Comparison of Seismic Design Methodologies and Licensing Precedents for Advanced Reactors under 10 CFR Parts 50/52, 53, and Proposed Part 57

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1. Introduction

U.S. seismic licensing follows two precedents. A generic design certification (DC) or standard design approval (SDA) fixes certified seismic spectra and site parameters before a site is chosen; a site-specific application instead develops hazard, ground motion, and soil-structure interaction (SSI) directly in a construction permit (CP), operating license (OL), or combined license (COL). Site-specific ground motion follows a probabilistic seismic hazard analysis (PSHA) yielding a Ground Motion Response Spectrum (GMRS) [23] and Foundation Input Response Spectra (FIRS); generic designs instead use a bounding Certified Seismic Design Response Spectra (CSDRS). SSC seismic categorization increasingly follows ASCE/SEI 43-19 and ANSI/ANS-2.26 [24,25], relating design margin to safety significance. AP1000, APR1400, and NuScale illustrate the generic approach; Natrium, Xe-100, BWRX-300, Kairos, and KRONOS use Part 50; Oklo pursues a COL without an antecedent DC. These precedents inform Part 53 (effective Apr. 29, 2026) and proposed Part 57.

This paper compares actual licensing precedents—AP1000, APR1400, NuScale, Natrium, Xe-100, BWRX-300, Kairos, Oklo, KRONOS, and Korea's i-SMR—to show that a bounding generic seismic envelope combined with site-specific hazard and soil-structure-interaction verification offers a practical framework for future SMRs and microreactors, including 5MWe He gas-cooled UO2 fuel BeSMART.

2. Comparison of Licensing and Seismic Precedents

Table I shows Advanced Reactor seismic licensing precedents.

Table I. Advanced-reactor seismic licensing precedents

Reactor / Project	Technology	Pathway / Status	Seismic characteristic
AP1000 / Vogtle 3&4	Large LWR	Part 52 DC + site-specific COL	CSDRS → GMRS/FIRS verified
APR1400	Large LWR	Part 52 DC	Site-indep. CSDRS; generic SSI/site profiles; no U.S. COL
NuScale US600	LWR SMR	Part 52 DC	CSDRS + certified site params; COL applicant verifies site bounding
NuScale US460	LWR SMR	Part 52 SDA (2025)	Updated generic seismic design
Natrium / Kemmerer	Na-cooled fast reactor	Part 50 CP (Mar. 2026)	Site specific hazard + risk-informed SSC; Reactor Seismic Isolation appl.
Xe-100 / Long Mott	HTGR	Part 50 CP; EA/FONSI (May 2026)	Site specific geology/seismology+ risk-informed SSC
BWRX-300 / Clinch River	BWR SMR	Part 50 CP; staff-rec. SER(2026)	Site PSHA in CPA
Kairos Hermes / Hermes 2	Fluoride Salt-cooled test reactors	Part 50 CPs (2023/2024)	Site-specific non-LWR; graded safety approach; Seismic Base Isolation appl.
KRONOS / UIUC	HTGR microreactor	Part 50 CP (Mar. 2026)	Site-specific Microreactor-scale siting
Korea i-SMR	Integral PWR SMR	Korean SDA application (2026)	Generic standard design; 0.3g seismic design target
Oklo Aurora / INL	Liquid-metal fast reactor	Part 52 COL pre-application	Site-specific seismic design basis under NRC review
BeSMART	He gas cooled UO2 fuel microreactor	Part 50/52, 53, and proposed 57	0.3g SSE, DC, RIPB SSC
Part 53 No direct application precedent yet	Technology-inclusive	DC/SDA/CP /OL/COL/ ML(manufacturing license) available	Risk-graded DBGM & SSC
Part 57 (proposed) No direct application precedent yet	Microreactor /low-consequence	SDA/ML/CP /OL pathways	Generic design + graded site /external-hazard verification

2.1 AP1000

AP1000 is the clearest U.S. precedent for transferring a certified seismic envelope to a site. Its CSDRS is anchored at 0.30g; for Vogtle 3&4, site GMRS/FIRS were developed and verified against the CSDRS rather than repeating the full generic design [3,4]. The model: generic DC (CSDRS + SSI) → site COL (PSHA→GMRS→FIRS→comparison) is directly applicable to standardized SMR/microreactor deployment.

2.2 APR1400

APR1400's Part 52 Appendix F certification uses site-independent CSDRS (0.30g) enveloping multiple generic site profiles [5,6]. Unlike AP1000, no U.S. site-specific COL has followed, so it demonstrates the generic seismic-envelope method but not the full generic-to-site transition.

2.3 NuScale

NuScale's US600 DC establishes CSDRS and certified site parameters that a referencing COL applicant must bound [7]. The Carbon Free Power Project withdrew its COL pre-application in Nov. 2023, so no DC-to-COL precedent was completed. The NRC issued the NuScale US460 SDA on May 29, 2025, covering a six-module, 462-MWe plant, including Chapter 2 site parameters and Chapter 3 seismic design [8,9]. NuScale thus illustrates two reusable mechanisms: DC→COL, and SDA→subsequent DC or plant-specific license—the latter directly relevant to Part 53/57.

2.4 Natrium, Xe-100, and BWRX-300

TerraPower pursued a site-specific Part 50 CP for Natrium at Kemmerer without a prior DC; the NRC issued the construction permit on Mar. 4, 2026, combining Part 50 review with LMP-based, risk-informed structures, systems, and components (SSCs) classification [10].

Long Mott Energy's Xe-100 CP application (docketed May 2025) similarly develops the seismic design criteria for the Xe 100 SSCs in a risk informed, performance based manner, and site geology, seismology, and geotechnical data directly in the PSAR; the NRC issued an environmental assessment/FONSI in May 2026, with the safety review ongoing [11].

TVA's BWRX-300 Clinch River CP application incorporates PSHA and site response directly into the licensing basis; NRC staff completed the safety evaluation report in Jun. 2026 and recommended Commission authorization, which remained pending as of this writing [12]. These cases establish an alternative to DC: standardized vendor design + site-specific Part 50 application.

2.5 Kairos and KRONOS

Kairos Power's Hermes (CP issued Dec. 2023) and Hermes 2 (Nov. 2024) demonstrate Part 50 licensing of non-LWR test reactors at Oak Ridge, addressing siting, external hazards, and graded SSC classification [13,14].

The University of Illinois KRONOS microreactor CP application, submitted Mar. 31, 2026, is a closer commercial-scale microreactor analogue, providing review experience relevant to future Part 57 applications [15].

2.6 Korean i-SMR

Korea's i-SMR standard-design application, received by the NSSC on Feb. 27, 2026, separates generic design information from site-specific data supplied later, paralleling the U.S. DC/SDA model [16]. KHNP's design target increases reactor-building seismic capacity from Korea's conventional 0.2–0.3g to 0.3g–0.5g —a developer characteristic pending regulatory confirmation [17].

2.7 Oklo Aurora

Oklo's Aurora Powerhouse (≤75 MWe liquid-metal fast reactor, Idaho National Laboratory) illustrates a third architecture: a site-specific Part 52 COL pursued without an antecedent DC. As of 2026, NRC review remains in Phase 2 COL pre-application; no permit has issued [18]. This differs from a separate DOE Nuclear Safety Design Agreement approved in Mar. 2026 for a companion DOE-authorized project, which uses DOE's own siting authority rather than an NRC license [19].

2.8 Microreactor, BeSMART

The seismic method for APR1400 DC under Part50/52 is preliminarily used as a benchmarking purpose.

A risk-informed seismic categorization process consistent with RG 1.233 and NEI 18-04, in which safety classification (SR / NSRST / NSR-NST) is used as the primary input. SR SSCs are assigned Seismic Category I [20] and qualified for the SSE. NSRST SSCs are assigned Seismic Category II with graded special treatment. NSR-NST SSCs are assigned Seismic Category III or conventional seismic design. This graded approach is explicitly similar to the Xe-100 seismic methodology and supports TIRIPB licensing under 10 CFR Part 53 and proposed Part 57.

3. Implications for Part 53 and Proposed Part 57

Part 53, effective Apr. 29, 2026, permits CP, OL, COL, DC, SDA, and manufacturing-license pathways, explicitly grading seismic design requirements to SSC safety significance [21]. No Part 53 application precedent has yet emerged; the preceding cases are

transferable: AP1000 (DC envelope→site verification), APR1400 (generic CSDRS/SSI), NuScale (DC/SDA + site interface), Natrium (risk-informed Part 50), Xe-100/BWRX-300 (site-specific Part 50 alternatives to DC), Kairos/KRONOS (graded non-LWR/microreactor precedents), i-SMR (international analogue), and Oklo (COL without DC). As of Aug. 2026, review duration among Part 50 applications appears driven more by completeness of site-specific geotechnical/seismic data than by pathway choice—relevant to Part 53's risk-graded approach.

Proposed Part 57 extends standardization to microreactors [22] via SDA/manufacturing-license pathways: a postulated site envelope and standardized design are qualified generically, and site applications verify against that envelope, adding analysis only if exceeded—an evolution of the AP1000/NuScale model.

4. Conclusions

AP1000, APR1400, and NuScale establish the feasibility of a generic seismic design envelope; Natrium, Xe-100, BWRX-300, and Kairos establish site-specific Part 50 seismic licensing; and Oklo illustrates an intermediate COL-without-DC model. AP1000/Vogtle remains the strongest precedent for standardized reactors, having completed the full CSDRS-to-GMRS/FIRS verification process.

Part 53 can combine both approaches by grading seismic performance to SSC safety significance, and proposed Part 57 can extend the generic model to repetitive microreactor deployment such as BeSMART under development.

A practical future methodology is therefore a bounding seismic design envelope, standardized reactor design, site-specific PSHA/SSI verification, and risk-informed SSC performance requirements.

REFERENCES

[1] U.S. NRC, 10 CFR Part 50, Appendix S.
[2] U.S. NRC, 10 CFR Part 52.
[3] U.S. NRC, AP1000 Design Certification, 10 CFR Part 52, App. D.
[4] Southern Nuclear Operating Co., Vogtle 3&4 UFSAR, Sec. 3.7.
[5] U.S. NRC, APR1400 Design Certification, 10 CFR Part 52, App. F, 2019.
[6] KEPCO/KHNP, APR1400-E-S-NR-14001-NP, Rev. 0, 2014.
[7] U.S. NRC, NuScale SMR Design Certification, 10 CFR Part 52, App. G, 2023.
[8] U.S. NRC, Final SER, NuScale US460 SDA, May 28, 2025.
[9] U.S. NRC, News Release 25-033, May 29, 2025.
[10] US SFR Owner LLC / U.S. NRC, Kemmerer Unit 1 CP CPAR-1, issued Mar. 4, 2026.
[11] Long Mott Energy LLC / U.S. NRC, Long Mott Xe-100 CP Application and EA/FONSI, May 20, 2026.
[12] TVA / U.S. NRC, Clinch River BWRX-300 CP Application and SER, Jun.–Jul. 2026.
[13] U.S. NRC, Kairos Hermes CP CPTR-6, Dec. 14, 2023.
[14] U.S. NRC, Kairos Hermes 2 CPs CPTR-7/8, Nov. 21, 2024.
[15] Univ. of Illinois Urbana-Champaign, KRONOS MMR CP Application, Mar. 31, 2026.
[16] NSSC Korea, i-SMR SDA Application, received Feb. 27, 2026.
[17] KHNP, i-SMR Technology Brochure.
[18] Oklo Inc., Aurora Powerhouse COL Pre-Application Activities, U.S. NRC, 2023–2026.
[19] Oklo Inc., DOE Nuclear Safety Design Agreement Approval, Mar. 2026.
[20] Bong Yoo et al., Economy and Standardization applying Seismic Isolation for a Microreactor, BeSMART Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, May 7-8, 2026
[21] U.S. NRC, 10 CFR Part 53, 91 FR 15696, Mar. 30, 2026, eff. Apr. 29, 2026.
[22] U.S. NRC, Proposed 10 CFR Part 57, 91 FR 23628, May 1, 2026.
[23] U.S. NRC, Regulatory Guide 1.208, Rev. 0, 2007.
[24] ASCE, ASCE/SEI 43-19, 2020.
[25] ANS, ANSI/ANS-2.26-2004 (R2021)