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RESEARCH ARTICLE

Radiological dose assessment due to hypothetical nuclear power plant operation in Mersing, Johor, Malaysia

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Abstract

Malaysia has considered for some time to adopt nuclear power to cater to the increasing demand of electricity following other developed Asian countries such as Japan, Korea, and China. In implementing a nuclear power plant, strict regulations and guidelines by the International Atomic Energy Agency (IAEA) and International Commission on Radiological Protection (ICRP) must be fulfilled before any construction license is given for a new nuclear power program. One of the assessments include the estimation of potential radiological risks to both humans and environment from routine and accidental release of radioactive effluent from the nuclear power plant (NPP). In this work, simulations of radionuclide dispersion from a hypothetical NPP site in Mersing, Johor will be presented. The simulation was performed based on the Lagrangian atmospheric dispersion model using the HYSPLIT software. The radioactive effluent release rate was approximated to the value found in the Fukushima Dai-ichi accident in 2011. Meteorological data of 2017 were utilized in this study. Simulation results showed that the dispersion of radioactive effluent from the hypothetical NPP can potentially affect areas around Johor Bahru district, Singapore, and even some areas in Indonesia.

Keywords: Lagrangian dispersion model, atmospheric dispersion, hypothetical nuclear accident, emergency respond plan

INTRODUCTION

In 2014, more than 2,400 billion kWh of electricity were produced around the globe by using nuclear power [1]. Malaysia at one time was preparing to establish its own nuclear power generation program by the year 2030 to cater to the increasing demand of electricity usage. The pioneer nuclear power plant (NPP) would generate 1000 kWh of electricity [2-3]. Moreover, researches have been performed to identify potential sites for the construction of NPP throughout the Peninsular Malaysia [4]. A major theme of the work in [4] is to search for potential site(s) with accordance to the guidelines prepared by the authorities. The selected site(s) should adhere to strict regulations and guidelines set by the International Atomic Energy Association (IAEA) and International Commission on Radiological Protection (ICRP) [5,6].

One important method to assess the suitability of the NPP site is through the radionuclide dispersion analysis performed using state-of-the-art dispersion models. Such research works have been performed and reported, for instance in Mersing, Johor [7] and in Lumut, Perak [8] using the Gaussian Plume Model (GPM). Fig. 1 summarizes the locations of potential NPP sites in Malaysia where the dispersion analyses had been performed [9].

In the work of Ref. [7,8], the studies were performed using a rather simple simulation set-up in that only the annual average wind speed and direction were considered. More realistic simulation set-up is needed since these two parameters would not be able to provide an actual representation in the event of an accident. Furthermore, the simple GPM approach do not allow for fluctuation of wind direction and thus making it less relevant for real-time assessment [10,11]. Unlike Gaussian, Lagrangian model takes into consideration the concentration due to turbulence of the wind components which could cause changes

in the effluent movement, mean fluid velocity, and molecular diffusion [12]. The term Lagrangian means that the dispersion is carried out in moving frame of reference for the advection and diffusion along with the trajectory [13,14]. Lagrangian dispersion model is special as it can analyze the dispersion of radionuclide in both homogenous and stationary conditions which are more realistic.

In view of the limitations in previous study, this work reports on the preliminary findings on the consequences in the event of a hypothetical nuclear accident in candidate site number four i.e at Tenggaroh, Mersing, Johor using the Lagrangian model. The main emphasis was given to the variation in the dispersion pattern according to the month of the accident. Other than that, dose received by the public in the event of nuclear accident was assessed. This paper is divided into four sections. The Simulation Details section provides a general information regarding the Lagrangian model and its application in Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) software, as well as on the study area and methodological data. Next, Results and Discussion are presented, followed by the Conclusion section.

SIMULATION DETAILS

HYSPLIT- Lagrangian dispersion model simulation

Atmospheric dispersion was carried out by means of HYSPLIT, which was developed by Air Resource Laboratory, National Oceanic, and Atmospheric Admiration (NOAA), USA [15]. It is claimed as a complete analysis software for computing air parcel trajectories as well as complex transport, dispersion, and deposition model simulation of radionuclide effluent. Its specialty is to calculate forward and backward trajectories analysis in order to determine the origin of radionuclide

effluent and establish source-receptor analysis [16]. The software calculation method uses Lagrangian approach to determine the advection and diffusion calculation and Eulerian methodology which uses fixed three-dimensional grid as a frame of reference to compute the radionuclide air concentrations.

In the recent publication of Ref. [9], the software was used to reconstruct Cs-137 deposition from a hypothetical nuclear power plant candidate site in normal operating hours. The study was able to produce good dispersion results. In this current work, we expanded on the work of Ref. [9] and configured the model with hypothetical nuclear accident simulation at one of the candidate site by using Malaysia meteorological conditions to investigate the dose received by the public in the event of nuclear power plant accident.

Choice of hypothetical nuclear power plant site

Candidate site number four, Tenggaroh is located in Mersing district which situated in the Southern of Malaysia. According to IAEA siting guideline, the population at the selected siting site need to remain as low as possible. With total areas of 2,836.6 km^2 populated by 69,028 people, this location was selected as one of the possible locations to build an NPP.

The wind speed in Mersing ranges from 1.6 to 3.3 ms^{-1} and the wind direction varies according to the monsoon season. The meteorological data used in this study was from 2017 provided by the Air Resources Laboratory Archive.

The hypothetical nuclear accident was assumed to take place on the first day of each month with three hours of emission. The radionuclide dispersion was focused on the dispersion of Cs-137 due to its long half-life. The radionuclide was released into the atmosphere at the rate of 1×10^{20} Bq/sec which approximate to the values from Fukushima Dai-ichi accident in 2011, Japan [17-19]. The doses obtained from the analyses were then calculated by using dose equation from Ref. [20].

Fig. 1 Potential NPP sites in Peninsular Malaysia extracted from Ref. [9]. There are four candidate sites, namely 1) Rungkup, Hilir Perak, Perak; 2) Pasir Panjang, Sabak Bernam, Selangor; 3) Jugra, Kuala Langat, Selangor; and 4) Tenggaroh, Mersing, Johor.

RESULTS AND DISCUSSION

Dispersion pattern

In this section, the dispersion patterns of Cs-137 radionuclide effluent into the atmosphere within the first week of accident were reported. Fig. 3, 4, and 5 show the dispersion patterns if nuclear accidents occur in January, June, and December 2017, respectively.

Fig. 3 to 5 show that the radionuclide effluent was dispersed into the atmosphere corresponding to the wind direction and wind speed. In January, the wind direction mostly came from Northeast while in June, the wind direction was from Southwest. With different wind speed for each day, the size of the radionuclide dispersion in the air were changing and it is important to study its behavior. The results showed that, if nuclear accident will happen in Malaysia, it will cause harm not only to Malaysia but also to our neighboring countries such as, the radionuclide effluent could even reach Northern of Vietnam by the second day of the accident in month of June. Our closest neighbor, Singapore will always be affected by the radionuclide effluent if NPP to be built in the candidate site number four. Thus, it is important to predict accurately the change in wind direction in order to analyze the flow of radionuclide effluent and also to determine the affected areas due to the nuclear power plant accident.

Deposited dose

The results from our analyses using HYSPLIT are tabulated in Table 1. In order to calculate the dose to the public, the concentration of radionuclide effluent, Cs-137 was needed. The dose calculation were performed according to Ref. [20] as proposed by IAEA. The values in Column 2 of Table 1 are the concentrations of Cs-137 radionuclide at three hours after the start of the nuclear accident. The concentration was taken 10 km from the NPP. The highest dose received by the public will be in the month of May and December with 1.3×10^{-4} Sv.

Table 1 Dose analysis for the hypothetical nuclear accident at candidate site number four on the first day of the hypothetical nuclear accident.

Month	Maximum concentration of Cs-137 (Bq m^{-3})	Maximum Dose (Sv)
Jan	6.1×10^4	1.8×10^{-5}
Feb	1.1×10^5	3.2×10^{-5}
Mac	8.5×10^4	2.5×10^{-5}
Apr	4.2×10^5	1.2×10^{-4}
May	4.6×10^5	1.3×10^{-4}
Jun	1.4×10^5	4.1×10^{-5}
July	2.0×10^5	5.8×10^{-5}
Aug	1.5×10^5	4.4×10^{-5}
Sept	2.0×10^5	5.8×10^{-5}
Oct	1.8×10^5	5.2×10^{-5}
Nov	2.8×10^5	8.2×10^{-5}
Dec	4.4×10^5	1.3×10^{-4}

By assuming that the release of radionuclide effluent was constant throughout the year, the annual dose proposed ICRP which 1 mSv per year has exceeded at three hours post-accident as shown in the Fig.2.
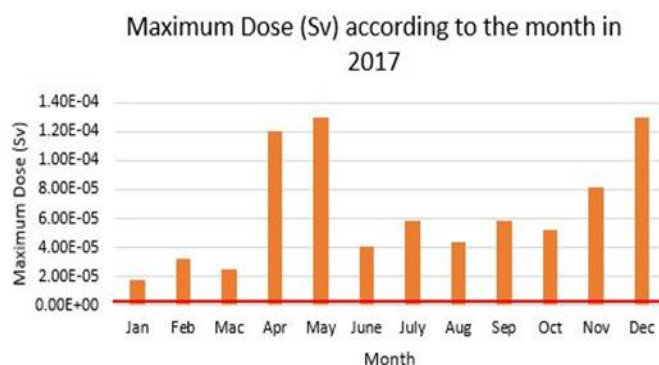

Fig. 2 The variation of maximum dose to the public as discussed in Table 1. With constant release of Cs-137 throughout the year, the annual dose received by public will be exceed the ICRP recommended values which is 1 mSv per year (red line).
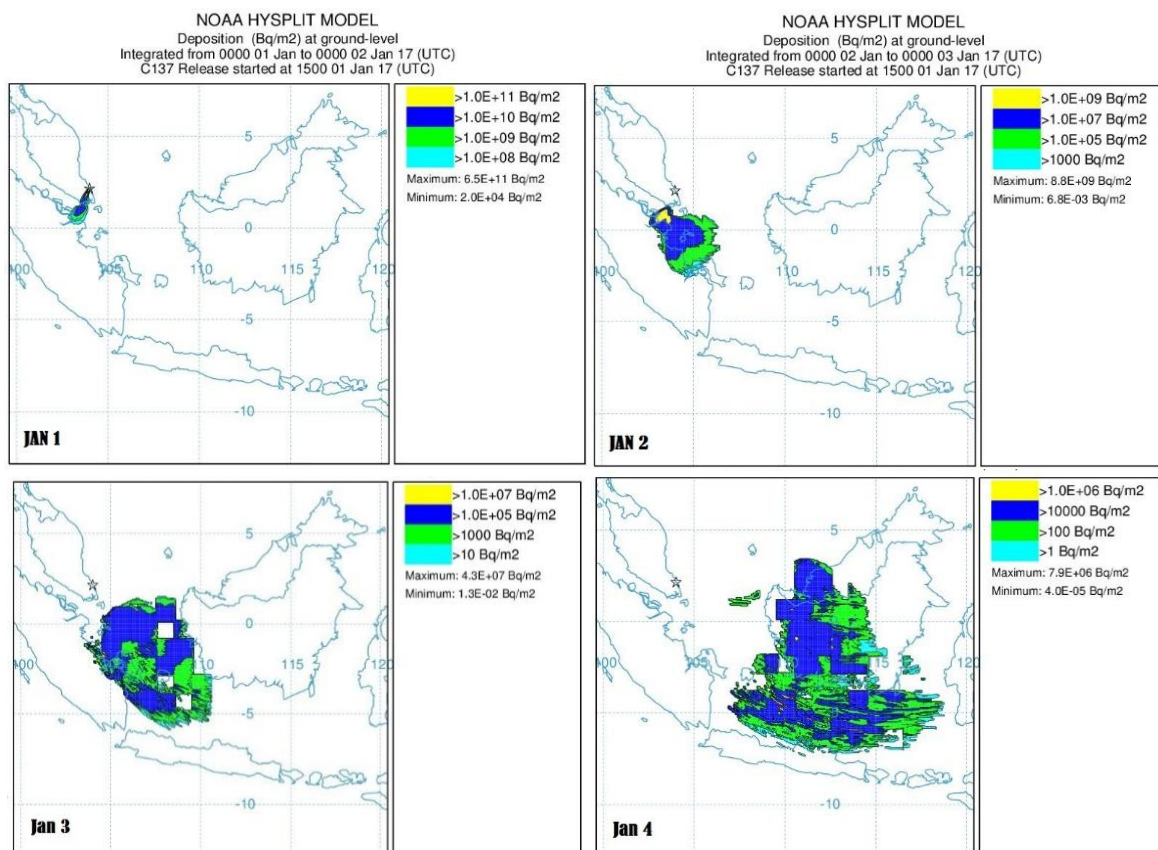
Fig. 3 The movement of Cs-137 radionuclide effluent which was released from hypothetical NPP accident in Mersing, Johor in January 2017. The release of Cs-137 radionuclide effluent affects Kalimantan, Indonesia within two days from the initial release day.
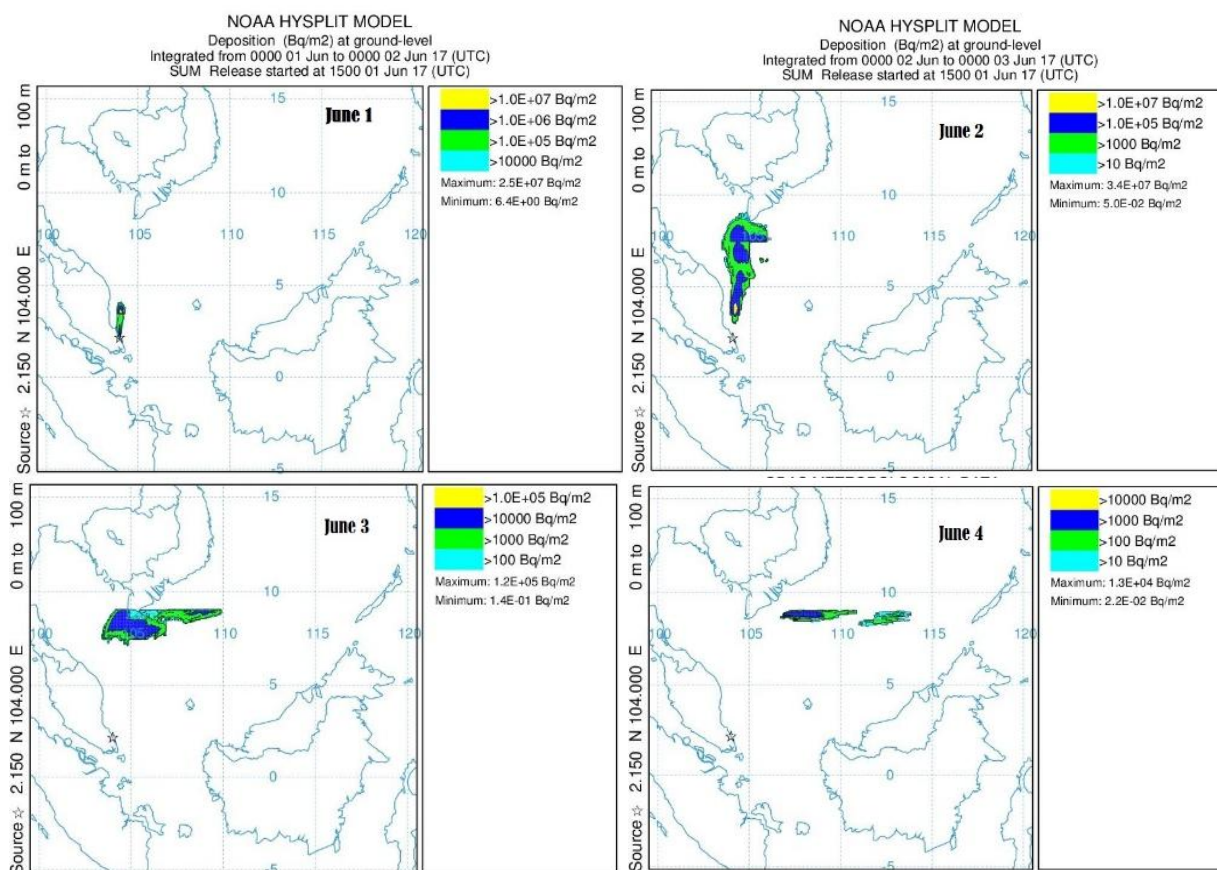
Fig. 4 The movement of Cs-137 radionuclide effluent which was released from hypothetical NPP in Mersing, Johor in June 2017. The radionuclide effluent moves towards Southern Vietnam and expected to divert to the Philippine island.
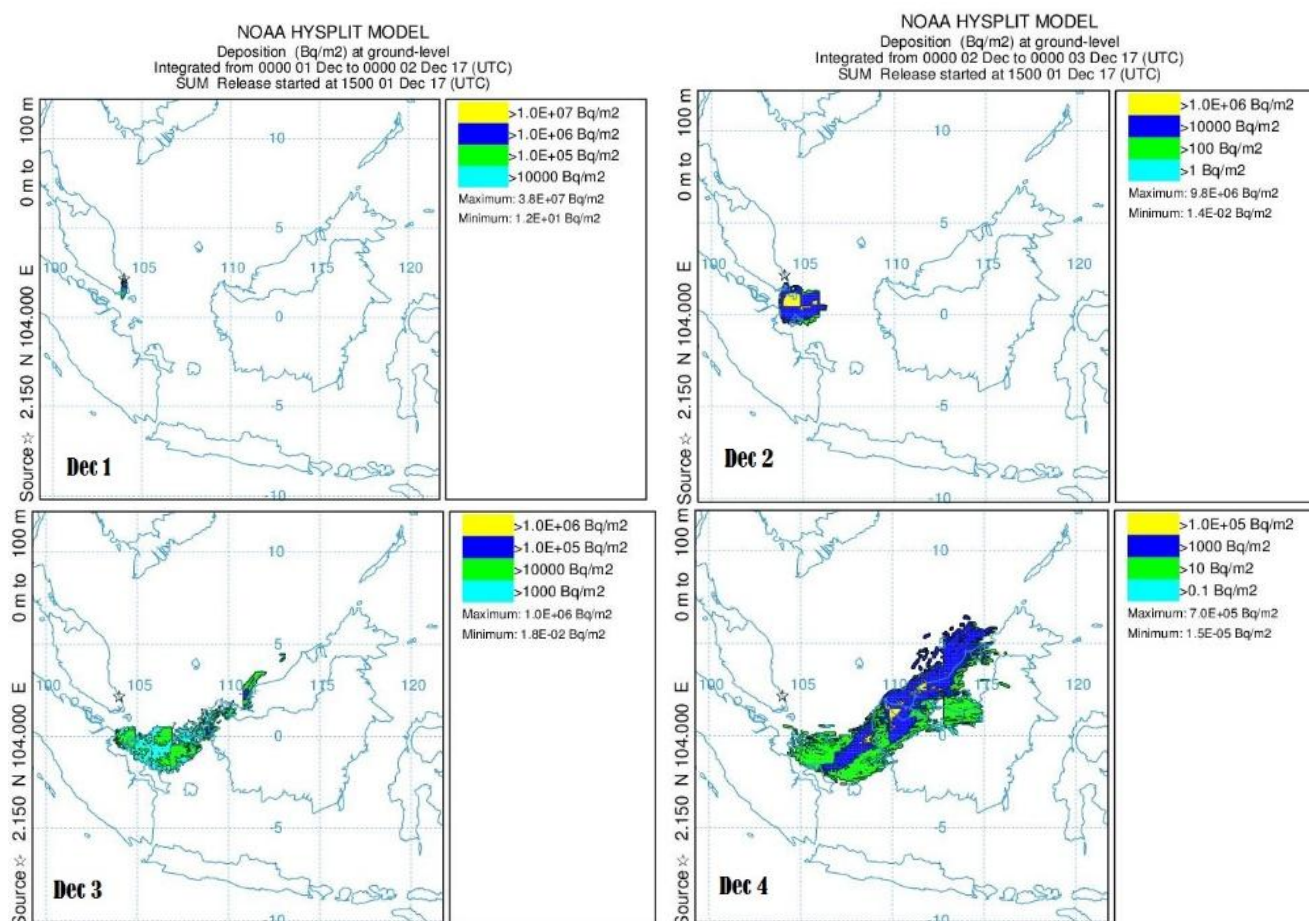
Fig. 5 The movement of Cs-137 radionuclide effluent which was released from hypothetical NPP in Mersing, Johor in December 2017. The movement of Cs-137 radionuclide effluent is due to Northeast Monsoon.

CONCLUSION

In this paper, we investigated the deposition of Cs-137 which was released from a hypothetical NPP candidate site at Tenggaroh, Mersing Johor. From the obtained results, it is apparent that in the event of nuclear accident, the radionuclide effluent does not only affect Malaysia but also the neighboring countries such as Singapore and Vietnam due to wind movement and its speed. Assuming that the release of radionuclide was constant throughout the year, the dose received by the public will be higher than the permissible limit set by the ICRP. However, the released of the radionuclide in this study were assumed to be on the first day of the month. Further studies are needed to investigate the variation in dispersion patterns and the impacts towards the human and environment.

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