Development of Risk Assessment Method for Fires Caused by Earthquake (V)

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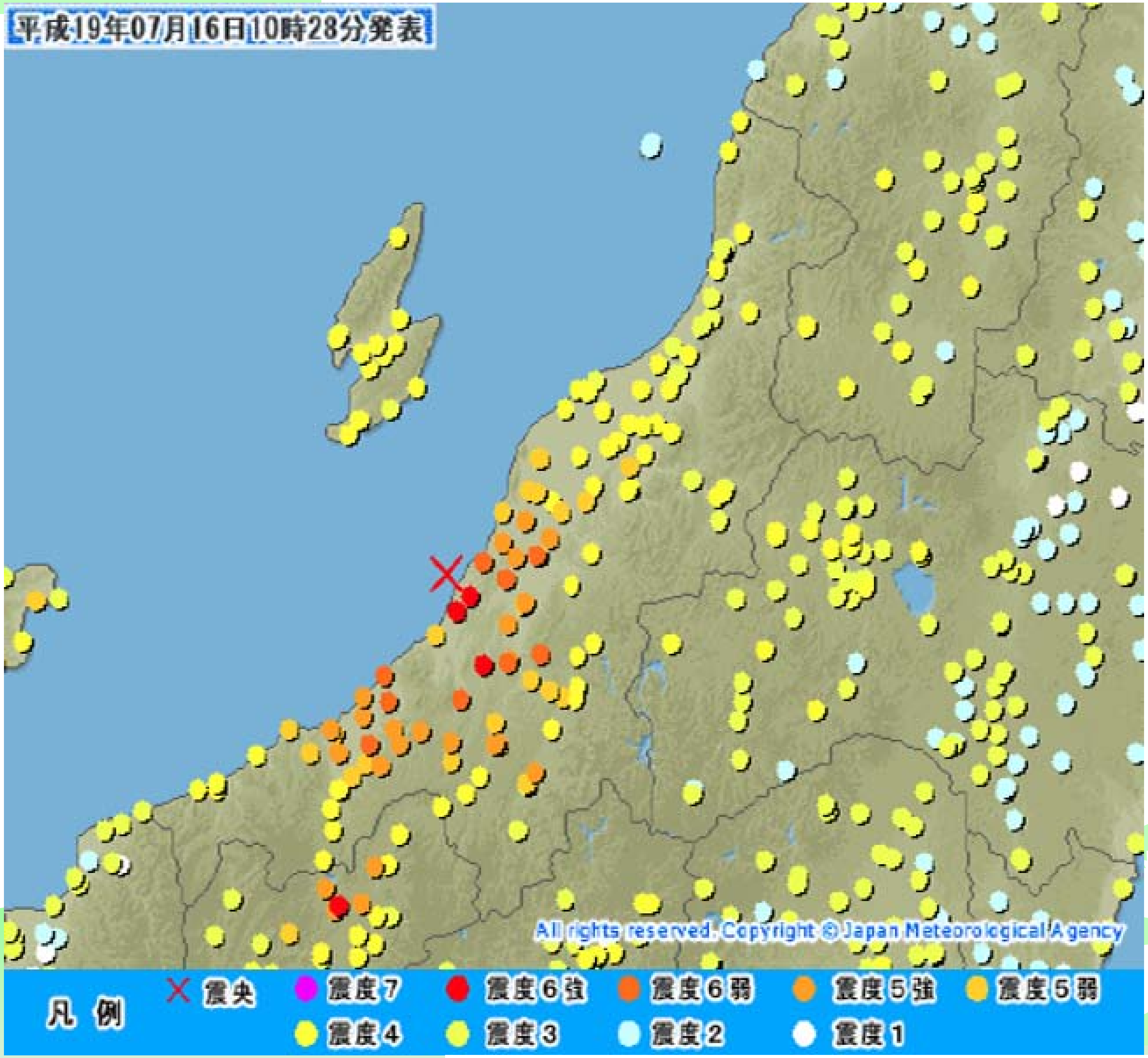
"*The Niigataken Chuetsu-oki earthquake*" has occurred on 16th July 2007.

The epicenter of earthquake was about 16 km north of the site of the Kashiwazaki-Kariwa nuclear power plant.

Eathquake-Fire PSA



from TEPCO's Web site

A fire incident has occurred in the unit 3.
It is the first case of earthquake-induced fire at nuclear power plant in the world.

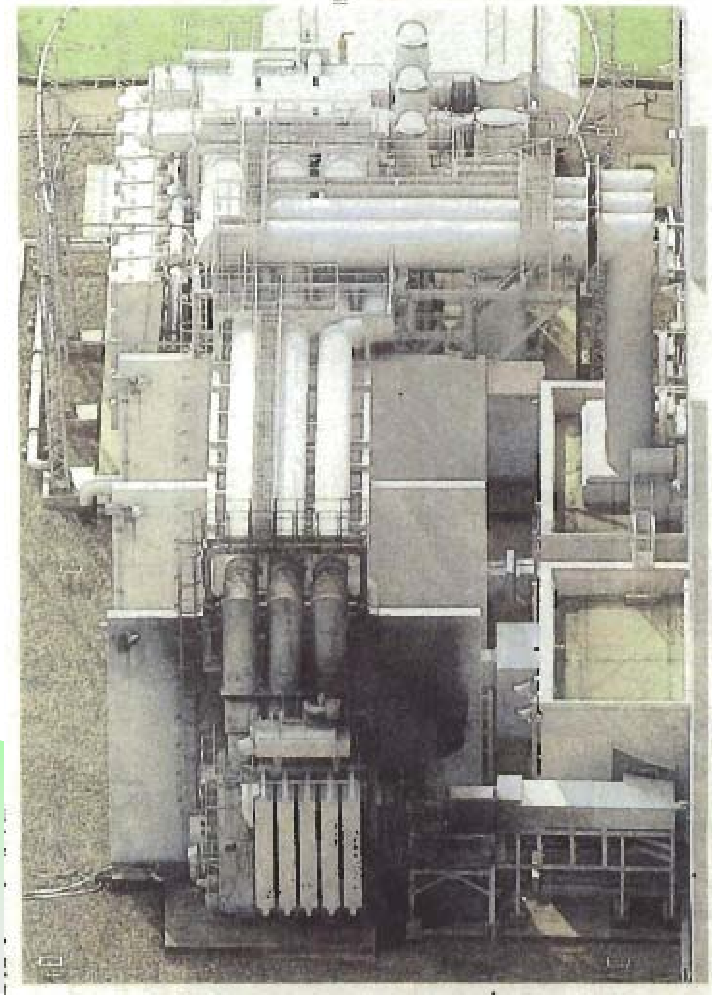


Photo by Mainichi Newspaper

We have been long pointing out the necessity to assess the risks of fires caused by earthquake in nuclear power plants.

IN THIS PRESENTATION

1. This fire incident is briefly described with some statistical data.
2. A calculation form is presented for the conditional occurrence probability of fire in case of earthquake.
3. The values of parameters used in the form are discussed.
4. The values are estimated based on the data obtained in this earthquake.
5. A formula is given for the calculation of increased risks by earthquake-induced fire.
6. The procedure of risk assessment for fires caused by Earthquake is briefly described.

Fire Incident at The Kashiwazaki-kariwa NPP

The Unit 3 in-house electrical transformer fire occurred as one of the consequences of the earthquake.

The fire was initiated by sparks from a short circuit caused by large ground displacements between the connecting structure and the transformer foundation.

The sparks caused the ignition of oil leaked from the broken porcelain, which was also caused by the earthquake.

There are five oil leakages from transformers and switching station on the site, as well as the fire in the in-house electrical transformer of Unit 3.

The only one fire ignition occurred among the five oil leakage.

Total of 40 transformers and switching stations exist on this site.

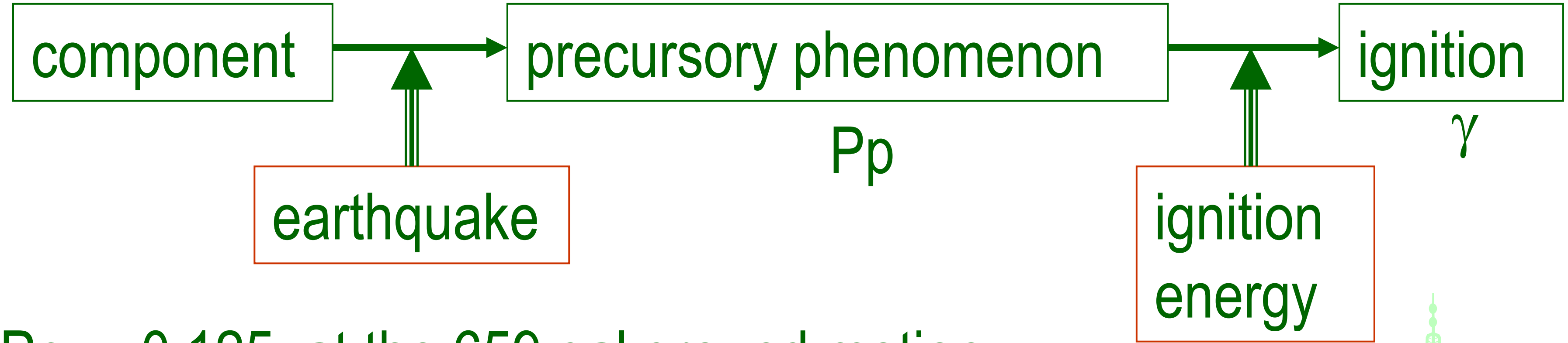
Value of Acceleration at NPP

Vertical and horizontal motions were recorded at various places on the plant site.

The representative value of acceleration at lowest floor of the reactor building was estimated at 659 gal.

Fire Occurrence Probability(P_f) due to Earthquake

Electrical Transformer



Pp = 0.125 at the 659 gal ground motion.

∵ 5 oil leakages/ 40 transformers.

γ = 0.2,

∵ One ignition was observed for 5 oil leakages.

$$P_f = P_p \times \gamma = 0.125 \times 0.2 = 0.025 \quad at \quad 659 gal$$

Fire Occurrence Probability(P_f) due to Earthquake(2)

Oil Tank

Oil leakage was observed in the lubricating oil tank room for turbine driven reactor feedwater pump.

→fire ignition did not occur.

There are 49 similar lubricating oil tanks on this site.

Pp = 0.0204(=1/49) at the room floor motion.

γ = 0.00072, ← based on the discussion in section 3.4.

$$P_f = P_p \times \gamma = \ 1.48\text{x}10^{-5} \quad at \quad ???\, gal$$

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The median value of seismic capacity of oil tank =3.4G (with β =0.26)

assumption of log-normal distribution of the capacity
assumption of precursory phenomenon of oil tank ≒ failure

The failure probability of 0.0204

→ Oil tanks might be actually suffered by 2.91G acceleration.

$$P_f = P_p \times \gamma = 1.48 \text{x} 10^{-5} \quad at \quad 2850 gal$$

Concept of Fire Capacity (A_f) of Component

$$P_f = \Pr(A_f < M_i) = \gamma_m \int_0^{M_i} f_f(A_f)\,dA_f = \gamma_m \int_0^{M_i} \frac{1}{\sqrt{2\pi\sigma_f}\,x} \exp\left(-\frac{(\ln x - \ln A_{fm})^2}{2\sigma_f^{\ 2}} \right) dx$$

A_{fm} : Median value of fire capacity

M_i : the magnitude of acceleration act on a component.

β : Logarithmic standard deviation

γ_m : Maximum ignition probability

Relations: $\beta_f = \sqrt{\exp(2\ln A_{fm} + \sigma_f^{\ 2})\{\exp(\sigma_f^{\ 2}) - 1\}}$

$$\sigma_f^{\ 2} = \ln\left\{ \frac{A_{fm} + \sqrt{A_{fm}^{\ 2} + 4\beta_f^{\ 2}}}{2A_{fm}} \right\}$$

$$\left[\gamma_m\right]$$

If very large acceleration is applied to a component, the failure probability becomes nearly 1.0.

But the ignition probability may not be 1.0.

There is some upper limit γ_m .

The equation of P_f does not contain P_p and γ .

Fire occurrence probabilities(P_f) is directly determined by fire capacity A_f .

Ignition Probability

- There was no experience of earthquake induced fire in NPPs, except Kashiwazaki-Kariwa NPP.
- Consider the relation between the ignition probability (γ) and fire occurrence frequency (f_f) in NPPs.

$$\gamma = \gamma_m \left\{ 1 - \exp(-\alpha f_f) \right\}$$

Above equation is similar to logistic curve, and it satisfies the boundary conditions (γ =0 with f_f =0) and ($\gamma = \gamma_m$ with $f_f = \infty$).

Eathquake-Fire PSA

- Engineering judgment : γ_m =0.5
- Electrical transformer : $f_f = 1.45 \times 10^{-3}$/y
- Fact : γ =0.2 (=1/5)

$$\longrightarrow \quad \gamma = 0.5\left\{1 - \exp(-353 f_f)\right\}$$

There is no fire incident for oil tank in EPRI (NUREG/CR-6850 EPRI-1011989).

1/2 time fire incident is assumed for Oil Tank, then $f_f = 4.1 \times 10^{-6}$/y .

Ignition probability (γ) of lubricating oil tank is 0.00072

Estimation of Median Value of Fire Capacity

The relation between median values of seismic capacity(A_m) and median values of fire capacity(A_{fm})

$$A_{fm} = 1.33 A_m$$

$$\beta = \sqrt{(\beta_s{}^2 + \beta_f{}^2)}$$

Eathquake-Fire PSA

Table 1: Median values of fire capacity for various components

Component	Median value of seismic capacity: A_m	Fire occurrence frequency: f_f	Ignition probability: γ	Median value of fire capacity: A_{fm}	Uncertainty: β
Transformers	0.66G	1.45×10^{-3}/y	0.2	1.02G	0.27
Lubricating oil tanks	3.4G	4.1×10^{-6}/y	0.00072	3.82G	0.26
Large oil tanks	3.4G	6.7×10^{-6}/y	0.023	4.72G	0.26
Main control board	6.5G	1.2×10^{-3}/y	0.173	8.56G	0.23
Cable duct and inside cables	7.0G	5.2×10^{-5}/y	0.0091	9.67G	0.32
Pipes connecting to a tank	3.4G	2.0×10^{-3}/y	0.25	4.44G	0.115
Hydrogen pipes	3.4G	4.2×10^{-3}/y	0.39	4.39G	0.115
Diesel generators	2.2G	4.0×10^{-3}/y	0.33	2.79G	0.12
Turbines	2.7G	6.0×10^{-3}/y	0.44	3.54G	0.045

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Core damage frequency of earthquake-induced fire

$$CDF_{EF} = \sum_{i=1}^{n2} F(E_i)\left\{\sum_{j=1}^{j_m} P({}^{IG_j}/_{E_i})\left\{\sum_{k=1}^{n4} P({}^{IE_k}/_{E_i, IG_j})\left\{\sum_{l=1}^{S_n} P({}^{S_{f,l}}/_{E_i, IG_j, IE_k})\right\}\right\}\right\}$$

Core damage frequency produced by earthquake vibration without any fire incident

$$CDF_{Ew/oF} = \sum_{i=1}^{n2} F(E_i)\left\{\left(\sum_{j=1}^{j_m} P({}^{IG_j}/_{E_i})\right)\cdot\left\{\sum_{k=1}^{n4} P({}^{IE_k}/_{E_i})\left\{\sum_{l=1}^{S_n} P({}^{S_{e,l}}/_{E_i, IE_k})\right\}\right\}\right\}$$

Eathquake-Fire PSA

Increase of core damage frequency by fires occurred at earthquake incident

$$CDF_{EF} - CDF_{Ew/oF}$$

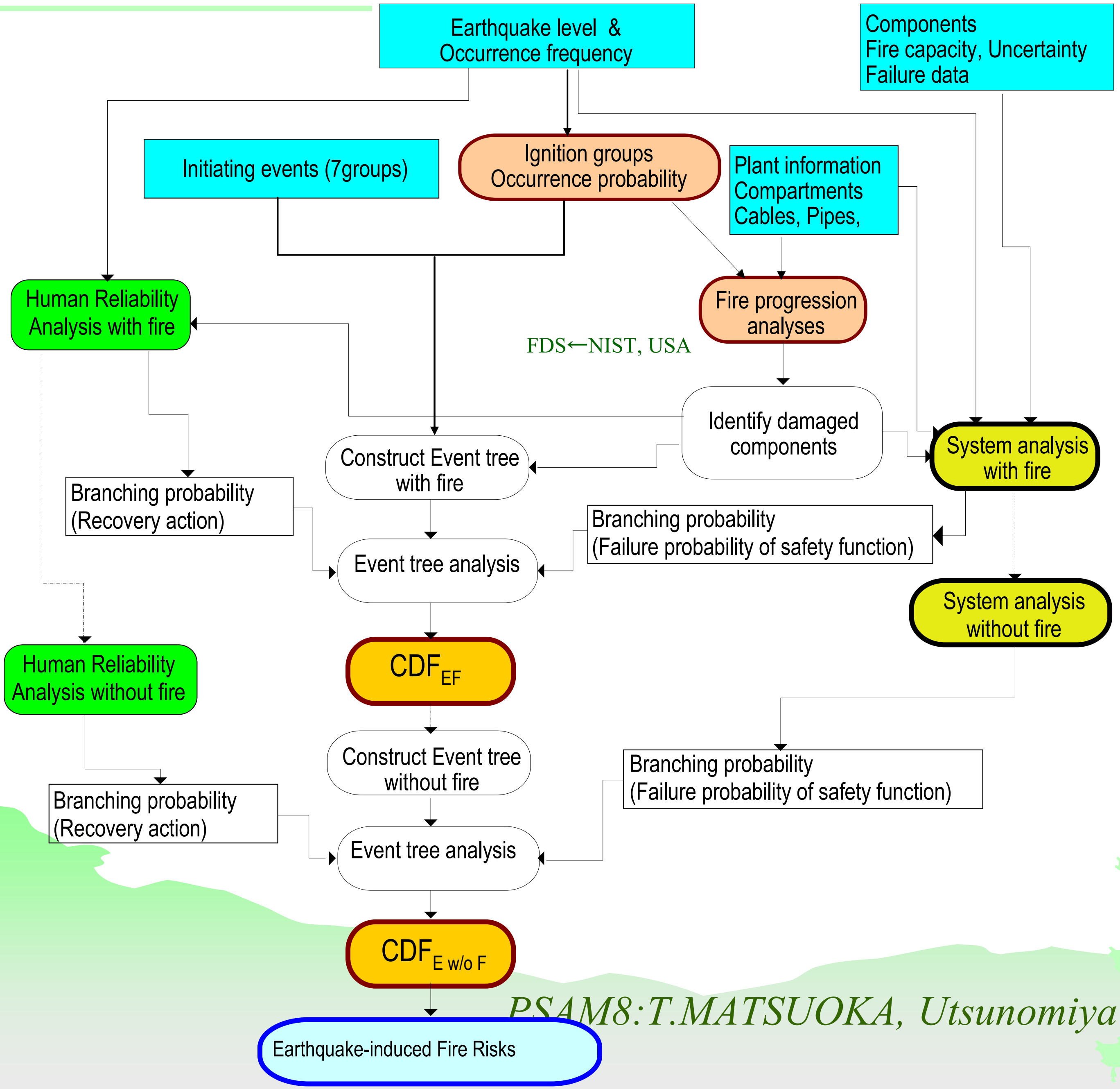
The equations suggest us the calculation procedure is more or less tedious.

We have to consider many different acceleration levels,

and for each level to identify possible ignition sources

and all the possible combinations of these sources.

A FRAMEWORK TO ASSESS EARTHQUAKE-INDUCED FIRE RISKS



CONCLUSIONS

- A concept of fire capacity is proposed and a formula is presented for the conditional occurrence probability of fire in case of earthquake.
- A fire incident on the Kashiwazaki-Kariwa NPP is used for determining parameters appeared in the formula.
- A relation between the ignition probability (γ) and fire occurrence frequency (f_f) in NPPs is also proposed, and it is used for the assessment of fire occurrence probabilities and Median values of fire capacity(A_{fm}).

CONCLUSIONS(2)

- Median values of fire capacity(A_{fm}) for important components are calculated by the proposed formula and results are listed up.
- A method to calculate increased risks by earthquake-induced fire is presented.
- Finally, the procedure of risk assessment for fires caused by Earthquake is explained with a flow chart.