EVENT SEQUENCE ASSESSMENT OF TORNADO AND STRONG WIND IN SODIUM COOLED FAST REACTOR BASED ON CONTINUOUS MARKOV CHAIN MONTE CARLO METHOD WITH PLANT DYNAMICS ANALYSIS

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A new approach has been developed to assess event sequences under external hazard considering a plant status quantitatively and stochastically so as to take various scenarios into account automatically by applying a Continuous Markov Chain Monte Carlo (CMMC) method coupled with a plant dynamics analysis. In the paper, a tornado and a strong wind are selected as the external hazard to assess the plant safety in a loop type sodium cooled fast reactor (SFR). As a result, it is demonstrated that the various scenarios where the order of the occurrence event and its occurrence time differs from each other can be assessed simultaneously as well as the statistical characteristics of plant parameter such as the coolant temperature. Furthermore, a weight factor is introduced so as to investigate the low failure probability events with a comparative small number of the sampling.

I. INTRODUCTION

On July 8, 2013, Japan Nuclear Regulation Authority (NRA) issued new regulatory requirements for commercial power reactors and countermeasures for nuclear safety against external initiators, such as earthquakes, tsunamis and volcanic eruptions, were decided to be enhanced in the requirements as lesson learned from Fukushima Dai-ichi Nuclear Power Plant Accident[1].

A probabilistic risk assessment (PRA) is quite effective for safety assessment of nuclear power plants against external initiators. In the assessment, an event tree (ET) and a fault tree (FT) models are used generally. In the ET, branches of the event (heading) are determined taking into account the progress of the scenario and their failure probabilities are evaluated by the FT analysis. As a result, the probability of plant state, such as success or failure against a sever accident, is evaluated. In one ET analysis, various scenarios but same occurrence timing (order) of heading is investigated and thus the order of heading are carefully determined by an expected scenario's occurrence with an expert judgment. However, it is noted that an influence of various scenarios on the plant status should be taken into consideration in the risk assessment so as to reduce a complete uncertainty of scenario. It is also noted that a failure probability of each heading is significantly affected by the plant status at that time. Accordingly, a dynamic PRA approach has been developed[2].

In order to investigate the plant status under various scenarios statistically, a coupling of Continuous Markov Chain Monte Carlo (CMMC) method with a plant dynamics analysis has been developed for a loop type sodium-cooled fast reactor (SFR)[3]. In this paper, a tornado and a strong wind are selected as an external hazard and the plant status during the hazard is investigated with the CMMC method. Furthermore, a weight factor is considered so as to investigate various scenarios with a comparative small number of samplings.

II. PLANT DYNAMICS ANALSYIS WITH CMMC METHOD

Figure 1 shows the schematic of the present CMMC method. When the current plant status is calculated with the plant dynamics analysis (upper left of Fig. 1), one obtains local parameters such as a temperature and a pressure in each component or function as well as a current condition of the hazard. A state transition probability of the component or the function can be evaluated based on the local parameters (lower left of Fig. 1). A random number is generated to judge the state transition of the component and the change of the state is modeled in the plant dynamics analysis (right side of Fig. 1). Then the subsequent plant state is re-calculated based on the latest condition.

After one computation is finished, one unique scenario is investigated where occurrences of events and their timings are determined by Monte Carlo sampling. Finally, one will obtain the statistical information by getting a number of computations.

Since a variety of the scenario and the plant status in the corresponding ET method is a key issue in the present CMMC method, events (change of the state transition probability of the component or the functions in the analysis) are selected based on headings in the ET method.

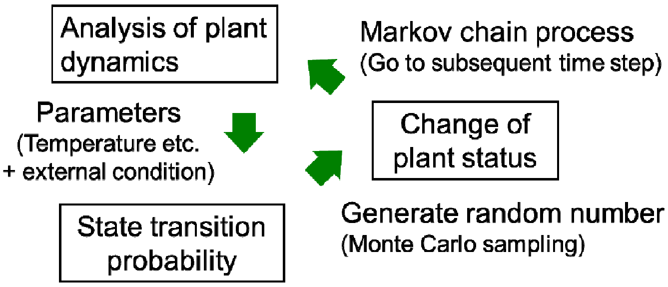


Fig. 1. Schematic of CMMC method

III. DECAY HEAT REMOVAL IN LOOP TYPE SODIUM COOLED FAST REACTOR

A schematic of heat transport system in the present loop type SFR is pictured in Fig. 2. There are three heat transport lines of, primary, secondary and water-steam lines (the water-steam line is not shown in Fig.2).

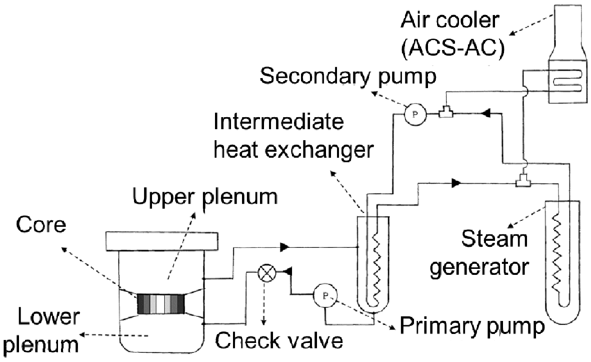


Fig. 2. Heat transport lines in present loop type SFR

In a rated full-power operation, heat output generated in the core region transports to the secondary line via an intermediate heat exchanger (IHX) and then moves to the water-steam line through the steam generator. When a shutdown is operated, the secondary cooling line will be switched from the steam generator line to an auxiliary cooling system (ACS) line. Then a forced convection heat transfer at the IHX and ACS-AC is initiated. Since liquid sodium has a high boiling point (approximately 880ºC at atmospheric condition) and its density will vary widely in accordance with the temperature increase, a natural circulation decay heat removal can be easily achieved when an ultimate heat sink system is located significantly higher than the core region even in case of a station black out (SBO). In the present study three independent transport systems (the primary and the secondary lines and the ACS-AC) are taken into account. When the ACS-AC is implemented in the secondary cooling line, it is called “intermediate reactor auxiliary cooling system (IRACS)”.

It is mentioned that the present plant also has an alternative decay heat removal system of a maintenance cooling system (MCS) in the upper plenum for a countermeasure against a severe accident. However, the MCS is not considered in the following event sequence assessments for a conservative investigation as well as a simplicity.

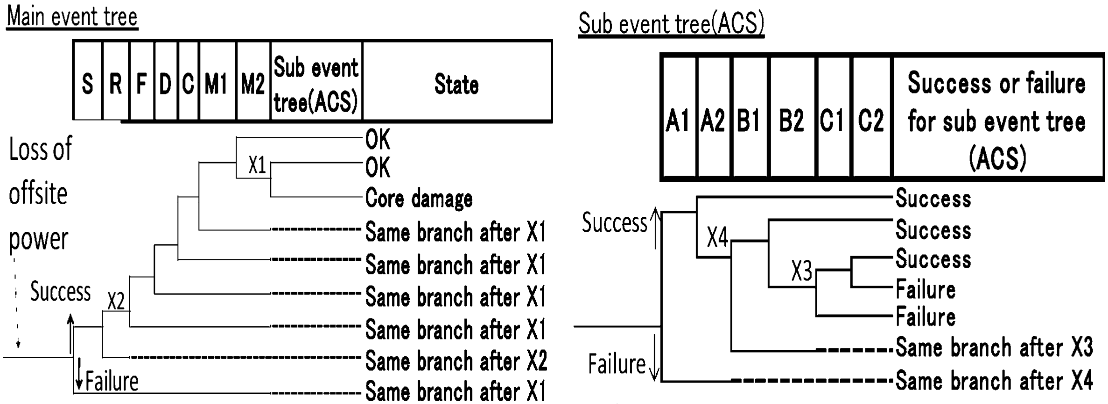
IV. EVENT SEQUENCE ASSESSMENT OF TORNADO AND STRONG WIND

IV.A. Event Selection and Failure probability

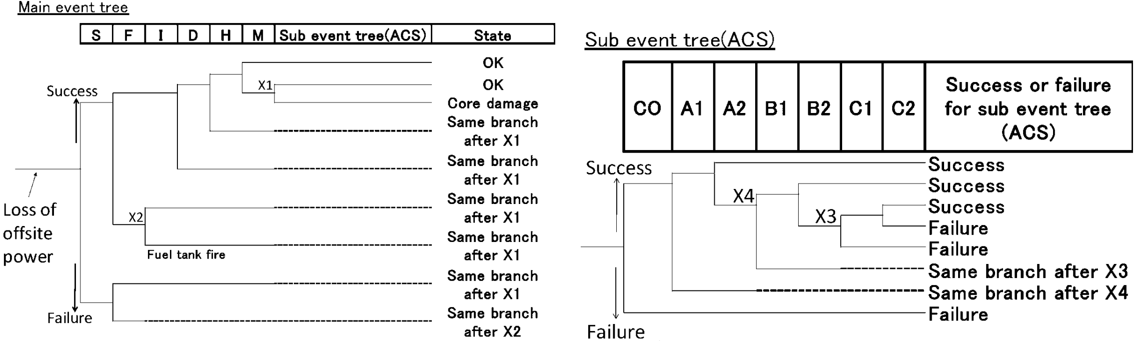
In the event sequence assessment, a plant dynamics analysis with the CMMC method is applied and the events considered in the plant dynamics analysis are selected based on the existing ET analyses[4,5,6]. TABLE I and Fig. 3 summarize the headings in the trees.

TABLE I. Headings in event trees[4,5,6]

Code	Heading	Note
S	Air stack	Collapse of air stack due to wind load
R	Structures on roof of reactor building	Structures on roof of reactor building are broken by the wind load. When the structures are broken, missiles are generated by the broken structures (only for tornado)
F	Fuel tank of diesel generators	Failure of fuel tank of diesel generator by missiles
I	Fuel tank fire	Fire of fuel after tank failure (only for strong wind)
D	Diesel generator	Failure of diesel generator by missiles
H	HVAC	Failure of air ventilator intel of heating, ventilation, air conditioning (HVAC)
M, M1, M2	MCS	Failure of maintenance cooling system by missiles
A1, B1,C1	ACS (inlet)	Failure of ACS inlet by missiles
A2, B2, C2	ACS (outlet)	Failure of ACS outlet by missiles
CO	Common failure of ACSs	Common cause failure of ACSs due to fuel tank fire (only for strong wind)



(a) Tornado[4]



(b) Strong wind[5,6]

Fig. 3. Event trees (tornado and strong wind)[4,5,6]

Since missiles generated by strong wind are dominant cause of the functional failure, the similar event trees are considered in the ET analyses as seen in Fig.3. In the tornado hazard, a strong (high speed) missile will be generated due to vortex and upward flow comparing with that in the strong wind hazard. Hence the heading of "structures on roof of reactor building" (R in Fig. 3) is added in the ET of the tornado.

On the contrary, a period of hazard duration in tornado is quite short (at longest several tens of minute) rather than that in the strong wind hazard. Therefore, firefighting of the fuel tank could be initiated quickly in case of the tornado hazard and thus the heading of the fuel tank fire is taken into account only in the strong wind hazard.

The headings in Fig. 3 can be categorized into three functional failures as; failure of emergency power supply (S, R, F, D and H in Table 1), failure of ACS (A1 to C1, A2 to C2 and CO) and failure of MCS (M). When the emergency power supply fails under the loss of offsite power condition, the forced convective decay heat removal will also fail and the natural convective decay heat removal is initiated. Therefore, losses of pump torques (pump trip) both in the primary and secondary lines are modeled in the analysis. The shift to the natural convective decay heat removal is calculated automatically in the plant dynamics analysis.

As concerns the failure state probability of the pump trip (Pf_{pump}), the same models with the ET analyses are applied where the probaility was evaluated based on the similar approach with NUREG/CR-4458[7]. In case of the tornado hazard, Pf_{pump} is set to 0.126 under the Fujita tornado damage scale F5, in which wind speed exceeds 418km/hr (116m/s)[8]. Pf_{pump} in the strong wind hazard is set to 0.0966 under the Saffir-Simpson Hurricane Wind Scale category 5 (SSHS5) where wind speed exceeds 252km/s (70m/s)[9].

With regard to the ACS failure, a failure of heat transfer function in the air cooler of ACS (ACS-AC) is modeled. The failure state probability (Pf_{ACS}) is set to 0.108 in case of the tornado hazard as well as 0.0019 in case of the strong wind hazard. Since ACS inlet and outlet are located at comparatively high elevation considering the natural circulation decay heat removal, Pf_{ACS} in the strong wind hazard is smaller than that in the tornado hazard approximately by two orders of magnitude.

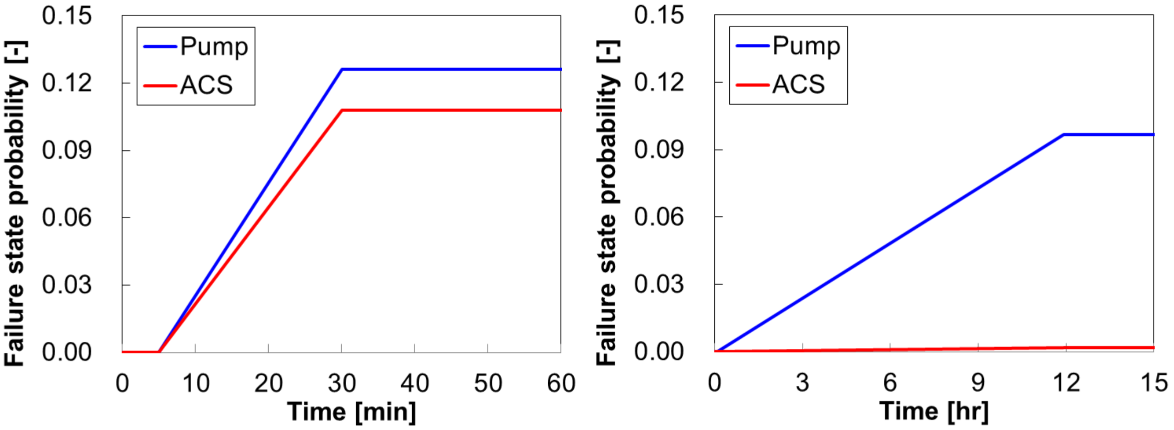
In the ET analysis of the strong wind, the fuel tank fire (I in TABLE I) is taken into account as an initiator of the common cause failure of ACSs as a conservative evaluation. In the present analysis, an increase of inlet temperature at ACSs due to the fire is computationally modeled. Consequently, the fuel tank fire is separately considered and the temperature increase of 100ºC at all ACS-ACs' inlet is modeled in the analysis. The conditional probability of the fire occurrence after the tank failure is set to 0.5 that is same with the ET analysis.

In the present plant dynamics analyses, the MCS is not modeled as mentioned above. Accordingly, the MCS failure in the ET analyses is not taken into account.

IV.B. Analytical Conditions

Both in the analyses of the tornado and the strong wind hazards, a rated full-power plant operation is considered at the beginning. After 5min from the computation, the loss of offsite power and the emergency core shutdown is operated due to the hazard. The period of durations are set to 30min in the tornado hazard and 12hr in the strong wind. A constant failure rate is assumed during the hazard period as shown in Fig. 4. The period of simulation is set to 24hr in each computation.

In each assessment, 1000 samples are calculated. With regard to the random number generation, Mersenne Twister method is applied[10]. The maximum core outlet temperature after 30min from the initiating event is chosen as a target of statistical investigation for a long term cooling performance. As concerns the plant dynamics analysis, Super-COPD code[11] is applied.



(a) Tornado (b) Strong wind

Fig. 4. Failure state probability of pump and ACSs

IV.C. Results and Discussion

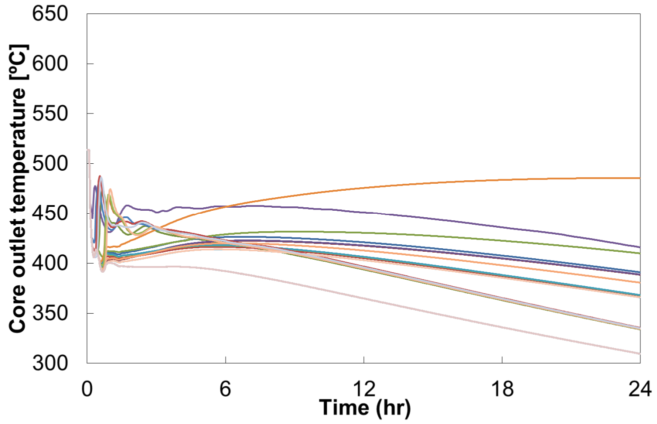
IV.C.1. Tornado hazard

Analytical result of the tornado hazard and the categorization of scenario based on the last status of each computation are summarized in Fig. 5 and TABLE II respectively.

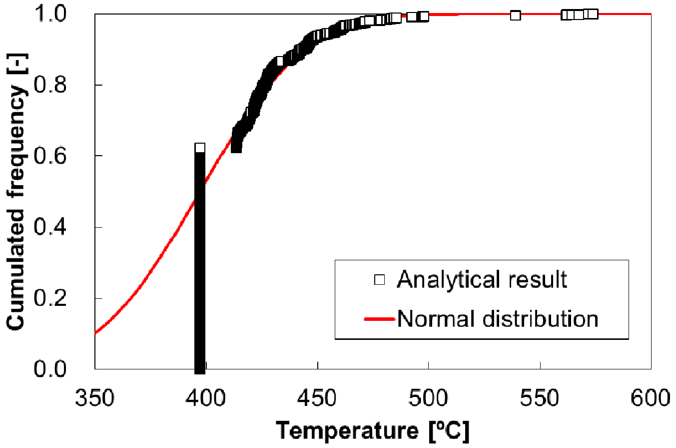
TABLE II. Categorization of scenario (Tornado)

No.	Pump trip	ACS-AC			Counts [-]	Fraction [-]	Av. Temp. [°C]	Category	
		A	B	C					
1	0	0	0	0	623	0.623	397.1	Normal operation	
2	0	0	0	1	84	0.084	416.3	No pump trip	One ACS-AC failure
3	0	0	1	0	77	0.077	425.7		
4	0	1	0	0	82	0.082	424.2		
5	0	0	1	1	4	0.004	496.1		Two ACS-ACs failure
6	0	1	0	1	8	0.008	471.2		
7	0	1	1	0	7	0.007	483.4		
8	0	1	1	1	2	0.002	572.8		All ACA-ACs failure
9	1	0	0	0	78	0.078	444.9	Pump trip	No ACS-AC failure
10	1	0	0	1	11	0.011	459.5		One ACS-AC failure
11	1	0	1	0	2	0.002	475.5		
12	1	1	0	0	17	0.017	458.7		
13	1	0	1	1	2	0.002	565.8		Two ACS-ACs failure
14	1	1	0	1					
15	1	1	1	0	3	0.003	554.3		
16	1	1	1	1					All ACA-ACs failure

0: success, 1: failure



(a) Transient of core outlet temperature (100samples)



(b) Cumulated frequency of maximum core outlet temperature
Fig. 5. Analytical result of tornado hazard

In the computation, the core outlet temperature starts to decrease after the core shutdown operation. Then it turns to increase when the pump trip or the ACS-AC failure take place. Therefore, the maximum value after 30min from the beginning (start of the loss of offsite power) is investigate in the statistical process. It is also mentioned that no scenario appears at the gray colored category in TABLE II during the analysis.

As shown in TABLE II, no functional failure occurs in approximately 60% of scenarios. Therefore, the cumulated frequency in Fig. 5(b) would be divided into the uniform line of the normal operation at 397ºC and the normal approximation distribution with some functional failure. The red line in Fig. 5(b) is the normal approximation with 75% and 95% of one-sided confidence intervals. When the design limitation of the coolant temperature is assumed to 650ºC[12], the conditional core damage probability (CCDP) will be obtained approximately 4.3×10^{-12} using the normal approximation in the analysis. It can be concluded that the present SFR plant will be highly resistant to the tornado hazard at least 24hr after the hazard happens. It is also noted that one ACS has a sufficient capacity of the decay heat in the present plant design. Accordingly, no core damage will be occurred except in case of all ACS-ACs failure. In the present assessment, all ACS-ACs failure scenario, which is categorized into a protected loss of heat sink (PLOHS) event in SFR and is treated as a core damage scenario in the ET analysis, is investigated in two samples (scenario No. 8 in TABLE II). However, the average maximum temperature is approximately 570ºC. Consequently, it can also be said that one has a comparative enough time margin for an accident management against the tornado hazard.

IV.C.2. Strong wind hazard

TABLE III summarizes the analytical result in terms of the final status category. Since the failure state probability of ACS-AC is small in case of the strong wind hazard (Pf_{ACS} =0.0019), a limited scenario will appears in 1000 sampling. It is apparent that the low probability event is a key challenge in the Monte Carlo sampling.

TABLE III. Categorization of scenario (Strong wind)

No.	Pump trip	ACS-AC			Fire	Counts [-]	Fraction [-]	Av. Temp. [ºC]	Category		
		A	B	C							
1	0	0	0	0	0	905	0.905	397.1	Normal operation		
2	0	0	0	1	0				No pump trip	No fire	One ACS-AC failure
3	0	0	1	0	0	4	0.004	397.1			
4	0	1	0	0	0	1	0.001	407.6			
5	0	0	1	1	0						Two ACS-ACs failure
6	0	1	0	1	0						
7	0	1	1	0	0						
8	0	1	1	1	0						All ACA-ACs failure
9	1	0	0	0	0	47	0.047	444.5	Pump trip	No fire	No ACS-AC failure
10	1	0	0	1	0						One ACS-AC failure
11	1	0	1	0	0						
12	1	1	0	0	0						
13	1	0	1	1	0						Two ACS-ACs failure
14	1	1	0	1	0						
15	1	1	1	0	0						
16	1	1	1	1	0						All ACA-ACs failure
17	1	0	0	0	1	43	0.043	536.8		Tank fire	No ACS-AC failure
18	1	0	0	1	1						One ACS-AC failure
19	1	0	1	0	1						
20	1	1	0	0	1						
21	1	0	1	1	1						Two ACS-ACs failure
22	1	1	0	1	1						
23	1	1	1	0	1						
24	1	1	1	1	1						All ACA-ACs failure

In order to reduce the number in the Monte Carlo sampling, a failure state probability should be modified to be higher value. In the case, the weighting factor will be needed to investigate the original occurrence probability of the scenario. In general, the probability of i-th scenario is obtained theoretically as;

$$P_i = \prod_{j \in failure} Pf_{i,j} \times \prod_{j \in sucess} (1 - Pf_{i,j}) \qquad (1)$$

Where Pf is the failure state probability and subscripts j means the number of the events. Consequently, the weight factor can be calculated in the following when one modifies the failure state probability.

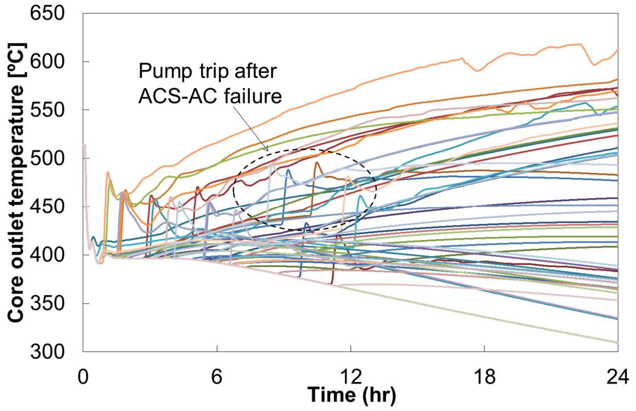
$$\omega_i = \prod_{j\in failure} \frac{Pf_{i,j}}{Pf^*_{i,j}} \times \prod_{j\in sucess} \frac{(1-Pf_{i,j})}{(1-Pf^*_{i,j})} \qquad (2)$$

Where the superscript * indicates the modified probability. As in Eq. (2), the weight factor should include both effects of failure and success events. In order to investigate the applicability of the present weight factor, a parametric study in which the failure probabilities are modified as in TABLE IV has been carried out. As shown in TABLEIV, a different multiplier (×250, ×5) is applied to achieve the probability of approximately 0.5.

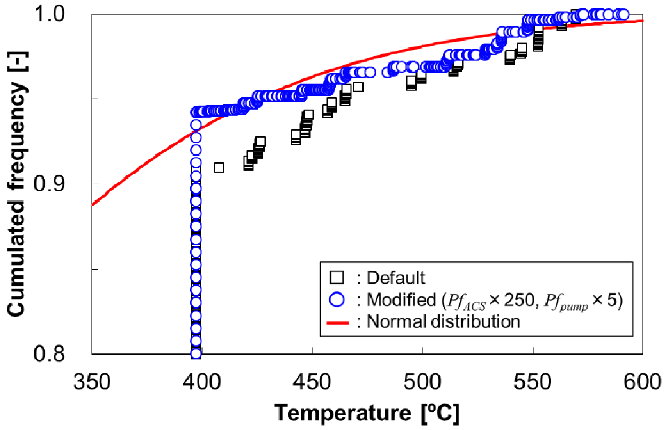
TABLE IV. Modification of state probability (strong wind hazard)

	Pf_{pump}	Pf_{ACS}	Remarks
Original	0.0966	0.0019	
Modified	0.483	0.475	Pf_{pump}×5, Pf_{ACS}×250

Figure 6(a) shows the transient of the core outlet temperature. In the ET analysis, the failure of the emergency power supply is considered firstly as in Fig. 3. However, in the present CMMC method, the pump trip after the functional failure of ACS-AC is investigated in some scenarios as seen in the dashed black circle of Fig. 6(a). It can be concluded that the present method has an advantage of investigating various scenarios automatically without any engineering judgement of occurrence order. The cumulated frequency of the maximum core outlet temperature in all cases is plotted in Fig. 6(b).



(a) Transient of core outlet temperature (modified probability, 100samples)



(b) Cumulated frequency of maximum core outlet temperature
Fig. 6. Analytical result of strong wind hazard

In Fig. 6(b), the weight factor is considered in the modified probability case. Although there are some disagreement between the cases near the normal operation (397ºC), the frequency of the modified case agrees comparatively with the default case. Comparing with the cumulated frequency in the tornado hazard (Fig. 5(b)), non-smooth plotting is obtained in case of the strong wind hazard. When the pump trip occurs, a step wise temperature increase appears due to the delay of the natural circulation initiating. In case of the strong wind hazard, the pump trip event will occur in wide range of time (5min - 12hr) resulting in the non-smooth plotting. The normal approximation in the modified case (red line in Fig. 6(b)) is calculated with 95% and 99% of one-sided confidence intervals. The CCDP in case of the strong wind is evaluated to 1.66×10^{-3}. The CCDP is much higher than that in case of the tornado hazard (4.3×10^{-12}). However, it can be said that the CCDP is also small and that the present plant is also highly resistant against the strong wind hazard.

The comparison of the final status category is shown in TABLE V. All scenarios and their occurrences are investigated in the modified case. Taking into account the original failure state probability (0.0966 of the pump trip and 0.0019 per one ACS-AC), the occurrence of the normal operation (scenario No. 1) is evaluated to 0.898 theoretically. Consequently, the original case seems to be reasonable rather than the modified case. Accordingly, more precise investigations of the applicability of the weight factor, such as an influence of sampling number and their generation method, will be carried out in future work.

TABLE V. Comparison of category (strong wind hazard)

		ACS-AC				Counts [-]		Fraction* [-]		Av. Temp. [ºC]				
No.	Pump trip	A	B	C	Fire	Original	Modified	Original	Modified	Original	Modified	Category		
1	0	0	0	0	0	905	126	0.905	0.941	397.1	397.1	Normal operation		
2	0	0	0	1	0		62		9.74E-04		401.8	No pump trip	No fire	One ACS-AC failure
3	0	0	1	0	0	4	69	0.004	0.001	397.1	402.2			
4	0	1	0	0	0	1	90	0.001	0.001	407.6	403.9			
5	0	0	1	1	0		66		2.18E-06		440.8			Two ACS-ACs failure
6	0	1	0	1	0		86		2.84E-06		424.9			
7	0	1	1	0	0		28		9.25E-07		436.9			
8	0	1	1	1	0		67		4.66E-09		516.3			All ACA-ACs failure
9	1	0	0	0	0	47	25	0.047	0.021	444.5	444.2	Pump trip	No fire	No ACS-AC failure
10	1	0	0	1	0		18		3.24E-05		443.0			One ACS-AC failure
11	1	0	1	0	0		44		7.91E-05		456.9			
12	1	1	0	0	0		36		6.47E-05		448.6			
13	1	0	1	1	0		26		9.83E-08		495.9			Two ACS-ACs failure
14	1	1	0	1	0		32		1.21E-07		471.4			
15	1	1	1	0	0		8		3.03E-08		489.6			
16	1	1	1	1	0		25		1.99E-10		556.7			All ACA-ACs failure
17	1	0	0	0	1	43	40	0.043	0.034	536.8	530.6		Tank fire	No ACS-AC failure
18	1	0	0	1	1		24		4.31E-05		523.7			One ACS-AC failure
19	1	0	1	0	1		20		3.60E-05		529.2			
20	1	1	0	0	1		36		6.47E-05		540.7			
21	1	0	1	1	1		16		6.05E-08		563.9			Two ACS-ACs failure
22	1	1	0	1	1		24		9.08E-08		539.6			
23	1	1	1	0	1		12		4.54E-08		544.4			
24	1	1	1	1	1		20		1.59E-10		563.0			All ACA-ACs failure

* The fraction is calculated using weight factor (ω) in modified case.

As in TABLE V, the occurrence probability of PLOHS (scenario No. 8, 16 and 24) is evaluated to 5.02×10^{-9} in the modified case. Comparing the theoretical probability of PLOHS (6.86×10^{-9} in the present condition), it might be said that a comparative good agreement is obtained in terms of the low probability event with the present weight factor. It is also noted that the average maximum value in case of PLOHS event does not exceed the design limitation (650ºC) after 24hr from the start of the hazard same as in case of the tornado hazard. From an effective accident management's point of view, the time margin to the core damage is quite important information especially when an external hazard happens. It can be concluded that the present method with the weighting factor is quite useful to get the information of the time margin as well as the influence of various scenarios.

II. CONCLUSIONS

An event sequence assessment of the tornado and the strong wind hazards in loop type sodium-cooled fast reactor has been carried out using a continuous Markov chain Monte Carlo (CMMC) method coupled with a plant dynamics analysis. In the assessment, a pump trip due to a loss of emergency power supply and a loss of air cooler function in an auxiliary cooling system (ACS-AC) are selected as a CMMC event considering the existing event tree (ET) analyses both in the hazards. Furthermore, an occurrence of the fuel tank fire is taken into account in the strong wind hazard by modeling the air temperature increase of 100ºC in the computation when it happens.

As a result, the conditional core damage probability (CCDP) is evaluated to 4.3×10^{-12} in case of the tornado hazard (tornado damage scale F5) and 1.66×10^{-3} in case of the strong wind hazard (Saffir-Simpson Hurricane Wind Scale category 5) based on the normal approximation and the design limitation of the coolant temperature (650ºC). It will be concluded that the present SFR has a sufficient resistance against the both hazards. It is also demonstrated that the maximum value does not exceed the limitation after 24hr even in case of protected loss of heat sink (PLOHS) event (all ACS-ACs failure event). Accordingly, it can be said that one has a comparative enough time margin for an accident management against the hazards. It can also be said that the present method has an advantage to get the information of the time margin as well as the influence of various scenarios, which are key issue for an effective accident management.

Since the failure state probability of ACS-AC is comparative low in case of the strong wind hazard (=0.0019), a weight factor concept is introduced so as to investigate the various scenarios with a comparative small number of sampling. As a result, all possible scenarios are investigated with 1000 samples. Although the occurrence of the low probability event (all ACS-ACs failure) considering the weight factor agrees comparatively with the theoretical value, there are some discrepancy in the occurrence of the normal operation (no functional failure) between the present weight factor and the theoretical value. Since the weight factor concept can save enormous amount of the sampling, more precise investigations of the applicability will be carried out in future work.

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REFERENCES

1. Nuclear Regulation Authority, "Enforcement of the New Regulatory Requirements for Commercial Nuclear Power Plant", https://www.nsr.go.jp/data/000067212.pdf (2013).
2. Tunc Aldemir, "Recent Trends in Nuclear Reactor Safety Assessment and Available Tools", *Proc. 10th International Topical Meeting on Nuclear Thermal-Hydraulics, Operation and Safety* (NUTHOS-10), Okinawa, Japan, Dec. 14-18, NUTHOS10-KL06 (2014).
3. T. Takata, et al., "Event sequence assessment of deep snow in sodium-cooled fast reactor based on continuous Markov chain Monte Carlo method with plant dynamics analysis", *Journal of Nuclear Science and Technology*, DOI: 10.1080/ 00223131.2016.1155508 (2016).
4. H. Nishino, et al., "Development of Margin Assessment Methodology of Decay Heat Removal Function Against External Hazards (2) Tornado PRA Methodology", *Proc. 10th International Topical Meeting on Nuclear Thermal-Hydraulics, Operation and Safety* (NUTHOS-10), Okinawa, Japan, Dec. 14-18, NUTHOS10-0168 (2014).
5. H. Nishino, et al., "Development of risk assessment methodology of decay heat removal function against external hazards for sodium-cooled fast reactors (2) Probabilistic risk assessment methodology against strong wind" *23th International Conference on Nuclear Engineering* (ICONE-23), Chiba, Japan, May 17-21 (2015).
6. H. Yamano, et al., "Development of risk assessment methodology against natural external hazards for sodium-cooled fast rectors: Project overview and strong wind PRA methodology" *'15 International Congress on Advances in Nuclear Power Plants* (ICAPP 2016), 15031, Nice, France, May 3-6 (2016).
7. U.S.NRC, "Shutdown Decay Heat Removal Analysis of a Westinghouse 2-Loop Pressurized Water Reactor", NUREG/CR-4458, 1987.
8. NATIONAL WEATHER SERVICE, Fujita Tornado Damage Scale, http://www.spc.noaa.gov/faq/tornado/f-scale.html.
9. NATIONAL WEATHER SERVICE, Saffir-Simpson Hurricane Wind Scale, http://www.nhc.noaa.gov/aboutsshws.php.
10. M. Matsumoto, et al., "Mersenne Twister: A 623-dimensionally equidistributed uniform pseudorandom number generator", *ACM Trans. on Modeling and Computer Simulation*, 8,1, 3-30 (1998). (http://www.math.sci.hiroshima-u.ac.jp/~m-mat/MT/ emt.html)

11. FBR Plant Engineering Center, “External Evaluation on the Logical Adequacy of the Safety Measures and Coolability of the Reactor Core and others in Monju considering Earthquake and Tsunami”, *Japan Atomic Energy Agency*; JAEA-Evaluation 2011-004 (in Japanese) (2011).
12. Advisory Committee on Monju Safety Requirements, “Safety Requirements Expected to the Prototype Fast Breeder Reactor ‘Monju’,” *Japan Atomic Energy Agency*, JAEA-Evaluation 2014-005, p.120. (in Japanese) (2014).