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Simulation of Dispersion Modeling of ^{137}Cs for the Possible Leakage of Malaysia's Nuclear Power Plant Operation

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ABSTRACT

The world's energy needs increase in line with population growth. One alternative to overcome this problem is the construction of a nuclear power plant, a source of energy that is cheap, clean, and safe. Malaysia has a plan to construct nuclear power plants by 2025, which is located close to Indonesian waters. This study aimed to determine the distribution model of ^{137}Cs radionuclide released by the nuclear power plant in the event of a leak in east coast of Peninsular Malaysia and its impact on the presence of ^{137}Cs in Indonesian waters. A quantitative method was used in this study with a scenario 2D modeling using hydrodynamics module and transport module in MIKE software. The results showed that the highest concentration of ^{137}Cs would be found in the area around the nuclear power plant with a value of 10^{11} PBq/m^3, then it would decrease through diffusion and advection processes. On the 15th day, the spread of ^{137}Cs would reach Indonesian waters with a distance of up to 76 km and would expand on the 30th day with a distance of up to 130 km from the released source. The movement of ^{137}Cs follows the dominant current pattern due to its nature. The presence of ^{137}Cs in Indonesian waters after the 15th and 30th days would reach a value of 1 Bq/m^3 due to advection and diffusion processes.

INTRODUCTION

Several countries in Southeast Asia including Malaysia have planned to build nuclear power plants (NPP) as a new renewable energy for their countries. There are 7 potential site locations in Peninsular Malaysia and 5 of them are on the coast. One candidate site is located in the state of Kedah; two candidate sites are in the state of Perak; two candidate sites are in the state of Terengganu; and two candidate sites are in the state of Johor [1]. Among those 7 sites, one site will be selected by building two NPPs with a power of 1000 MW for each.

Something that is very much concerned by the public today on an NPP is if an accident occurs either due to nature (e.g., earthquake) such as the ones happened in Fukushima [2,3] or human error like the Chernobyl accident [4] that release tremendous amount of radionuclide radiations into the ocean, terrestrials, and the atmosphere [5,6] causing global damage [7] both to the marine life and food safety [8,9], and it would take long to recover [10,11] the psychological effects.

Indonesia as a neighboring country needs to be alert in the event of an accident when the NPPs are operating. Radionuclide distribution modeling if Malaysia builds an NPP and a leak occurs is a form of emergency preparedness [12]. In this paper, a scenario is made in the event of a release, where the radionuclides release will enter the waters so that it becomes a threat to living things in the area [13] and has the potential to enter Indonesian waters.

Research related to dispersion modeling of radionuclide releases in Indonesia is still very limited. Prediction of the dispersion and distribution of radiocesium in the waters of Gosong Beach

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has been carried out to anticipate the contribution of nuclear power plants in Indonesia [14,15]. This study focuses on one of the radionuclides produced by NPP, namely ^{137}Cs [16]. Radionuclide of ^{137}Cs has a relatively long half-life (30.2 years) and is toxic [17]. Radionuclide of ^{137}Cs is conservative in seawater, which means that its distribution process is strongly influenced by the movement of seawater mass [18]. Therefore, it is necessary to model the distribution of ^{137}Cs radionuclide to determine how far the distribution is, so it can be a reference for taking further action in the future.

EXPERIMENTAL METHODS

Materials

The materials used in this research were primary and supporting data. The primary data include wind direction and speed data obtained from Copernicus, bathymetry data obtained from BATNAS (National Bathymetry), ^{137}Cs input parameter data, and tidal prediction data from MIKE software. Supporting data in this study includes tidal data prediction obtained from the Geospatial Information Agency (BIG). Other data used are:

1. SHP (shapefile) map of Malaysia Scale 1 : 750,000
2. SHP map of Indonesia Scale 1 : 750,000
3. Indonesian Waters Boundary from PUSRISKEL (Marine Research Center)

This simulation carried out using a Laptop to run every single program. To do the modeling, MIKE program is used. To support that, Ms. Excel is used to processing the data of all the component included such as wind direction and speed. A software called ODV, along with notepad, is used as a support program to converting the wind data, which then the data is processed in Ms. Excel. Finally, the result of the model is portrayed in a shape of map with ArcGIS (Table 1).

The data used in this simulation are divided into 3 types. The first one is Modeling support data, which is used to support the component needed in the modeling for the model can run properly. This data consists of bathymetry and ^{137}Cs input data. The second one is Modeling input data, which is used as a main source of the modeling data. This data consists of wind and tide prediction data. Verification data is the last type which is used to verified the tide prediction data from the software. This data is tide prediction data from BIG (Table 2).

Table 1. The research tools used for simulation.

Name	Function	Spesification
Laptop	Running the program, such as MIKE program	ASUS
Ms. Excel	Processing data, such as wind direction and speed data in txt format, sorting data	Ms. Excel 2019
Arcgis	Processing data: to process bathymetry files in tif format to get contour lines and boundaries	10.4
MIKE	Modeling data: such as to obtain and create tidal prediction charts from the tide prediction of height option.	MIKE 21
ODV	To extract and convert wind data from NetCDF format to txt format.	ODV 4
Notepad	To change bathymetry and boundary data in txt format into xyz format.	

Table 2. The research materials used for simulation.

Name	Function
Bathymetry data	Modeling support data
Wind data	Modeling input data
Tide prediction data from DHI	Modeling input data
Tide prediction data from BIG	Verification data
^{137}Cs input data	Modeling input data

Methods

The research locations were determined based on the areas included in the NPP site candidates, namely Mersing, Kota Tinggi, Muar, and Batu Pahat districts. The Sedili Kecil Cluster (Fig. 1) from the Mersing district was chosen because of its proximity to Indonesian waters. This simulation model is for January 2025 (Northeast Monsoon), where in that month the ocean currents move southward parallel to the coastline [19]. The geographic coordinates of the source of the ^{137}Cs radionuclide release at Sedili Kecil are 104°12'9.19"E and 1°45'1.82"N.

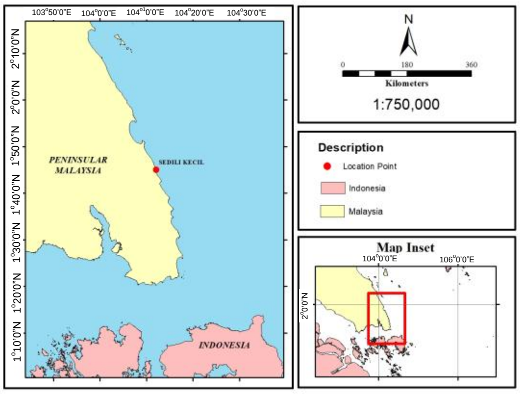

Fig. 1. The research site.

It is a simulation model, so it is simulated the emergency state of Malaysia NPP in 2025. The data used for simulating the emergency state in 2025 is the wind data from 2017-2019 (January from each year) which then averaged. The averaged data is considered to represent the wind data in January 2025.

Wind data were obtained from the Copernicus website. The data used is data for 1 month for January starting from 2017 to 2019 with a measurement time interval of 6 hours. The data obtained is in the form of a NetCDF file. The data is then converted into a txt file with Ocean Data View (ODV) software. The txt data is then processed using Microsoft Excel to obtain wind direction and speed data. Wind direction and speed data for 3 years are then be averaged. The average result is considered to represent the direction and speed of the wind in January 2025.

Tidal data used in the modeling will be obtained through prediction tide with MIKE software for January 2025. Other data used is predicted data from BIG for January 2025. Predicted tide data with MIKE software is then verified with tidal prediction data from BIG using the RMSE (Root Mean Square Error) method, where the results show the error value of the predicted data. If the verification results show a small error value indicator, the MIKE prediction data is considered to be able to represent tidal data in the field.

Bathymetry data were obtained from BATNAS. The data obtained is in the form of a tif file. The data is then inputted into the ArcMap 10.4 software to obtain a bathymetry file in dbf format. The data is then sorted using Microsoft Excel and saved in txt file format. The txt file is then opened via Notepad and saved in the xyz file format. The xyz file then becomes depth data which is inputted into the MIKE software. The spatial resolution of bathymetry data from BATNAS is 6 arc-seconds (180 km).

Parameter of ^{137}Cs as input to the transport module was obtained through a similar research literacy. Table 3 shows several parameters used as input for the transport module model.

Table 3. The parameters value used as input for the transport module model.

Parameter	Value
Direct discharge of ^{137}Cs	3.5 PBq
Decay	7.32×10^{-10}
Horizontal Dispersion	$10\ m^2s^{-1}$

This simulation was carried out from day 1 to 30 of January 2025 (Northeast Monsoon). Particles of ^{137}Cs would begin to be released on the 1st January 2025 with the location of the release source, namely the Small Sedili Cluster at 00.00 continuously and would end on 30th January, 2025. The release is assumed to occur at each time step with the same value.

For the discharge simulation of ^{137}Cs, there are some things that should be arranged according to the needs. Those things are discharge start time and end time, which is from 1 to 30 January 2025. Moreover, 6 hours interval is used for the model with 120-time steps in total (Table 4).

Table 4. The setting of ^{137}Cs discharge simulation.

Parameter	Description
Discharge start time	1 January 2025
Discharge end time of ^{137}Cs	30 January 2025
Time step	120
Time step interval	21600 s

Verification of tidal data is carried out using the RMSE method. RMSE value is the average error in a sample of data with the RMSE equation as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \bar{y}_i)^2}{n}}$$

The n and $\bar{y}i$ symbols are the number of data, field data and modeling data, respectively [20]. To determine the suitability and quality of the model results, it can refer to the interpretation of the calculation results based on Table 5.

Table 5. RMSE interpretation.

RMSE	Error
0.00 – 0.299 (0 % - 29.9 %)	Small
0.30 – 0.599 (30 % - 59.9 %)	Medium
0.60 – 0.899 (60 % - 89.9 %)	High
>0.9 (>90 %)	Very high

RESULTS AND DISCUSSION

The bathymetry of Sedili Kecil waters has a relatively constant depth following the shoreline to a depth of 25 meters. The maximum depth reaches 75 meters as shown in Fig. 2. The bathymetry around the NPP site has a depth of 1 – 5 m.

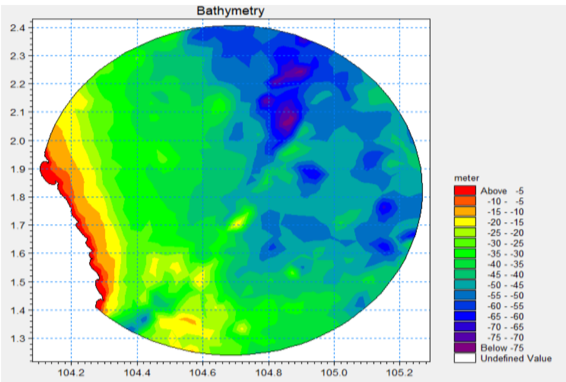

Fig. 2. The bathymetry of Sedili Kecil waters data obtained from BATNAS.

Figures 3 and 4 are the results of a modeling of the current movement pattern in January during high and low tide conditions. The pattern of current movement at high tide is dominant to the northeast, while at low tide, the dominant current is to the southeast.

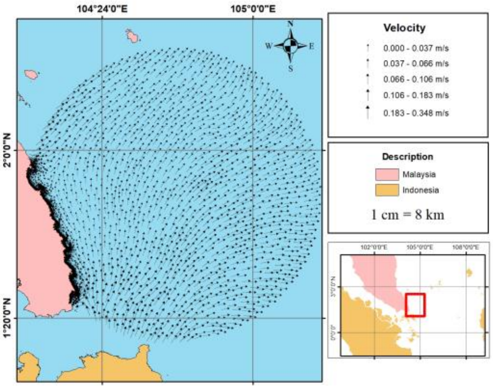

Fig. 3. Current movement pattern for January 2025 in a high tide condition.

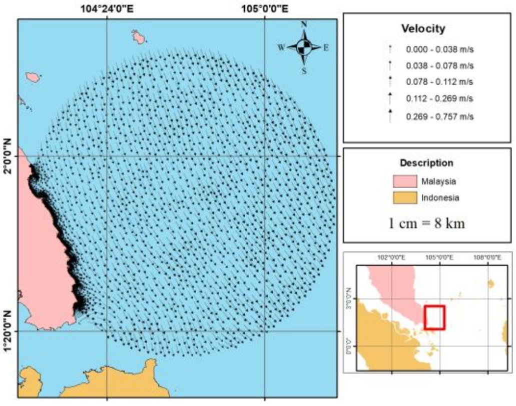

Fig. 4. Current movement pattern for January 2025 in a low tide condition.

The current at low tide has a velocity ranging from 0.038 – 0.757 m/s (Fig. 4), which is higher than the current at high tide which has a speed ranging from 0.037 – 0.348 m/s (Fig. 3). This makes the current at low tide more dominant.

The distribution of ^{137}Cs on day 15 (Fig. 5) is dominant towards the southeast and has crossed the border between Indonesia-Malaysia waters with a distance of up to 76 km from the released source. After crossing the border, the distribution partly leads to the waters of Bintan Island with the outermost concentration reaching 1 Bq/m^3. This distribution occurs due to the deflection of the current to the south around Bintan Island, as seen in Fig. 4. On day 30 (Fig. 6), the distribution becomes more widespread with a distance of up to 130 km from the release source. The distribution of ^{137}Cs leading to the waters of Bintan Island does not change much, but the distribution of ^{137}Cs is getting closer to the waters of Kalimantan with the outermost concentration reaching 1 Bq/m^3. The distribution of ^{137}Cs corresponds to the pattern of current movement due to its conservative nature [21]. If viewed from detection of the wind in Fig. 7, it can be seen that the dominant current that works is in accordance with the direction of the wind blowing from the north towards Indonesian waters. This is in accordance with the statement of Octavian et al., that surface currents are influenced by the working wind [22].

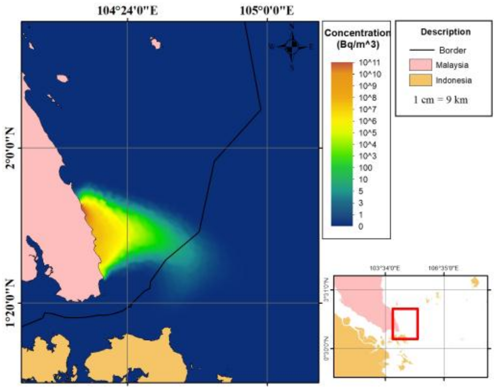

Fig. 5. The ^{137}Cs distribution pattern on day 15 after release.

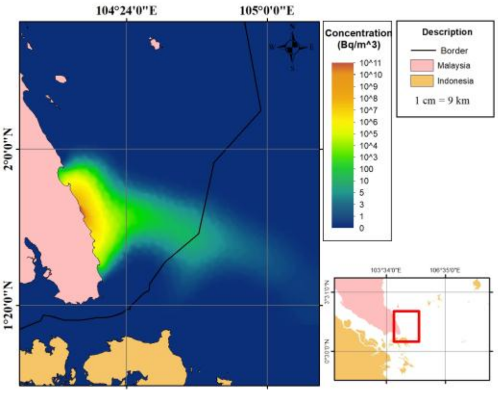

Fig. 6. The ^{137}Cs distribution pattern on day 30 after release.

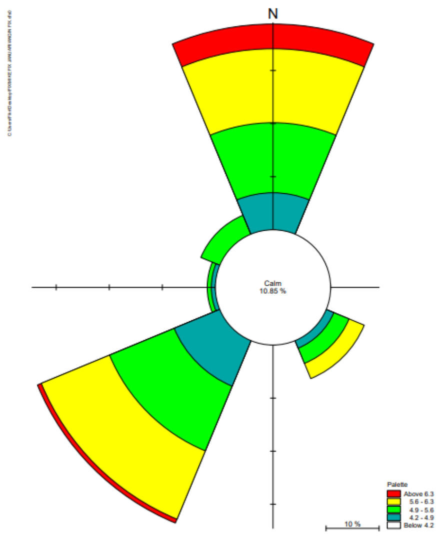

Fig. 7. The windrose of January 2025.

The concentration of the ^{137}Cs on day 15 and day 30 after release in the area around the release source tends to be constant, which is 10^{11} Bq/m^3. This occurs because the surface currents continuously carry the continuously released ^{137}Cs away from the discharge source. Surface currents help distribute the ^{137}Cs to areas of lower concentration so that over the time the distribution area of ^{137}Cs becomes wider. This increase in the distribution area will be followed by a decrease in the concentration of ^{137}Cs. This event is in accordance with our previous work by Muslim et al. that radionuclides entering the sea will undergo advection and diffusion processes, where the advection process causes the radionuclides to be carried away by ocean currents and the diffusion process makes the radionuclides dissolved and scattered to areas with lower concentrations than the released source [23].

Tidal verification was done by comparing BIG tidal prediction data and tidal prediction data from MIKE software. Verification was done by using the RMSE method and by making a correlation graph of the R-squared value.

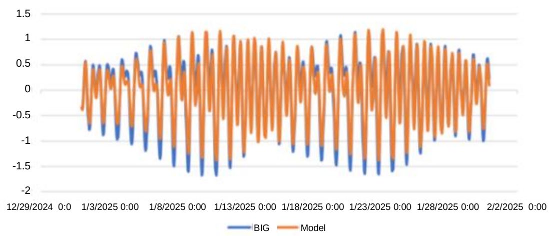

Fig. 8. The tidal chart.

The tidal data for MIKE predictions (orange chart) and the tidal data for BIG predictions (blue chart) are similar, which is shown by the matched chart on Fig. 8. After testing the RMSE method, the MIKE tidal prediction data has an error value of 0.28 or 28 %. This value is included in the small category because according to Huang et al. [24] it is still below 40 %.

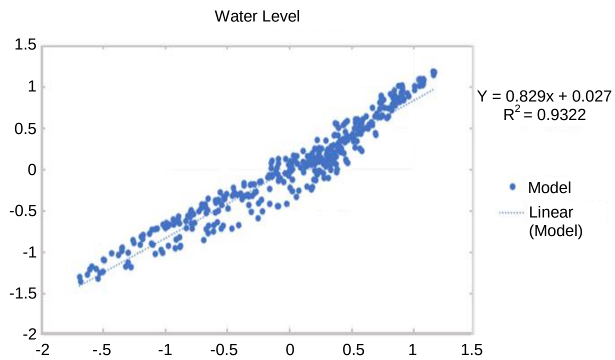

Fig. 9. The tidal regression chart.

The smaller the error value, the better the result. The obtained R-squared value is 0.9 (Fig. 9). This means that the MIKE tidal prediction data has a good correlation with the BIG tidal prediction data. The magnitude and the tidal phase of the model are considered to be representative by comparison when the R-squared value is close to 1 [25].

CONCLUSION

According to the modeling results for January 2025, the distribution of ^{137}Cs will enter Indonesian waters with a distance of up to 76 km from the release source on the 15th day, and up to 130 km on the 30th day. The distribution of ^{137}Cs will enter the waters of Bintan Island and will head to the waters of Kalimantan. The distribution pattern of ^{137}Cs in Sedili Kecil waters will spread following the direction of the dominant surface current, which is to the southeast. The concentration of ^{137}Cs tends to be constant in the release source area and decreases with increasing distribution area.

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AUTHOR CONTRIBUTION

Muslim, Fikri Irwan Maulana, Heny Suseno and Sri Yulina Wulandari are equally contributed as the main contributors of this paper. All authors read and approved the final version of the paper.

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