

Scenario Specific Sensitivity of Uncertain Parameters in OPR1000 : A Comparative Study Using CINEMA

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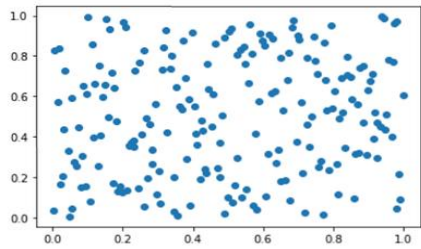
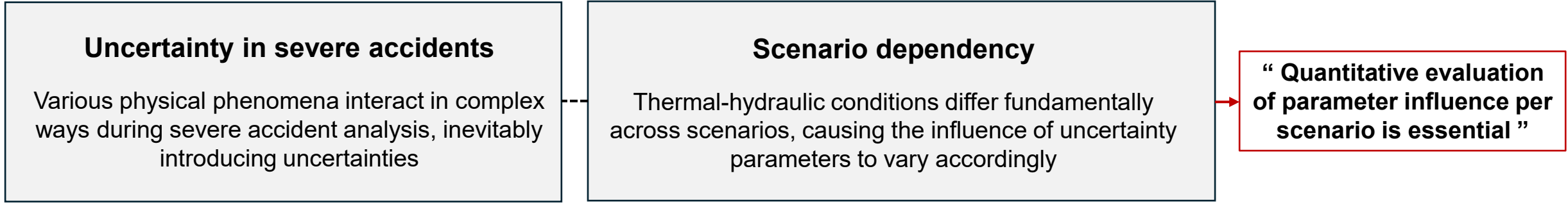
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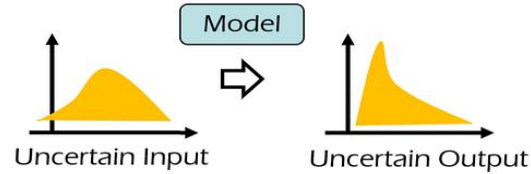
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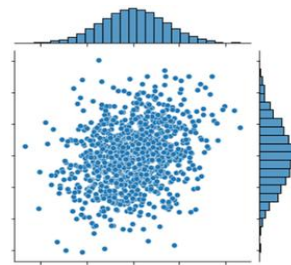
❖ Objective



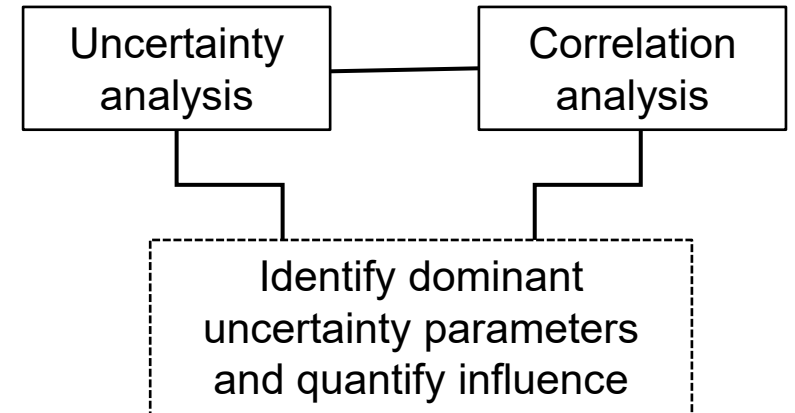
Random sample Generation



Uncertainty Propagation



Uncertainty Visualization



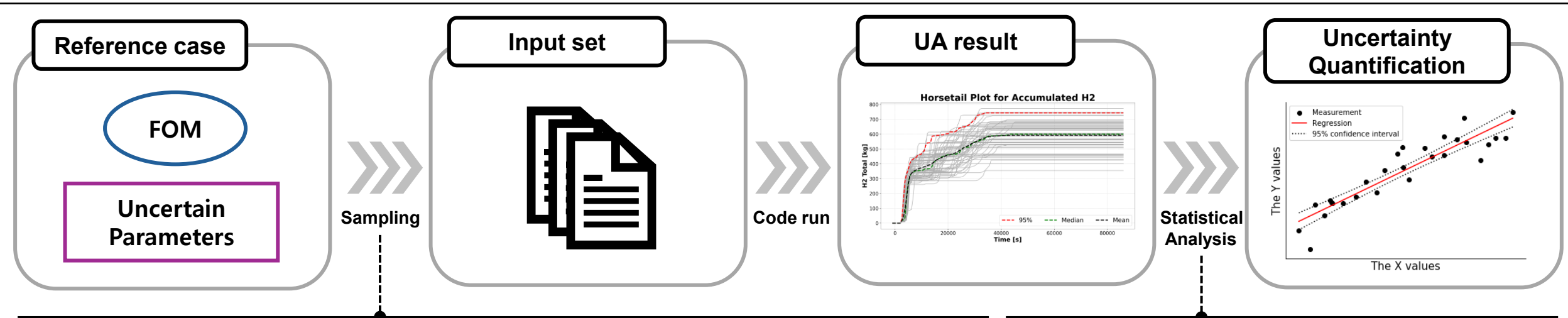
❖ UA Parameters and FOM

Parameter	Description	Range	Distribution
VF_c	Sensitivity coefficient for radial heat transfer	0.3 – 0.7	Uniform
Exp_blockage	Exponent for the calculation of flow blockage area	1.0 – 4.0	Normal
TZr_melt	Zircaloy melting temperature	2029 – 2229	Uniform
TZrO ₂ _melt	Oxidized Zircaloy melting temperature	2199 – 2399	Uniform
TUO ₂ _melt	UO ₂ melting temperature	2400 – 2600	Uniform
Comb_ratio1 (I → CsI)	CsI combination ratio	0.0 – 1.0	Uniform
Comb_ratio2 (2Cs → Cs ₂ MoO ₄)	Cs ₂ MoO ₄ combination ratio	0.0 – 1.0	Uniform
CSF	Aerosol (CsI) collision shape factor	1.0 – 4.0	Uniform
SSF	Aerosol (CsI) particle settling factor	1.0 – 4.0	Uniform
DCF	Aerosol (CsI) density correction factor	0.5 – 1.0	Uniform
PCE	Aerosol (CsI) adjustable particle capture efficiency	0.5 – 1.0	Uniform

FOM	
1	SAMG entry timing
2	LH relocation timing
3	RPV failure timing
4	H2 generation
5	CsI release fraction in containment

COMPASS
: In-vessel core degradation parameters

SIRIUS
: Fission Product behavior parameters



Wilks' Formula

$$1 - \sum_{k=n-p+1}^n \binom{n}{k} \alpha^k (1 - \alpha)^{n-k} \geq \beta$$

n : sample size
 α : CDF value
 β : confidence level
 p : order of wilks' formula

rank	Confidence / Coverage combination							
	95% / 95%		95% / 99%		99% / 95%		99% / 99%	
	Bound	Interval	Bound	Interval	Bound	Interval	Bound	Interval
1	59	93	90	130	299	473	459	662
2	93	153	130	198	473	773	662	1001
3	124	208	165	259	628	1049	838	1307

Simple Random Sampling

Linear Regression

SRCC value (ρ): 0.24
PCC value (r): 0.25

❖ UA Scenarios

Framework

Scenario	Base case (SBLOCA and SBO)
Code version	CINEMA 2.2.0.442
Number of cases	59 (Wilks' formula 95/95, 1st order)
Computation Time	3 days (72 hours)

COMPASS	value	SIRIUS	value
VF_c	1.0	Comb_ratio1	1.0
Exp_blockage	4.0	Comb_ratio2	1.0
TZr_melt	2129.15K	CSF	1.0
TZrO2_melt	2350K	SSF	1.0
TUO2_melt	2400K	DCF	1.0
		PCE	1.0

Events	SBLOCA time (hrs)	SBO time (hrs)
Start of core dry-out	0.12	1.36
End of core dry-out	0.57	1.99
CET > 923.15 K	0.58	2.03
Start of gap release	0.58	2.09
Initiation of oxidation	0.62	2.09
Relocation to core material to CSP	4.08	2.65
Relocation to core material to LP	6.83	4.31
RPV failure	8.84	5.38

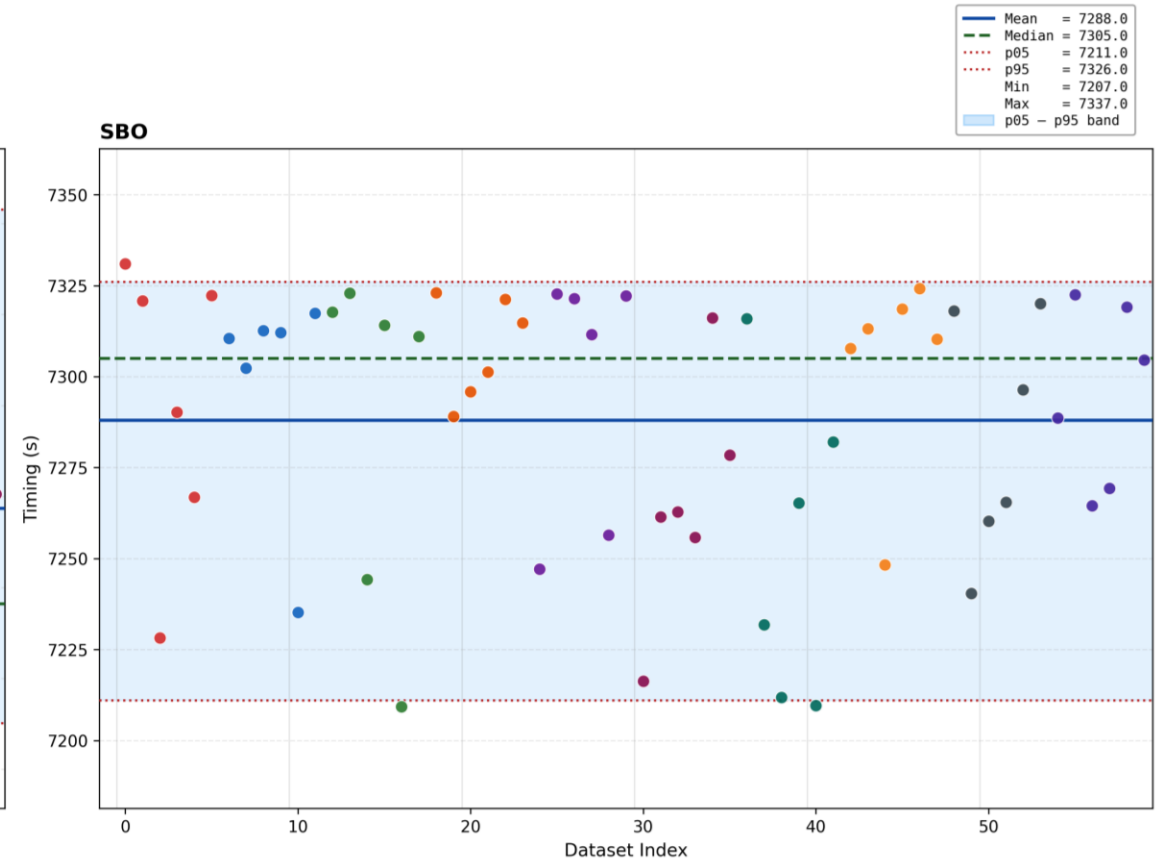
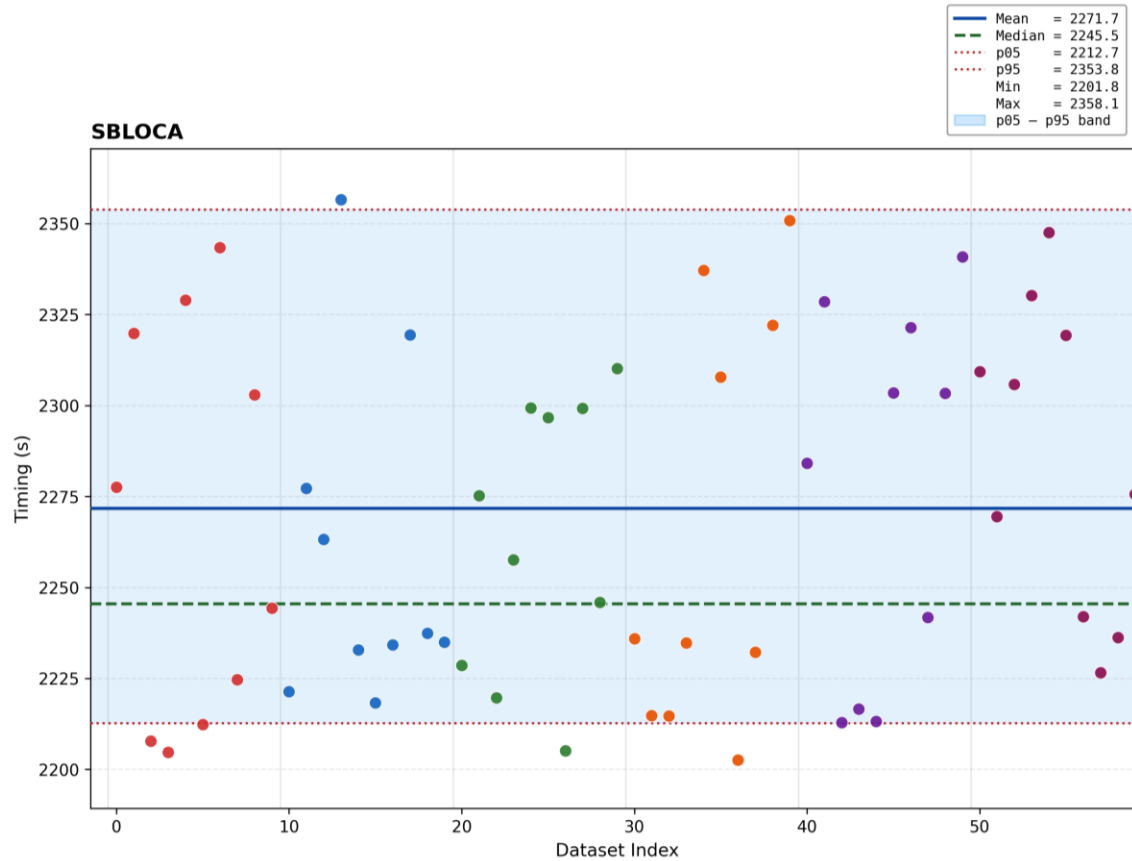
Accident sequence for SBLOCA and SBO from base case

Result and Discussion

Uncertainty Analysis : SBLOCA & SBO

❖ FOM 1. SAMG Entry timing

▪ Scatter plot

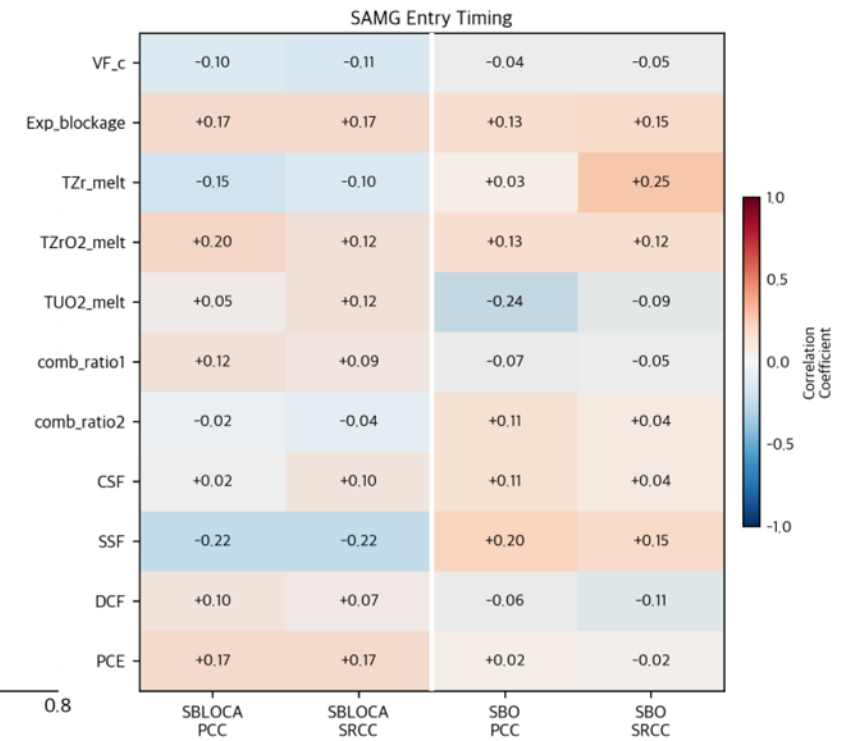
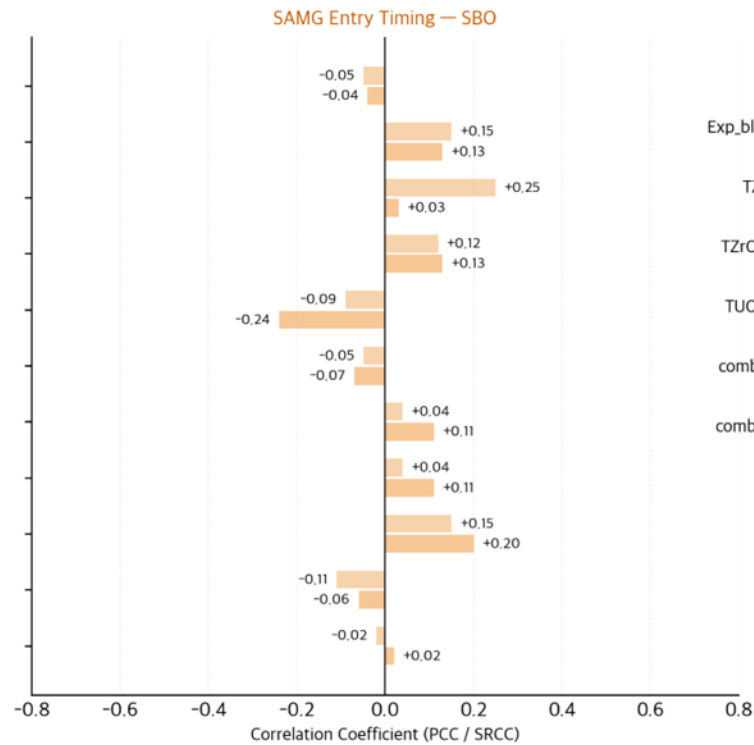
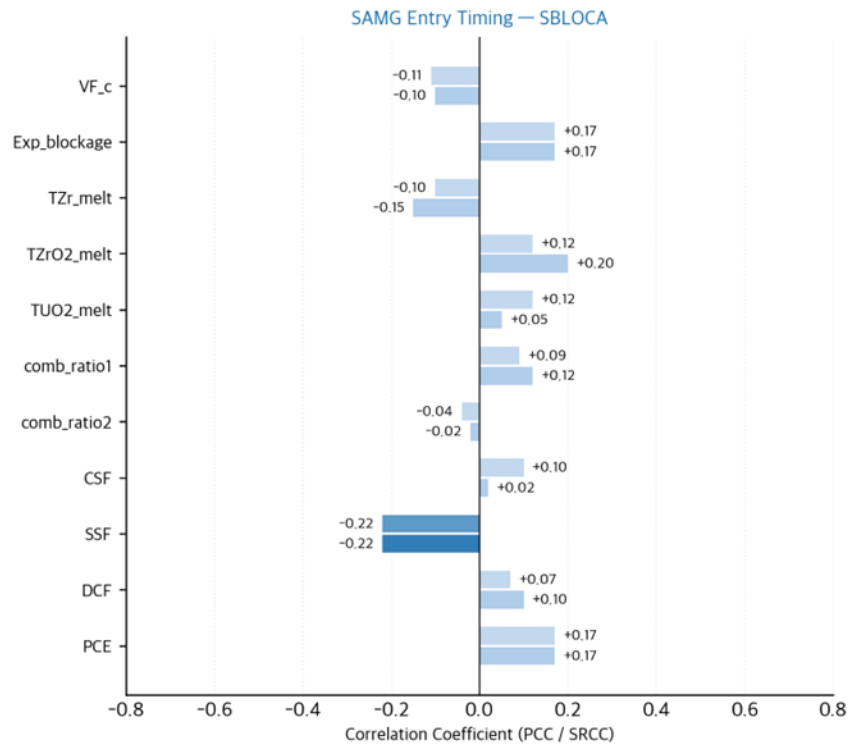


Result and Discussion

Uncertainty Analysis : SBLOCA & SBO

❖ FOM 1. SAMG Entry timing

- PCC/SRCC correlation coefficient



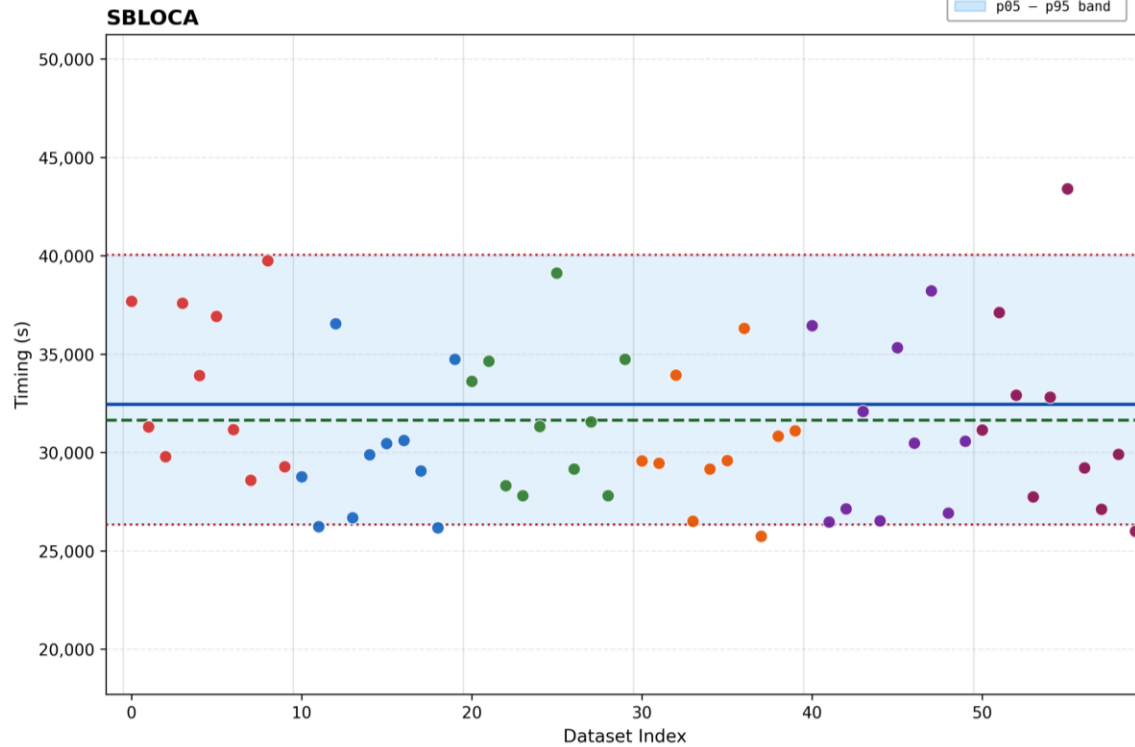
Result and Discussion

Uncertainty Analysis : SBLOCA & SBO

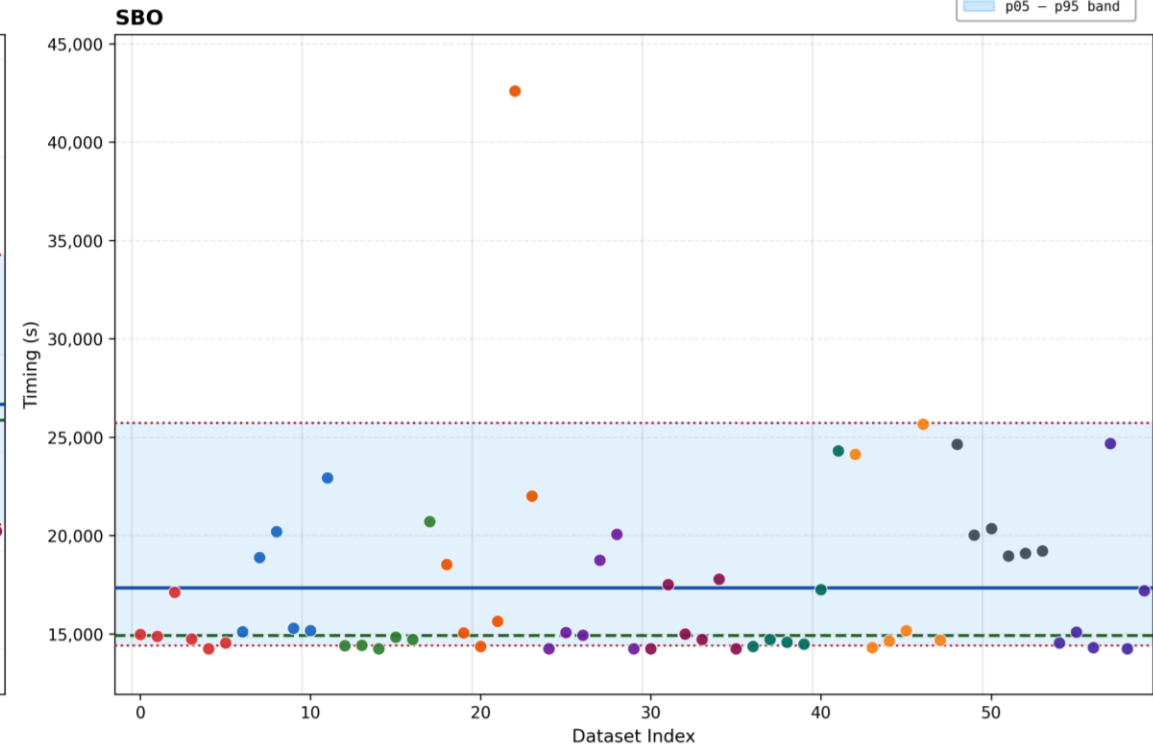
❖ FOM 2. Lower Head Relocation timing

▪ Scatter plot

— Mean = 32,433
- - Median = 31,627
... p05 = 26,329
... p95 = 40,038
Min = 24,676
Max = 44,272
p05 - p95 band



— Mean = 17,336
- - Median = 14,909
... p05 = 14,401
... p95 = 25,727
Min = 14,236
Max = 43,151
p05 - p95 band

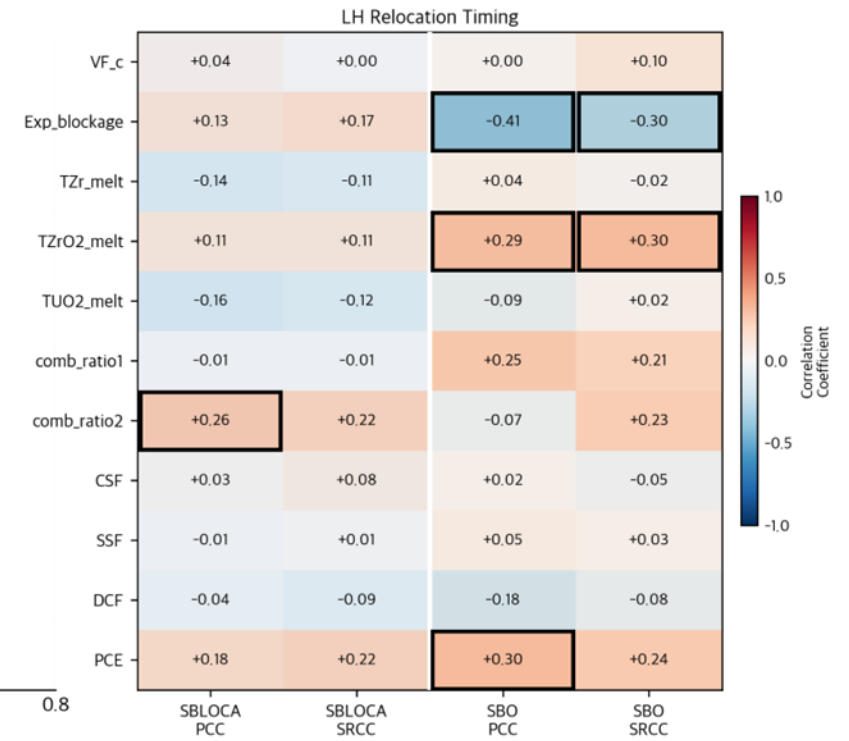
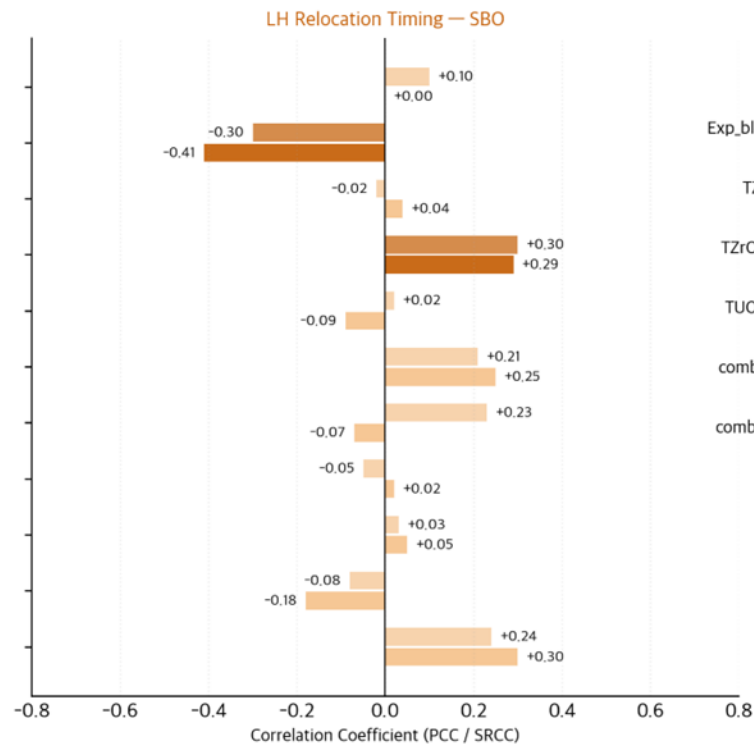
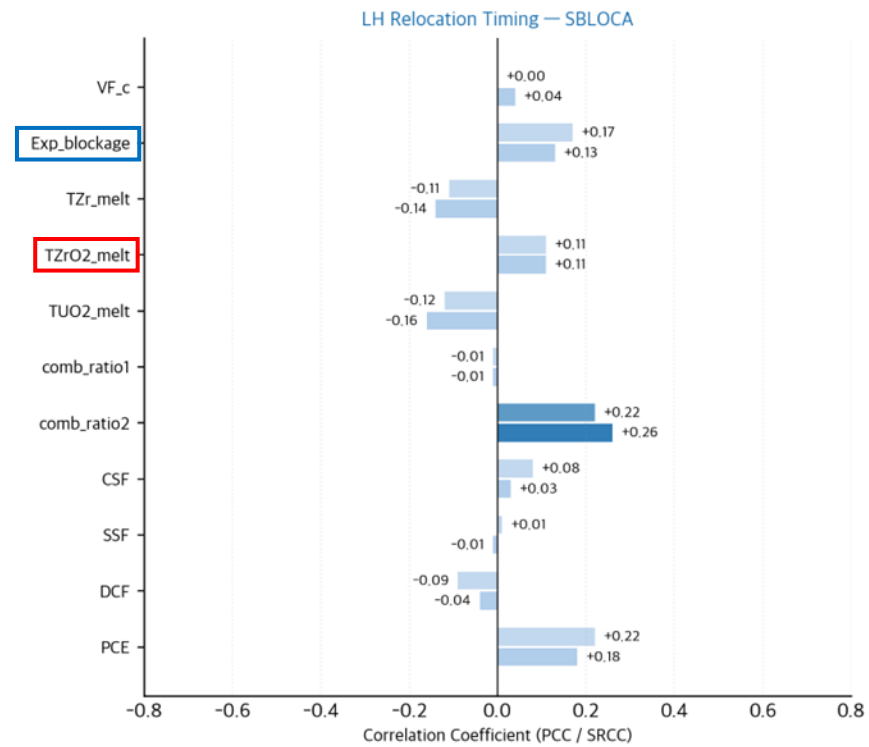


Result and Discussion

Uncertainty Analysis : SBLOCA & SBO

❖ FOM 2. Lower Head Relocation timing

▪ PCC/SRCC correlation coefficient

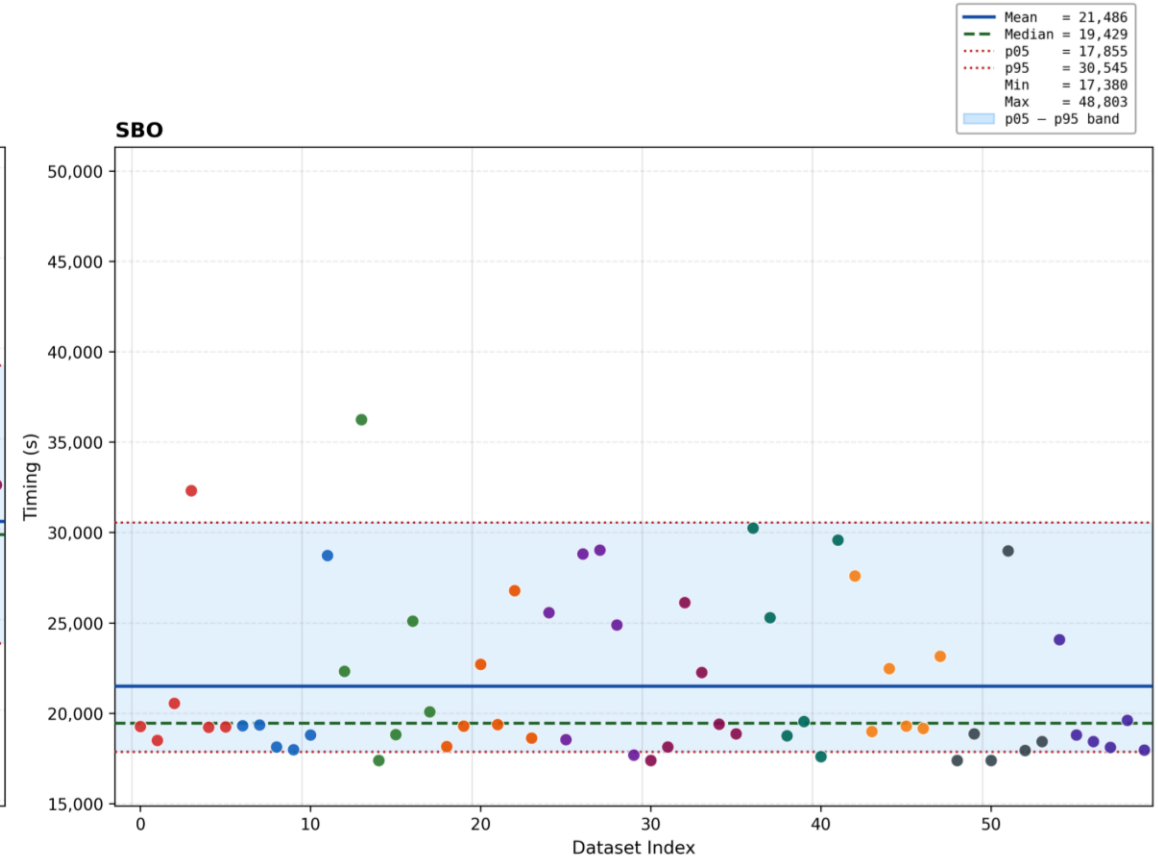
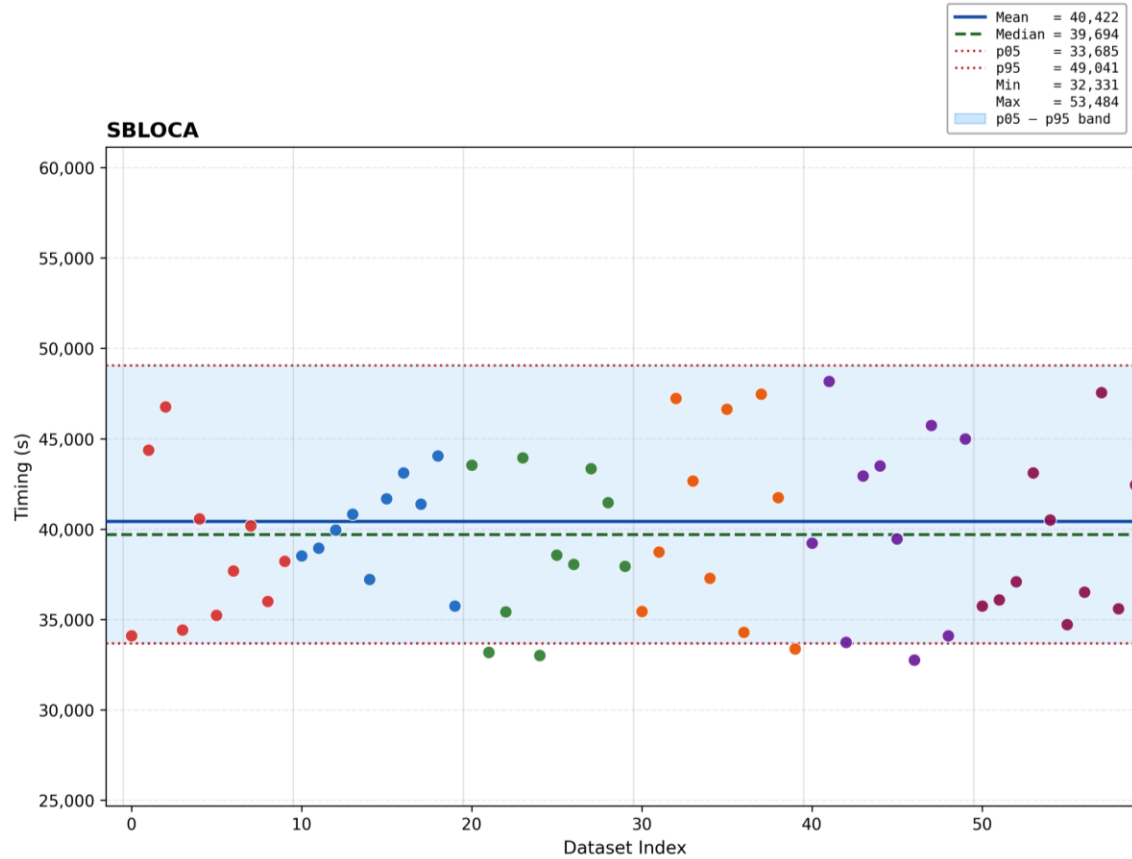


Result and Discussion

Uncertainty Analysis : SBLOCA & SBO

❖ FOM 3. RPV Failure timing

▪ Scatter plot

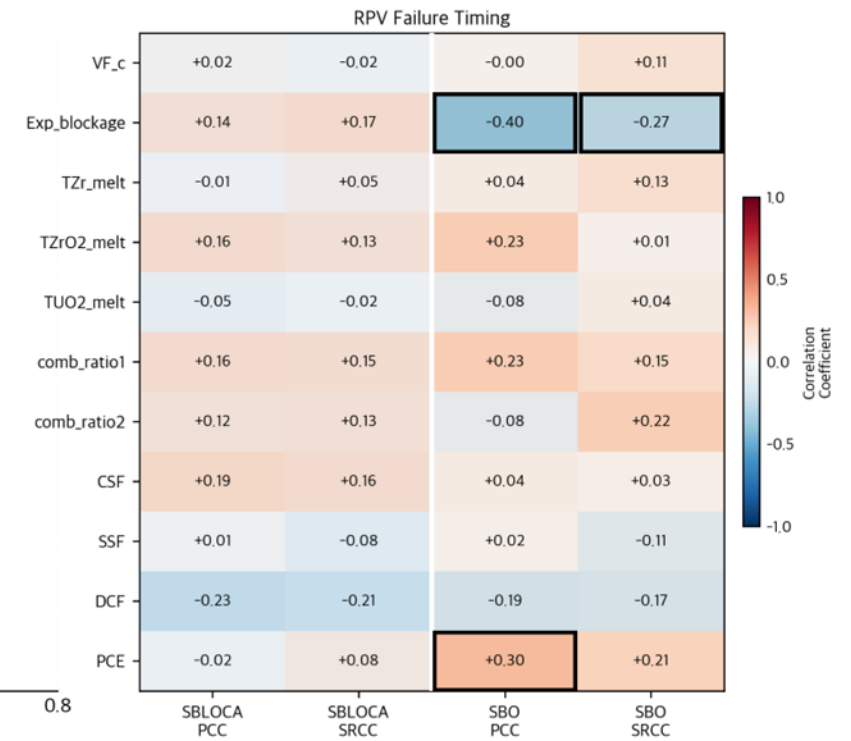
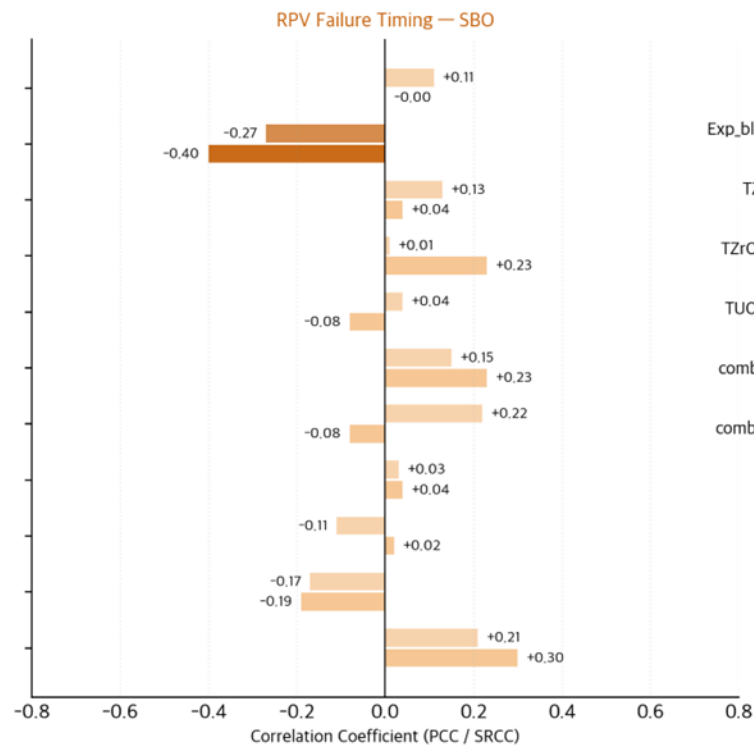
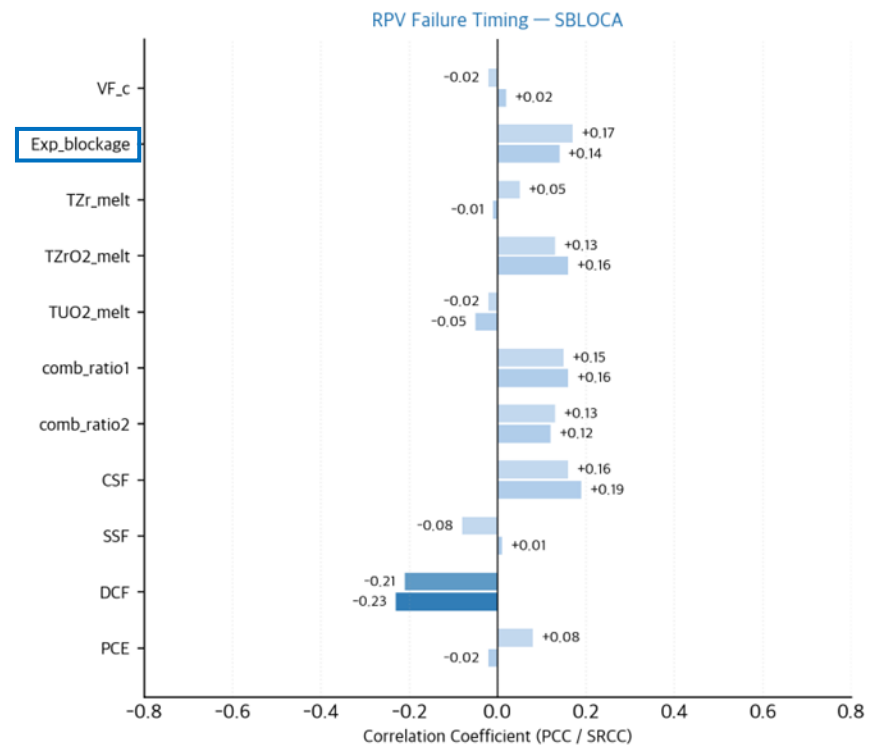


Result and Discussion

Uncertainty Analysis : SBLOCA & SBO

❖ FOM 3. RPV Failure timing

▪ PCC/SRCC correlation coefficient

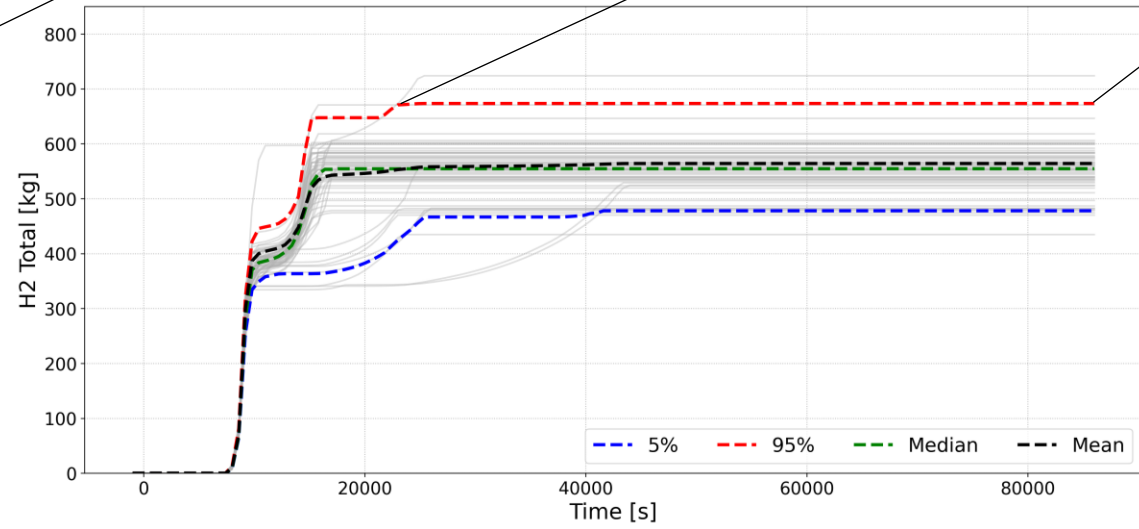
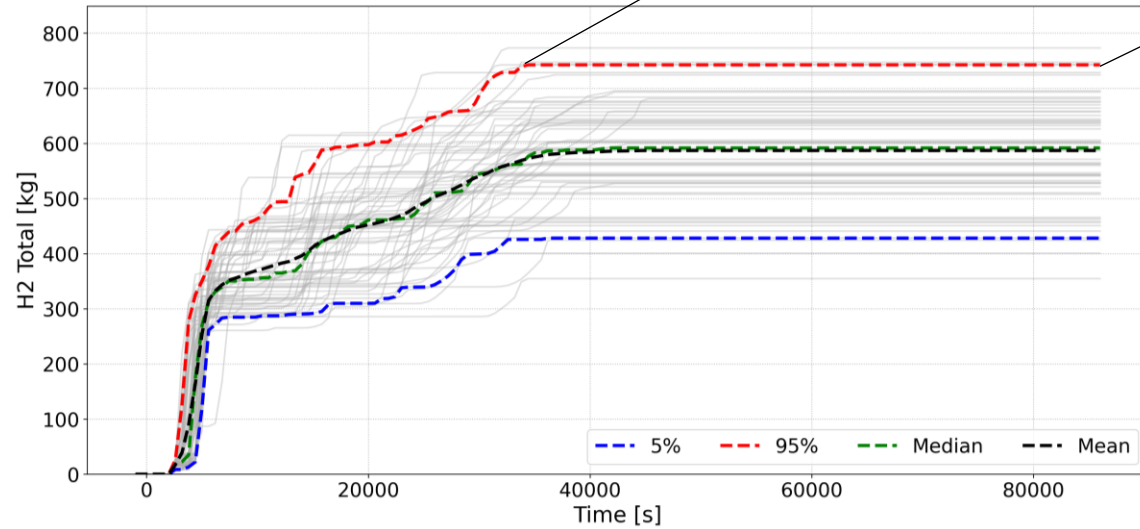
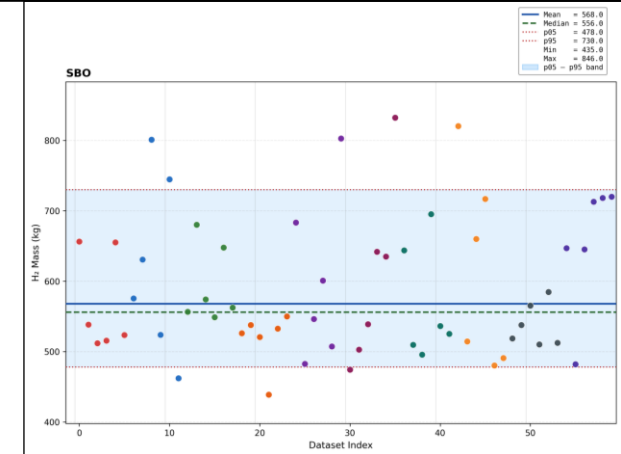
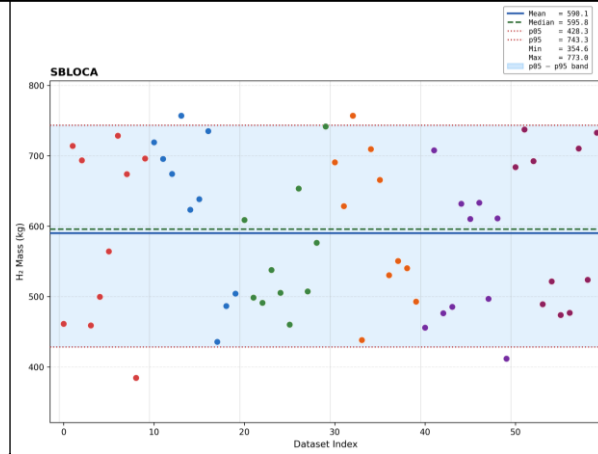


Result and Discussion

Uncertainty Analysis : SBLOCA & SBO

❖ FOM 4. Hydrogen Generation

▪ Horsetail plot

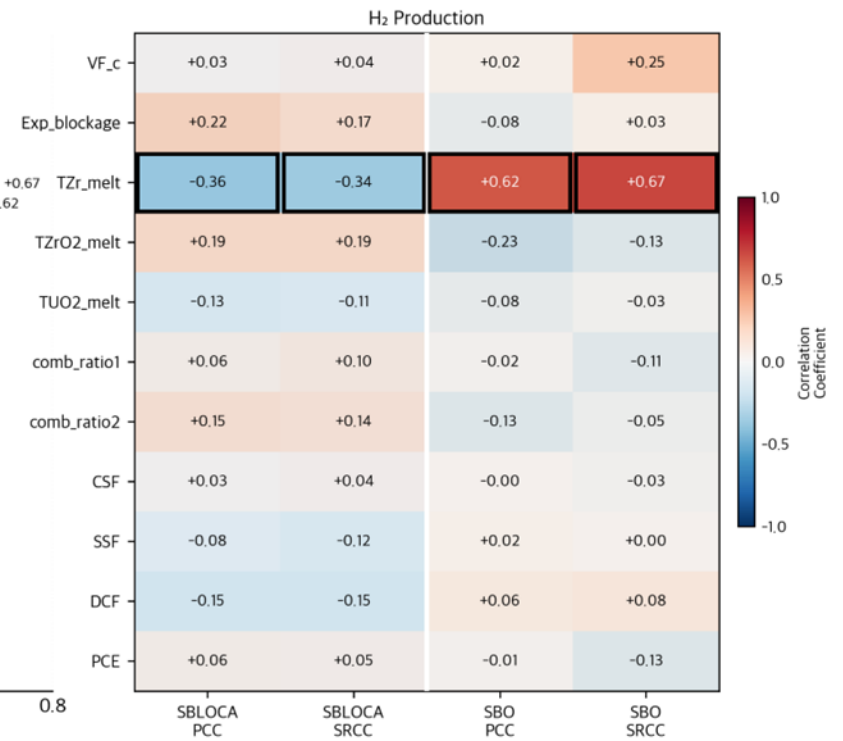
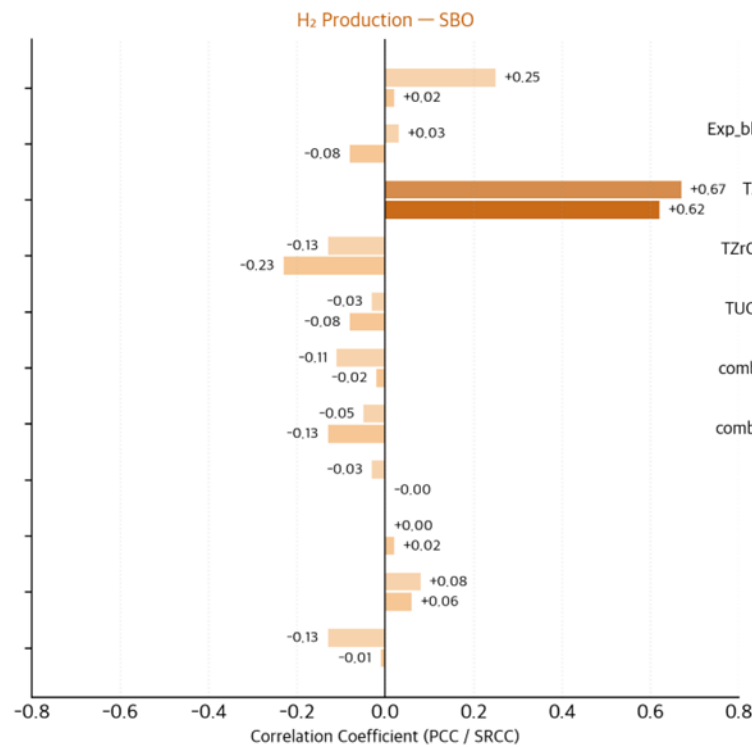
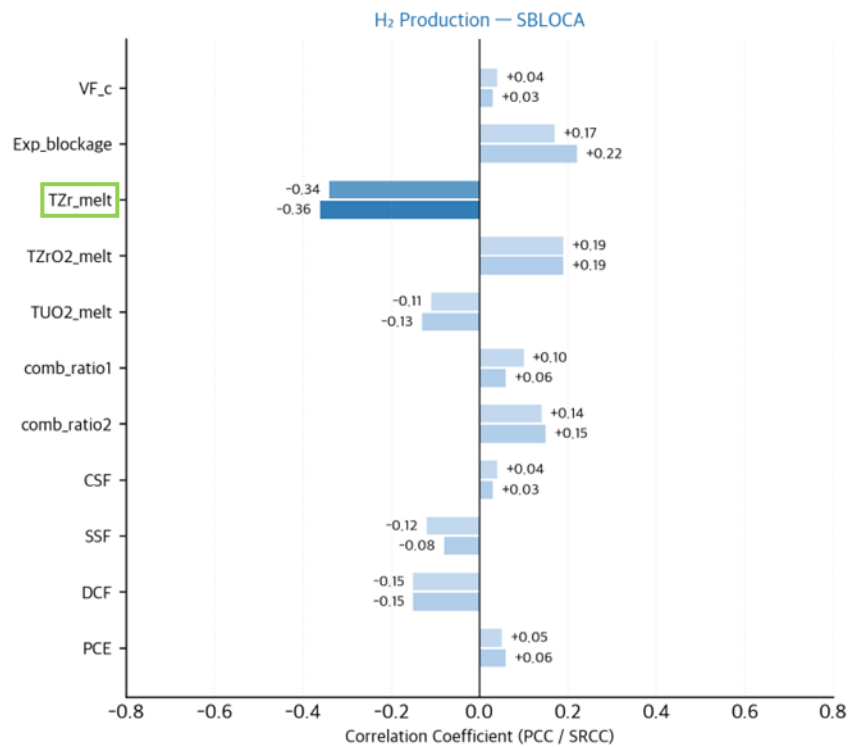


Result and Discussion

Uncertainty Analysis : SBLOCA & SBO

❖ FOM 4. Hydrogen Generation

▪ PCC/SRCC correlation coefficient

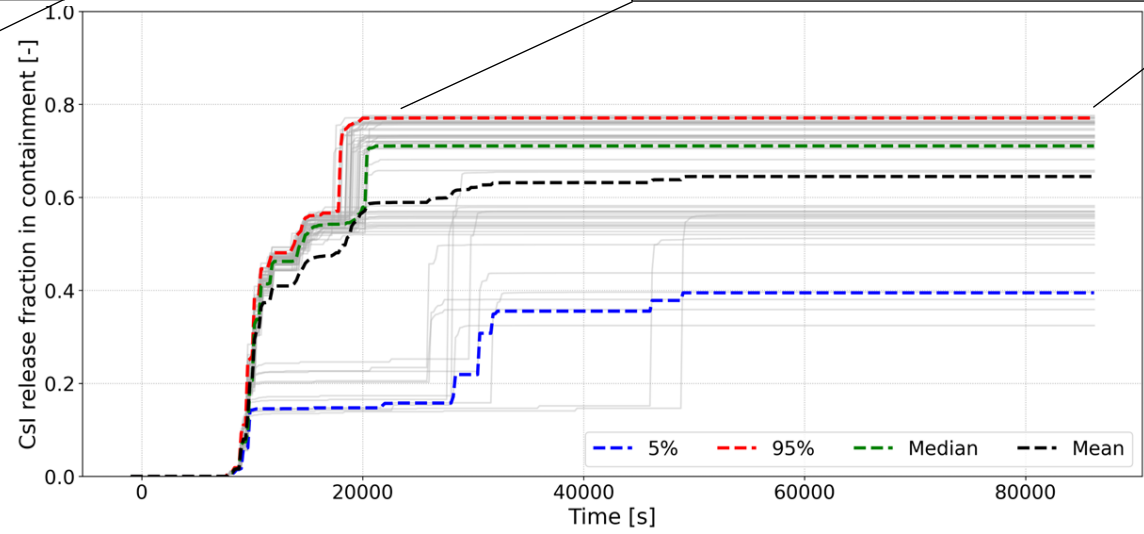
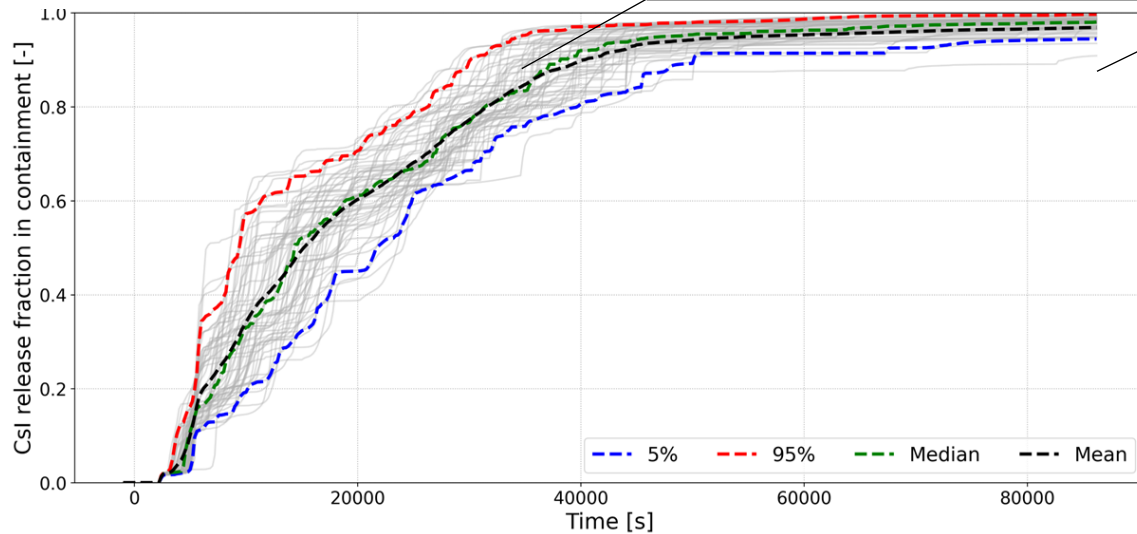
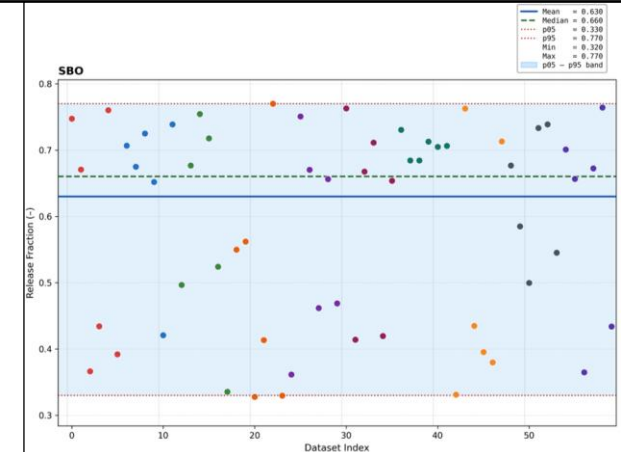
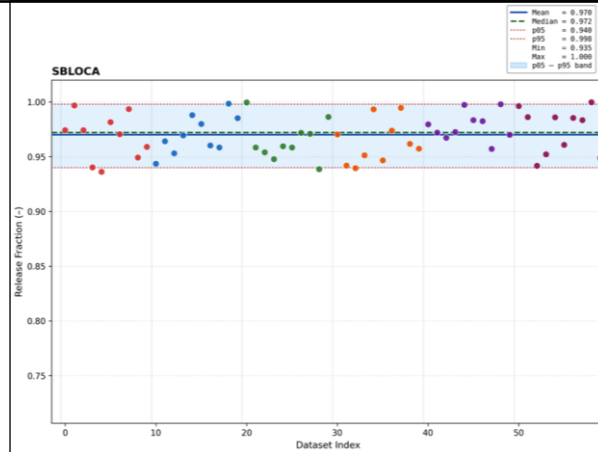


Result and Discussion

Uncertainty Analysis : SBLOCA & SBO

❖ FOM 5. CsI Release Fraction in Containment

- Horsetail plot

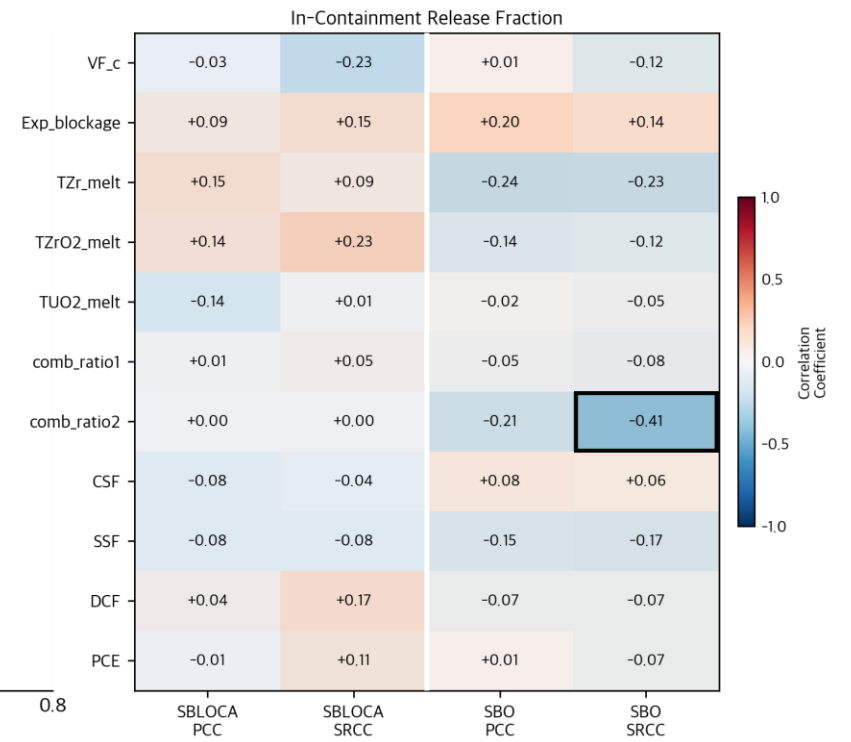
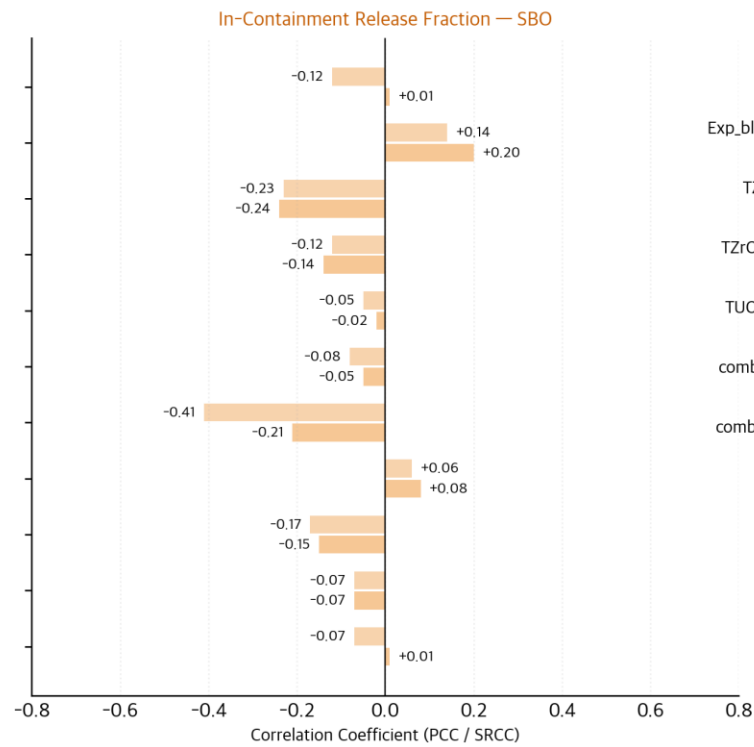
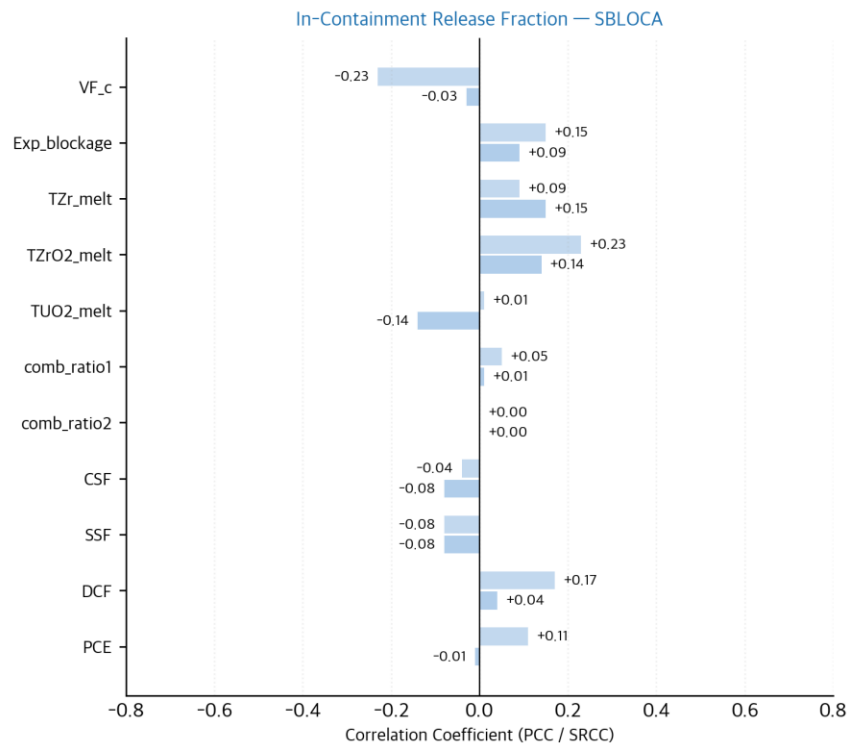


Result and Discussion

Uncertainty Analysis : SBLOCA & SBO

❖ FOM 5. CsI Release Fraction in Containment

▪ PCC/SRCC correlation coefficient

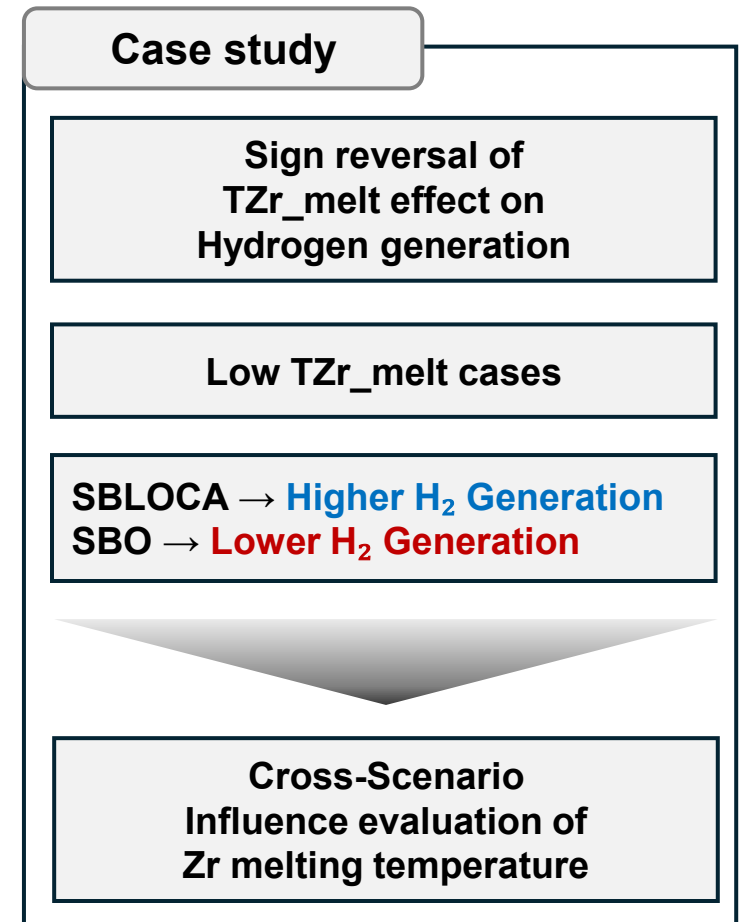


Result and Discussion

Comparative Study : SBLOCA & SBO

❖ Correlation coefficient comparison

	SBLOCA	SBO
CINEMA version	2.2.0.442	2.2.0.442
SAMG entry timing	Positive: TZrO ₂ _melt (0.20) Negative: SSF (-0.22)	Positive: TZr_melt (0.25) Negative: TUO ₂ _melt (-0.24)
LH relocation timing	Positive: Comb_ratio2 (0.26) Negative : TUO ₂ _melt (-0.16)	Positive: TZrO₂_melt (0.30) Negative : Exp_blockage (-0.41)
Reactor failure timing	Positive: CSF (0.19) Negative : DCF (-0.23)	Positive: PCE (0.30) Negative : Exp_blockage (-0.40)
H2 mass production	Positive: Exp_blockage (0.22) Negative : TZrO₂_melt (-0.36)	Positive: TZr_melt (0.67) Negative : TZrO ₂ _melt (-0.23)
Csl release fraction in containment	Positive: TZrO ₂ _melt (0.23) Negative : VF_c (-0.23)	Positive: Exp_blockage (0.20) Negative : Comb_ratio2 (-0.41)

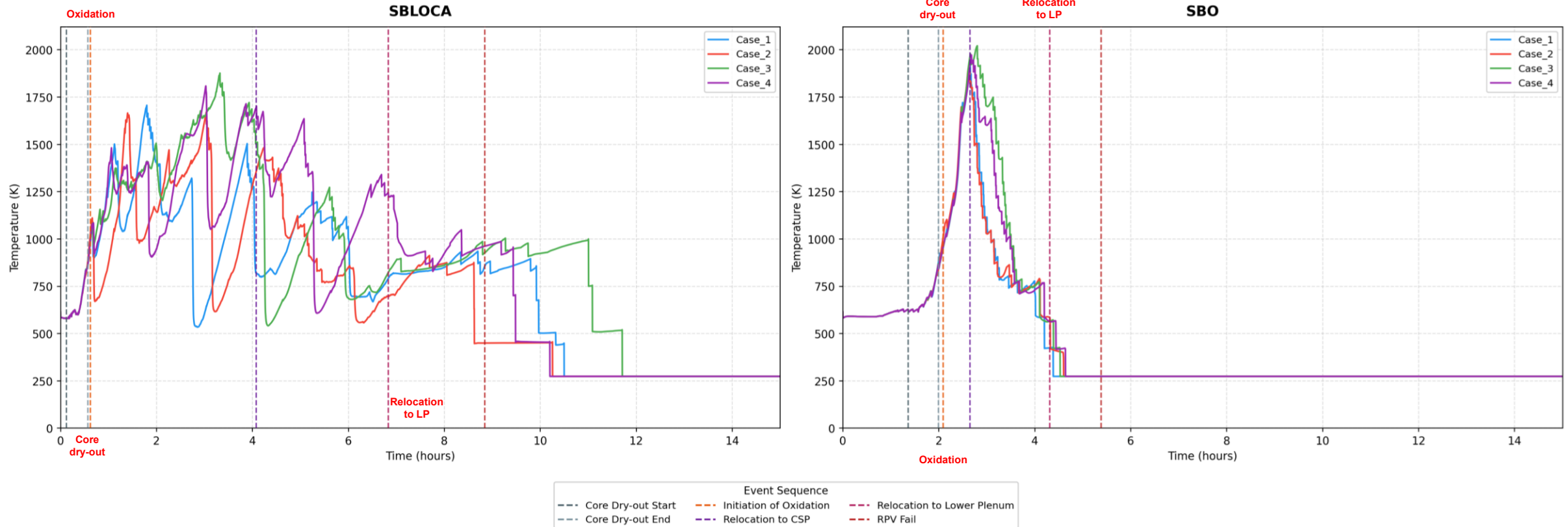


Result and Discussion

Comparative Study : SBLOCA & SBO

❖ Hydrogen generation

▪ Cladding temperature

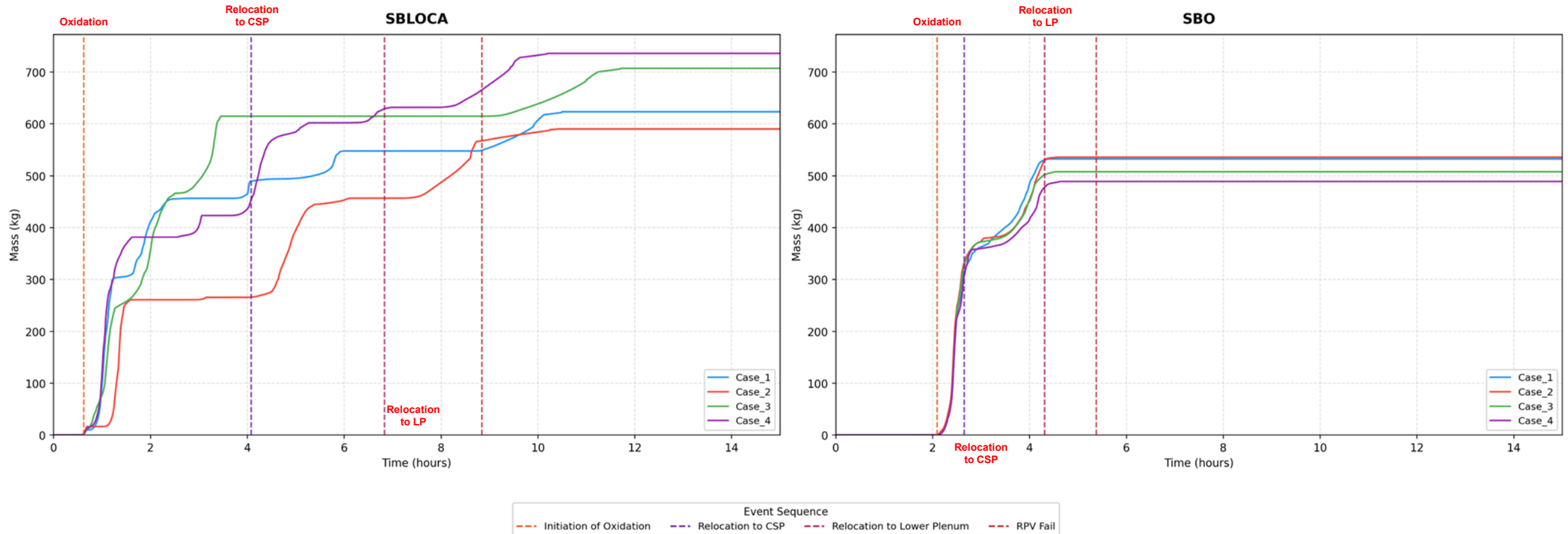


Result and Discussion

Comparative Study : SBLOCA & SBO

❖ Hydrogen generation

▪ Hydrogen generation mass

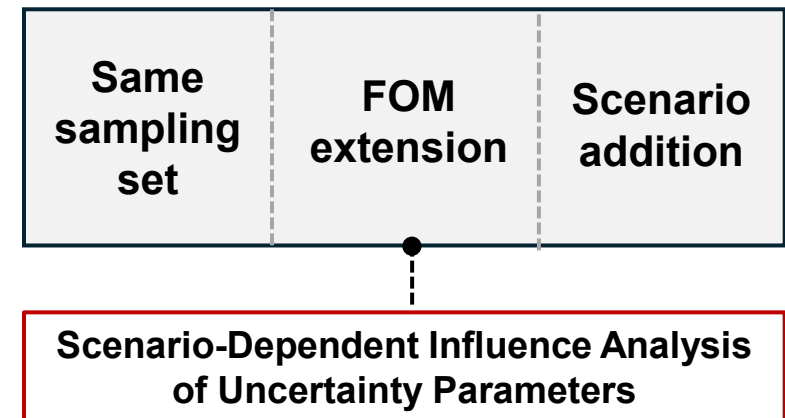


Conclusion

- Uncertainty Analysis: SBLOCA and SBO → Different TH conditions
- Key Finding: Sign reversal of **Zr melting temperature** → **Hydrogen generation** (two scenarios)
- Case Analysis: Same parameter → Opposite effects of FOM depending on scenario characteristics
- Implication: Cross **scenario comparisons** is essential in severe accident uncertainty analysis

Future work

- **Same sampling** set: Fair cross scenario comparison
- **Additional scenarios**: LBLOCA expansion
- **Fission Products related FOMs**: Broader uncertainty evaluation
- **Case expansion**: Wilks' formula 95/95 2nd order (93)



Thank you for your attention

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