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Risk Assessment of Radiological Dispersal Device Terrorism in Malaysia Cities

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ABSTRACT

Research has revealed that a terror attack in Malaysia, a developing nation, is a cause for alarm as it could create panic among its citizens. To address this, a study was conducted to investigate the dispersion of radionuclides after a hypothetical explosion, considering multiple cities in Malaysia as potential targets, including Kuala Lumpur, Kuching, and Kota Kinabalu. The primary aim of the research was to analyze the dose concentrations released from the RDD explosion over a 24-hour period and to assess the associated health risks in terms of morbidity and mortality per 100,000 people in these cities. The Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) software was employed to simulate the trajectory and dispersion of air particles, taking into account parameters such as time, altitude, and potential target cities, based on meteorological data from the Global Data Assimilation System (GDAS) of the National Oceanic and Atmospheric Administration (NOAA). The research focused on the analysis of Cs-137 at 50 TBq and was conducted with simulations on December 22, 2020. Results from the simulations revealed that the dose concentration in the air within 24 hours was 3.3 mSv, 1.8 mSv, and 7.7 mSv for Kuala Lumpur, Kuching, and Kota Kinabalu, respectively, while the dose deposited on the ground was 150 mSv, 71 mSv, and 310 mSv for the same cities. Furthermore, it was found that the dose concentration was most significant within the first four hours after the release of Cs-137, peaking between 30 to 90 minutes at altitudes of 60 to 80 meters. In terms of risk assessment, the research indicated that, for individuals located at this altitude during the timeframe of 0045 hours to 0100 hours after the dispersion of Cs-137, there could be 88 fatalities and 128 injuries per 100,000 residents in the city. The simulation offers valuable insights and guidance for governmental efforts to improve radioactive waste management and formulating or enhancing protocols to address such incidents promptly. It is essential to take swift and effective actions in order to protect the lives of the population in the event of a radiological terrorist threat.

1. Introduction

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In the wake of the 9/11 incident, which resulted in the destruction of the World Trade Center in New York City, people have become increasingly vigilant against the possibility of another terrorist attack. The proliferation of advanced technological devices has made it easier for terrorists to acquire radiological devices, such as smoke detectors, chemotherapy treatments, and food irradiation. This has raised the risk of a terrorist attack using a dirty bomb, also known as a Radiological Dispersal Device (RDD). The radioactive components of a dirty bomb can be found in abandoned medical centers, hospitals, and doctor's offices. Furthermore, RDDs can be spread passively without the need for an explosive incident [1].

During the release of RDD in the middle of city, the concentration of the air contaminated with the radioactive nuclei is important because it can be used to carry out necessary counter measures and the air risk assessment. Many studies about air quality involving radio nuclei with the environment has been carried out for the Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) like radon and uranium by Ho [2] and Voitsekhovitch *et al.,* [3]. The study that investigates the outcomes of accidental and intentional release of radioactive material in the atmosphere is also abundant. For example, the study of radioxenon plumes by Stocki *et al.,* [4], hazard risk analysis of soil samples by Khalis *et al.,* [5], naturally occurring radioactive material in selected building materials by Sabarina *et al.,* [6] and hypothetical dispersal of radioactivity in an urban area by Thiessen *et al.,* [7]. Unfortunately, there is not much study of RDD dispersion in Malaysia.

Currently, there is not enough study of RDD after it is released to the atmosphere in Malaysia. The study about radiological dispersion in air mostly is being carried out by the other country like Sweden by Jonnson *et al.,* [8], Canada by Sinclair and Fortin, [9] and South Korea by Jeong *et al.,* [10] which is mainly a high-income country and can be used as a preparation for radiological dispersion in the air. The main concern here is that if any RDD is being released to the atmosphere in the city of Malaysia, there would be not enough study thus inhibiting the process of handling the matter at hand. Following the simulation of an NPP, data on the radionuclide levels in the air and their surface deposition were examined to determine the effects on the environment and human health [11]. Since there is also no past data involving radiological dispersion at the atmosphere disaster in Malaysia, this study can become a guideline for how some steps can be taken to reduce the risk of fatality.

Through the usage of RDD in public areas it will create a huge problem in the area contaminated with the radio nuclei. This is because the radiation that is emitted by the radio nuclei after it explodes can cause stochastic and deterministic effects to the people or maybe even the environment around it. Table 1 below shows the nuclei that can be used to build RDD. Hence, in this study we investigate the atmospheric hazards that a RDD attack may cause to the population of selected cities in Malaysia.

Table 1
Radionuclides used in RDD

Properties	Radionuclide										
	^{241}Am	^{252}Cf	^{60}Co	^{137}Cs	^{131}I	^{192}Ir	^{238}Pu	^{239}Pu	^{226}Ra	^{90}Sr	^{235}U
Emission	α, γ	α, n	β, γ	β, γ	β, γ	β, γ	α	α	α, γ	β	α, γ
Half-life	432y	2.65y	5.3y	30y	8d	73.8d	87.7y	24100y	1600y	28.2y	7000y

*y = years, d = days

2. Methodology

Materials involved are the HYSPLIT dispersion model and the software needed to run the HYSPLIT model. HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) is a computer model used for simulating the dispersion and trajectory of airborne particles, pollutants, and gases in the atmosphere. The location and time of the event during the simulation will also be discussed in this chapter including the method to collect the necessary data is like the modelling of the radioactive dispersal device distribution according to the total activity of radioactive involve in the Goiania, Brazil accident and the modelling of air dispersion by the HYSPLIT model, the time and location of the event. HYSPLIT employs the log-normal particle distribution which assigns a proportional share of the overall 137Cs activity to each particle size bin [12]. Moreover, the dose conversion of the output that will get from HYSPLIT is also being described including the morbidity and the mortality too. This study mainly focuses on designing a HYSPLIT simulation model of hypothetical NPPs based on FDNPP incident on selected potential sites in Malaysia as well as computing a radiological assessment, hazard evaluation and spatial distribution at affected areas. Figure 1 shows the flow chart of HYSPLIT model.

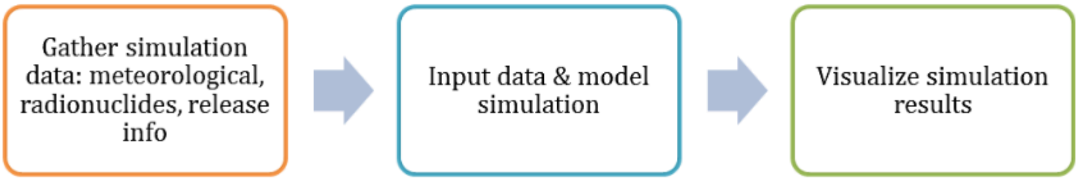


Fig. 1. Process flow chart for running the HYSPLIT model

2.1 Air Dispersion Model

In the air dispersion model, the HYSPLIT will be used to make a simulation of the RDD incidence. This software is capable of creating air parcel trajectories and simulating local, regional, and long-distance movement. Additionally, it can predict the dispersion and deposition of air pollutants on various geographical and temporal scales [13]. In the event of chemical and nuclear accidents, HYSPLIT has also been used to forecast the dispersion of airborne products such as volcanic ash, wind-blown dust, and smoke [14, 15]. By factoring in the contributions of individual pollutant puffs that are transported across the grid cell in accordance with their trajectory, the Lagrangian modeling technique is used to calculate air concentrations [16]. The HYSPLIT model used two types of puff that need to be calculated using the incremental contribution of each puff of mass to a grid point [17]. The first is top-hat puff as in Eq. (1):

$$\Delta c = m(\pi r^2 \Delta z)^{-1} \tag{1}$$

where vertical extent is Δc = 3.08σz and the horizontal radius is r = 1.54σh. Next is the Gaussian puff expressed in the Eq. (2).

$$\Delta c = m(2\pi\sigma_h^2 \Delta z)^{-1} \exp(-0.5x^2 / \sigma_h^2) \tag{2}$$

where the distance from the puff center to the grid-node is x vertical distance coefficient equal to σz, and horizontal distance coefficient equal to σh.

The distance from the puff center to the grid-node will affect the vertical and horizontal distance coefficient. Then, the deposition concentration that will be taken from wet and dry removal process need to be calculated using the Eq. (3):

$$D_{wet} + dry = m\{1 - \exp[-\Delta t \beta_{dry} + \beta_{gas} + \beta_{in} + \beta_{bel}]\} \tag{3}$$

where dry deposition is βdry, removal process for gas is βgas, in-cloud wet removal of particles is βin and below-cloud wet removal of particles is βbel.

2.2 Location and Time of Study

The HYSPLIT will be used to calculate the dispersion of Cs-137 from the location of RDD being release which is at Kuala Lumpur (3.14° N, 101.71° E), Kuching (1.55° N, 110.36° E) and Kota Kinabalu (5.98° N, 116.072° E). This study will be conducted by assuming the dispersal of Cs-137 is in the duration of 24 hours. Taking the incident time as the 22nd December 2020 starting at 1200 AM UTC.

2.3 Explosion Scenario

The incident that occurred in Goania, Brazil in 1987 is a tragedy that must be avoided at all costs [18]. It was reported that around 50.9 TBq from a teletherapy machine in an abandoned clinic were released, resulting in four fatalities (IAEA, 1988). This event served as a reference for our study, taking into account the release of 50 TBq of Cs-137 emitted from a hypothetical explosion scenario in the Malaysian cities of Kuala Lumpur, Kuching and Kota Kinabalu.

2.4 Morbidity and Mortality

This study will analyze the health risks resulting from the RDD explosion by evaluating the morbidity and mortality of the population. According to Landrigan and Friedman [19], morbidity is an unfavorable event or complication that is not a natural consequence of the patient's disease or treatment under optimal conditions. One of the diseases that can arise as a result of this complication is cancer. Mortality, on the other hand, is the number of deaths due to the event. The morbidity (Mb) and mortality (Mt) can be calculated by using Eqs. (4) and (5) respectively, based on the inhalation rate of the public.

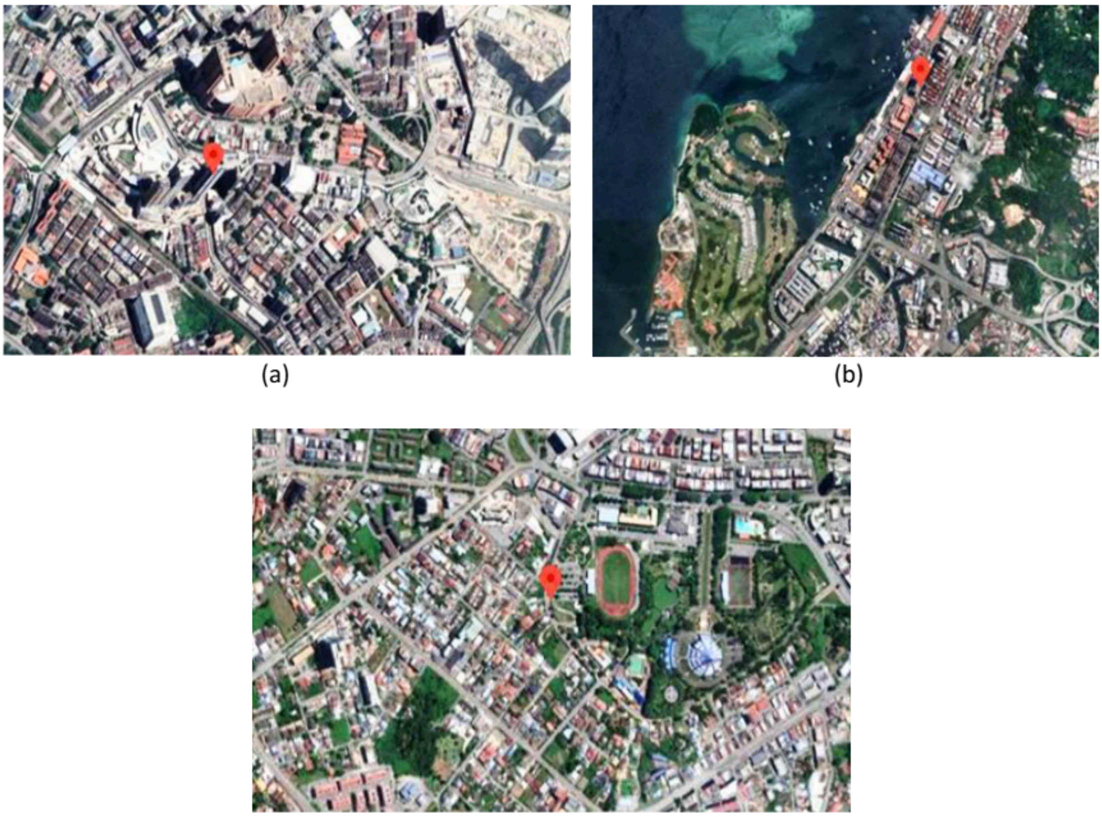
$$Mb = Ac(Br)(Mb_0) \tag{4}$$

$$Mt = Ac(Br)(Mt_0) \tag{5}$$

where the air concentration (Bqh/m^3) is Ac, breathing rate (m^3/h) as Br, morbidity coefficient as Mb_o, and mortality coefficient as Mt_o. The breathing rate, morbidity and the mortality coefficient will be taken from the US EPA (1999).

3. Results

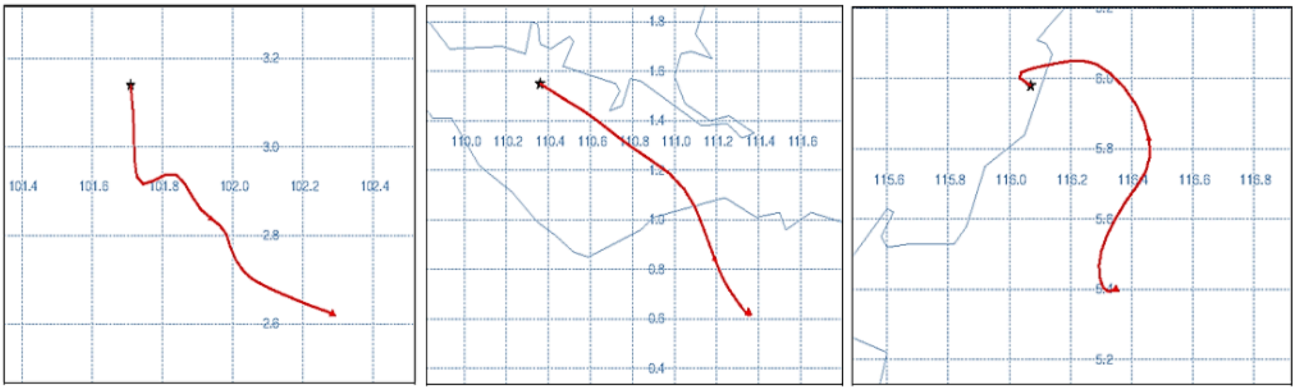
The rough trajectory and dispersion of the radionuclide Cesium-137 have been studied and simulated by using the trajectory and concentration tab from the HYSPLIT dispersion model. Ni [20] explains that contaminant dispersion is the movement of the aerial contaminant in the atmosphere after being released from the origin. The trajectory is the path that has been followed by a certain object after a certain amount of time due to some force. Figure 2 shows the rough trajectory of the contaminant after 24 hours whereas Figures 3(a), 3(b) and 3(c) is the dispersion of contaminant Cesium-137 for the air and ground activity concentration for Kuala Lumpur, Kuching and Kota Kinabalu, respectively.



(a) (b)

(c)

Fig. 2. Satellite view of (a) Kuala Lumpur (b) Kota Kinabalu (c) Kuching

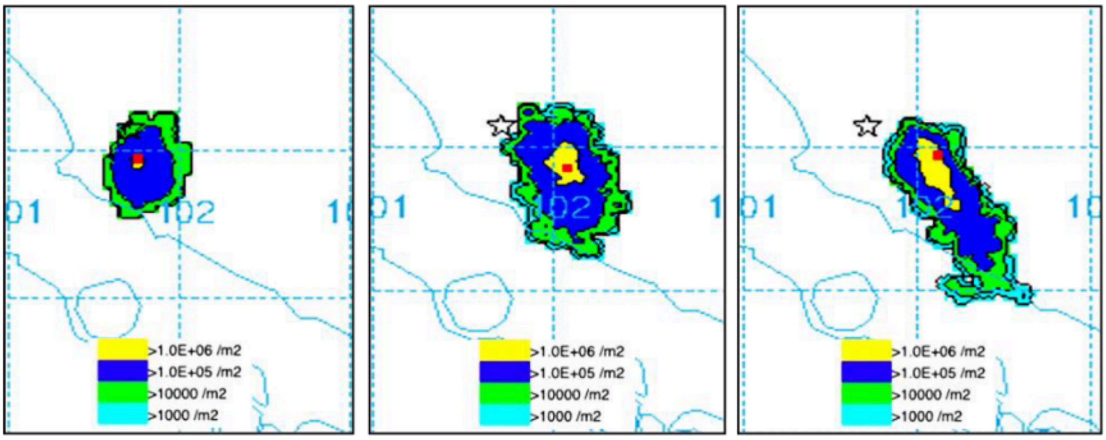


(a) (b) (c)

Fig. 3. Cs-137 trajectory after 24 hours from the 3 cities (a) Kuala Lumpur (b) Kuching (c) Kota Kinabalu

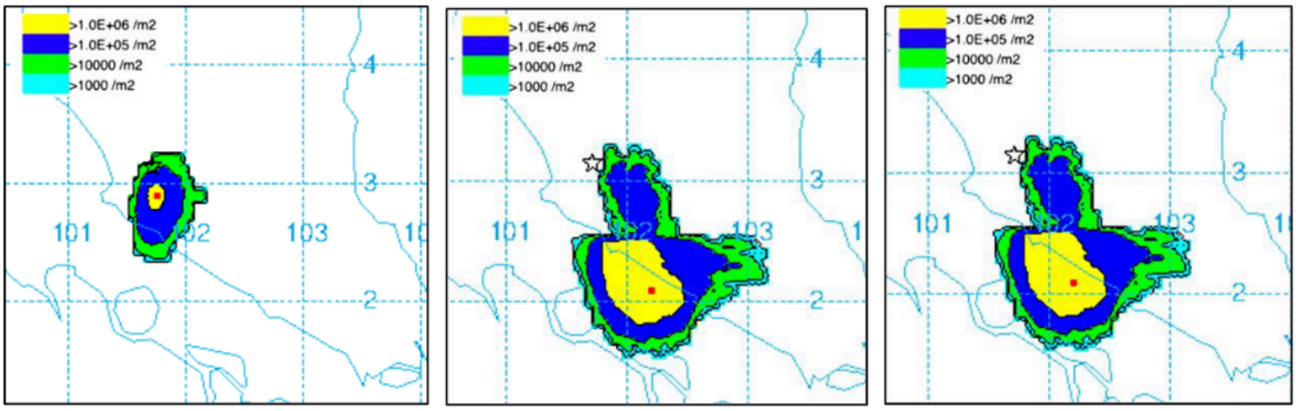
3.1 Trajectory

The trajectory of the Cs-137 is simulated by assuming that there was only a single particle of Cs-137, this is because the movement of the contaminant due to the wind and other factor can be seen much easier and to avoid from being confused due to a very scatter movement of the Cs-137 particles. Based on Figure 2, it can be seen that the path followed by the contaminant is different based on their initial location. The trajectory of the contaminant Cs-137 from Kuching, Sarawak shows the most direct which is almost moving in a straight path to the southeast compared to the radionuclide from Kuala Lumpur and Kota Kinabalu. However, the trajectory of the Cs-137 from Kota Kinabalu, Sabah showed the most complicated path with moving to the west before finally going back to the south. All of the trajectories seem like to follow the same displacement which all of it displaced to the southeast. This is probably because of the wind direction during the day. Figures 4 to 9 shows the dispersion of the radionuclides.



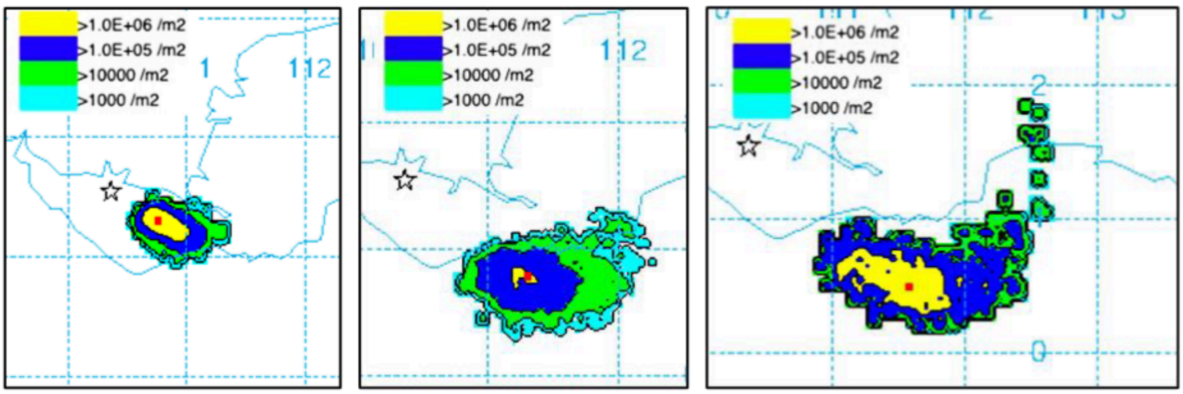
(a) (b) (c)

Fig. 4. Cs-137 Air concentration dispersion from Kuala Lumpur (a) 8 hours (b) 16 hours (c) 24 hours after release



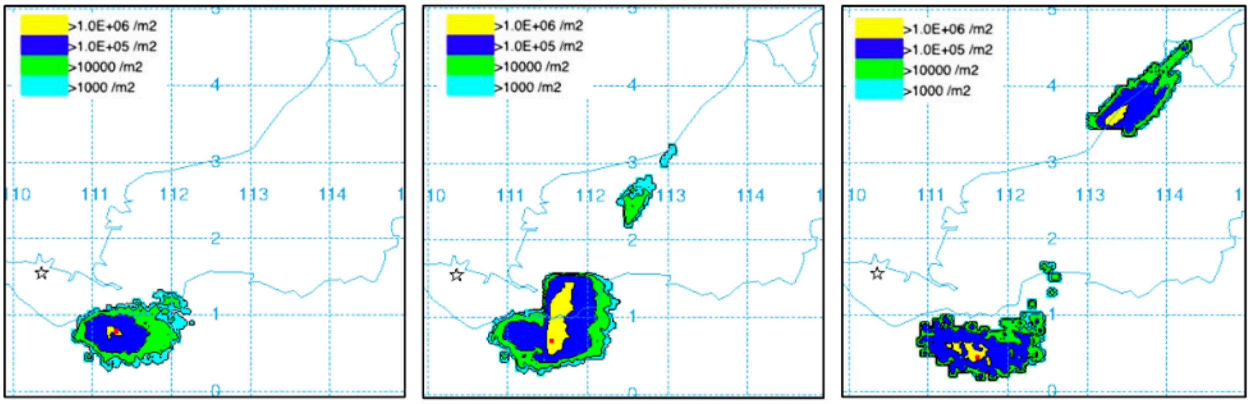
(a) (b) (c)

Fig. 5. Cs-137 ground deposition from Kuala Lumpur (a) 8 hours (b) 16 hours (c) 24 hours after release



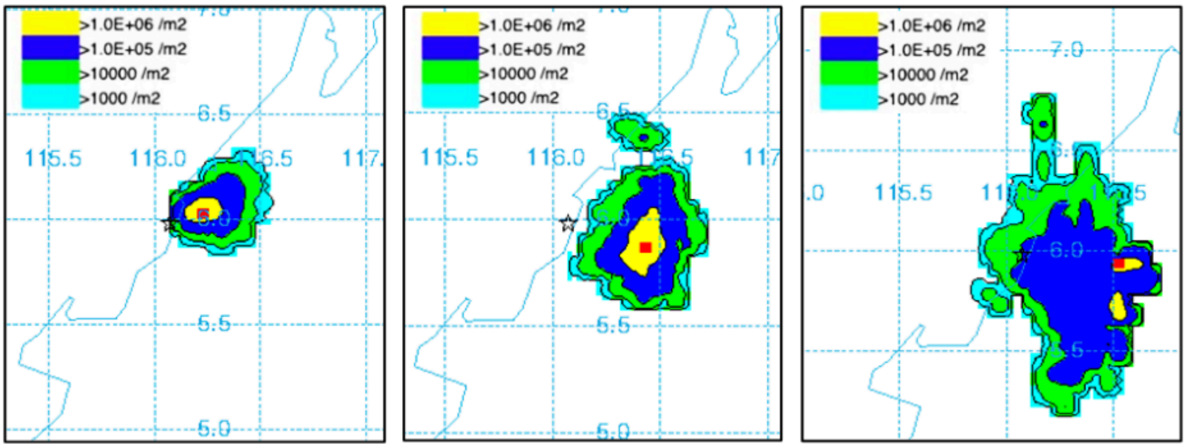
(a) (b) (c)

Fig. 6. Cs-137 Air concentration dispersion from Kuching (a) 8 hours (b) 16 hours (c) 24 hours after release



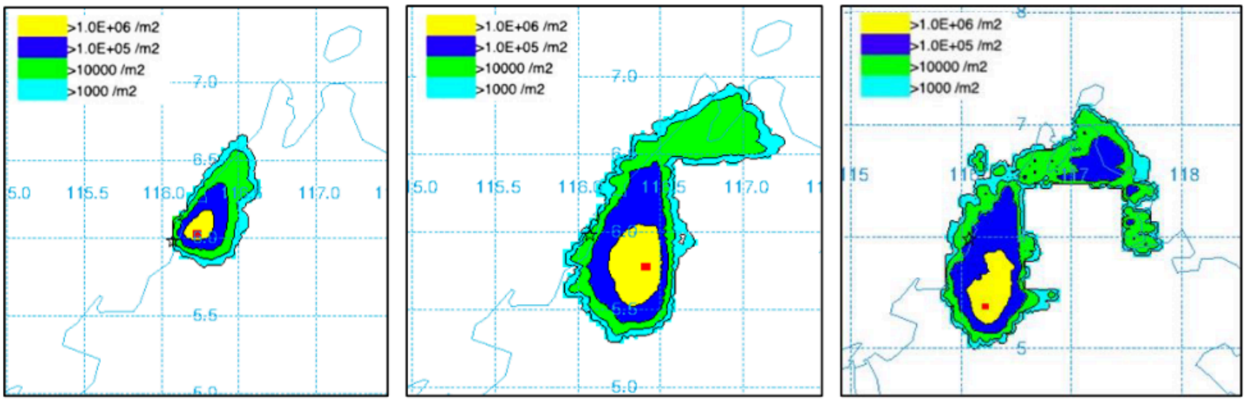
(a) (b) (c)

Fig. 7. Cs-137 Ground deposition from Kuching (a) 8 hours (b) 16 hours (c) 24 hours after release



(a) (b) (c)

Fig. 8. Cs-137 air concentration dispersion from Kota Kinabalu (a) 8 hours (b) 16 hours (c) 24 hours after release



(a) (b) (c)

Fig. 9. Cs-137 ground depostion Kota Kinabalu (a) 8 hours (b) 16 hours (c) 24 hours after release

3.2 Air Concentration and Deposition

As for air concentration, it was simulated to show the precise and much more thorough analysis of the contaminant Cs-137. Furthermore, the area that has been affected by the radionuclide was able to be identified by simulating the dispersion of the contaminant from the radioactive dispersal device. The dispersion of the radionuclide was simulated in the air and on the ground. From Figures

3, 4 and 5, the dispersion of the radionuclide in the air followed the trajectory of their respective initial location. However, the dispersion of Cs-137 on the ground shows a remarkable difference compared to the dispersion in the air especially for the ground dispersion from Kuching and Kota Kinabalu. Some reasons for why this difference occurs is because the radionuclide that has been deposited on the ground can also be carried by the rain and the rivers. Radionuclide deposited on Kota Kinabalu shows a somewhat very difference in shape probably because due to the terrain that is high and rocky mountain around the location thus preventing the contaminant from reaching a certain part of the region.

Getting the max radioactivity and dose concentration value is crucial in this case because from the highest value, the worst possible scenario can be imagined thus emergency warning can be announced right away. The max radioactivity and dose concentration for three cities are tabulated in Table 2 and Table 3.

Table 2
Maximum radioactivity in the air and on the ground after 24 hours

Location	Air radioactivity (MBq)	Ground radioactivity (MBq)
Kuala Lumpur	0.41	570
Kuching	0.22	270
Kota Kinabalu	0.95	1200

Table 3
Max dose concentration in the air and on the ground after 24 hours

Location	Air concentration (mSv)	Ground deposition (mSv)
Kuala Lumpur	3.3	150
Kuching	1.8	71
Kota Kinabalu	7.7	310

From Table 2 and Table 3, the radioactivity and dose concentration in Kota Kinabalu show a very significant value that is more than twice the value from Kuala Lumpur. The lowest concentration value is at Kuching but however, both values of dose concentration in air and ground that is 1.8 mSv and 71 mSv surpassed the dose limit of only 1 mSv in a year for normal civilians based on the Atomic Licensing Act, (1984).

Although the max radioactivity and dose concentration for 24 hours was able to be taken, the data is not enough because the value is too general for 24 hours only. This means that the time that is the most crucial cannot be discovered. For this reason, the max dose concentration for 24 hours is divided by 4 hours each to find out the significant dose value during the 4 hours each. The dose conversion factor that was inserted into the Contours tab will be changed to 4.32E-11 and 1.37E-9 for deposition and airborne concentration multiplier respectively.

Figure 10 and Figure 11 show the value of the effective dose for 24 hours by 4 hours each. Both graphs show that the highest effective dose concentration is during the first 4 hours with the leading value that was carried on by the radionuclide from Kota Kinabalu. In Figure 10 the lowest dose concentration in the air is the contaminant Cs-137 from Kuching, Sarawak with the value of 1.8E-03 mSv followed by Kuala Lumpur that is 3.4E-03 mSv. Based on Figure 11 which is for the dose deposited on the ground, it follows the same trend as the graph in Figure 10 that is the highest and the lowest dose concentration are from the same place. Based on the graph it is important to know that the first 4 hours after the explosion of RDD is the riskiest duration.

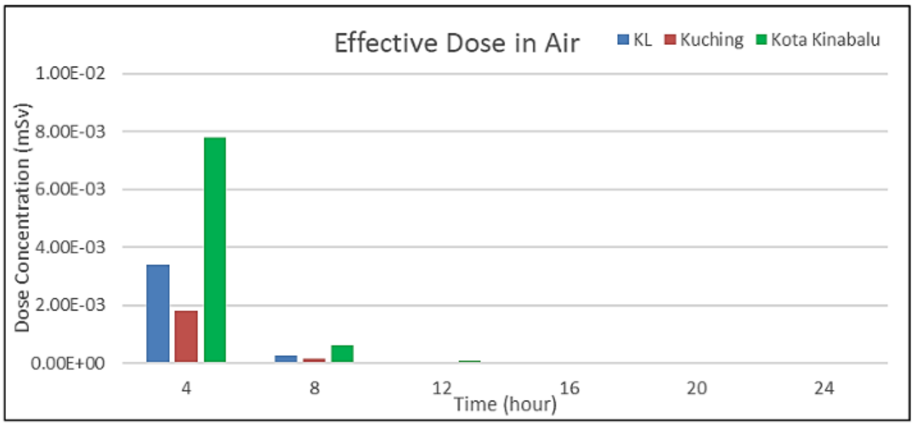


Fig. 10. Effective dose in the air after 24 hours by 4 hours each

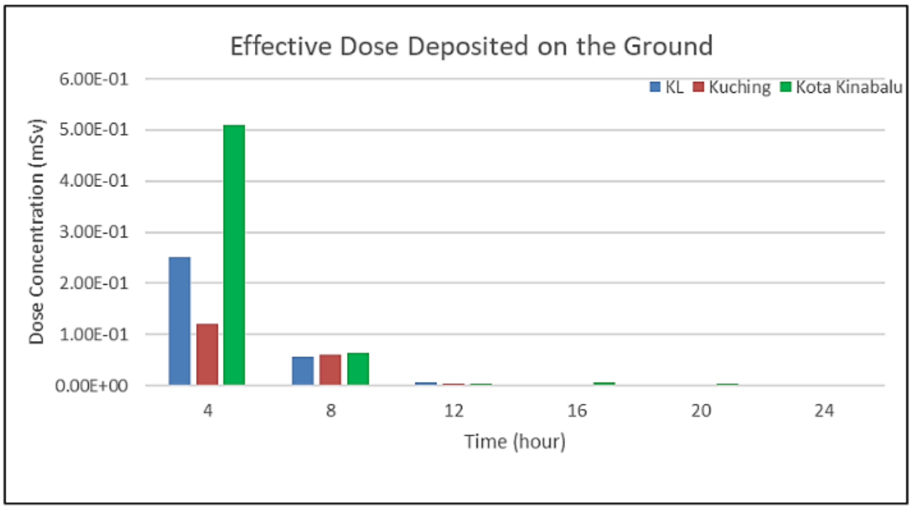


Fig. 11. Effective dose deposited on the ground for 24 hours by 4 hours each

3.3 Dose Concentration After 24 Hours

Since the significant dose concentration is at the first 4 hours after the explosion scenario. Further in-depth analysis in the first 4 hours will be carried out by analyzing the dose concentration during the 15 minutes each. The dose conversion multiplier value will be 2.7E-12 and 8.35E-11 for ground deposition and airborne concentration respectively. The investigation of the dose concentration will also be divided into several levels or height which are 0-20, 20-40, 40-60, 60-80 m and the ground deposition. The result is tabulated in Table 4 for Kuala Lumpur, Table 5 for Kuching and Table 6 for Kota Kinabalu. The result is also put into a graph form which can be found in Figures 12, 13 and 14 for Kuala Lumpur, Kuching and Kota Kinabalu respectively.

3.3.1 Kuala Lumpur

The dose was simulated by assuming there is no background radiation or external factor during the initial release of Cs-137 by the RDD which means at 0 minutes there will be zero mSv. The highest effective dose concentration that can be seen from Table 4 and Figure 12, is during the 30 to 75 minutes mark with the highest value that is 1.10E-03 mSv coming from the altitude at 60 to 80 metres. Soon after the dose concentration reaches the highest value, it showed a sharp decline during the 90 to 105 minutes. The dose concentration then steadily decreases until the 240 minutes with some very small increment sometime during the duration after 105 minutes.

Table 4
Highest dose concentration for certain level for 15 minutes in 4 hours via Kuala Lumpur

Minutes	Concentration by each level (mSv)				
	00-20	20-40	40-60	60-80	Ground deposition
0	0	0	0	0	0
15	9.50E-05	1.40E-04	2.20E-04	5.00E-04	8.00E-05
30	6.10E-04	7.50E-04	8.50E-04	1.10E-03	2.00E-04
45	7.50E-04	8.40E-04	8.70E-04	9.80E-04	2.20E-04
60	7.80E-04	8.40E-04	8.90E-04	9.30E-04	2.70E-04
75	9.90E-04	8.50E-04	9.50E-04	8.40E-04	4.00E-04
90	6.70E-04	7.20E-04	7.80E-04	6.20E-04	3.70E-04
105	3.40E-04	3.80E-04	4.20E-04	4.10E-04	2.50E-04
120	3.90E-04	4.10E-04	4.10E-04	4.10E-04	3.00E-04
135	3.70E-04	3.30E-04	2.70E-04	3.00E-04	2.70E-04
150	2.50E-04	1.70E-04	1.80E-04	2.50E-04	1.90E-04
165	1.60E-04	1.30E-04	2.20E-04	2.40E-04	2.00E-04
180	1.50E-04	1.40E-04	2.00E-04	1.50E-04	1.80E-04
195	1.60E-04	8.90E-05	1.50E-04	7.70E-05	1.30E-04
210	1.00E-04	1.10E-04	1.20E-04	1.10E-04	1.20E-04
225	7.50E-05	9.20E-05	6.90E-05	9.80E-05	1.00E-04
240	8.70E-05	8.40E-05	6.70E-05	8.40E-05	8.30E-05

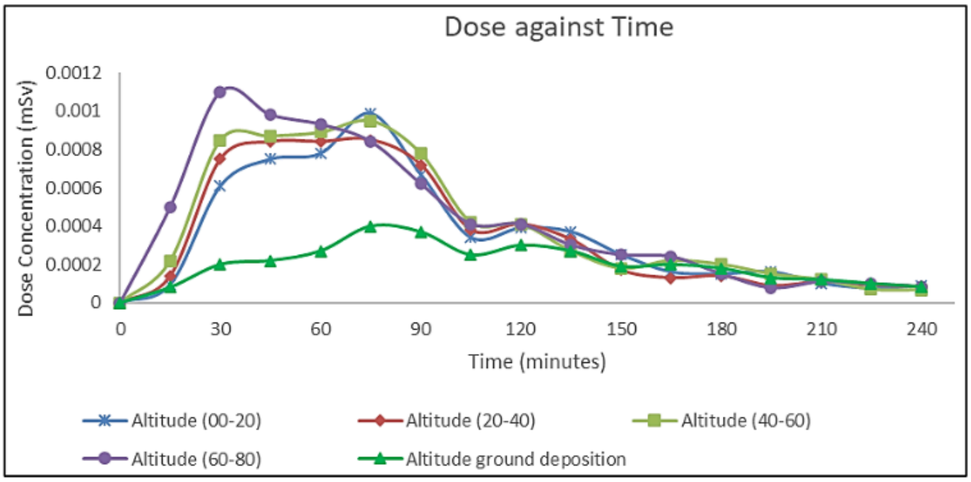


Fig. 12. Highest dose concentration for certain altitude for 15 minutes in 4 hours via Kuala Lumpur

3.3.2 Kuching

The same goes with the dose concentration in Kuching, the value for the initial dose value at 0 minute is considered as 0 mSv assuming that there is no background radiation or any external factor that can affect the simulation. From the Table 5 and Figure 13, the dose concentration dramatically increases from 0 minute to 30 minutes for all altitudes except for the dose that has been deposited on the ground that increases at a much slower rate. However, as the dose concentration in the air showed a peak at the 30 minutes to 60 minutes, the dose deposited on the ground peaked at a much more later time which is at the 195 minutes with the dose deposited value as 2.3E-04 mSv before slowly decreasing. Only at the altitude of 60 to 80 metre was shown the dose concentration bounced back a little bit with an increment of 4.3E-05 mSv from the 225 minutes to 240 minutes.

Table 5
Highest dose concentration for certain level for 15 minutes in 4 hours via Kuching

Minutes	Concentration by each level(mSv)				
	00-20	20-40	40-60	60-80	Ground deposition
0	0	0	0	0	0
15	2.70E-04	3.10E-04	3.30E-04	4.10E-04	1.20E-04
30	4.70E-04	4.40E-04	5.00E-04	5.00E-04	1.70E-04
45	4.00E-04	4.60E-04	5.00E-04	5.10E-04	1.70E-04
60	4.40E-04	4.30E-04	4.50E-04	4.90E-04	1.90E-04
75	3.30E-04	3.10E-04	3.80E-04	3.50E-04	2.10E-04
90	3.50E-04	3.80E-04	3.30E-04	3.70E-04	1.20E-04
105	3.00E-04	2.80E-04	2.00E-04	2.70E-04	9.20E-05
120	2.50E-04	1.90E-04	1.80E-04	1.40E-04	1.00E-04
135	1.90E-04	1.40E-04	2.60E-04	1.80E-04	1.10E-04
150	1.60E-04	1.10E-04	1.50E-04	1.60E-04	1.00E-04
165	1.30E-04	1.10E-04	1.10E-04	1.20E-04	8.00E-05
180	1.80E-04	9.20E-05	7.00E-05	1.10E-04	8.60E-05
195	1.10E-04	7.30E-05	8.80E-05	7.60E-05	2.30E-04
210	1.10E-04	6.30E-05	5.20E-05	5.80E-05	1.60E-04
225	3.80E-05	3.30E-05	5.10E-05	3.60E-05	1.40E-04
240	3.40E-05	4.50E-05	3.70E-05	7.90E-05	1.30E-04

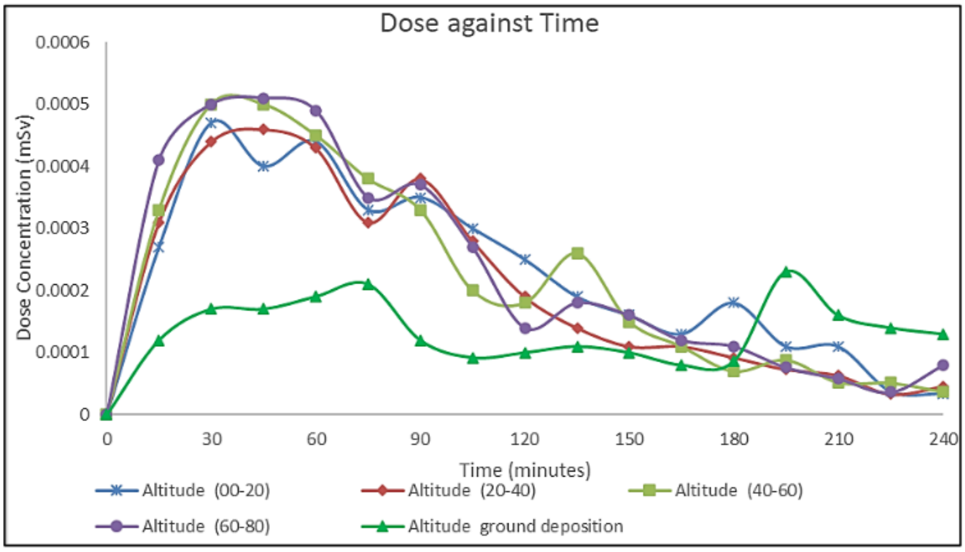


Fig. 13. Highest dose concentration for certain altitude for 15 minutes in 4 hours via Kuching

3.3.3 Kota Kinabalu

Based on Table 6 and Figure 14, the dose concentration for all altitudes increases at a normal rate for 1 hour after the release of the contaminant from the RDD. The dose concentration is at the peak at around 60 minutes to 90 minutes before finally undergoing a downward trend until the last 240 minutes with some minimal increment that can be considered as insignificant. The highest dose concentration for the dispersion of contaminant from RDD in Kota Kinabalu is at the altitude 60 to 80 metres with the value of 1.80E-03 mSv whereas the lowest dose concentration of the peak value is for the ground deposition level with the value of only 5.80E-04 mSv.

Table 6
Highest dose concentration for certain level for 15 minutes in 4 hours via Kota Kinabalu

Minutes	Concentration by each level(mSv)				
	00-20	20-40	40-60	60-80	ground deposition
0	0	0	0	0	0
15	1.80E-06	3.40E-05	8.50E-05	4.50E-04	1.20E-04
30	1.00E-04	2.80E-04	7.40E-04	1.30E-03	3.10E-04
45	2.90E-04	5.70E-04	1.10E-03	1.60E-03	4.60E-04
60	6.00E-04	8.70E-04	1.20E-03	1.80E-03	5.80E-04
75	9.40E-04	1.10E-03	1.40E-03	1.30E-03	5.60E-04
90	1.00E-03	1.00E-03	9.10E-04	1.00E-03	4.70E-04
105	8.00E-04	7.20E-04	6.50E-04	6.90E-04	3.50E-04
120	4.60E-04	6.00E-04	5.40E-04	4.30E-04	2.70E-04
135	6.00E-04	6.90E-04	6.90E-04	5.10E-04	2.90E-04
150	6.60E-04	7.10E-04	6.20E-04	6.00E-04	2.50E-04
165	5.60E-04	5.80E-04	5.10E-04	3.70E-04	2.10E-04
180	3.50E-04	4.20E-04	3.80E-04	3.70E-04	2.30E-04
195	4.50E-04	4.80E-04	2.80E-04	4.40E-04	2.00E-04
210	4.50E-04	3.70E-04	3.60E-04	3.50E-04	1.50E-04
225	2.60E-04	3.10E-04	2.10E-04	2.20E-04	1.30E-04
240	2.20E-04	1.70E-04	2.30E-04	2.10E-04	1.20E-04

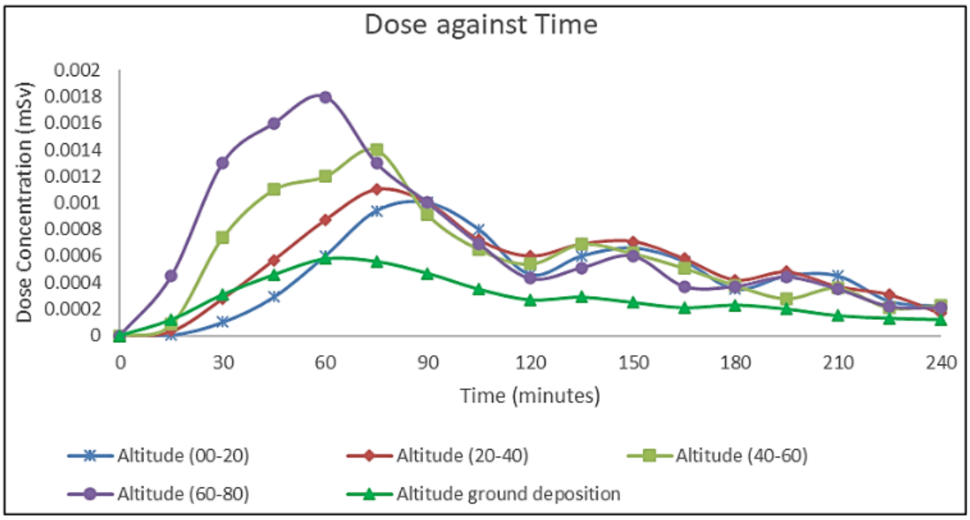


Fig. 14. Highest dose concentration for certain altitude for 15 minutes in 4 hours via Kota Kinabalu

In general, the value of the dose concentration usually reaches the highest at the 30 to 90 minutes mark and at the altitude of 60 to 80 metre. However, there is an exception for this statement as in Kuching, Sarawak, the dose concentration for ground deposition is at the highest during 195 minutes. Moreover, the dose concentration always decreases steadily after reaching its peak which can be seen clearly in all Figures 12, 13 and 14. Lastly, the effective dose concentration at a ground level always shows the least value compared to the dose concentration at the altitude of 0 to 20, 20 to 40, 40 to 60 and 60 to 80 metres.

3.4 Morbidity and Mortality

Morbidity and mortality are study to measure an incident related to the health and how severe it is to the population [21, 22]. In this research, the morbidity and the mortality per 100000 people will be found out. The research will use the radioactivity in the air concentration, breathing rate for adults and the morbidity and mortality coefficient from US EPA, 1999. Morbidity and mortality were calculated from Eqs. (4) and (5) respectively: The breathing rate for an average adult is 0.74 m^3/h, morbidity coefficient is 2.19×10^{-10} Bq^{-1} while mortality coefficient is 3.21×10^{-10} Bq^{-1} (US EPA,1999). The data has been compiled in the Tables 7 to 9.

Table 7
Mortality and morbidity per 100000 people in 15 minutes time for 4 hours via Kuala Lumpur

Minutes	Mortality per 100000 people based on the altitude (m)				Morbidity per 100000 people based on the altitude (m)			
	(00-20)	(20-40)	(40-60)	(60-80)	(00-20)	(20-40)	(40-60)	(60-80)
15	5	7	11	24	7	10	16	36
30	30	36	41	53	43	53	61	78
45	36	41	42	48	53	60	62	70
60	38	41	43	45	56	60	63	66
75	48	41	46	41	71	61	68	60
90	33	35	38	30	48	51	56	44
105	17	18	20	20	24	27	30	29
120	19	20	20	20	28	29	29	29
135	18	16	13	15	26	24	19	21
150	12	8	9	12	18	12	13	18
165	8	6	11	12	11	9	16	17
180	7	7	10	7	11	10	14	11
195	8	4	7	4	11	6	11	5
210	5	5	6	5	7	8	9	8
225	4	4	3	5	5	7	5	7
240	4	4	3	4	6	6	5	6

Table 8
Mortality and morbidity per 100000 people in 15 minutes time for 4 hours via Kuching

Minutes	Mortality per 100000 people based on the altitude (m)				Morbidity per 100000 people based on the altitude (m)			
	(00-20)	(20-40)	(40-60)	(60-80)	(00-20)	(20-40)	(40-60)	(60-80)
15	13	15	16	20	19	22	24	29
30	23	21	24	24	33	31	36	36
45	19	22	24	25	29	33	36	36
60	21	21	22	24	31	31	32	35
75	16	15	18	17	24	22	27	25
90	17	18	16	18	25	27	24	26
105	15	14	10	13	21	20	14	19
120	12	9	9	7	18	14	13	10
135	9	7	13	9	14	10	19	13
150	8	5	7	8	11	8	11	11
165	6	5	5	6	9	8	8	9
180	9	4	3	5	13	7	5	8
195	5	4	4	4	8	5	6	5
210	5	3	3	3	8	4	4	4
225	2	2	2	2	3	2	4	3
240	2	2	2	4	2	3	3	6

Table 9
Mortality and morbidity per 100000 people in 15 minutes time for 4 hours via Kota Kinabalu

Minutes	Mortality per 100000 people based on the altitude (m)				Morbidity per 100000 people based on the altitude (m)			
	(00-20)	(20-40)	(40-60)	(60-80)	(00-20)	(20-40)	(40-60)	(60-80)
15	0	2	4	22	0	2	6	32
30	5	14	36	63	7	20	53	93
45	14	28	53	78	21	41	78	114
60	29	42	58	88	43	62	86	128
75	46	53	68	63	67	78	100	93
90	49	49	44	49	71	71	65	71
105	39	35	32	34	57	51	46	49
120	22	29	26	21	33	43	38	31
135	29	34	34	25	43	49	49	36
150	32	35	30	29	47	51	44	43
165	27	28	25	18	40	41	36	26
180	17	20	18	18	25	30	27	26
195	22	23	14	21	32	34	20	31
210	22	18	18	17	32	26	26	25
225	13	15	10	11	19	22	15	16
240	11	8	11	10	16	12	16	15

It is clearly shown that the radioactivity in the air of Kota Kinabalu after the dispersion of Cs-137 can cause the most damage to the people because it has the highest mortality at 88 and the highest morbidity at 128 compared to Kuala Lumpur and Kuching. The seriousness of the situation in Kuching is the lowest with a maximum amount of morbidity and mortality barely able to reach 50 people. The morbidity and mortality tables also show that in Kuching and Kuala Lumpur, the severity of the situation during the first 15 minutes is lower than the final 15 minutes in 4 hours however the situation in Kota Kinabalu is the opposite with 0 morbidity and 0 mortality at the high of 0 to 20 metre during the first 15 minutes and 11 mortality and 16 morbidity at the final 15 minutes in 4 hours.

For this research, a dispersion model Cesium-137 was able to be simulated by using the HYSPLIT software. The dispersion model was simulated under the assumption that 50 TBq of Cs-137 has been dispersed by the RDD on 22nd December 2020 UTC in Malaysia's cities which is Kuala Lumpur, Kuching, and Kota Kinabalu. The location that will be affected by the contaminant Cs-137 was able to be located from the trajectory and dose concentration map of the Cs-137 dispersion. It is found out the place with the highest concentration after 24 hours of the Cs-137 dispersion is Kota Kinabalu with a concentration of 7.7 mSv in the air compared to Kuala Lumpur and Kuching at the value of 3.3 mSv and 1.8 mSv which cannot even reach half of Kota Kinabalu dose concentration. The most critical time for the dose concentration is during the first 4 hours which show that the dose concentration is at the highest around 30 to 90 minutes mark and at the altitude of 60 to 80 metre.

4. Conclusions

A risk assessment analysis was conducted based on the dose concentration collected. The morbidity and mortality rate of the city residents per 100000 people were evaluated by taking into account the radioactivity in the air, the breathing rate for an adult human, and the coefficient of morbidity and mortality reported by the United States Environmental Protection Agency in 1999. Results revealed that within 15 minutes of being in a tall building of 60 to 80 meters high, up to 88 people per 100000 would die due to the radioactivity in the air from 0045 hours to 0100 hours in Kota Kinabalu. Additionally, the number of people affected by permanent health problems is considerably higher than the number of fatalities. This suggests that the radiation dose from Cs-137 dispersion poses a severe hazard to the country, potentially hindering Malaysia's progress toward becoming a developed nation.

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