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Application of RASCAL code for multiunit accident in domestic nuclear sites

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1. Introduction

There have been many lessons and action plans following the accident at TEPCO's Fukushima Daiichi Nuclear Power Station. Because it was a multiunit event by great natural disaster, dose assessment or dose projection capability for the multiunit events should be equipped as a part of emergency preparedness part [1, 2]. All of domestic nuclear power plant sites are multiunit site (at least 5 – 6 reactors are operating), so this capability has to be quickly secured for nuclear licensee and institutes responsible for nuclear emergency response.

In this study, source term and offsite dose from multiunit event were assessed using a computer code, RASCAL. An emergency exercise scenario was chosen to verify applicability of the codes to domestic nuclear site accident. Employing tools and new features of the code, such as merging more than two individual source terms and source term estimate for long term progression accident, main parameters and information in the scenario, release estimates and dose projections were performed.

2. Methods and Results

In this section, accident scenario and methodology employed to assess radiological consequence from multi-units accident were described. Also calculated results using different source term calculation options were compared.

2.1 Multiunit Accident Scenario

In this study, an accident scenario, in which three pressurized water reactors (PWR), all of them were Korea Standard Nuclear Power plants (KSNP) type reactors with 2,872 MW thermal power level, were damaged due to great natural disaster, was considered. Offsite power was lost as power transmission towers were collapsed by landslide caused by a huge typhoon and heavy rain. The reactors were shut down automatically. About an hour later, tsunami accompanied by the typhoon caused floods in some parts of the sites, including emergency diesel generator (EDG) buildings and alternative alternate current diesel generator (AAC DG) buildings. This caused total loss of AC power and changed the event from loss of offsite power to station blackout (SBO). Loss of feed water from auxiliary feed water system (AFWS) and steam generators (SG) made reactor cores begin to be uncovered. Concentration of hydrogen generated from uncovered core was increased and accumulated in containments. About 4 hour later after core began uncovered, hydrogen explosion was occurred at a plant. This explosion and containment venting caused major release of fission products into environment for about 2 hours. Containments of other two plants were remained intact. Typhoon is typical natural disaster in Korea and some huge ones caused havoc throughout the country. Timeline and sequences of major events were summarized at Table 1.

Table I: Timeline and main sequences of the scenario

Time	Unit 1	Unit 2	Unit 3
08:30	Total loss of offsite power and automatically reactors shut down due to typhoon		
09:30	Onsite AC power lost due to tsunami (SBO).		
10:00	Loss of all feed water (SG[a] water depletion, and AFWP[b]s trip)		
12:00	Core began uncovered, CNMT[c] Spray off		
12:20	Try to recover coolant using fire engine		
13:00	General emergency declared		
13:30	Spray on		Spray on
13:40		Spray on	
14:40	Core cooling restarted using SG, Spray off	Core cooling restarted using AFWPs	
16:10	Spray on		
16:20		H_2 explosion, CNMT isolation function failure, exhausting valve fail open (Estimated leak rate, % vol : 25 % /h)	
18:30		Major release closed	
32:00	Core recovered completed		

[a]SG : Steam Generator, [b]AFWP : Aux Feed Water Pump, [c]CNMT : Containment

2.2 RASCAL Code Calculation

RASCAL version 4.3 was employed to assess source terms and offsite doses for the multiunit accident [3].

Source term and dose estimates were based on calculations for surrogate U.S reactors using the default parameters in the code, such as fuel burnup, reactor coolant system water mass, release path parameters. Palo Verde unit 1, 2 and 3 were chosen as surrogate for damaged plants, because they were the reference plants of KSNP. But reactor power was modified as 2,872 MW_{th}, since normalized core inventories (Ci/MW_{th}) would be used for source term estimates. Core inventories data built in the code were based on the calculation from a reactor with 193 assemblies per core and 3,479 MW_{th} power level.

"LOCA" source term option of the code was used to evaluate potential fission product release during accident. This source term option was based on NUREG-1465 release sequence [4].

For core damage estimate, the time when core began to be uncovered was used as input parameter. But the restart time of core cooling was not applied for source term estimates. Because the core recovered time in the code is the refill completion time. So source term reduction by refilling during uncovered period (about 17 hours according to the scenario) was ignored. In other words, the code regarded the core was remained unrecovered during the accident and estimated fission products fraction released into containment under 100 % core melting condition.

Spray on / off time and leakage rate (% vol) were main input parameters to define release pathway through containment leakage. Design leakage rate (0.1 %/day) was applied to containment intact plants, unit 1 and 3.

The code required some meteorological data to model transport and atmospheric dispersion of radiological materials in environment. The meteorological data used in this study were listed in table 2.

Table II: Meteorological data for modeling radiological release into environment

Time	Wind direction (degree)	Wind speed (m/s)	Precipitation	Stability
12:00	248	10	15 mm/h	C
15:50	338	5	No	C
17:20	315	3	No	B
19:00	225	5	No	B

Using the "Source Term to Dose (STDose)" tool, source term from each unit was assessed. Then, total source terms of three units and integrated dose assessment data was acquired by employing "Source Term Merge / Export" tool [5].

2.3 Results of multiunit event

Estimated source terms were presented in Table 3. Estimated results of unit 1 and 3 were much smaller than those of unit 2. Containment integrity was main factor of the difference. Total amounts of release into environment were $3.5*10^{18}$ Bq.

Table III: Radionuclide release estimates from unit 1, 2 and 3 using surrogate plants [unit: Bq]

	Unit 1	Unit 2	Unit 3
Noble gas	$3.1*10^{15}$	$3.5*10^{18}$	$5.9*10^{15}$
Iodines	$1.7*10^{14}$	$1.3*10^{14}$	$8.5*10^{13}$
Other	$1.2*10^{14}$	$1.1*10^{16}$	$2.9*10^{13}$
Total	$3.4*10^{15}$	$3.5*10^{18}$	$6.0*10^{15}$

Figure 1 displayed offsite dose calculated from each unit and integrated results. Though the total amount was relatively high (The total amount of release into environment of the Chernobyl accident was estimated about 10^{18} Bq.), containment spray before major release by hydrogen explosion could reduce major dose contributors such as iodine and cesium. The code estimated the contribution of these two nuclides to inhalation dose as relatively 13% and 3%.

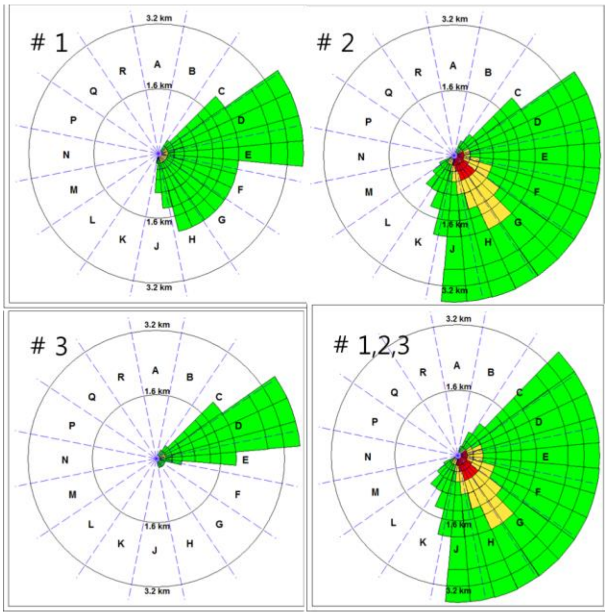

Fig. 1. Offsite dose (from release point to 3.2 km) calculated from multiunit event using RASCAL. (green : 0.1 ~ 10 mSv, yellow : 10 ~ 50 mSv, red : > 50 mSv)

From the results, the maximum radius for protective actions, such as sheltering (Generic Intervention Level, GIL : 10 mSv), evacuation (GIL : 50 mSv) and thyroid blocking (GIL : 100 mGy), were just within about 2 km. So recommendation of protective action from the code would not be necessary because people within the near site, for example precautionary action zone (3 to 5 km from reactor), had to be evacuated as general emergency declared, 3 hours earlier than major release.

2.4 Comparison of results from different source term options.

One of the new features of RASCAL version 4.3 is long term SBO (LTSBO) source term option. LTSBO release type option facilitates source term estimates for accidents which have much longer time frame than LOCA. The basic scenario for the LTSBO is initiated by an external event that results in a total loss of offsite power [6]. And then onsite diesel powers are lost due to following event, such as earthquake. After SBO, reactor cooling is maintained for a period and then ultimately core damage and release begin. This accident sequence was very similar to the accident scenario in this study.

Source term of unit 2 was re-estimated using this option and compared with that of LOCA source term. LTSBO source term option gives 8 hours default delay from the time the core begins to become uncovered until it becomes fully uncovered and fission products begin to be released from the core. Also this option allows up to 48 hours of delay before the core begins to be uncovered. This delay is based on duration of emergency core cooling systems (ECCS). In the scenario, ECCS duration since the reactor shutdown was 3.5 hours. So totally 11.5 hours delay time was applied and then core uncovered time (start of fission product release from core) was shifted to 20:00. For the calculation, major release event, such as hydrogen explosion, and time of meteorological data were shifted too. Table 4 compared radiological release estimates between LTSBO and LOCA source term options. Except iodines, LOCA showed higher values.

Table IV: Radionuclide release estimates from LTSBO and LOCA source term options. [unit : Bq]

	LTSBO	LOCA	LTSBO / LOCA
Noble gas	$3.0*10^{18}$	$3.5*10^{18}$	0.86
Iodines	$1.9*10^{15}$	$1.3*10^{14}$	14.6
Other	$7.9*10^{15}$	$1.1*10^{16}$	0.72
Total	$3.0*10^{18}$	$3.5*10^{18}$	0.86

Offsite doses calculated from two source term options were displayed in figure 2. For LTSBO source term options, the area where exceeding 10 mSv and 50 mSv (GILs for sheltering and evacuation) were larger than LOCA option. Table 5 compared dose estimates for LTSBO and LOCA source term options at a distance of 3.2 km.

Except cloudshine, calculated doses from LTSBO source term option were higher than LOCA option. This caused by higher iodine release and feature of delayed and continual release. Figure 3 compared release timing of cesium and iodine for LTSBO and LOCA source term options.

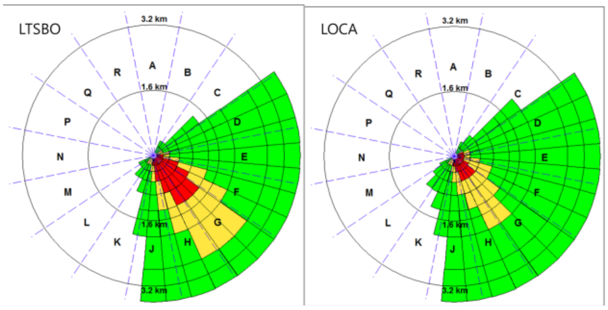

Fig. 2. Offsite dose (from release point to 3.2 km) calculated using LTSBO (left) and LOCA (right) source term options in RASCAL. (green : 0.1 ~ 10 mSv, yellow : 10 ~ 50 mSv, red : > 50 mSv)

Table V: Comparison of dose estimates from LTSBO and LOCA source term options. [unit : mSv]

Dose	LTSBO	LOCA	LTSBO / LOCA
TEDE	7.9	1.7	4.65
Thyroid EDE	11.0	0.24	45.8
Child thyroid EDE	22.0	0.51	39.2
Inhalation CEDE	6.4	0.11	58.2
Cloudshine	0.76	1.5	0.51
4 day groundshine	0.8	0.38	2.11

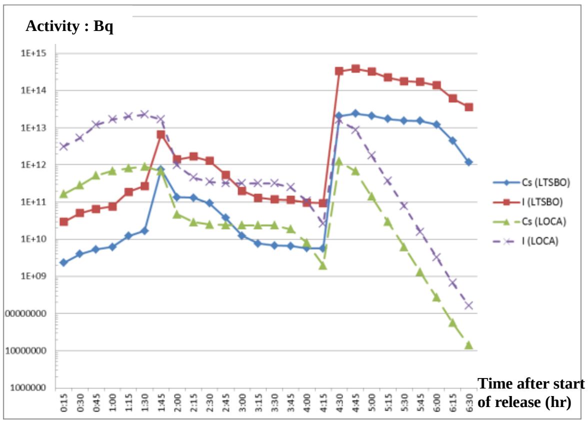

Fig. 3. Comparison of activity release to the environment in first 6 hours after beginning of release for LTSBO and LOCA events in unit 2

3. Conclusions

Radiological releases and offsite doses from multiunit accident were calculated using RASCAL. A scenario, in which three reactors were damaged coincidently by a great natural disaster, was considered. Surrogate plants were chosen for the code calculation. Source terms of each damaged unit were calculated individually first, and then total source term and integrated offsite dose assessment data was acquired using a source term merge function in the code.

Also comparison between LTSBO and LOCA source term estimate options was performed. Differences in offsite doses were caused by release characteristics. From LTSBO option, iodines were released much higher than LOCA. Also LTSBO source term release was delayed and the duration was longer than LOCA. This option would be useful to accidents which progress with much longer time frame than LOCA.

RASCAL can be useful tool for radiological consequence assessment in domestic nuclear site accidents. Some newly equipped functions, such as merging multiunit source terms and LTSBO source term options, provide emergency responders with several options to cope with postulated accidents. As a stand-alone computer code, RASCAL will be useful for early phase radiological consequence prediction in nuclear emergency response.

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