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# Effect of Correlations of Component Failures and Cross-connections of EDGs on Seismically Induced Core Damage of a Multi-unit Site

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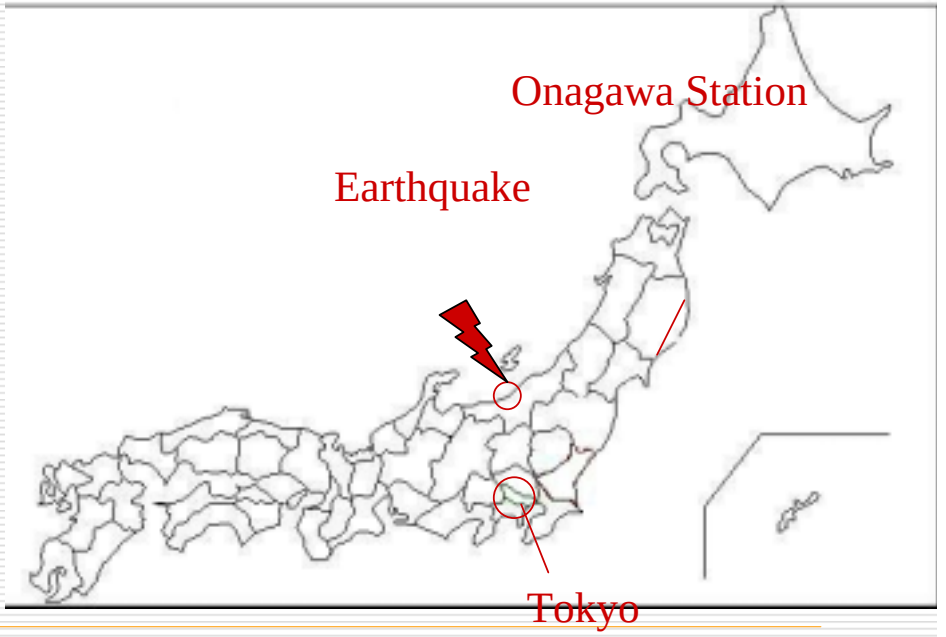
# Background

- Japan is an earthquake-prone country, seismic safety of NPPs is highly concerned.

A Recent Example:

An earthquake with a magnitude of 6.8 occurring at the off shore of Niigata Prefecture on July. 16, 2007 caused the emergency shut down of all the reactors on operation at the Kashiwazaki-kariwa station

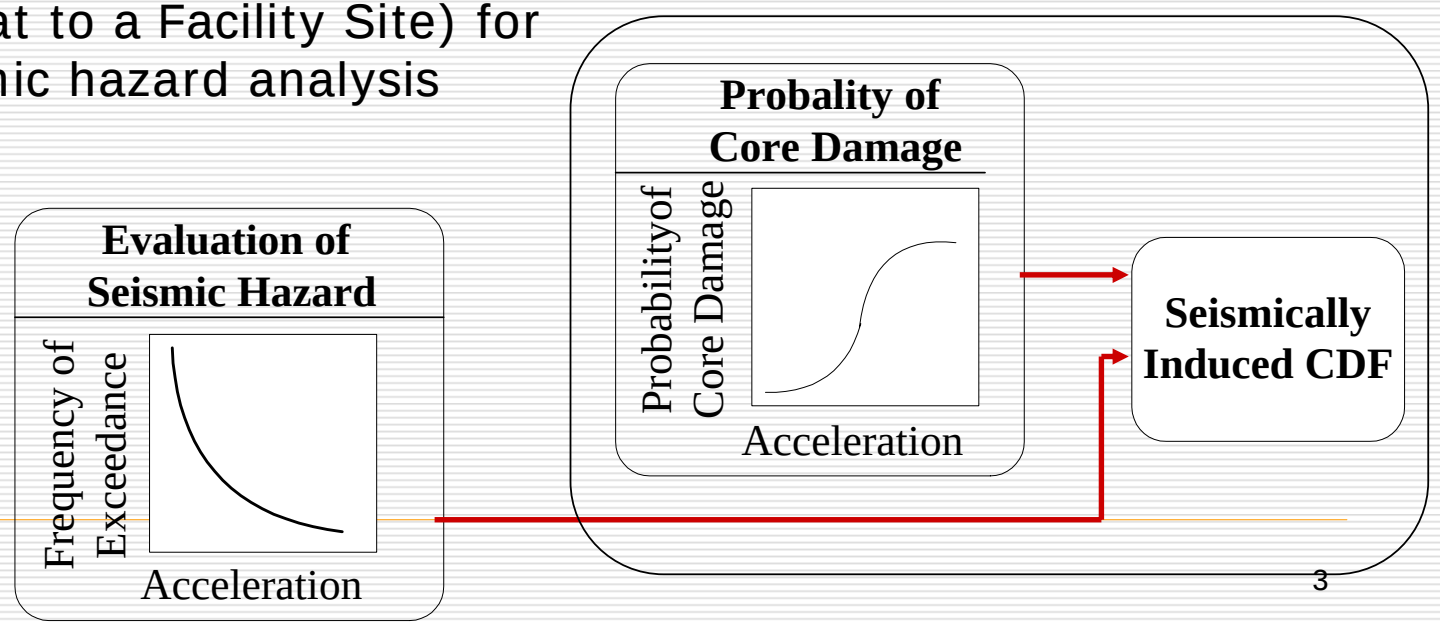


# Seismic PSA Activities in JAEA

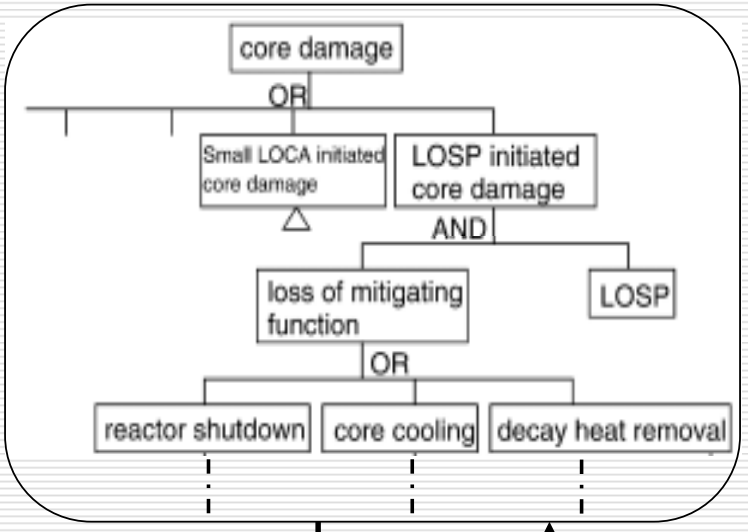
- JAEA (formerly JAERI) has been developing Level 1 Seismic PSA procedures and computer codes since 1986.

1. SHEAT(Seismic Hazard Evaluation for Assessing the Threat to a Facility Site) for seismic hazard analysis

2. SECOM (Seismic Core Melt Frequency Evaluation Code).

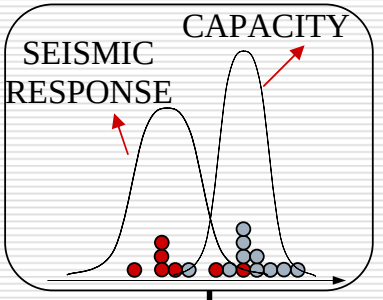


# Conditional Core Damage Probability(CDP) Calculation




Quantitative Calculation of Top Event Occurrence Frequency

With Monte Carlo Simulations




Component Failure (0? 1?)

Top Event happen(0? Or 1?)

$$CDP = \frac{N_{happen}}{N_{total}}$$

$N_{happen}$ : the occurrence times of top event

$N_{total}$ : total iteration number

# Features and Functions of SECOM2

- Feature:
  - Direct quantification of fault Tree with Monte Carlo simulations is adopted.
  - Correlation of component failures is considered
    - Correlation of Component Capacity
    - Correlation of Component Response
- Functions:
  - Conditional Core Damage Probability at any seismic intensity level
  - Core Damage Frequency
  - Accident Sequence Occurrence Probability and Frequency
  - Importance Measure (FV, RAW etc.)

# Purpose of This Study

- Aiming at promoting effective application of seismic PSA for design and risk management of nuclear facilities.
- Examining the effect of correlation of component failure on core damage (CD) of a multi-unit site.
- Examining the effectiveness of an accident management measure, i.e., the cross connection of emergency diesel generators (EDGs) between adjacent units in the site.

# Model Description

- Twin units (110MWe BWR5 with MARK II containment) located at the same site were chosen as the object under study.
- They have the same construction with the Model Plant in our previous Seismic PSA study(JAERI-Research 99-035, 1999). In addition, the site where the twin units were located was the same with that selected for the Model Plant(JAERI-Research 99-035, 1999).
- Five initiating events, i.e., RPV failure, small LOCA (Loss of Coolant Accident), medium LOCA, large LOCA and LOSP (Loss of offsite power) were studied.
- Integrated fault trees, event trees were developed based on those developed for the Model Plant.

# Correlation of Component Failure

- Correlation of Component Failure
  - Correlation of Response and Correlation of Capacities
- Correlation of Response was determined based on the rules developed in NUREG-1150 Program.
  - E.g., (1) For components at the same floor, and sensitive to the same spectral frequency range, the response coefficient is 1.0....

| | Condition of Correlation | | |
|---|---|---|---|
| | Correlation of Responses in the Same Unit | Correlation of Responses between Different Units | Correlation of Capacity |
| Case 1a | Independent | Independent | Independent |
| Case 2a | Rules of NUREG-1150 | Rules of NUREG-1150** | Independent |

** To be conservative, the correlation coefficient of component responses in the same building was applied to those of components in different buildings of the same type.

# Effect of Correlation of Component Failure on CDF

| Case No. | CDF of a Single Unit (/Reactor · Year) | CDF of This Two-Unit Site (/Reactor · Year) | Frequency of Simultaneous Core Damage of Both Units (/Reactor · Year) |
|---|---|---|---|
| Case 1a | $2.29\times10^{-5}$ | $4.07\times10^{-5}$ | $5.51\times10^{-6}$(14%) |
| Case 2a | $2.99\times10^{-5}$ | $4.76\times10^{-5}$ | $1.27\times10^{-5}$(27%) |

- CDF of a single unit, CDF of this two-unit site as well as frequency of simultaneous core damage of both units increased when correlations of component failures were considered.
- Frequency of simultaneous core damage of both units increased quickly, about 2.3 times higher than that with correlation of component failure not considered.

# Effect of Correlation of Component Failure on Core Damage Sequences

Top 10 Sequences contributing to CD at the site(case 2a)

| | UnitA | UnitB | Freq. | Ratio | Sum |
|---|---|---|---|---|---|
| 1 | **TB** | | 5.1E-6 | 10.8% | 10.8% |
| 2 | | **TB** | 5.1E-6 | 10.7% | 21.5% |
| 3 | **TW** | | 3.9E-6 | 8.1% | 29.6% |
| 4 | | **TW** | 3.8E-6 | 7.9% | 37.5% |
| 5 | **$TBU_1$** | | 2.7E-6 | 5.6% | 43.1% |
| 6 | | **$TBU_1$** | 2.5E-6 | 5.3% | 48.4% |
| 7 | **TB** | **TB** | 2.1E-6 | 4.5% | 52.8% |
| 8 | **TBU** | | 1.1E-6 | 2.3% | 55.2% |
| 9 | | **TBU** | 1.1E-6 | 2.3% | 57.4% |
| 10 | **$S_2B$** | | 8.5E-7 | 1.8% | 59.2% |

Top 10 Sequences contributing to Simultaneous CD of both units (case 2a)

| | UnitA | UnitB | Freq. | Ratio | Sum |
|---|---|---|---|---|---|
| 1 | **TB** | **TB** | 2.1E-6 | 4.5% | 4.5% |
| 2 | **TBU** | **TBU** | 8.4E-7 | 1.8% | 6.3% |
| 3 | **TB** | **TBU** | 6.0E-7 | 1.3% | 7.5% |
| 4 | **TBU** | **TB** | 5.9E-7 | 1.2% | 8.8% |
| 5 | **$S_2B$** | **TB** | 2.9E-7 | 0.6% | 9.4% |
| 6 | **TB** | **$S_2B$** | 2.9E-7 | 0.6% | 10.0% |
| 7 | **$TBU_1$** | **$TBU_1$** | 2.8E-7 | 0.6% | 10.6% |
| 8 | **TW** | **TB** | 2.8E-7 | 0.6% | 11.1% |
| 9 | **TB** | **TW** | 2.7E-7 | 0.6% | 11.7% |
| 10 | **TW** | **TW** | 2.4E-7 | 0.5% | 12.2% |

**T: Loss of offsite power**

**$S_2$: Medium Loss of coolant**

**B: Emergency power supply sys.**

**W: Residual heat removal sys.**

**U1: Reactor core isolation cooling sys.**

**U= U1+high press. core spray sys.**

# Cross Connection of EDGs between Two Units

- The EDGs of each unit was composed of two separate systems. The EDGs of one unit were connected to those of the other unit.

| | Condition of Correlation | | | Whether there is cross connection of EDGs or not? |
|---|---|---|---|---|
| | Correlation of Responses in the Same Unit | Correlation of Responses between Different Units | Correlation of Capacity | |
| Case 2a | Rules of NUREG-1150 | Rules of NUREG-1150** | Independent | No |
| Case 2b | Rules of NUREG-1150 | Rules of NUREG-1150** | Independent | Yes |

# Effect of Cross Connection of EDGs on CDF

| Case No. | CDF of a Single Unit (/Reactor · Year) | CDF of This Two-Unit Site (/Reactor · Year) | Frequency of Simultaneous Core Damage of Both Units (/Reactor · Year) |
|---|---|---|---|
| Case 2a | $2.99\times10^{-5}$ | $4.76\times10^{-5}$ | $1.27\times10^{-5}$(27%) |
| Case 2b | $1.97\times10^{-5}$ | $2.78\times10^{-5}$ | $1.13\times10^{-5}$ (41%) |

- CDF of a single unit as well as CDF of this two-unit site decreased greatly when cross-connection of EDGs between two units was available.
- Frequency of simultaneous core damage of both units decreased slightly when correlation of component failure was considered.
- CDF of this two-unit site was smaller than CDF for a single unit site.

# Effect of Cross Connection of EDGs on Core Damage Sequences

Top 10 Sequences contributing to CD at the site when cross connection of EDGs was cosidered (Case 2b).

| | UnitA | UnitB | Freq. | Ratio | SUM |
|---|---|---|---|---|---|
| 1 | TW | | 4.5E-6 | 16.3% | 16.3% |
| 2 | | TW | 4.5E-6 | 16.0% | 32.3% |
| 3 | TB | TB | 2.4E-6 | 8.6% | 40.9% |
| 4 | TBU | TBU | 8.1E-7 | 2.9% | 43.8% |
| 5 | $TU_1W$ | | 7.4E-7 | 2.7% | 46.5% |
| 6 | $S_2W$ | | 6.3E-7 | 2.3% | 48.8% |
| 7 | | $TU_1W$ | 6.2E-7 | 2.2% | 51.0% |
| 8 | TUX | | 6.0E-7 | 2.2% | 53.2% |
| 9 | TB | TBU | 5.9E-7 | 2.1% | 55.3% |
| 10 | | $S_2W$ | 5.9E-7 | 2.1% | 57.4% |

Top 10 Sequences contributing to CD when cross connection of EDGs was not considered (case 2a)

| | UnitA | UnitB | Freq. | Ratio | Sum |
|---|---|---|---|---|---|
| 1 | TB | | 5.1E-6 | 10.8% | 10.8% |
| 2 | | TB | 5.1E-6 | 10.7% | 21.5% |
| 3 | TW | | 3.9E-6 | 8.1% | 29.6% |
| 4 | | TW | 3.8E-6 | 7.9% | 37.5% |
| 5 | $TBU_1$ | | 2.7E-6 | 5.6% | 43.1% |
| 6 | | $TBU_1$ | 2.5E-6 | 5.3% | 48.4% |
| 7 | TB | TB | 2.1E-6 | 4.5% | 52.8% |
| 8 | TBU | | 1.1E-6 | 2.3% | 55.2% |
| 9 | | TBU | 1.1E-6 | 2.3% | 57.4% |
| 10 | $S_2B$ | | 8.5E-7 | 1.8% | 59.2% |

**T: Loss of offsite power**

**$S_2$: Medium Loss of coolant**

**B: Emergency power supply sys.**

**W: Residual heat removal sys.**

**U1: Reactor core isolation cooling sys.**

**U= U1+high press. core spray sys.**

# Conclusions

- Effect of the correlations of component failures on seismically induced core damage of a hypothetical two-BWR site as well as the effectiveness of an accident management measure, i.e., cross-connection of EDGs between adjacent units was examined.
- When the correlation of component failure was considered, the seismically induced CDF of a single unit, CDF of this two-unit site and the frequency of simultaneous core damages of both units increased.
- No matter correlations of component failures were considered or not, it is likely that pairs of different accident sequences in addition to pairs of the same sequence contributed to simultaneous core damage of both units.
- When the cross-connection of EDGs between the two units was available, the frequency of core damage at this two-unit site was smaller than the CDF for a single unit site.
- It seemed that corss-connection of EDGs between units would be benefical and are worthy of detailed examination for a multi-unit site.

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