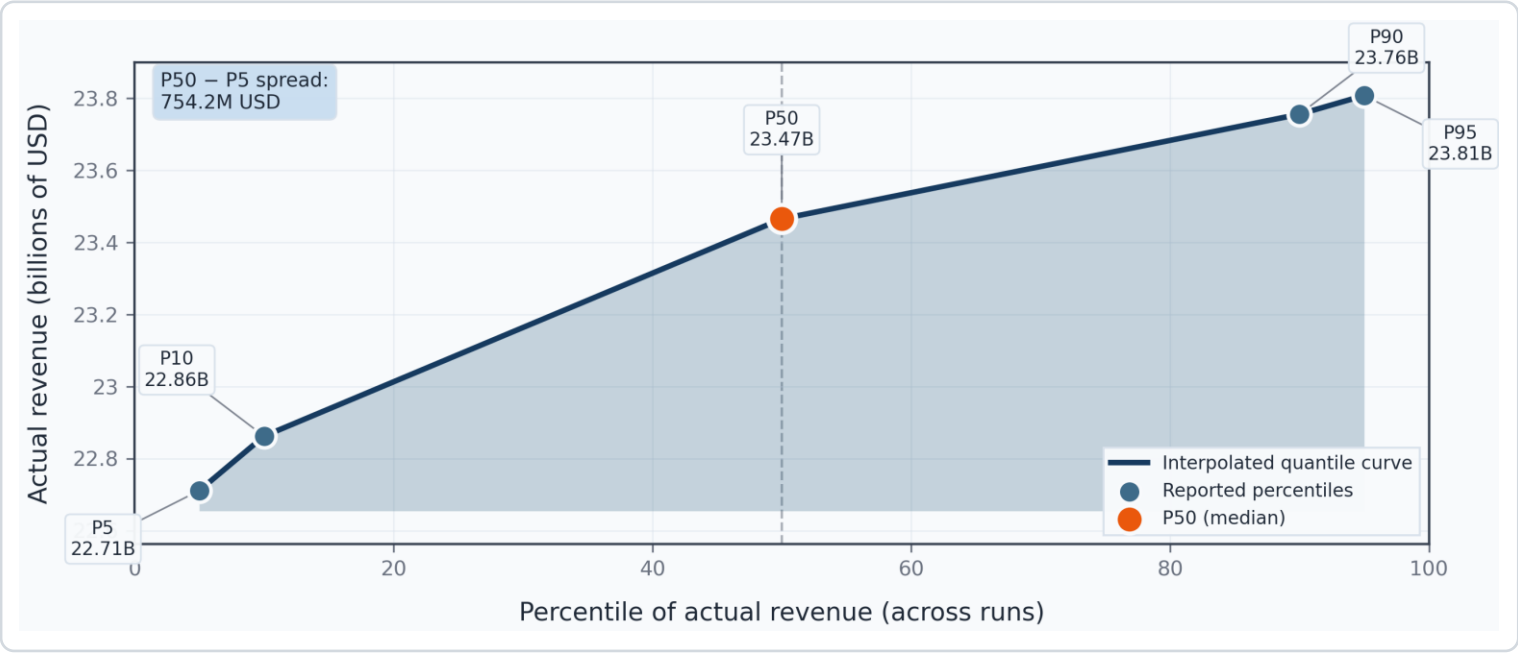
Reading
inner scatter > outer shift under current priors

Nested MC separates parameter uncertainty from stochastic operating variability.

Illustrative case study · not a plant forecast

BACKUP · Q&A

Revenue-at-risk: definition and scale



Definition

$RaR_q = R_{50} - R_q$

median minus lower-percentile lifetime revenue

60-year baseline

$R_{50} \approx \$23.47B$

$RaR_5 \approx \$754M$

$RaR_{10} \approx \$603M$

P5–P95 spread ≈ $1.1B

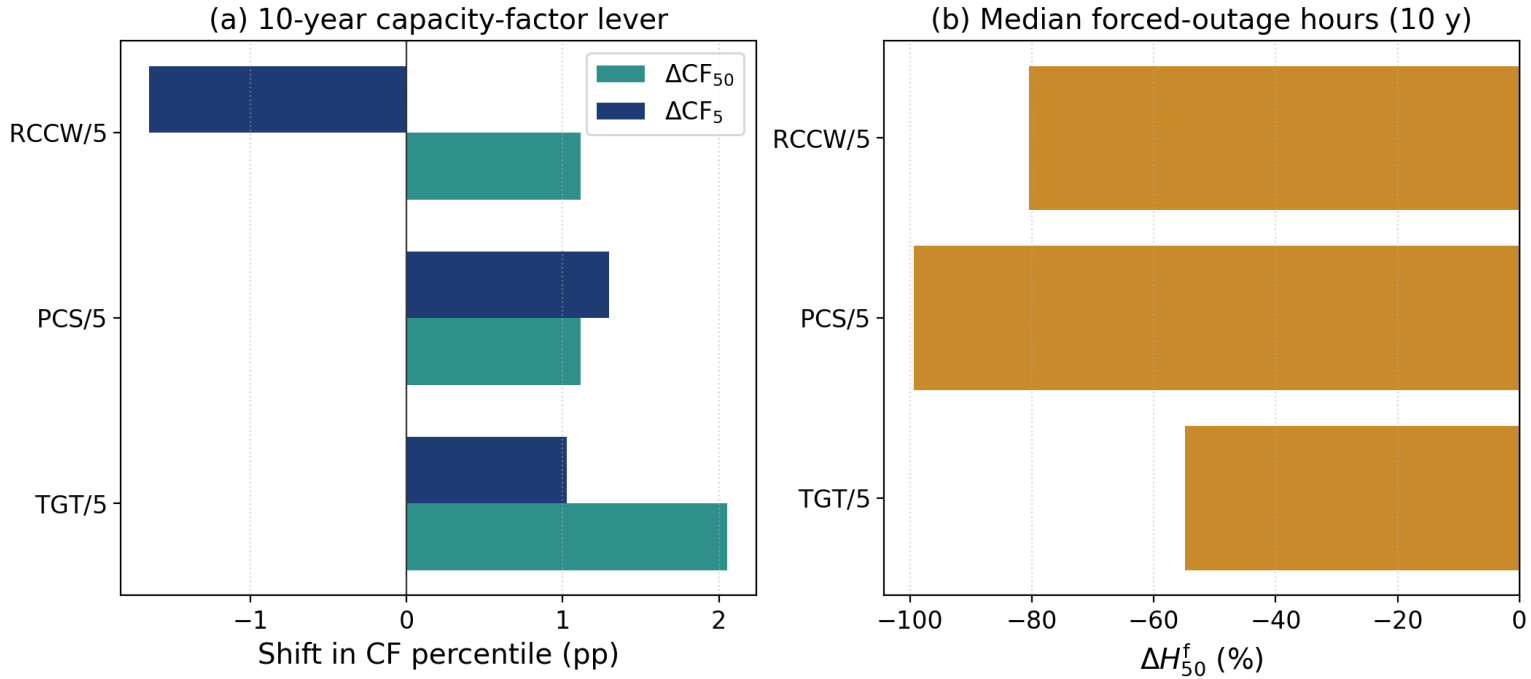
RaR_5 is an operational downside revenue shortfall — not 5% of revenue.

Illustrative case study · not a plant forecast

BACKUP · Q&A

Reliability levers: distributional importance

λ/5 study on selected component families



Setup

Divide one family's failure-rate value by 5

10-year · Policy M · Balanced bundle

Different endpoints

TGT: median-throughput lever

PCS: tail-risk lever

RCCW: shared-support lever (tail noisy, N=50)

Interpretation

No single winner — ranking depends on objective

Importance depends on the endpoint: median output, lower-tail CF, outage hours, or cost.

Illustrative case study · not a plant forecast

BACKUP · Q&A

Scope and limitations

What this is

- DES + nested MC from failures to CF and revenue distributions
- PRA vocabulary applied to generation economics
- NuScale-inspired 12 × 77 MWe case
- Public / generic reliability and repair inputs

What this is not

- Not licensing-grade PSA or safety CDF endpoint
- Not vendor-calibrated performance forecast
- Not market dispatch or bankable project finance
- Not validated against operating multi-module SMR data

Data anchors: public NuScale licensing material · generic LWR reliability data · structured repair and economic assumptions

Numerical values are illustrative; the contribution is the integrated framework.