Preliminary results of consequence assessment of a hypothetical severe accident using Thai meteorological data

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Abstract. Consequence assessment of a hypothetical severe accident is one of the important elements of the risk assessment of a nuclear power plant. It is widely known that the meteorological conditions can significantly influence the outcomes of such assessment, since it determines the results of the calculation of the radionuclide environmental transport. This study aims to assess the impacts of the meteorological conditions to the results of the consequence assessment. The consequence assessment code, OSCAAR, of Japan Atomic Energy Agency (JAEA) is used for the assessment. The results of the consequence assessment using Thai meteorological data are compared with those using Japanese meteorological data. The Thai case has following characteristics. Low wind speed made the radionuclides concentrate at the center comparing to the Japanese case. The squalls induced the peaks in the ground concentration distribution. The evacuated land is larger than the Japanese case though the relocated land is smaller, which is attributed to the concentration of the radionuclides near the release point.

1. Introduction
Probabilistic risk assessment (PRA) is a common way to assess the risks of accidents in a nuclear power plant. PRA is divided into three levels. In level 1 PRA, the accidents which can possibly damage the reactor core are selected, and the core damage frequencies (CDFs) are calculated. Then in level 2 PRA, the accidents which can cause release of radionuclides to the environment are selected out of the core damage accidents, and the containment failure frequencies (CFFs) and the large early release frequencies (LERF) are evaluated along with the source term. Finally, in level 3 PRA, the consequence assessment of the release of the radionuclides to the environment are performed. This is a very important step of the risk assessment, since it helps the assessor understand the extent of the consequences which may be attributed to a severe accident, and helps them plan for appropriate accident management strategies. It starts from the determination of the source term i.e. the amount, time and period of the release of radionuclides, then continues with the evaluation of the environmental transport where the atmospheric dispersion calculation is performed. After that the radiation dose is estimated, and the associated risks are finally calculated in terms of health effects, number of affected people, or size of the affected area [1].
It is widely known that the meteorological conditions can significantly influence the outcomes of such assessment, since it determines the results of the calculation of the radionuclide environmental transport [2]. Thus it is important to correctly select the representative meteorological conditions of the site of interest.

Several pieces of research have been performed in the past inside [3] and outside of Thailand [2,4–8], while the effects of different meteorological conditions in Thailand on the results of the consequence assessment of a hypothetical severe accident in a nuclear power plant have not yet been systematically performed. Therefore, the objective of this research is to study the effects of Thai meteorological conditions to the consequence assessment results. The results of the consequence assessment using Thai meteorological data are compared with those using Japanese meteorological data in order to identify the characteristics of the consequences of a hypothetical severe accident in Thailand. The influences of the meteorological conditions are indicated in terms of differences in air and ground concentrations of the released radionuclides, and differences of consequences, e.g. collective dose, number of affected people and size of affected area.

2. Methodology

2.1. Consequence assessment code, OSCAAR
The consequence assessment code, OSCAAR (Off-Site Consequence Analysis code for Atmospheric Releases in reactor accidents) of Japan Atomic Energy Agency (JAEA) is used for the assessment [9]. It can take into account the meteorological conditions hourly, and has the ability to perform the sampling of the meteorological data. The calculation scheme of OSCAAR is shown in Figure 1, and its detailed description can be found in Homma et al. [3].

2.2. Calculation conditions
The basic calculation conditions are shown in Table 1. THA and JPN stand for the cases where Thai and Japanese meteorological data sets are used. The authors assumed the long-term station blackout accident [10] as the hypothetical accident in this study, since it has a large CFF and the scenario is similar to the accident happened in the Fukushima Daiichi Nuclear Power Plant. The source term data is shown in Table 2, where the release is divided into two steps in order to accurately represent the release. Population distributions of the two cases are shown in Figure 2. The peaks represent the highly populated cities, which is Bangkok and its vicinities for the Thai case, and Mito and Tokyo for the Japanese case.

![Figure 1. Calculation scheme of OSCAAR.](image-url)
**Table 1.** Calculation conditions.

| Items                                    | Conditions                                                                 |
|------------------------------------------|---------------------------------------------------------------------------|
| Reactor type                             | 1,100 MWe BWR-5                                                           |
| Location                                 | THA: Headquarters of Thailand Institute of Nuclear Technology              |
|                                          | JPN: Tokai Research and Development Center, Japan Atomic Energy Agency     |
| Hypothetical accident                    | Long-term station blackout [10]                                           |
| Coverage of meteorological data          | Within the radius of 200 km from the release point                        |
| Meteorological data taken into account   | Hour wind speed, wind direction, precipitation, weather stability          |
| Year                                     | THA: 2014                                                                 |
|                                          | JPN: 1990                                                                 |
| Sampling method                          | Random sampling (300 samples)                                            |
| Calculated parameters                    | Air concentration, ground deposition, collective dose, evacuated and relocated people, evacuated and relocated area |
| Dose criteria for radiation protective actions | Sheltering: 10 mSv/1 day [11]                                      |
|                                          | Evacuation: 50 mSv/7 days [11]                                            |
|                                          | Relocation: 20 mSv/year [12]                                             |

**Table 2.** Source term data of the hypothetical accident.

| Release time [hr] | Release duration [hr] | Noble gas 1 | Organic I 2 | Inorganic I 3 | Cs-Rb 4 | Te-Sb 5 | Sr-Ba 6 | Ru 7 | La 8 |
|-------------------|-----------------------|-------------|-------------|--------------|---------|---------|---------|------|------|
| 12.7              | 4.0                   | 2.9E-1      | 1.7E-4      | 3.1E-3       | 5.4E-3  | 1.1E-3  | 2.5E-4  | 4.5E-9 | 3.1E-7 |
| 16.7              | 25.0                  | 7.1E-1      | 6.3E-3      | 1.2E-1       | 4.2E-2  | 7.4E-2  | 2.7E-3  | 3.1E-8 | 3.3E-6 |

**Figure 2.** Population distributions of Thai and Japanese cases.
3. Results and Discussion

Figures 3–7 show (1) the average air concentration of radionuclides relative to distance from release point, (2) the average ground concentration of deposited radionuclides relative to distance from release point, (3) the total collective dose relative to distance from release point, (4) the total collective dose from all pathways and (5) the numbers of evacuated and relocated people, and the areas of abandoned land, respectively. Since a pile of meteorological data is used for the calculation, the results above are shown in expected values, i.e. the probability weighted averages.

It can be seen from Figure 3 that the air concentration when the Thai meteorological data is used (hereinafter referred to as Thai case) is larger until the radius of around 100 kilometers. However, at the distance further than 100 kilometers, the case that the Japanese meteorological data is used (hereinafter referred to as Japanese case) gives larger air concentration. Similar trends can be observed in Figure 4, though not as obvious as Figure 3. This is because the wind speed of the Thai case is basically lower than that of the Japanese case, thus the radionuclides could not migrate as far as the Japanese case.

The average ground concentrations of the deposited radionuclides of both cases gradually decrease with the distance. However, some peaks can be observed in the Thai case (notable peak can be found at 90 km from the release point). This can be attributed to the difference in the characteristics of the rainfall. Except for the case of typhoons, the rain in Japan normally falls constantly and continues for a long time (several hours or days). On the other hand, the rain in Thailand is usually in the forms of squall, which is a heavy rain but lasts only for a short period of time and falls only at specific area. If the squall passes the area where the radioactive plume stays in the atmosphere, it will bring the radionuclides down to the ground, and consequently create the peaks in the ground concentration at some specific distance.

The average air concentration of radionuclides and the average ground concentration of deposited radionuclides are used to calculate the effective doses from each pathway: cloudshine, groundshine, inhalation, resuspension and food intake. The total effective doses are used to determine sheltering, evacuation and relocation based on the criteria specified in Table 1. The sums of the effective dose after taking into account all radiation protective actions of the whole population, i.e. collective dose, at each distance band which represent the extent of the stochastic health effects from the accident is shown in Figure 5. It can be observed from the figure that the total collective doses of the Japanese case has two peaks, while there is only a single peak in the Thai case. This may be attributed to the difference in the distribution of the population of the two countries. The peaks match with the location of large cities of the two countries. A single peak in the Thai case matches with the location of Bangkok, and the two peaks in the Japanese case represent Mito and Tokyo.

The difference of the total collective doses within the radius of 200 kilometers of the two cases in Figure 6 is relatively small comparing to the uncertainties associated with the inputs of the assessment. This implies that most of the radionuclides have not travel beyond the radius of 200 kilometers. It can thus be assumed that the size of the target area is appropriate for the assessment. Note that the slight difference of the total collective doses between the two cases is probably due to the difference in the sizes of the total population.

It can be seen from Figure 7 that the numbers of evacuated people of the two cases are quite the same whereas the evacuated land of the Thai case is larger than that of the Japanese case. This is attributed to the larger air concentration and ground deposition in the area near the release point as shown in Figures 3 and 4. On the other hand, the relocated area, and the time-integrated relocated area of the Thai case is smaller, since the air concentration and ground deposition are smaller than the Japan case in the area further from the release point. These differences are also caused by the lower average wind speed of the Thai case.
Figure 3. Average air concentration of radionuclides relative to distance from release point.

Figure 4. Average ground concentration of deposited radionuclides relative to distance from release point.

Figure 5. Total collective dose relative to distance from release point.
4. Conclusions
Consequence assessment using Thai meteorological data was performed in order to study the effects of meteorological conditions to the consequence assessment results. The results are compared with the case where Japanese meteorological data was used, and following characteristics are confirmed. Lower wind speed of the Thai case made the radionuclides concentrate at the center, while the radionuclides migrated and deposited further in the Japanese case. The squalls induced the peaks in the ground concentration in the Thai case. The evacuated land of the Thai case is larger than the Japanese case though the relocated land is smaller. This is because the radionuclides concentrated in area near the release point in the Thai case, which is again attributed to the low wind speed.

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References

[1] Till J E 2008 Radiological Risk Assessment and Environmental analysis ed Till J E and Grogan H A (New York: Oxford University Press) chapter 1 pp 1–30

[2] Homma T, Tomita K and Hato S 2005 Nuc. Eng. Technol. 37(3) 245–258

[3] Kuasakul P and Wongsawang D 2015 Proc. Conf. STOU Graduate Research (Bangkok) vol 5 (Bangkok: Sukhothai Thammathirat Open University) P-ST 012

[4] Helton J C, Johnson J D, Shiver A W and Sprung J L. 1995 Reliab. Eng. Syst. Saf. 48(2) 91–127

[5] Helton J C, Johnson J D, Rollstin J A, Shiver A W and Sprung J L. 1995 Reliab. Eng. Syst. Saf. 50(2) 137–177

[6] Haste T, Birchley J, Cazzoli E and Vitazkova J 2006 Nucl. Eng. Des. 236(10) 1099–1112

[7] Baklanov A, Mahura A, Jaffe D, Thaning L, Bregman R and Andres R 2002 J. Environ. Radioact. 60(1–2) 23–48

[8] Cao J Z, Yeung M R, Wong S K, Ehrhardt J and Yu K N 2000 J. Environ. Radioact. 48(3) 265–277

[9] Homma T, Ishikawa J, Tomita K and Muramatsu K 2000 Radiological Consequence Assessments of Degraded Core Accident Scenarios Derived from a Generic Level 2 PSA of a BWR: JAERI-Research-2000-060 (Ibaraki: Japan Atomic Energy Agency) chapter 2 pp 2–15

[10] Japan Nuclear Energy Safety Organization 2006 Methodology of level 2 PSA (BWR): JNES/SAE06-046 (Tokyo: Japan Nuclear Energy Safety Organization)

[11] International Atomic Energy Agency 1994 Intervention Criteria in a Nuclear or Radiation Emergency (Vienna: International Atomic Energy Agency)

[12] International Commission on Radiological Protection 2007 Annals of the ICRP Publication 103: The 2007 Recommendations of the International Commission on Radiological Protection (Ontario: International Commission on Radiological Protection)