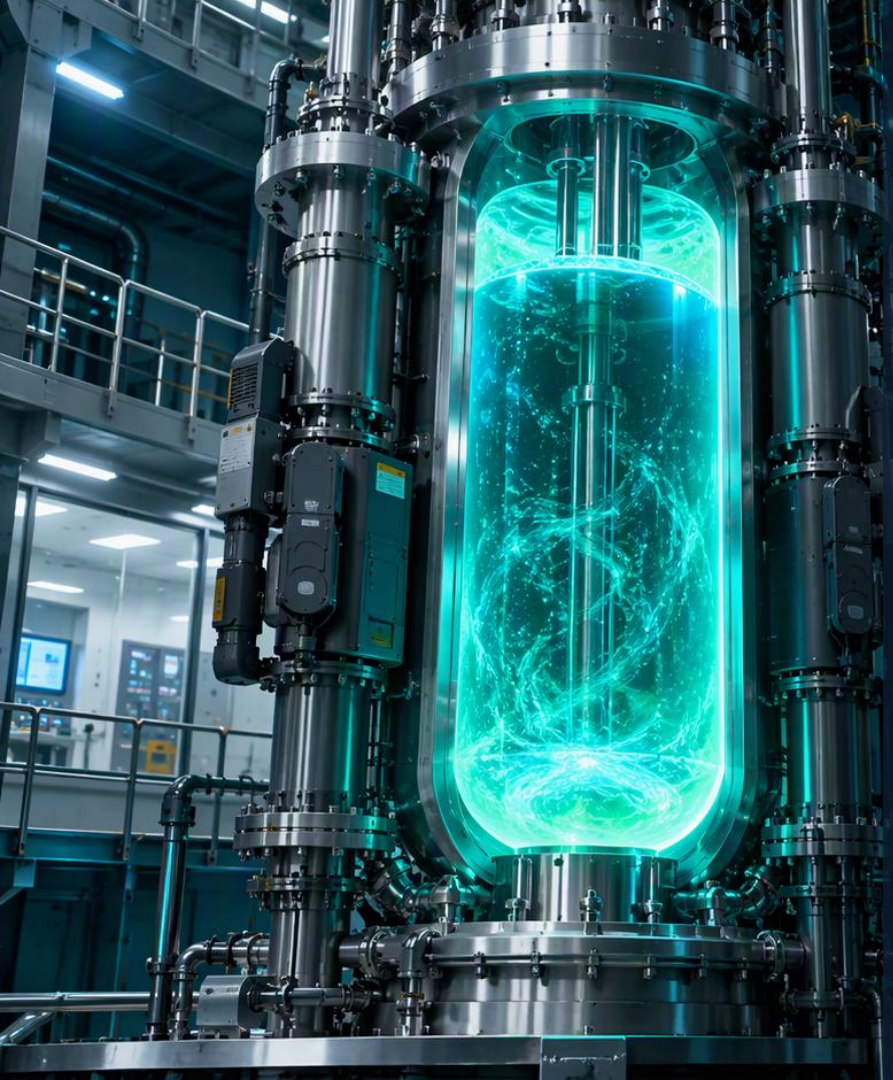


KNS AUTUMN MEETING 2026

Similarity Analysis between the MARINA Molten Salt Reactor and a Critical Experiment Facility

Using Neutron Spectrum-Based Indices and the Sensitivity/Uncertainty Method

Inwon Cho
Hyundai Engineering & Construction

Contents

01 **Introduction**
Background and motivation

02 **Methods and Models**
SCALE 6.3.1 models, S/U and spectral indices

03 **Results and Discussion**
Spectrum, integral indices, E/G components, EALF

04 **Conclusions**
Representativeness of the critical facility

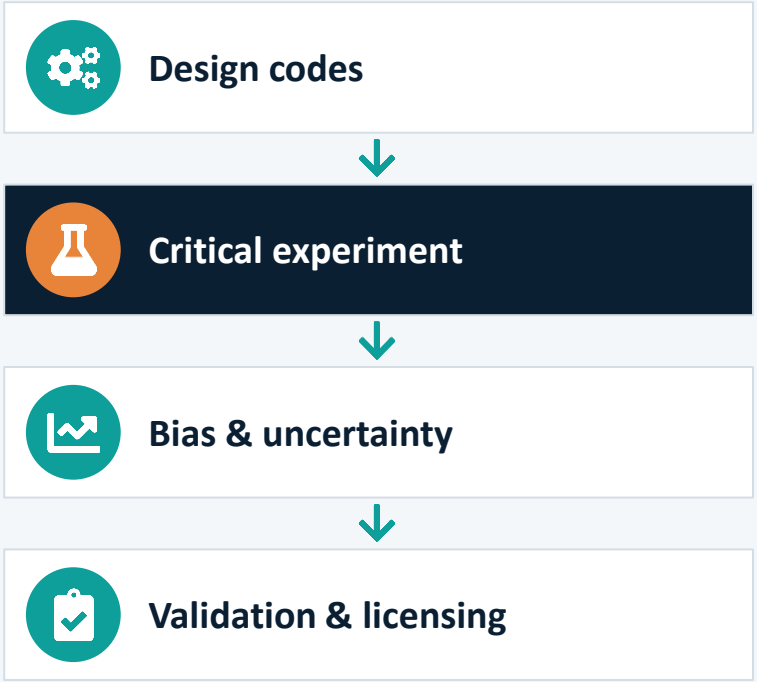
Why a Critical Facility for MARINA?

MARINA

- Fast-spectrum molten salt reactor (MSR)
- $NaCl–KCl–UCl_3$ based fuel salt

Validation need

- Neutronic design methods and tools must be validated against experiments
- A dedicated critical experiment facility is being developed for this purpose



Is the facility truly representative of MARINA? → must be quantified, not assumed from fuel type or enrichment

Motivation: Complementing c_k

Conventional: S/U coefficient c_k

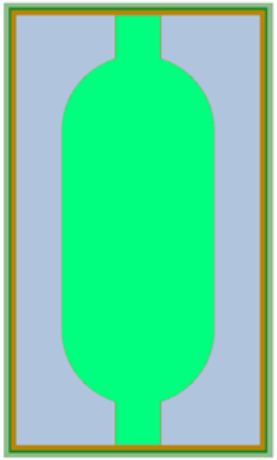
- Correlation of k-eff sensitivities to nuclear data, propagated through covariance data
- Widely used for benchmark selection [1,2]
- **Limitation: may show high similarity even for systems of quite different composition**

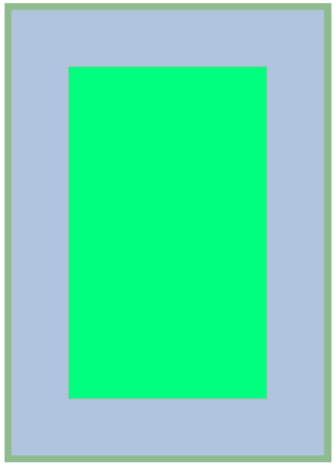
Complementary: spectrum-based indices

- Compare neutron spectra directly [3]
- **Index S · PCC · Cosine · JSD**
- Captures physical spectral differences not seen by c_k alone

This study c_k (with E, G by reaction) + four spectral indices + EALF (complementary), all with SCALE 6.3.1

Computational Models and Geometry





MARINA **Critical facility**

Fuel salt (green) / MgO reflector (blue)

Parameter	MARINA	Critical
Fuel salt	$NaCl–KCl–UCl_3$	
Fuel radius (cm)	76.0	70.0
Height (cm)	**432**	**234**
Fuel shape	cyl. + hemi.	cylinder
Fuel-volume ratio	**~2.2**	1
MgO reflector o.r. (cm)	121.9	110.4
Vessel o.r. (cm)	134.4	115.4
Reflector	MgO	MgO
k-eff	1.06403	1.06383

SCALE 6.3.1 · CSAS6 (KENO-VI) · CE ENDF/B-VII.1

Analysis Workflow

Spectrum-based path

CSAS6
KENO-VI, CE ENDF/B-VII.1

→

252-group flux
Main fuel region of each system

→

Normalization
p, q (Σ = 1)

→

4 indices + EALF
Index S, PCC, Cosine, JSD

Sensitivity/uncertainty path

TSUNAMI-3D
k-eff sensitivity calculation

→

SDF files
One per system

→

TSUNAMI-IP
252-group ENDF/B-VII.1 covariance

→

c_k, E, G
E, G by fission / capture / scatter

Application = MARINA, Experiment = critical facility

Neutron Spectrum-Based Similarity Indices

Cosine

1 = identical

$\cos\theta = (A \cdot B) / (\|A\|\|B\|)$

Angle between the two flux vectors

PCC

1 = identical

Cosine of mean-subtracted spectra

Pearson product-moment correlation

JSD

0 = identical

$\frac{1}{2}\Sigma\, p \log_2(p/M) + \frac{1}{2}\Sigma\, q \log_2(q/M),\ M = (p+q)/2$

Symmetric, bounded in [0, 1]; 1 − JSD also reported

Index S

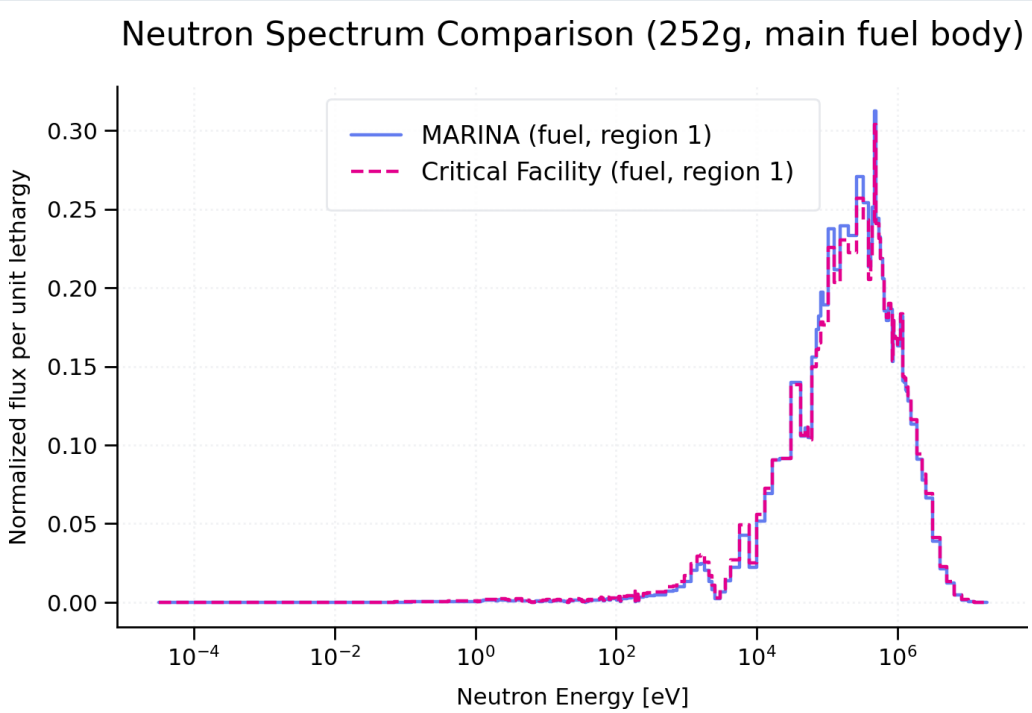
1 = identical

$S = \Sigma\, w \cdot \min(p,q) / \max(p,q),\ w = (p+q)/2$

Average weighted min-max ratio over all groups

Cosine and PCC are dominated by large flux components; Index S weights every group and stays sensitive to low/intermediate-energy tails.

Result 1: Neutron Spectrum Comparison



0.673 / 0.660 — Fast fraction (>100 keV) MARINA / Critical

0.326 / 0.338 — Epithermal fraction MARINA / Critical

< 0.2 % — Thermal fraction (both)

0.024 — Total variation between normalized spectra

Result 2: S/U-Based Similarity (TSUNAMI-IP)

c_k

0.9985

± 0.0013

Well above the 0.90 threshold commonly recommended for criticality-safety validation

E	0.9934	± 0.0028 Sensitivity-only index
G	0.9335	± 0.0143 Sensitivity coverage index

The two systems share nearly identical k-eff sensitivities to nuclear data.

Result 3: Spectrum-Based Indices

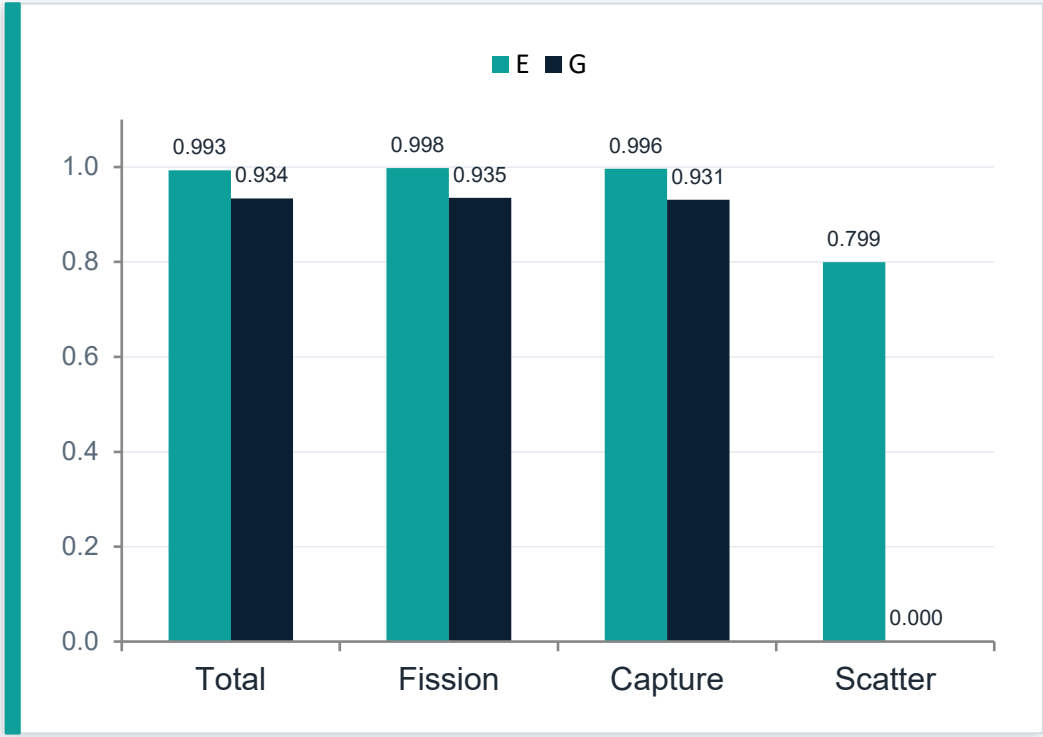


Raw JSD = 0.0011

Index S = 0.9547
Strongest discrimination among spectral metrics

Cosine 0.9993 · PCC 0.9992
Saturated near unity — dominated by flux components near the spectral peak

Result 4: Reaction-Wise E and G



Fission & capture dominate
E ≈ 0.996–0.998, G ≈ 0.93

Scattering is weak
E(sct) = 0.7993 (s.d. 2.58), G(sct) ≈ 0

High overall similarity does not imply equally high similarity for every reaction

EALF as a Complementary Indicator

EALF – MARINA

1.555×10^{4}

eV

EALF – Critical

8.626×10^{3}

eV

~1.8×

difference in EALF

The overall flux spectra are similar, but differences exist in some energy ranges. EALF reflects the fission-rate-weighted energy distribution rather than the flux distribution alone.
In this study, EALF is used as a complementary indicator.

CONCLUSIONS

The compact facility represents MARINA

1 High similarity despite different size and shape

~2.2× fuel-volume difference, yet c_k = 0.9985 and Index S = 0.9547, Cosine = 0.9993,

PCC = 0.9992, 1 − JSD = 0.9989

2 High similarity in fission and capture

E = 0.996–0.998, G ≈ 0.93; scattering requires further assessment

3 Complementary spectral similarity assessments

Use multiple metrics together; score differences do not establish metric superiority

4 Quantitative basis for validation and licensing

Supports use of the critical facility for MARINA neutronic design-method validation

References

[1] B. L. Broadhead et al., Sensitivity- and Uncertainty-Based Criticality Safety Validation Techniques, Nucl. Sci. Eng., Vol. 146, pp. 340-366, 2004.

[2] H. J. Park and J. W. Park, Similarity Coefficient Generation Using Adjoint-Based Sensitivity and Uncertainty Method and Stochastic Sampling Method, Energies, Vol. 17, 827, 2024.

[3] M. J. Kim, Development of an MC-based Extended Similarity Analysis System for Criticality Benchmark Selection, M.S. Thesis, Kyung Hee University, 2026.

[4] B. T. Rearden and M. A. Jessee (Eds.), SCALE Code System, ORNL/TM-2005/39, Ver. 6.3.1, Oak Ridge National Laboratory, 2023.

Thank you

Questions & Discussion

Inwon Cho | Hyundai Engineering & Construction