

MCS Based Quantification Approach for Seismic PRA Considering Seismic Correlation and its Application to Hypothetical Nuclear Power Plant

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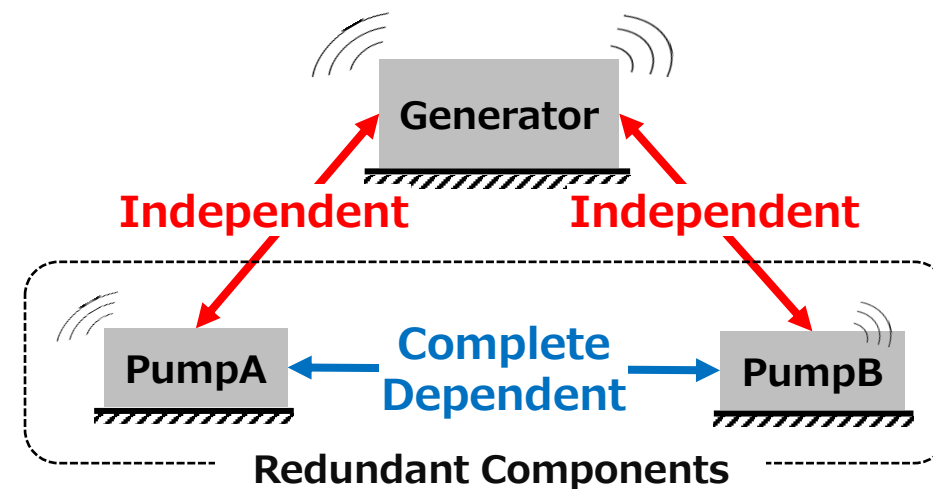
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◆ Traditional Practice_(NUREG/CR-7237)

- **Complete Dependence** among Redundant Components
- **Independent** among different components
- Confirm the impact of the assumption through sensitivity analysis

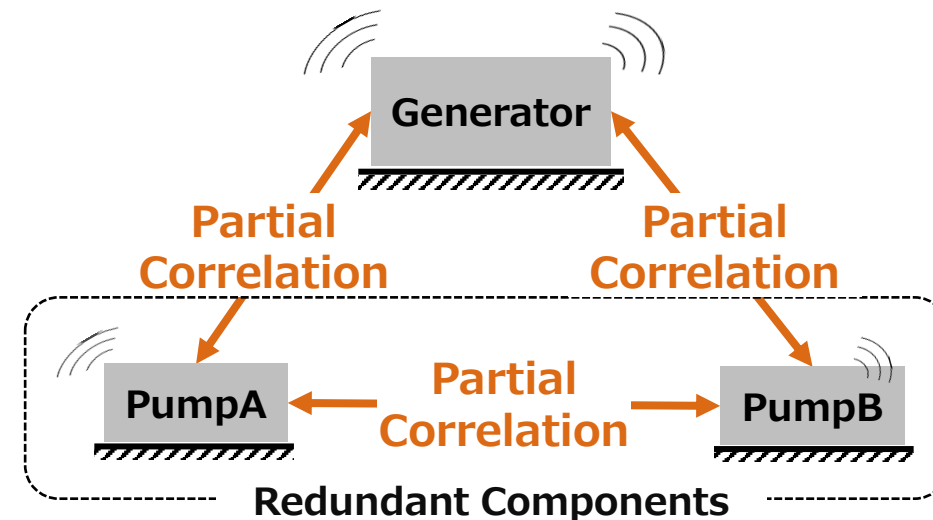


◆ Reality

- **Partial Correlation** among all components
(Seismic event has a simultaneous impact on the whole site.)
- Extensive combinations of components



One of the proposed method is DQFM Method



◆ DQFM Method(Direct Quantification of Fault-Tree using the Monte Carlo Simulation)

- proposed and developed by the Japan Atomic Energy Research Institute in the 2000s.
- the states(Success or Failure) of each SSC are determined by the Monte Carlo Simulation.
- the occurrence of system failure(e.g. Core Damage) is evaluated through **FT analysis**.

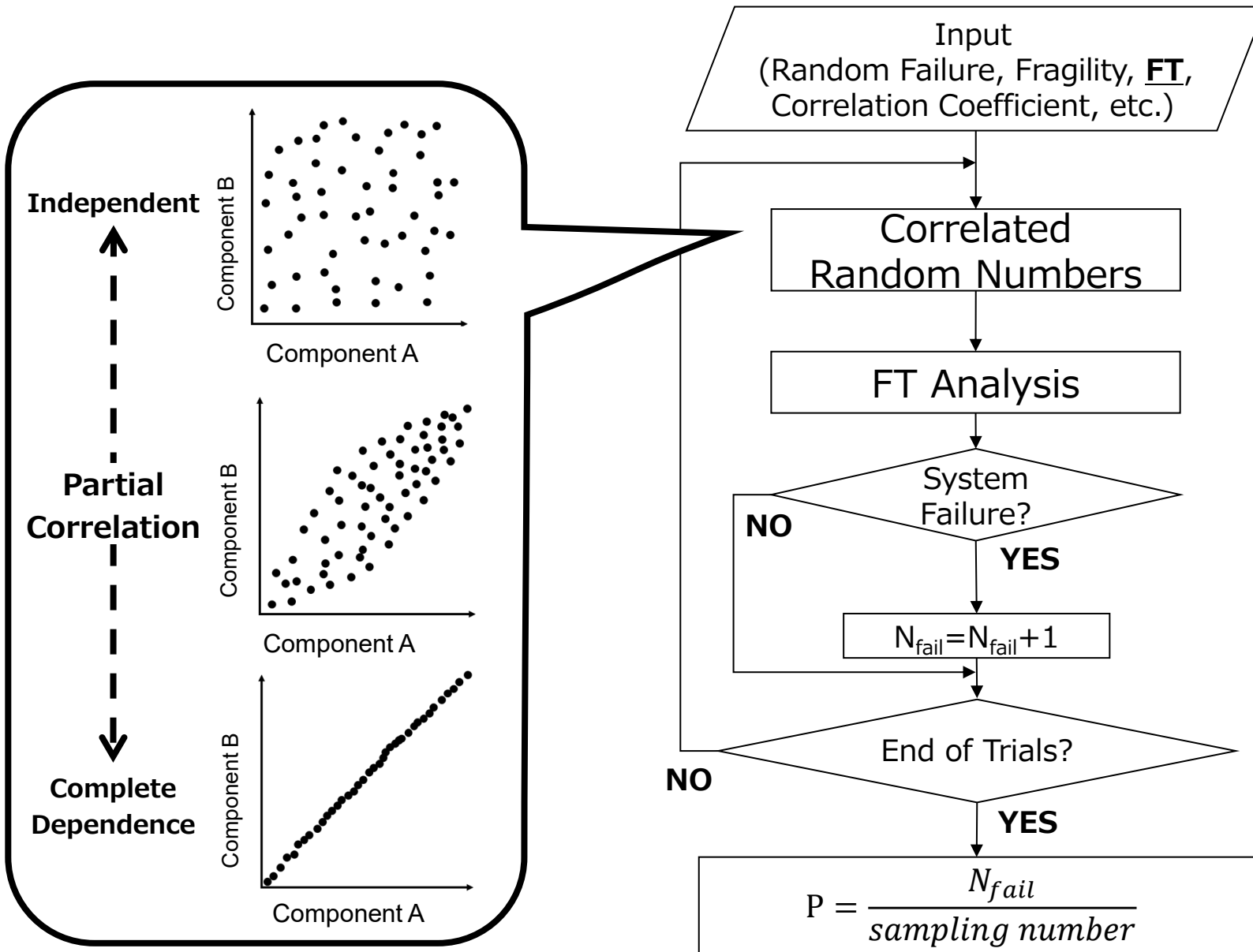
	DQFM Method	MCS Method(e.g. RiskSpectrum PSA)
Pros	Enable to conduct Seismic PRA with seismic partial correlation	Applied to Seismic PRA of the actual NPPs
Cons	Impractical to apply to actual NPPs (Necessary to input thousands of FTs)	Impractical to model all seismic correlations of SSCs



Integration of the DQFM Method with MCS Method
will enable to conduct Seismic PRA
with seismic partial correlation of the actual NPPs

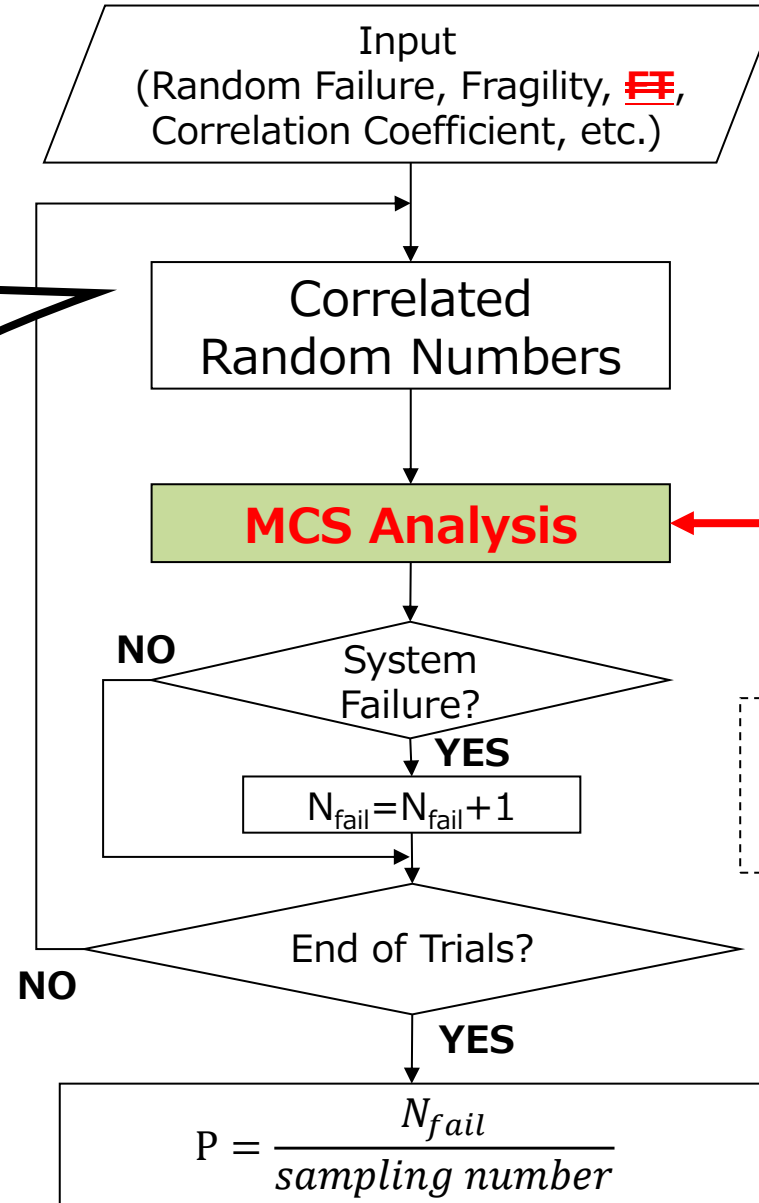
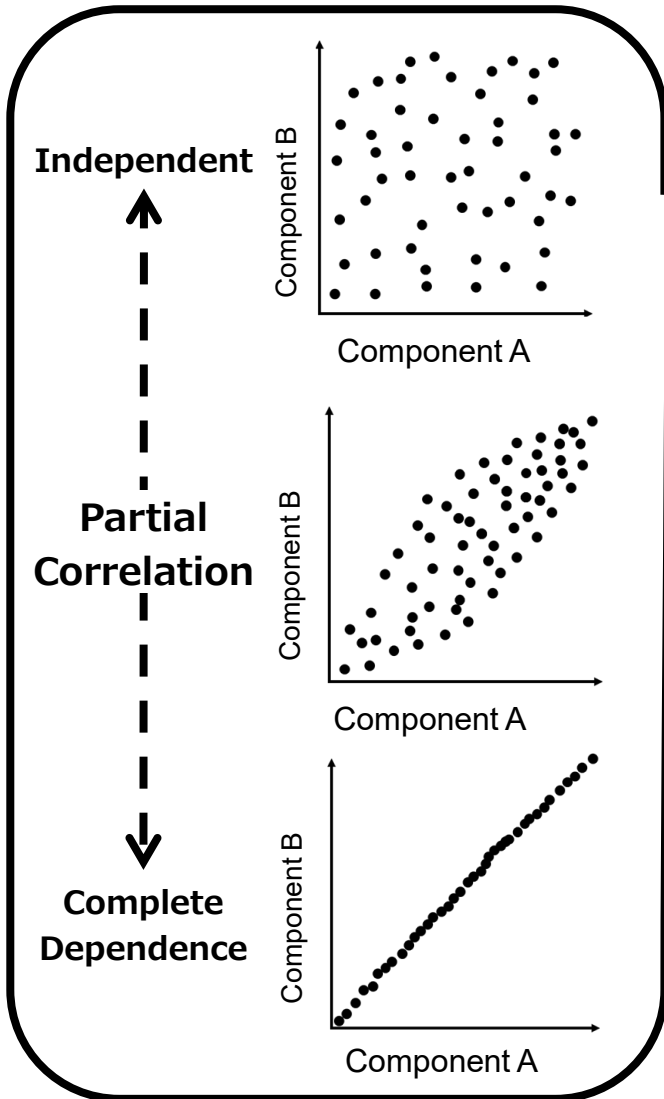
Yuichi Watanabe, Tetsukuni Oikawa, and Ken Muramatsu, "Development of the DQFM method to consider the effect of correlation of component failures in seismic PSA of nuclear power plant", Reliability Engineering and System Safety 79 (2003) 265-279

Quantification Approach : Overview of DQFM Method

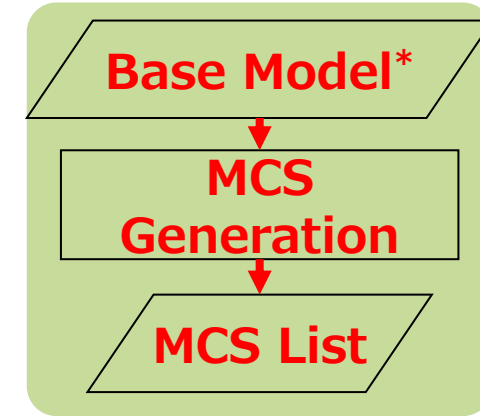


Quantification Approach : DQFM Method integrated with MCS Method

Proposed Method



External Tool
(e.g. RiskSpectrum PSA)



*To extract MCSs that capture possible combinations of seismic failures, independent model is necessary.

➤ Typical PWR plant model with approximately 500 SSCs was developed by RiskSpectrum PSA.

➤ **Results of MCS Method and the proposed method are compared in 3 Cases.**

I. Complete Independence

II. Partial Correlation among specific* components (correlation coefficient=0.5)

*Necessary to calculate the beta factor for MCS method

III. Complete Dependence among redundant components

➤ For this comparison, the beta factor is applied to model seismic correlation in the MCS Method.

$$\beta = \frac{(2Q - 1) + \sqrt{1 - 4Q + 4P}}{2Q}$$

β : beta factor

P : simultaneous failure probability of redundant SSCs
(Evaluated by Monte Carlo simulations)

Q : seismic failure probability of an SSC

➤ Sampling Number : 10^6

Demonstration : Applicability of MCSs for DQFM Method(Result)

【Lower Acceleration(0.52G) : Random Failure Scenario】

- Shows good consistency(0.4%, 0.2%)
- The difference originated from the low CCDP values and sampling uncertainty in Monte Carlo Simulation

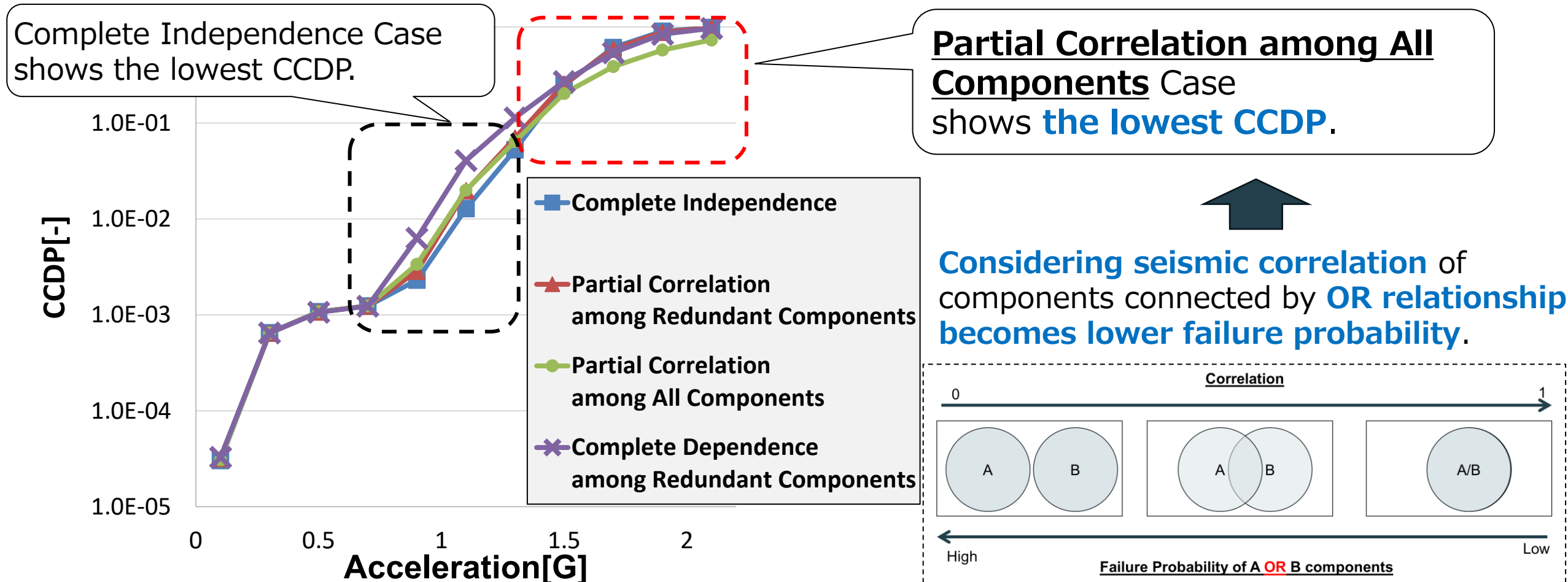
【Higher Acceleration(1.46G) : Random and Seismic Failure Scenario】

- Shows good consistency in Complete Independence(0.3%)
- The larger difference in Partial Correlation and Complete Dependence(3.8%,3.2%)
- the difference originated from the modeling limitation in the beta factor modeling

Accele ration [G]	Complete Independence			Partial Correlation			Complete Dependence		
	MCS Method	Proposed Method (MCS+DQFM)	Difference (%)	MCS Method	Proposed Method (MCS+DQFM)	Difference (%)	MCS Method	Proposed Method (MCS+DQFM)	Difference (%)
0.52	1.11E-3	1.12E-3	0.4	1.11E-3	1.12E-3	0.4	1.11E-3	1.12E-3	0.2
1.46	1.67E-1	1.67E-1	0.3	1.76E-1	1.83E-1	3.8	2.25E-1	2.18E-1	3.2

Demonstration : Impact considering Seismic Correlation

- CCDPs in 4 Cases are calculated based on the MCS+DQFM Method.
- Result Indicates the potential importance of seismic correlation considerations including not only redundant but also non-redundant components



- The concept of **the DQFM method integrated with the MCS method** has been developed.
- The DQFM method integrated with the MCS method enables...
 - ✓ To consider **seismic partial correlation of all SSCs' combinations**
 - ✓ To utilize the **MCS lists from actual NPPs' model**
- Through the demonstration, **the applicability** of the DQFM method integrated with the MCS method **is confirmed**.
- The demonstration indicates **the potential importance of seismic correlation** considerations including not only redundant but also **non-redundant components** in actual NPPs.
- Expansion of the proposed method to evaluate the risk profile is in progress.

