UNIVERSITI PUTRA MALAYSIA

ATMOSPHERIC DISPERSION AND DOSE ASSESSMENT OF131I AND 137Cs FROM SIMULATED NUCLEAR POWER PLANT EXPLOSIONS IN SOUTH-EAST ASIA

LOKMAN HAKIM BIN MUHAMAD

ATMOSPHERIC DISPERSION AND DOSE ASSESSMENT OF ^{131}I AND ^{137}Cs FROM SIMULATED NUCLEAR POWER PLANT EXPLOSIONS IN SOUTH-EAST ASIA

By

LOKMAN HAKIM BIN MUHAMAD

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Bachelor of Science In Physics with Honours

February 2022

ATMOSPHERIC DISPERSION AND DOSE ASSESSMENT OF ^{131}I AND ^{137}Cs FROM SIMULATED NUCLEAR POWER PLANT EXPLOSIONS IN SOUTH-EAST ASIA

By

LOKMAN HAKIM BIN MUHAMAD

Thesis Submitted to the Department of Physics, Universiti Putra Malaysia, in partial Fulfilment of the Requirements for the Bachelor of Science in Physics with Honours
February 2022

DEDICATION

I would like to dedicate this dissertation to :

My beloved parents, Muhammad bin Mohd. Shah and Atiyator-Rahman binti Hamzah for always supporting me during completing this thesis. To be honest, it is not easy to complete it in this pandemic situation and they always supporting me.

The most important person for this project who is my supervisor, Dr Muhammad Khalis Bin Abdul Karim for guide me in this project. Thanks for suggest this interesting topic and also teach me about it from nothing until I able to complete my dissertation successfully.

All my fellow friends for all the discussions and also contribute some ideas and motivation for me to always do the best in this project. We have shared together in the process of completing this dissertation.

Thank you to everyone who directly or indirectly assisted me.

ABSTRACT

Atmospheric dispersion and dose assessment of ^{131}I and ^{137}Cs from simulated nuclear power plant explosions in South East Asia

By

Lokman Hakim Bin Muhamad

198362

February 2022

Supervisor: Dr. Muhammad Khalis Abdul Karim (PhD)

Faculty: Faculty of Science

Radiological incident is considered as one of tremendous disaster as it could cause significant amounts of radionuclides dispersed and lead to potential cancer risk. Hence, it is necessary for responsible authorities to simulate hypothetical accidents from a potential nuclear reactor. Therefore, this study aimed to evaluate the dispersion of ^{131}I and ^{137}Cs from the hypothetical incident scenario in Ninh Thuan, Vietnam (11.6906°N, 109.1753°E) and Bangi, Malaysia (2.9156°N, 101.7832°E) and to determine the potential exposure to the interest population. Furthermore, this data is crucial for the authority to determine the risk of mortality from the accidents if it eventually happen. The HYSPLIT model is used and configured based on the meteorological conditions in the two potential sites for Nuclear Power Plant (NPP) in southeast Asia. This model is used to simulate atmospheric dispersion of fission emissions and then assess the public health effects from the hypothetical nuclear accident. The maximum distance of radionuclides was determined by analysing activity concentration from the source term at different locations, time and altitudes. By extract this data, the mortality rate among the population can be obtained from the total individual dose intake and effective dose absorbed by the population living around the potential site. The results were compared with the allowed dose limits suggested by the *International Atomic Energy Agency* (IAEA) which is 1 mSv/yr for the public. The results indicate that the mean activity concentration for both radionuclides (^{131}I &^{137}Cs) are higher at Bangi compared to Ninh Thuan for the first day of accident. With the highest activity concentration of ^{137}Cs and ^{131}I which are 13.00 MBq/m^2 and 470.00 MBq/m^2 respectively at Bangi, there are approximately about 0.001227 mSv and 1.33 mSv effective dose from releasing of ^{137}Cs and ^{131}I, respectively. However, for incident in Ninh Thuan, there are approximately about 4.9 x10^{-5} mSv and 0.0559 mSv effective dose from releasing of ^{137}Cs and ^{131}I respectively. For risk estimation, the highest mortality risk due to the inhalation of ^{137}Cs is 15 out of 100,000 of population at Bangi within for altitude between 0 m to10 m within 4 hours after the accident. Meanwhile at Ninh Tuan there are about 3 out of 100,000 that is predicted to die due to the inhalation of ^{131}I each 4 level of altitudes. It is vital to minimize the radiological consequences on population, enhance the emergency protocols at the regions by taking location and geographical site into account. Some of the actions that should be taken are by evacuation, sheltering, ban the sale of local agriculture productions, and long-range resettlement of the population.

ABSTRAK

Penyerakan atmosfera dan penilaian dos ^{131}I dan ^{137}Cs daripada simulasi letupan loji kuasa nuklear di Asia Tenggara

Oleh

Lokman Hakim Bin Muhamad

198362

Februari 2022

Penyelia: Dr. Muhammad Khalis Abdul Karim (PhD)

Fakulti: Fakulti Sains

Insiden radiologi dianggap sebagai salah satu bencana yang besar kerana ia boleh menyebabkan sejumlah besar radionuklid tersebar dan membawa kepada potensi risiko kanser. Oleh itu, pihak berkuasa yang bertanggungjawab dalam bidang ini perlu untuk mensimulasikan kemalangan daripada reaktor nuklear yang berpotensi. Oleh itu, kajian ini bertujuan untuk menilai serakan ^{131}I dan ^{137}Cs daripada senario kejadian hipotetikal di Ninh Thuan, Vietnam (11.6906°U, 109.1753°E) dan Bangi, Malaysia (2.9156°U, 101.7832°E) dan untuk menentukan potensi pendedahan kepada penduduk . Tambahan pula, data ini penting untuk pihak berkuasa menentukan risiko kematian akibat kemalangan jika ianya berlaku. Model HYSPLIT digunakan dan dikonfigurasikan berdasarkan keadaan meteorologi di dua tapak berpotensi untuk Loji Tenaga Nuklear di Asia Tenggara. Model ini digunakan untuk mensimulasikan serakan pelepasan pembelahan di atmosfera dan kemudian menilai kesan kesihatan awam daripada simulasi kemalangan nuklear. Jarak maksimum radionuklid ditentukan dengan menganalisis kepekatan aktiviti dan dinilai berdasarkan lokasi, masa dan ketinggian yang berbeza. Dengan mengekstrak data ini, kadar kematian dalam kalangan penduduk boleh diperoleh daripada jumlah pengambilan dos individu dan dos berkesan yang diserap oleh penduduk yang tinggal di sekitar tapak berpotensi. Hasilnya dibandingkan dengan had dos yang dibenarkan yang dicadangkan oleh *International Atomic Energy Agency (IAEA)* iaitu 1 mSv/thn untuk orang ramai. Keputusan menunjukkan bahawa purata kepekatan aktiviti bagi kedua-dua radionuklid (^{131}I &^{137}Cs) adalah lebih tinggi di Bangi berbanding Ninh Thuan untuk hari pertama kemalangan. Dengan kepekatan aktiviti tertinggi iaitu ^{137}Cs dan ^{131}I iaitu 13.00 MBq/m2 dan 470.00 MBq/m^2 masing-masing di Bangi, terdapat kira-kira kira-kira 0.001227 mSv dan 1.33 mSv dos berkesan daripada pelepasan ^{137}Cs dan ^{131}I, masing-masing. Walau bagaimanapun, untuk kejadian di Ninh Thuan, terdapat kira-kira 4.9 x10^{-5} mSv dan 0.0559 mSv dos berkesan daripada pelepasan masing-masing ^{137}Cs dan ^{131}I. Untuk anggaran risiko, risiko kematian tertinggi disebabkan oleh penyedutan ^{137}Cs ialah 15 daripada 1000 dalam kalangan penduduk di Bangi iaitu di lingkungan ketinggian antara 0 m hingga 10 m dalam tempoh 4 jam selepas kemalangan. Manakala di Ninh Tuan terdapat kira-kira 3 daripada 100,000 yang diramalkan akan mati akibat penyedutan ^{131}I setiap 4 lapisan ketinggian. Adalah penting untuk meminimumkan akibat radiologi ke atas penduduk, meningkatkan protokol kecemasan di wilayah dengan mengambil kira lokasi dan tapak geografi. Beberapa tindakan yang perlu diambil adalah dengan pemindahan, perlindungan, pengharaman penjualan hasil pertanian tempatan, dan penempatan semula penduduk dalam jarak jauh.

ACKNOWLEDGEMENTS

First and foremost, I am grateful to the The Almighty God for giving me this golden opportunity and I would be able to be establish a complete study for this project. I would like to acknowledge and give warmest thanks to my supervisor Dr. Muhammad Khalis Abdul Karim (PhD) who made this work possible. His guidance and advice carried me through all the stages of writing my project. I would also like to thank to my committee members, Nuwair and Izham for letting my journey to complete this research as an enjoyable moment, and for brilliant ideas suggestions, and comments too.

I would like to express the deepest appreciation to my parents who continually giving support and motivate me to complete this research. Without their support and prayer, this dissertation would not have been possible.

Last but not least, my sense of gratitude goes to one and all who directly or indirectly have lent their helping hand in this dissertation.

APPROVAL

This thesis entitled "Atmospheric dispersion and dose assessment of ^{131}I and ^{137}Cs from simulated nuclear power plant explosions in South-East Asia " by Lokman Hakim Bin Muhamad (Matric No.: 198362), was submitted to the Department of Physics, Faculty of Science, Universiti Putra Malaysia and has been accepted as partial fulfilment of the requirement for the degree of Bachelor of Science (Hons.) Major in Physics.

Approved by,

Date: ………………………………

Dr. Muhammad Khalis Bin Abdul Karim
Project Supervisor
Department of Physics
Faculty of Science
Universiti Putra Malaysia

Date: ………………………………

Dr. Md Shuhazlly Bin Mamat @ Mat Nazir
Course Coordinator
Department of Physics
Faculty of Science
Universiti Putra Malaysia

Date: ………………………...……

Assoc. Prof. Dr. Suriati Paiman
Head of Department
Department of Physics
Faculty of Science
Universiti Putra Malaysia

TABLE OF CONTENT

CHAPTER 3 MATERIALS & METHODOLOGY

CHAPTER 4 RESULTS & DISCUSSIONS

CHAPTER 5 CONCLUSION

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

NOAA	National Oceanic and Atmospheric Administration
OECD	Organisation for Economic Cooperation and development
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
INES	International Nuclear and Radiological Event Scale
MAGNOX	Basic Gas-Cooled Reactor
BWR	Boiling Water Reactor
PWR	Pressurized Water Reactor
CANDU	Canada Deuterium Uranium
RBMK	Reaktor Bolshoy Moshchnosty Kanalny, high-power channel reactor
^{131}I	Iodine-131
^{134}Cs	Cesium-134
^{137}Cs	Cesium-137
^{134}Xe	Xenon-134
Bq	Becquerel
Sv	Sievert
m^3	Meter cube
m^2	Meter square
DNA	Deoxyribonucleic acid
HYSPLIT	Hybrid Single Particle Lagrangian Integrated Trajectory
EPR	Emergency preparedness respond
MKN	Majlis Keselamatan Negara
WANO	World Association of Nuclear Operators

ATDM	Atmospheric Transport and Dispersion Model
ASEAN	Association of Southeast Asian Nations
NPP	Nuclear Power Plant
WMO	World Meteorological Organization
UNCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
FDNPP	Fukushima Daiichi Nuclear Power Plant

CHAPTER 1

INTRODUCTION

1.1 Background of Study

In recent years, most of the countries in this world have been used nuclear source to produce energy. Nuclear source is one of the best alternatives of energy that can produce energy without produce massive amount of wastage. There are several countries that have been develop their technology in nuclear sector such as France, Armenia, South Korea, Spain and United States. Maintaining electricity is very important especially when the global population are increasing nowadays to 7.9 billion people and also world facing with the pandemic Covid-19 in 2021. When there are increasing demand of nuclear energy, it caused many countries to increase number of nuclear reactors. This situation will lead to the necessity of the atmospheric dispersion model together with nuclear risk assessment as the tool for emergency preparedness that will be explained further in the Chapter 2.

Generally, nuclear energy production has been divided into two types which are nuclear fusion and nuclear fission. Nowadays, all of the nuclear reactor in this world used nuclear fission to produce energy. There are three major accidents in the history of civil nuclear power which are accident at *Chernobyl* on 26 April 1986, Three Miles Island on 28 March 1979 and *Fukushima* on 11 March 2011 as shown in Figure 1.1. The main factors that contributed to the nuclear accidents are categorized into two types which are external and internal factors. External factors are including with earthquake, flood and also tsunami. Fukushima is an accident that is mainly caused by external factors. On the other hand, some examples of internal factors are loss of coolant which is one of the main problems that usually occur inside a nuclear reactor. It is undeniable that a proper and strict regulations should be provided as the workers are dealing with complex system in the nuclear reactor. In nuclear sector, safety is the most important aspect as nuclear energy contain radiation that might be harmful for people. In nuclear power plant, there are a lot of radioactive materials that are released from it and it should be one of the major concerns to the people surrounding. There are six types of nuclear reactor which are *Basic Gas-Cooled Reactor (MAGNOX), Boiling Water Reactor (BWR), Advanced Gas-Cooled Reactor , Pressurized Water Reactor (PWR) , Pressurized Heavy Water Reactor (CANDU) and RBMK REACTOR Boiling Light Water, Graphite Moderated Reactor* (Murray, 2000). This type of reactors will be discussed in detail in Chapter 2.

Figure 1.1 Nuclear accidents effects in Chernobyl and Fukushima (Webster et al., 2016)

From the Chernobyl accident, it is stated that the amounts of radionuclides were increasing from 9.35 x10^3 PBq up to 1.25 x 10^4 PBq and it had been dispersed over Belarus, North of Ukraine and part of Russia. The released radionuclides were largely dispersed across many European countries due to the changes of wind direction (De Cort et al., 1998). To ensure that accident such as this does not cause big impact, there some agencies or researcher that used Complex computer codes for the analysis of the performance of NPPs which can be characterized into six categories (Martinez-Quiroga et al., 2015):

(a) Atmospheric dispersion and dose codes

(b) Reactor physics codes

(c) Containment analysis codes, possibly also with features for the transport of radioactive materials

(d) Thermohydraulic codes, including system codes, subchannel codes, porous media codes and computational fluid dynamics (CFD) codes

(e) Fuel behaviour codes

(f) Structural analysis codes

Computer codes of atmospheric dispersion is able to analyze the deposition of radionuclides on the ground and their transport or movement in the atmosphere. This assist researchers to estimate the radiation dose among the population. There are many dispersion models that can be used to analyze radionuclides dispersion and also its risk. There are some examples of dispersion model such as 3AERMOD, CALPUFF, CTDMPLUS and HYSPLIT. In this study, *Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT)* model will be used to analyse atmospheric dispersion and dose assessment of ^{131}I and ^{137}Cs from severe nuclear power plant accidents in South-East Asia. HYSPLIT is an example of ATDM that was first developed by Draxler and Hess at Air Research Laboratory of the National Oceanic and Atmospheric Administration of the United States to calculate the trajectory of air masses and dispersion and deposition of pollutants. The application and usage of HYSPLIT will be further discussed in Chapter 2.

1.2 Problem Statement

There are many evidences that show the increasing of wastage from energy production in this world. Based on the report *International Energy Outlook 2013,* it is estimated that world energy consumption will increase about 56% from 2010 until 2040 (Allouhi et al., 2015). Nuclear energy is one of the energy sources that has potential to solve this problem even though it is not considered as renewable energy. It is important for a developing country such as Malaysia to focus on study that related to nuclear energy sector. In the previous nuclear accident at Chernobyl, it can be observed that the effects were still remaining in long term which is from 1986 until 2017. It is dangerous for the population as the radionuclides will be dispersed widely to many areas and affected human surroundings. In the past nuclear accident at Chernobyl, most of the radioactive materials are dispersed within 20 km from the reactor. In 1990, four years after the Chernobyl disaster, a rise in thyroid cancer was discovered in kids who had been exposed to the accident's fallout (International Atomic Energy Agency (IAEA), 1991). It becomes difficult to analyze movement of radionuclides as it is very tiny and easily move by air. As a result, many people attacked by cancer disease without any sign. In Fukushima accident, even though there are no deaths recorded due to the cancer from the incidents, however it can be observed that large parts of Japan are contaminated for at least 300 years with ^{137}Cs, mainly in the northeast which consist of many people.

A study has been made to analyze the radiological component on a potential site at Baiji. The results of this study shown that people within the area of the potential site will receive high amount of dose intake for each person if the accident of the in the Baiji's nuclear reactor occur. The results were compared with the dose limits that is suggested by the International Commission on Radiological Protection (ICRP), and it was exceeding by 1 Sv for the areas that is near to the potential site (Saeed et al., 2019). This finding shows that by using computer model such as HYSPLIT, it allowing this study to provide some prediction on some location even though the reactor has not built yet there. In order to build a nuclear reactor, it is important to ensure that the place is suitable which means it will not cause big harmful effects to the residents if accident occur. This analysis is very relatable to the population density and geographical location. The specific location for built the reactor cannot be analyzed by using common radius measure only because the air movement should be accounted as the main factor that can increase the dispersion of radionuclides to the population (IAEA, 2016).

In the previous study, the calculation of the effective dose is not detail explained by the author of the study in the final result because it is not too accurate for analyze the cancer risk. To improve this, there use models that called BEIR VII dose-response to determine more accurate value that is useful for safety data. Previous studies have shown that radiation risks can be estimated by using HYSPLIT modelling. Based on several studies and project in Southeast Asia, there are few advanced developments and projects in nuclear energy sector. However, there are no comprehensive study if an accident happens in this area as people know nuclear energy will give short and long terms effects to the environment. Thus, this analysis should be computed as the emergency preparedness respond (EPR). In taxonomy of nuclear accident branch, it is stated that emergency preparedness is the one of the key terms that must be emphasized. It includes the criteria for hazard assessment for emergency preparedness and response and for the development of the protection strategy, including results of the hazard assessment and the protection strategy in place prior to the emergency response (IAEA, 2016).

1.3 Objectives of the study

1.3.1 General Objectives

In this study, the general aim is to evaluate ^{131}I and ^{137}Cs atmospheric dispersion and to create an inventory distribution for Southeast Asia region if there are nuclear accidents or it is called emergency preparedness within this area.

1.3.2 Specific Objectives

1) To evaluate the consequences of the worst hypothetical accident scenario in Southeast Asia region based on previous nuclear incident.
2) To determine cumulative effective dose of Malaysian population and other countries' population due to severe nuclear incident.
3) To quantify the risk from the simulation of accident and to establish reference data for Southeast Asia region nuclear safety authority.

1.4 Scope of Study

In this study, the analysis of the hypothetical accidents focused in Southeast Asia region. The assumption of the existence of reactor is within the potential country such as Indonesia and Vietnam. The specific location for analyzing the air dispersion is in the Vietnam and Malaysia region which means the assumption of the radioisotopes is coming from the hypothetical accidents from these countries. The reason Vietnam has been chosen to be place of accident is because they have high potential to be build the first nuclear reactor built in Southeast Asia region. The activity of the radionuclides that is focused on is ^{131}I and ^{137}Cs which can be released when a nuclear reactor's explosion occurs. However, the main tool that is used to analyze this information is by computing data in HYSPLIT. As a result, the produced data might not be too accurate but it can made as a reference to determine the most suitable places to build a nuclear reactor.

1.5 Significance of Study

In this study, the atmospheric dispersion of ^{131}I and ^{137}Cs radionuclides are evaluated to create a distribution of activity that is useful for emergency preparedness. Hence, this research could provide information for nuclear safety and security authority that is responsible in nuclear safety. For example, in Malaysia the authority is leaded by "*Majlis Keselamatan Negara"* (MKN). This data is very important for them to ensure safety of the residents if any nuclear accidents occur within the Southeast Asia region. Moreover, there are no proper analysis on the dispersed radionuclides in Southeast Asia region as there are none nuclear reactor has been built completely in this region. In addition, lack of expertise in this field also has leading for a country to ignore about this issue. In order to secure that the nuclear reactor is suitable to be built in a place, analysis of the effective dose is very crucial to determine risk assessment level. It is required to determine the spatial radionuclides molecular distribution and then convert to radiation dosage in order to analyze the effects of radioactive pollutants from nuclear reactor on human health and ecological dangers.

Analysis of nuclear accident is very important to ensure a country already have enough preparedness and security in some locations. There are many types of emergency preparedness that can be done in nuclear safety management and one of it is by using computing codes. Due to the Covid-19 pandemic situation, it has already restricted some movement of people to do some research physically. As a result, this research is focused more on the computing part to predict some results from a simulation nuclear accident. By analyze the hypothetical accidents of some nuclear reactor in certain location, this study able to detect number of populations that affected by some kind of dangerous radionuclides such as ^{131}I and ^{137}Cs. Figure 1.2 shows the research framework of this study by using HYSPLIT modelling.

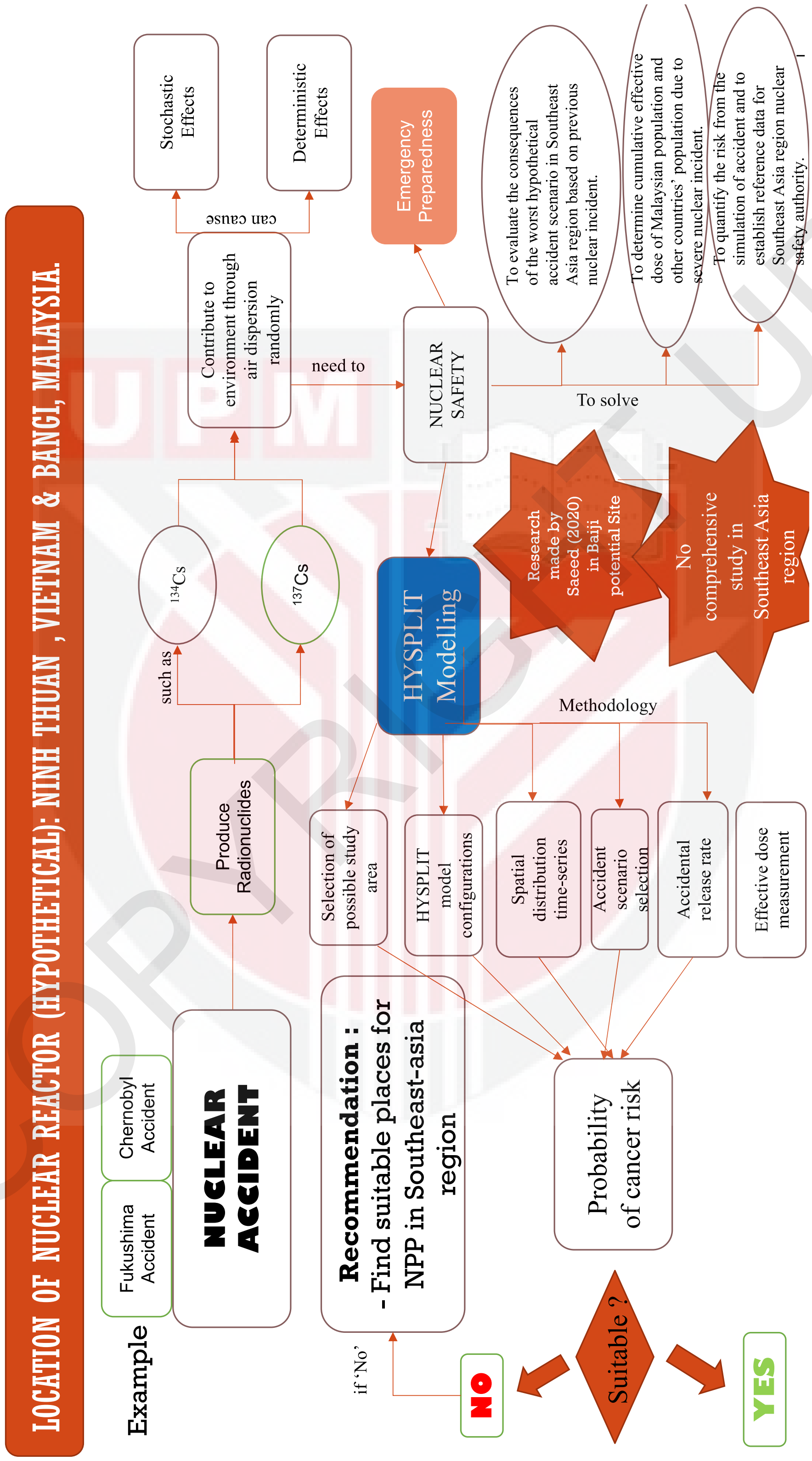


Figure 1.2 Research framework of this study

1.6 Thesis Outline

This thesis consists of five chapters in order to provide information and flow on how to do some analysis on the simulation nuclear accident. For Chapter 1, which is the introduction of this study explains about the background, problem statement, objectives, scopes and significance of study. Chapter 2 which is literature review, is focused more about the nuclear safety, radiobiological effects, dispersion models, previous works in this area and also some information regarding the development of nuclear field in southeast Asia region.

In Chapter 3, it emphasizes on the steps to produce dispersion of Cesium isotopes in some selected regions and also how HYSPLIT modelling able to convert the required information into dose estimation among the population. By using this activity concentration and estimated dose receive by the population, this study able to predict risk of mortality for different altitudes. In chapter 4, the results of the experiment have been outlined based on the method that is provided in chapter 3. As a results, this study can prepare for an emergency preparedness among the population in near the nuclear reactor.

Lastly, chapter 5 conclude the result and objectives of this study where Ninh Thuan and Bangi are suitable locations to build nuclear reactor and there are some recommendations that are suggested to improve this study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter describes the theory and latest development which are related to this study. It consists of nuclear safety, radiobiological effects, dispersion models, previous works in this area and also some information regarding the development of nuclear field in southeast Asia region. This is the section that explain in details about the previous chapter in this study.

2.2 Importance of Nuclear Safety

There are several organizations that are responsible to maintain and manage nuclear safety in this world. It is important to control it properly because releasing of radionuclides can harm public people directly or indirectly. Besides that, it is important to prevent previous accident that can cause big disaster such as in Fukushima and Chernobyl.

2.2.1 History and Regulatory

Nuclear safety sector is a very important to ensure systematic security in nuclear field. The main purpose of nuclear safety is to achieve good operating conditions and prevent at least reduce the radiological effects that released from nuclear accidents to the workers, public people and also environment. There are many organizations that are listed to contribute in this field such as IAEA, NEA, World Association of Nuclear Operators (WANO) and others. IAEA is one of the organizations that has huge responsibilities in this field. IAEA is stand for International Atomic Energy Agency and this agency has the responsible to promote peaceful by using nuclear energy. IAEA was established in 1957 in response to the significant anxieties and expectations engendered by the discoveries and various applications of nuclear technology.

It is common for the public to have bad looking to the nuclear energy as dangerous to the society. IAEA is the main organization that need to take action to convince people towards nuclear energy. IAEA also linked to NOAA organization as both of it concern about the activity of the radionuclides in the atmosphere. This model was used in simulating the dispersion of a variety of pollutants. The main elements of a nuclear safety regime can be described as Figure 2.1.

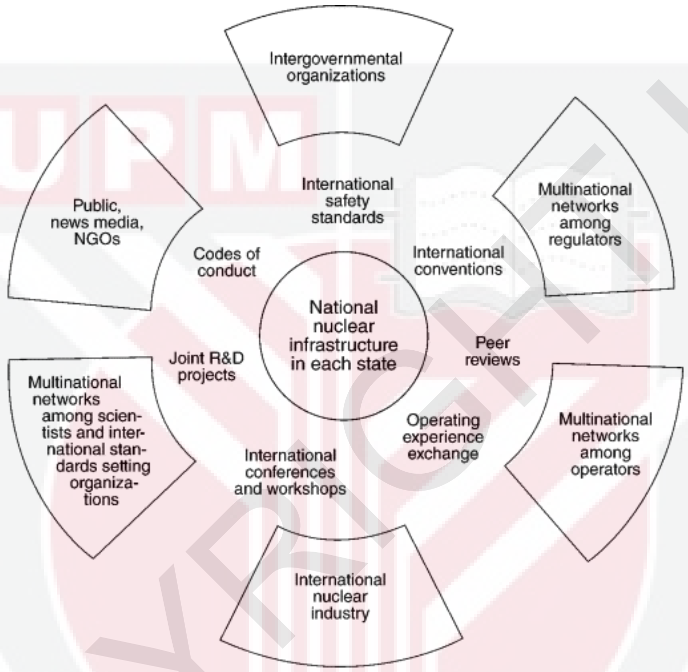


Figure 2.1 The wheel of the global safety regimen (Nuclear Fuel Cycle Science and Engineering, 2012)

Nowadays, there are lot of improvement that has been made in nuclear sector as the world want to avoid from big nuclear accident such as Chernobyl occur again in the future. It is undeniable that the world needs to choose nuclear energy as the main source in the future so it become compulsory for the physicist to make a lot of improvement in nuclear safety sector. Previous accident such as Chernobyl accident in 1986 showed that it is necessary for all countries to become active partners in a single global nuclear safety regime.

Besides that, there also many wars and also terrorist that used nuclear energy as weapons to kill people. These effects will harm not only to the targeted persons but also the people outside of the war's zone. As the number of terrorist attacks has increased, national authorities and international organisations, like the International Atomic Energy Agency (IAEA), have increased their security measures to protect nuclear power stations from such attacks (Alonso ,2012).

2.2.2 Previous and stage of nuclear incidents

Chernobyl

The Chernobyl disaster happened on 26 April 1986, as a result of plant operator mistakes. The mistakes were starting when 4 reactors are being shut down for the maintenance, then some of the operators was decided to take advantage of this shutdown to determine whether the slowing turbine could produce enough electrical power to operate the emergency equipment and core cooling water circulating pumps until the diesel emergency power source became operative again in the event of a station power blackout (OECD, 2002). Resulting from the accident, it has destroyed 4 reactors, killed 30 operators and firemen within 3 months . The main factor that caused this accident to occur is lack of safety precautions during manage the nuclear reactor.

The type of reactor that is used and damaged at Chernobyl is a RBMK (Reaktor Bolshoy Moshchnosty Kanalny, high-power channel reactor) as shown in Figure 2.2. It is water-cooled reactor with individual fuel channels and using graphite as its moderator. The interesting part of this reactor is if the power supply increases or flow of water decreases, it will triggered steam production on the fuel channel and increase the nuclear fission reaction in the fuel by using neutrons reaction.

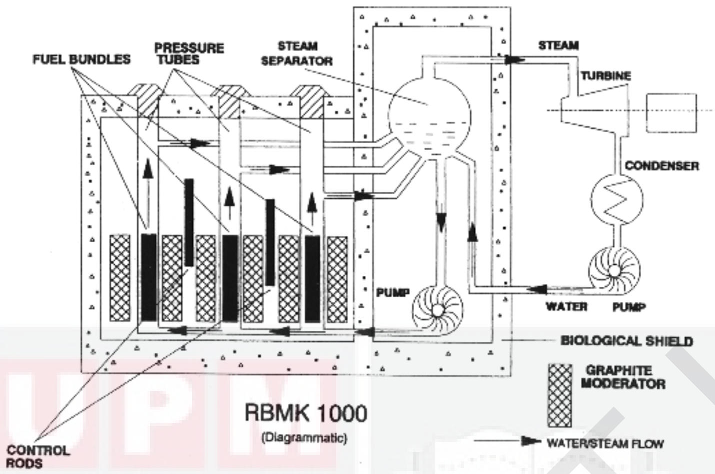


Figure 2.2 The RBMK Reactor in Chernobyl (OECD, 2003)

In term of the radioactive particles that is released to the atmosphere, it was estimated that all of the noble gases such as Xenon and Krypton was released from the core inventory meanwhile about 10% to 20% of the more volatile elements of iodine, Tellurium and Cesium. Doses from external irradiation has been increased during the first year after the accident. It is due to the ground deposition of radionuclides in the area close to the reactor but the radioisotope of cesium deposition was the greater contributors in distant areas one month after the accident (OECD, 2003).

Fukushima

Fukushima accident has happened on 11 March 2011. It was the second worst nuclear accident in this world. The main reasons that contribute into this accident are tsunami and a massive earthquake which can be considered as external factors. Almost 16,000 people were killed during the tsunami incident and more that 6,000 injured. The major difference between Fukushima accident and Chernobyl accident is Fukushima is caused by external factor which is earthquake while Chernobyl is caused by internal factor by the operators. At that time, Japan is one of the countries that used nuclear source to produce energy. Nuclear reactor at Fukushima is built on 26 March 1971 and it is very old compare to 2011. There are 6 units of boiling water reactors on the Fukushima site and each units consume different amount of power. 3 units of the unit reactors was operating during the tsunami accident and the other 3 are being shut down.

The effects of radionuclides from the accident clearly can be realized especially in the north west region of the Fukushima Daiichi Nuclear Power Plant (FDNPP). Although many radionuclides especially noble gases and volatile elements were emitted from the FDNPP disaster (Steinhauser et al., 2014), ^{134}Cs and ^{137}Cs are the major constituents of the radioactive contaminants of terrestrial and aquatic environments in Fukushima which both have long physical half-lives (Wada et al., 2019). These elements are actively lived in tree, soils and mushrooms in Fukushima. Based on the recorded data on ^{137}Cs activity in forest contaminated by Fukushima accident, there are about 407 activity concentration of ^{137}Cs from the mushrooms in 2017 (Hashimoto et al., 2020). This shows that some of the radionuclides are still active even though after 6 years after the nuclear accident occurred. In July 2011, there are up to 140 Bq m^{-3} and 153 Bq m^{-3} of ^{134}Cs and ^{137}Cs are located at the northern end of the Kuroshio Extension (KE) (Nakata & Sugisaki, 2015). Figure 2.3 shows the rough condition of earthquake during the Fukushima nuclear disaster in 2011.

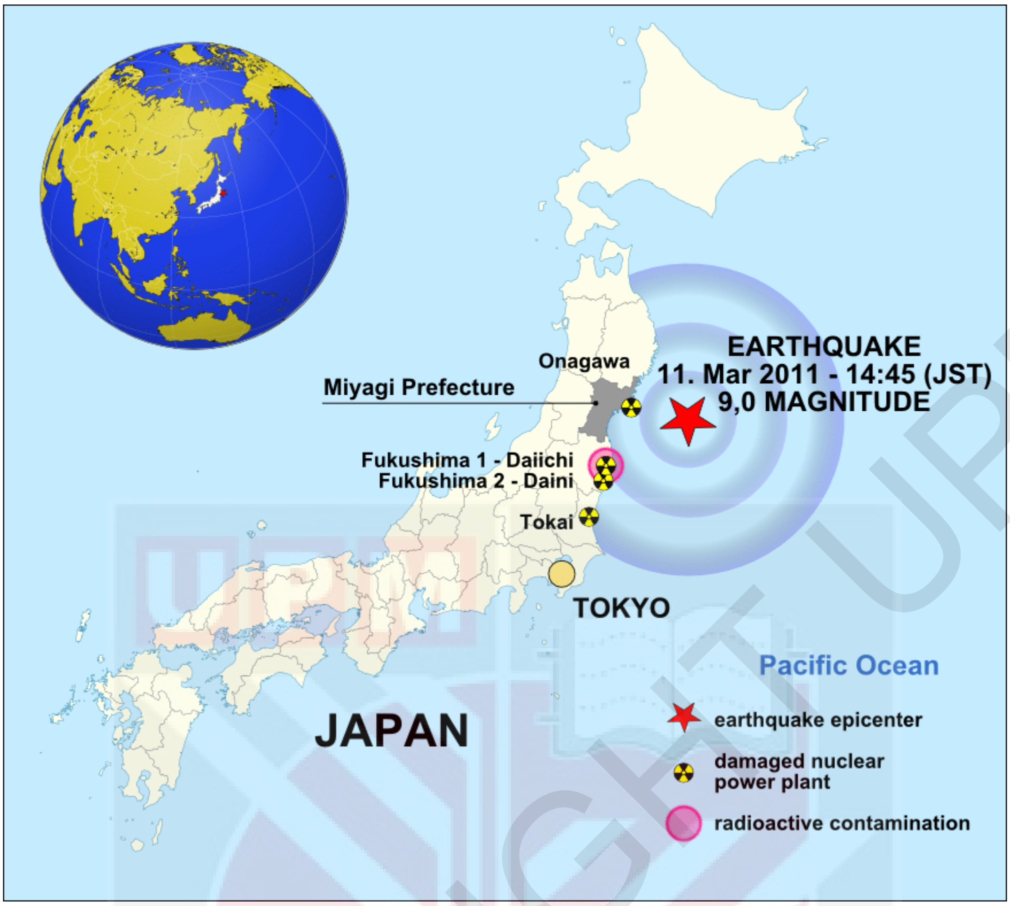


Figure 2.3 Map of Japan showing earthquake on the 11 March 2011 (Miyazaki, 2021)

To study about radioactivity of radionuclides in wild animal body, there is a study that used a mathematical model in order to analyze it. LnCsc which stand for ln-transformed total radioactive Cesium levels in function of T, time after the FDNPP accident in boar and black bears from over 7 years after the accident is computed in equation 2.1 (Shuryak ,2021).

$$
\begin{aligned}
&Ln\,\mathrm{Csc} = X + Q - \mu \times Tv + A \times \sin[2 \times \pi \times (T + P)] \\
&X = \ln[\exp(LnCs134_{t0r}) \times 2^{-T/ThCs}{}_{134} + \exp(LnCs137_{t0r}) \times 2^{-T/ThCs137}
\end{aligned}
\qquad (2.1)
$$

where X is stand for estimated average radioactivity Cesium level, A is stand for amplitude, v is stand for potential power dependance, P for phase shift and Q is fitted relationship between radioactive cesium levels in the animal.

In addition, the resulting of contamination of radioactive particles from Fukushima accident also has affecting omnivores in certain areas. Radionuclides from the Fukushima's nuclear accident have been discovered in saltwater and marine species all around the Pacific but because of the dilution in ocean , the radiological impacts in nations other than Japan appear to be minimal (Steinhauser et al., 2014). There is a research that found radionuclides from the accident able to reach North America in five days and Europe in eight days and returned back to Japan through Northern Hemisphere just in 20 days (Mészáros et al., 2016).

Stage of nuclear incidents

An expression called 'source term' is used to describe as a place that released radioactive material from nuclear power plants. In nuclear accidents, there are categorized into two types based on *State-of-the-Art Reactor* (SOARCA) scenarios which are bypass and station blackouts (SBOs). The model used to predict the dispersion of radioactivity with it causes is shown in Table 2.1 and Table 2.2.

Table 2.1 Description on each type of accident source term based on the report in Proposed nuclear power plants in the UK (McMahon et al., 2013).

Source-term identifier	Description (release scenario)
ST1	Long term station blackout
ST2	Short term station blackout
ST3	Short term station blackout with thermally-induced steam generator tube rupture
ST4	Interfacing System Loss of Coolant Accident with containment bypass
ST5	Loss of Coolant Accident (LOCA) followed by core meltdown

Table 2.2 Accidental release source terms from reactor to air used in assessment of nuclear accident(McMahon et al., 2013)

Type of Radionuclide	ST1 Release (GBq)	ST2 Release (GBq)	ST3 Release (GBq)	ST4 Release (GBq)	ST5 Release (GBq)
^{131}I	1E+07	3E+07	4E+07	6E+08	3E+03
^{134}Cs	0E+00	8E+05	3E+06	2E+07	5E+01
^{137}Cs	0E+00	5E+05	2E+06	1E+07	3E+01

2.3 Radiobiological Effects

There are several types of damage that can occur due to the high radioactivity. It can be classified into three types which are DNA Strand Break, stochastic effects and deterministic effects. To analyze effect of radiation on a human properly, it is compulsory to calculate absorbed and equivalent dose in order to determine the cancer risk.

2.3.1 Stochastic Effects

Stochastic effects are caused when a person is exposed to high level of radiation. It is harmful as it can modified a normal cell to become different from other cells or it is called a tumor. It is possible that ionization radiation at a very low doses, to transfer energy to a cell thus transform it. In stochastic process, there is no threshold and this means that stochastic effects can still occur even though at low level of doses. Occurrence of stochastic effects are directly proportional to the dose received by a person. It can be classified into two types which are Somatic stochastic effects and genetic effects.

Genetic effect occurs when ionization radiation effects genetic material in reproductive cell in human's reproductive system. As a result, this will affect a generation and the probability to have the defective descendants on a birth child when it is affecting the DNA. The main issue of the first stochastic event is the cancer induction. The ionizing radiation that is probably cause specific molecular changes in DNA through a process called "neoplastic transformation" which change the cell. In order to induce the molecular changes at the DNA site, a threshold is assumed.

The studies on workers exposed with radium-226 in the earlier of 20th century and those who inhaled radon and its daughter in the mining area show some stochastic effects. They found that the estimation of the dose is hard to be measured thus they are unable to determine the exact value of quantitative risk. To simplify, relationship between equivalent dose and the resulting increment in the probability of a stochastic effect to occur is directly proportional (Sowby, 1981).

In stochastic effects problem, there also linear-quadratic models of dose that is used to extrapolate from the experience of the Japanese atomic bomb survivors in order to estimate risks from low doses and low dose rates. The analysis is focused on the effect from Gamma radiation and Neutron radiation. DNA is stand for "Deoxyribonucleic Acid" and it consists of Adenine (A), Cytosine (C), Guanine (G), and Thymine (T). Each person has different sequence of DNA and this makes everyone has their owns identity. It shows the almighty of Allah SWT who made all human has its own identity. DNA sequence is a sensitive component as it can be affected by radiation from the carcinogen substances. DNA strand break can be classified into 2 types which are Single Strand Break (SBR) and Double Strand Break (DSB). Double Strand Break is occurred when two complementary stands of the DNA are broken at the same time and at the same sites that are sufficiently close to one another. There are two types of DSB's repair in mammalian cells which are homologous recombination (HR) and nonhomologous end joining (NHEJ).

If two strands are damaged and the fragments translocate or a "ring" chromosome is formed, an ionized fragment of a DNA chain can be re-joined in a new location. A centromere of each chromosome is essential to normal replication of each chromosomes. In addition to the DNA molecules in the chromosomes, any other vital molecule or key structure in the normal functioning cell can easily be destroyed by ionizing radiation. In fact, radiation and other carcinogens appear to add the number of cancers that already occur in human body instead of producing new cancers. Figure 2.4 shows mechanism of DSB repair in human body which consists of Non-homologous end joining and Homologous recombination.

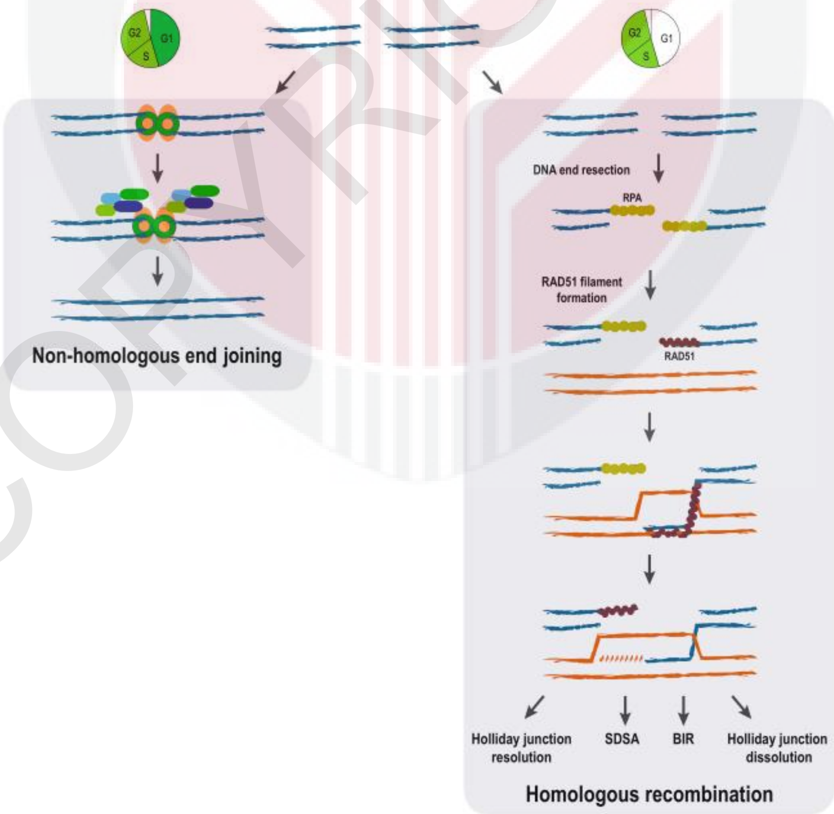


Figure 2.4 Pathways of DSB repair. The main steps of non-homologous end joining and homologous recombination repair mechanisms are represented (Vítor et al., 2020)

2.3.2 Deterministic Effects

In many organs and tissues of the body there is a continuous process of replacement and loss of cells such as epidermic cells. It shows the reason why human keep using energy to produce cell. In each increasing rate of loss, must be counter by increase in the replacement rate. Net reduction of cells is important to maintain the functions of the organ or tissue. If the rate of cell decrease is fast, it will affect the tissue function that is relatable to the exposure to radiation as it can increase the rate loss of cell (Sowby, 1981). Generally, deterministic effects is caused by the initial cellular changes that are randomly and followed by non-stochastic effects. This effects can lead to the malfunction of some parts in human body such as blood vessels.

Deterministic effects or it is called “non-stochastic" are related to the absorbed radiation dose and the severity of the effect increases as the dose increases. Cell death or cell killing is the main process involved in deterministic effects. Most cell types are not killed directly if the dose is very high, but there are some possibilities for it to have some damage effects on the chromosome part thus dies. Cell death usually becomes apparent a few hours or days after irradiation. Some of the deterministic effects are reversible shows that the damage is not too dangerous.

2.3.3 Hazardous effects of radionuclides ^{131}I and ^{137}Cs to human

There are many types of Cesium isotope such as Cesium-134 (^{134}Cs) and Cesium-137 (^{137}Cs). Generally, ^{137}Cs is more harmful than ^{134}Cs as it has longer half-life which is 30.23 years compared to ^{134}Cs which is only about 2.05 years. Half-life is defined as the time taken for the radioactivity of a specified isotope to fall to half of its original value. In fact, most of the Cesium compounds is water soluble but it does not rinse out into the groundwater.

Large amounts of ^{137}Cs were produced during atmospheric nuclear weapons tests conducted in the 1950s and 1960s. It is one of the by-products of nuclear fission processes in nuclear reactors. Usually, by-products of nuclear reaction have high radioactivity and this will lead to increase the risk of cancer to the human and also animals. The reason is radioisotopes such as Cesium contains high-energy gamma radiation. Usually, the cancer's risk will increase if a person is exposed internally with Cesium. Isotope ^{137}Cs also active inside the food such as mushroom and it will form Barium-134(^{134}Ba) while ^{134}Cs will produce Xenon-134 (^{134}Xe) after the decay process. The analysis of some samples of mushrooms from 1985 showed that the activity of Cesium-137 was higher compared to any other foodstuff (Grabowski et al., 1994).

Even though after 5 years of Fukushima accident, significant atmospheric radiocesium activity concentrations , on the order of approximately 10^{-4} Bq m^{-3}, have still been observed in the contaminated area (Ochiai et al., 2016). This finding shows that Cesium is one of the long-lasting radionuclides that can dispersed through long distance. Usually , the most dangerous radionuclides that are needed to be considered are ^{131}I and ^{137}Cs because it is harmful to people and also can increase the radiation exposure (OECD, 2003).

High exposed to the Cesium element can cause cells damage from the radiation and a person who might be facing this problem has the possibilities to acute radiation syndrome, which includes nausea, vomiting, diarrhea, bleeding, coma, and even death in cases of very high exposures. There were number of people in Brazil who used Cesium as the substances to perform a medical machine for radiation therapy become sick and some of them are died due to the high exposure to the radiation (ATSDR, 2004). However, it is highly unlikely that people die because of cancer that is mainly caused by Cesium's radiation only. Because of the radiation that it has, so carcinogenic effects similar to those observed in Japanese survivors of the

Fukushima incidents might be expected among people who are exposed to very high levels of radiation from a radioactive Cesium source. Table 2.3 shows the differences of properties between ^{131}I, ^{134}Cs and ^{137}Cs.

Table 2.3 The decay constant, surface clearance coefficient and effective dose conversion factor of ^{131}I, ^{134}Cs and ^{137}Cs

Type of Radiouclides	Half – Life	Effective dose rate coefficients for ground surface (Sv Bq^{-1} s^{-1} m^{2})
^{131}I	8.04 days	2.44 x 10^{-16}
^{134}Cs	2.05 years	9.98 x 10^{-16}
^{137}Cs	30.23 years	7.85 x 10^{-18}

2.3.4 Absorbed, Equivalent and Effective Dose

In nuclear safety, the physical units that is very important to be accounted is amount of dose. In this field, there are various types of dose that might be useful for medical sector. Dose is categorized into 3 types which are absorbed dose, equivalent dose and effective dose. Absorbed dose refers to the energy that is transferred locally in an absorbing medium or cells from ionizing radiation. Equivalent dose is calculated for individual organs while effective dose is calculated for the whole body. Each organ in human body has the amount of tissue weighting factor that is useful to determine effective dose by multiplying with equivalent dose. The equivalent dose, H, in tissue or organ T due to radiation R, is described in equation 2.2.

$$H_{T,R} = w_R . D_{T.R} \tag{2.2}$$

where $D_{T,R}$ is the average dose from radiation, R from any sources in the tissue or organ T and w_R is the radiation weighting factor. Equivalent dose is amount of dose that is generally absorbed by the whole body of a person. The effective dose, E, is the sum of the weighted equivalent doses in all the tissues and organs of the body. It can be expressed as equation 2.3 (McCollough & Schueler, 2000):

$$E = \sum_{T} w_T . H_T \tag{2.3}$$

where w_T is weighting coefficient per tissue or organ and H_T is equivalent dose. Unit for all types of soses is in Sievert, *Sv* or Gray, *Gy* but usually it is stated in Sievert unit as it is International System of Units (SI) in measuring radiation absorption. There are variables that can be changed to reduce absorbed dose by a person which are time, shielding and distance. Dose can be reduced by limiting exposure time and also the intensity of radiation decreases with distance from its source. In addition, water is one of the best shields from radiation. This is the reason of nuclear reactors are equipped with water. The total dosage intakes by inhalation and exterior exposure are calculated using equation 2.4 . (Saeed et al., 2020):

$$Dose_{total} = \sum_{t_1}^{t_2} AD_{cf} \tag{2.4}$$

where *A* is activity concentration of the radionuclides on air or ground, D_{cf} is radionuclide's dose conversion factor within an interval time.

2.3.5 Cancer Risk Analysis

Recently, there are many quantitative risk assessment methods have been improved to provide information about cancer risk such as non-threshold agents, potential carcinogens, where safe levels of exposure cannot be identified by conventional methods (Anderson, 1983). Usually, this data is very useful for provide information for public health policy decisions concerning increases in risk associated with increases in exposure to carcinogenic and other non-threshold pollutants. There are many methods that can be used to determine risk assessment in a certain location. Based on the National Academy of Sciences BEIR VII report on the Biological Effects of Ionizing Radiation, the report suggested to combine some of mathematical models in order to compute excess radiation-related cancer risk. Equation below shows the general form of BEIR VII dose-response models for both *excess relative risk* (ERR) and *excess absolute risk* (EAR) (Cahoon et al., 2020):

$$\beta_s D \exp(\gamma e + \eta \alpha + \delta t + \vartheta r t) \tag{2.5}$$

In HYSPLIT model, cancer risks due to the public exposure can be determined by measuring the annual effective dose. From the amount of annual effective dose, cancer risks are calculated using a formula introduced by ICRP organization which is based on the dose-to-risk coefficients (Sowby, 1981):

$$Risk_{Cancerfatality} = 0.05Sv^{-1} * E(t) \tag{2.6}$$

The cancer fatality risk in the population is calculated using Equation 2.6, where the dose-to-risk coefficient and *E(t)* is the total dose are multiplied to obtain the risk.(Saeed et al., 2020) . For the condition that involve with low-dose radiation, a linear non-threshold risk model and this LAR model assumed 5 years as the minimum latency for solid cancers to develop. LAR model is defined as the probability of radiation-induced cancers in 100,000 population who has been exposed to 100mGy and it is calculated using this equation 2.7 (Le & Duc, 2018):

$$LAR(D,e) = \sum_{a}^{80} M(D,e,a).S(a) / S(e) \tag{2.7}$$

where *M (D,e,a)* is excess relative risk for cancer incidence, *a* is attained age, *e* is exposure year, *S(a)* is probability of surviving until age a, *S(a)/S(e)* is probability of surviving to age a conditional on surviving to age *e* and *D* is radiation dose of specific organ.

2.4 Dispersion Model

There are many types of dispersion modelling that can be used to analyze air or radionuclides dispersion such as ADMS, CALPUFF, AERMOD, MERCURE and HYSPLIT. The *Atmospheric Transport and Dispersion Model* (ATDM) is established by *World Meteorological Organization* (WMO) in order to help *United Nations Scientific Committee on the Effects of Atomic Radiation* (UNCEAR) to assess the accident in Fukushima. Atmospheric dispersion model is useful to make realistic predictions in advance in any simulation accident to obtain information and develop emergency preparedness. Risk assessment of radiological effects to human and animal surrounding also can assisted by using this model.

2.4.1 HYSPLIT Model Configurations

The NOAA Air Resources Laboratory (National Oceanic and Atmospheric Administration: an agency of the United States Department of Commerce) created HYSPLIT (ARL) in 1982. HYSPLIT is one of the dispersion model that has been used by scientists or meteorologists to analyse many information related to atmosphere. HYSPLIT is stand for "Hybrid Single-

Particle Lagrangian Integrated Trajectory". The HYSPLIT model has evolved from time to time based on the improvement made by the developer. The initial version of the model used only rawinsonde observations and the assumption has been made to the dispersion which consist of uniform mixing during the daytime only (Draxler & Taylor, 1982). After that, dispersion due to wind variable strength mixing based on the temporally and spatially varying diffusivity profile were introduced. In the next version , the use of rawinsode data was replaced by gridded meteorological data from either analyses or short-term forecasts from numerical weather prediction models. In other words, HYSPLIT uses specially formatted meteorological data to estimate the transport and dispersion of atmospheric constituents. Figure 2.5 shows the HYSPLIT model which is created in United States.

Figure 2.5 HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory model) developed by the National Oceanic and Atmospheric Administration (NOAA) Air Resources Laboratory (R. Draxler et al., 2013)

This model is designed for quick response to atmospheric emergencies, diagnostic case studies, or climatological analyses using previously gridded meteorological data (R. R. Draxler & Hess, 1998). HYSPLIT model is a system for computing simple air parcel trajectories, as well as complex transport, dispersion, chemical transformation, and deposition simulations. It also capable to help on explaining how, when, and where potentially harmful materials are atmospherically transported, dispersed, and deposited. The HYSPLIT model is a complete system for computing both simple air parcel trajectories and complex dispersion and deposition simulations. Besides that , HYSPLIT also able to analyse volcanic ash, radioactive material, wildfire smoke and air pollutants movement. It is equipped by programs to convert meteorology to HYSPLIT format to produce various output display that useful in this study (Zali et al., 2017).

Source term is term referring to the sources that is released from the accidental reactor over a specific period whether in toxic emissions or active radionuclides. There are many types of substances or materials that are released during the accident such as Iodine, inert radioactive gases such as Xenon, and other radioactive nuclides. The rate of release as a function of time should be determined. Back-trajectories in this system able to determine the movement of wind came from at any given time at any given location while forward trajectories is able show the centre line of the plume from any atmospheric emissions source.

2.4.2 Lagrangian and Eulerian approaches

The model calculation in this system is a combination or hybrid between Lagrangian and Eulerian approaches. Lagrangian approach is useful to build model calculation method using a moving frame of reference to determine the trajectories or air parcels move from their initial location, and the Eulerian methodology, which uses a fixed three-dimensional grid as a frame of reference to display the air pollutants and also its concentration. From the average of the three-dimensional velocity vectors from the initial position $X(t)$ to the final estimation position $X'(t+\Delta t)$, advection of particles are able to be determined. Advection is define as the transfer of heat or matter by the flow of a fluid, especially horizontally in the atmosphere or the sea. Trajectories in complex dispersion and depositions simulations are calculated by using Langragian dispersion model (Zali et al., 2017). The velocity vectors are linearly interpolated in both space and time. The assumption to determine the position is,

$$X'(t+\Delta t) = X(t) + X(X,t)\Delta t \quad (2.7)$$

And the final position is

$$X'(t+\Delta t) = X(t) + 0.5[V(X,t) + V(X',t+\Delta t)]\Delta t \quad (2.8)$$

where *X* is indicate for position, *V* for velocity and t is for time . This calculation has been used to determine the air dispersion. Based on this formula, it can compute that time become one of the variable to air concentrations. There are two models that required which are Puff model and Lagrangian particle model. Δt is depending on the time released of the pollutants and it is different for each type of reactors. By using this formula, dispersion and final location of certain radionuclides can be detected.

2.4.3 Application of HYSPLIT

There are many usage and application that can be used in HYSPLIT modelling system. Recently, HYSPLIT model has been used to simulate the hypothetical accident by analysing dispersion of radionuclides from the fission reaction then assesses the effects to the public health in Baiji Potential site. In Baiji potential site, the results of the analysis was then be compared to the limiting doses suggested by International Commission on Radiological Protection (ICRP) (Saeed et al., 2020). By using the computer codes in the HYSPLIT, with the application of Eulerian and Lagrangian approaching, it allows a study to configure about the air concentration of the pollutant thus lead to calculate the estimation of dose absorbed by a population. HYSPLIT also can be configured to a specific types of radionuclides such as ^{131}I, ^{60}Co , ^{137}Cs and others that move in air to be analysed.

HYSPLIT also exist as an assessment tool to study differences of data of airborne pollens and its phenology in South-West Spain region. The type of pollens that is studied is Olea Pollen which released by Olive tree in Mediterranean region. By combining data from map with HYSPLIT modelling, it is useful to obtain a full understanding of some of the discrepancies between pollen content and phenology. By using daily 24-hrs backward dispersion analysis, the air mass transport patterns above Badajoz can be investigated (Monroy-Colín et al., 2020). Usually, HYSPLIT is useful when it is combined with meteorological data to display the movement of air and concentration of pollutants in certain areas.

In Bushehr Nuclear power plant, HYSPLIT atmospheric dispersion model has been used to determine radionuclides atmospheric dispersion near the power plant. Lagrangian dispersion model was used to calculate trajectories complex dispersion and simulation of depositions by considering terrain, meteorological data, emission rate and other important factors (Zali et al., 2017). This data is useful to compute annual effective dose among the public. HYSPLIT Model of the Air Resources Laboratory of NOAA database was also used along with isotopic compositions to study about atmospheric moisture by measuring concentration of Oxygen-18 and Hydrogen-2 in Bojnourd area, Iran (Bagheri et al., 2019). The correlation of moisture sources with the isotopic compositions of precipitation was assisted HYSPLIT modeling's trajectory analysis. HYSPLIT model also can be used as an emergency response. Figure 2.6 shows the result of Fukushima accident local dispersion at ground-level by using simulation in HYSPLIT modelling. High or altitude is one of the variable that can be varied in this system as it is related to the measurement of advection.

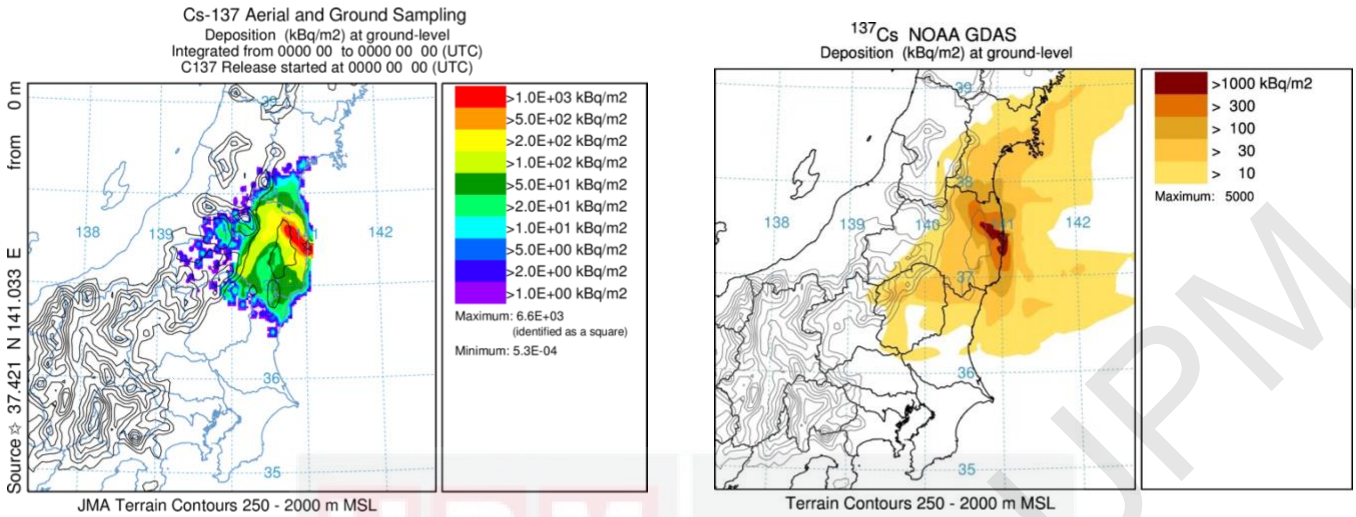


Figure 2.6 The ^{137}Cs deposition measurements is shown in the left image, averaged together from aircraft monitoring and ground based sampling and the model prediction is shown in the right image (R. Draxler et al., 2013)

During the El Nino events, HYSPLIT modelling used to analyse pollutants in Malaysia. The result found that the number of pollutant is higher during the super El Nino event compared to usual condition. One of the crucial comparison and analysis that is made is in Seremban when that area faced El Niño in 2015. Figure 2.7 shows the high amount of pollutant in some location in Malaysia due to long-range transboundary pollution from the large biomass burning in Indonesia and coincidence with the occurrence of the El Niño were recorded in 1997, 2002, 2009 and 2015 (Sentian et al., 2018).

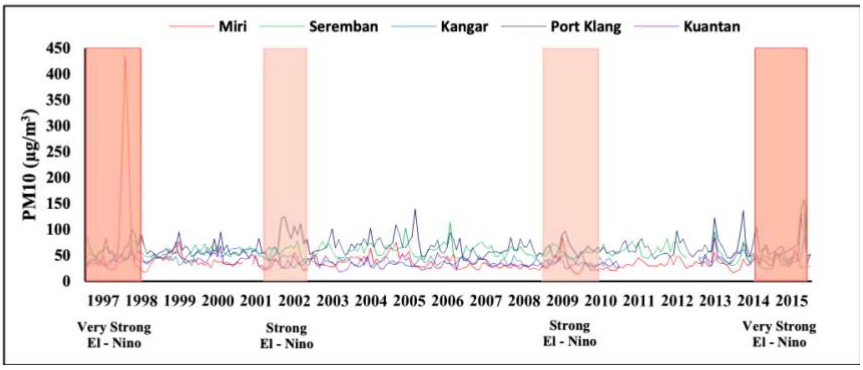


Figure 2.7 Time series analysis for selected monitoring stations (1997–2015) with El-Niño events (Sentian et al., 2018)

In a study area at Seoul, South Korea, HYSPLIT modelling system is used to simulate the Radiological Dispersion Devices (RDDs) that is assumed to be located at Gangnam. Usually, RDD is caused by a terrorism's attack. Gangnam is the central area of Seoul and it has high population. HYSPLIT was used to compute dispersions of ^{137}Cs for 2 hours of releasing time and the result found that in 100,000 persons in that location, it is about 1.88 persons could getting sick and 2.76 persons could die from the inhalation of ^{137}Cs (Jeong et al., 2013).

2.5 Nuclear reactor in Southeast Asia

2.5.1 Type of Nuclear Reactor

In the nuclear energy sector, there are many types of nuclear reactor. Each reactors has their own capability to produce energy. The type of nuclear reactors is depending on the suitability of the place and also sources provided by a country. Generally, A nuclear reactor produces and controls the release of energy from splitting the atoms of certain elements. In this section, it is more emphasized on PWR reactor as it is the most common reactor nowadays.

(i) Basic Gas-Cooled Reactor (MAGNOX)

Basic Gas-Cooled Reactor is a reactor that used Graphite as the moderator and it was built in the UK from 1957 to 1971 but now it has been replaced. It was called MAGNOX because of the case of fuel that is made by Magnesium alloy. The advantage of this reactor is it can be refueled even though it is still running (Murray, 2000). Figure 2.8 shows the structure of MAGNOX reactor.

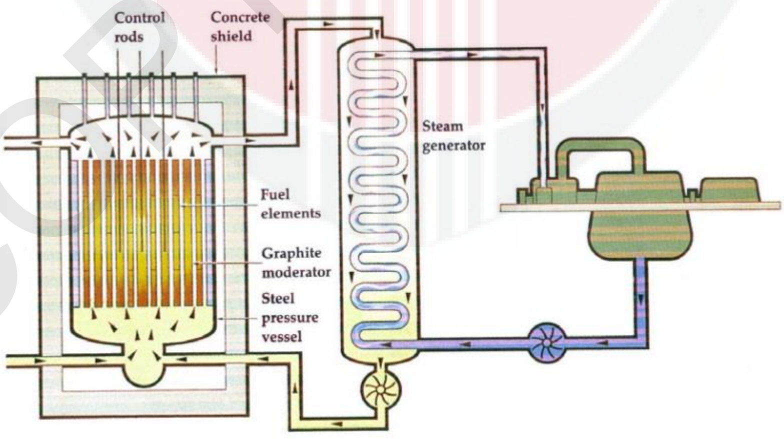


Figure 2.8 Schematic diagram of Basic Gas-Cooled Reactor (MAGNOX) (Murray, 2000)

(ii) Boiling Water Reactor (BWR)

The first BWR was built at the Argonne National Laboratory in Idaho, United States in 1952. It was an experimental reactor called *Borax I* . Size of hydrogen atoms in water caused water to be a good moderator for slowing fast neutrons because of its size that is similar to a neutron. BWR is a reactor that used light water as the moderator and also coolant. The process of producing energy is quite similar with PWR but the difference is the process of steam generation. A PWR generates steam indirectly by using two water circuits while BWR produces steam directly using a single water circuit. Figure 2.9 shows schematic diagram of Boiling Water Reactor in the early 20th century.

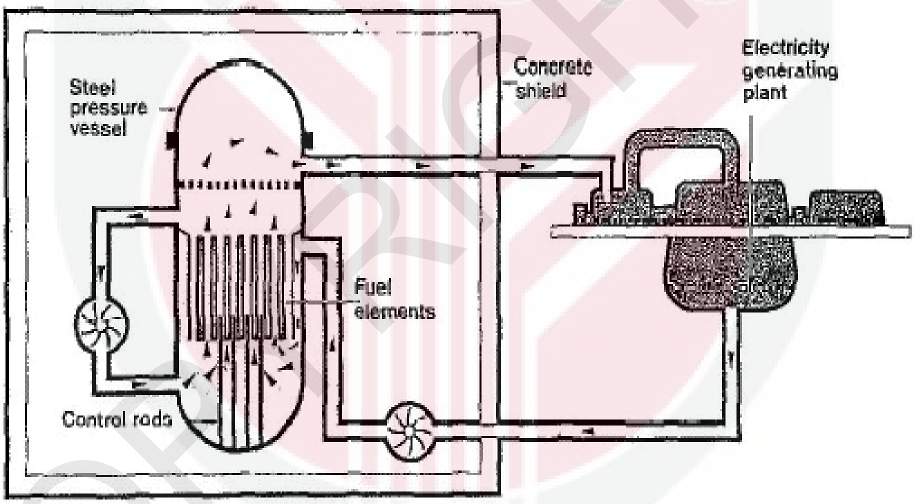


Figure 2.9 Schematic diagram of Boiling Water Reactor (BWR) (Murray, 2000)

(iii) Advanced Gas-Cooled Reactor (AGR)

Advanced Gas-Cooled Reactor is a reactor that used graphite and Carbon dioxide as the primary coolant. It needs to operate in a very high temperature so that the thermal efficiency is high. AGR is a reactor that is developed from *Basic Gas-Cooled Reactor (MAGNOX).* The concept of producing energy is similar to the others type of reactor which it will generates heat which turns water into steam as shown in Figure 2.10. The steam then powers turbines which, in turn, drive the electrical generators.

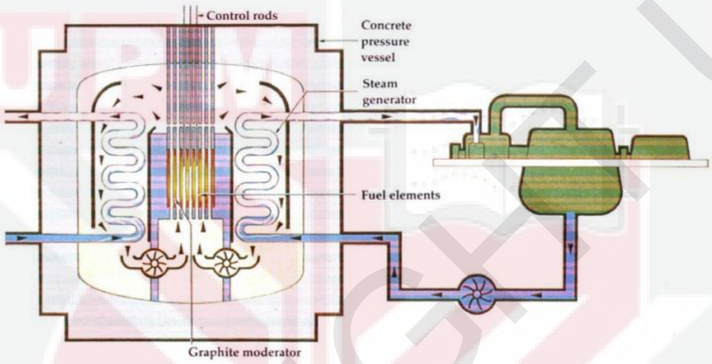


Figure 2.10 Schematic diagram for Advanced Gas-Cooled Reactor (AGR) (Murray, 2000)

(iv) Pressurized Water Reactor (PWR)

PWR is the most common reactor in use globally which is over 250 in operation. Figure 2.11 shows the structure of the PWR with its components. In 2015, there are about 283 PWR operating in this world. In 2017, PWR is the second of the two major nuclear power technologies in use (Breeze, 2017). The Steam cycle efficiency is about 32% and it uses light water as the moderator (Murray, 2000). Usually, PWR able to generate power capacity of 1000 MW(Breeze, 2014) . Meanwhile in 2021, United States is the country that has highest number of reactors which is 93 reactors.

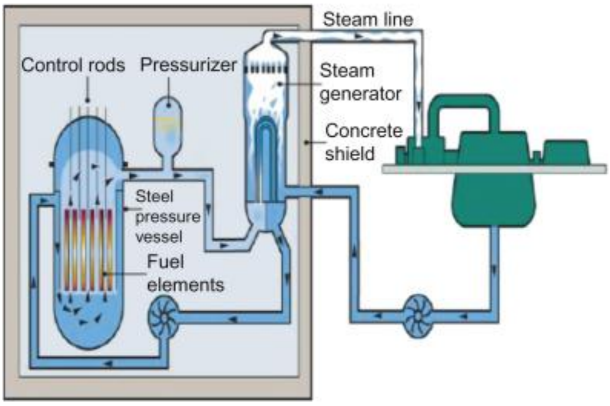


Figure 2.11 ***Pressurized Water Reactor component include its main component including Pressurizer water, control rods, and fuel elements*** **(Breeze, 2017)**

(v)Pressurized Heavy Water Reactor (CANDU)

This reactor is called “CANDU” because it has been built by using Canadian technology. It is stand for “"Canadian Deuterium Uranium" and the interesting part about this reactor is it uses heavy water as its regulator and this allowing natural uranium to be used as fuel. Cadmium rods from system unpressurised container (called a callandria) have the function to control the system . The whole assembly is shielded by the concrete and containment vessel (Murray, 2000) . Figure 2.12 shows the structure of CANDU reactor. The efficiency of this reactor is about 30% which is less than PWR and BWR.

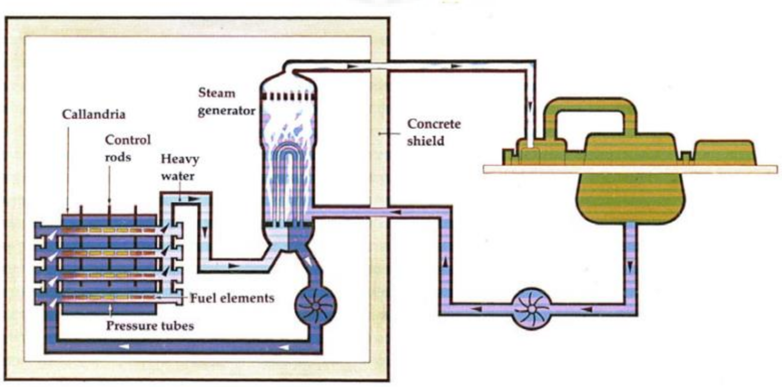


Figure 2.12 Pressurised Heavy Water Reactor (CANDU) Water (Murray, 2000)

(vi) RBMK REACTOR Boiling Light Water, Graphite Moderated Reactor

This is the type of reactor that is destroyed in Chernobyl and Fukushima accident. RBMK is type of reactor that is rarely been found in this world. There are about 1.8% to 2.0% of Uranium that is used in RBMK (Breeze, 2017). Because of previous accident that used this type of design, many of it already being shut down. Control rods inside the cores are based on Boron and consist of two types which are main control rods and short control rods. RBMK used graphite as the moderator and boiling water as the coolant as shown in Figure 2.13. Average power that usually produced by this design is 1000MW and it has been increased to 1500MW on the second design. In addition, RBMK is enriched by Uranium Dioxide by 1.8% of Uranium-235 (U^{235}) (Murray, 2000).

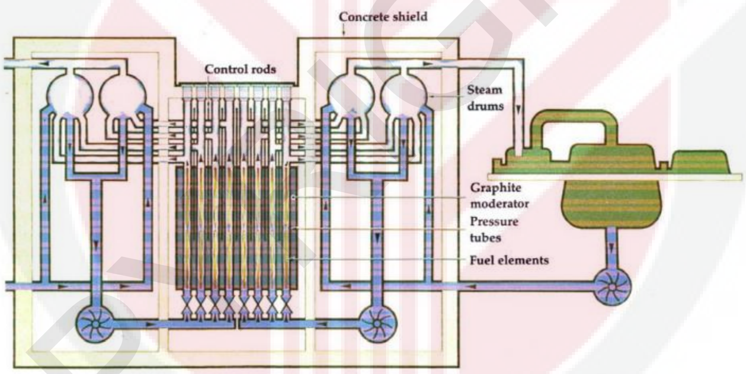


Figure 2.13 Structure of RBMK reactor including the main components such as Control Rods, concrete shield, and Graphite moderator (Murray, 2000)

2.5.2 Nuclear Reaction

There are two types of nuclear reaction which are nuclear fission and nuclear fusion. Nuclear fission is refer to a process in which an atoms are collide to subatomic particles such as neutrons to produce a huge amounts of energy. There are many nuclear reactors that rely on this reaction compared nuclear fusion in order to produce energy. Uranium is a type of element that is used in this reaction as it has the ability to produce high amount of energy. Usually when Uranium is bombarded with neutrons, it will produce an atom of Krypton, Barium, three more neutrons and also an amount of energies (Breeze, 2014). Equation 2.9 shows the reaction between Uranium and neutron before and after the collision.

$$ {}_{0}^{1}n + {}_{92}^{237}U \rightarrow {}_{56}^{140}Ba + {}_{36}^{96}Kr + 3{}_{0}^{1}n + 200\text{MeV} \quad (2.9)$$

The reaction also depending on the size of the piece of Uranium. If it is too small, then the probability of it to be collide with neutron is also small and the neutrons will escape to surroundings without any collision. The energy of neutrons that is released after collision in nuclear fission is very high and this will make it to move very fast. In fact, natural Uranium only can react if it is collided with slow-moving neutrons which means in optimum energy. So, in development of nuclear power, it is important to slow down or "thermalized" the neutrons by using water. Water is very effective moderator since protons in water molecules able to collide with neutrons and reduce neutron's energy.

On the other hand, the second type of nuclear reaction is called nuclear fusion. Nuclear fusion is defined as a process in which two atoms are combined to form heavier nucleus with the release of energy. It is related to the Einstein's formula , $E = mc^2$ which is useful to determine quantity amount of energy released. Based on this formula, the final product of the reaction usually has lower mass than the total of the initial product because some of the 'reduced mass' has been converted in form of the energy. Nuclear fusion is a reaction that is occur inside the core of the sun. Energy from the sun is created by nuclear fusion where it involved with the reaction of hydrogen atoms .

2.5.3 Type of nuclear exposure

Occupational exposure

Occupational exposure is a common for the occupation that is relatable with hazardous agent such as in mining area. There are many radioactive elements in the ground area that emit radiation such as Radon. There are 3 types of occupational exposure which are planned exposure, emergency exposure situation and existing exposure situation. Firstly, planned exposure is a situation where exposure are increasing due to the planned operation of a source. For example, when workers are getting involve with radioactive materials in some cite areas, there must be some estimation of dose per unit time. As a result, time consuming for the workers to work continuously can be determine efficiently. Secondly, is an emergency exposure situation which a situation of exposure that increases due to unexpected event and requires planned action in order to reduce big impacts. Lastly, existing exposure which is a situation of exposure which is a situation of exposure that already exists in nature in certain areas.

Medical exposure

In medical diagnosis or treatment, there are many radiation exposures. Radiation is necessary to kill cancer cells and produce image of internal part of the body. An amount of daily doses absorbed need to be estimate and the person who work in this field should be provided with strict regulations to prevent them from getting high cancer's risk.

Public exposure

The component of public exposure is usually due to natural sources randomly. Usually, the amounts of dose absorbed is very low as the distance is very far from the person. However, it also important to measure it to avoid long-term effects to the body. Table 2.4 stated the amount of dose limit for public exposure in Malaysia which is based on ICRP's guideline.

Table 2.4 Dose Limit for public exposure in Malaysia (Idris, 2012)

Unit of exposure	Dose Limit in each year
Effective Dose	1 mSv/year
In special circumstances	< 1mSv/year
Lens of the eye	15 mSv/year
Skin	50 mSv /year

2.5.4 Nuclear Sector proliferation

In 2021, there are many improvements in nuclear energy sector and there are lot of research on this field. It is undeniable that nuclear energy might be one of the main sources of energy in the next 20 years. Country in southeast Asia region such as Indonesia, Thailand Vietnam also have made a lot of investments to improve the research in this sector. All countries in southeast Asia are categorized within the the Association of Southeast Asian Nations (ASEAN) which means these countries are free from using of nuclear weapon.

Generally, most of the ASEAN countries choose nuclear energy as the solution and some countries such as Indonesia, Vietnam and Thailand are planned to build nuclear reactor in the next 5 to 10 years ahead. These countries have planned it with International Atomic Energy

Agency (IAEA) and this organization will ensure that these countries will follow strict guidelines in order to operate nuclear reactors(Nuclear, 2019) .

In southeast Asia, there are no nuclear reactor has been built yet. However, it is stated that the first operation of nuclear power plant could take place in Southeast Asia region in 2030. This is because of the developed legal and regulatory frameworks, development in nuclear energy research and also the availability of human resources in this field (*Pre-Feasibility Study on the Establishment of Nuclear Power Plant in ASEAN*, 2018). However, it is common for the common people to have bad views about nuclear energy as it has caused a lot of destructions in the Chernobyl and Fukushima accident.

In Malaysia, Tun Dr Mahathir which is one of the former prime minister announced that Malaysia will not use nuclear power plants to generate electricity as the country is lacked of expertise and not ready to maintain nuclear technology in term of safety and security. The government has established Tun Ismail Atomic Research Centre (PUSPATI) and later it was officially named as *Agensi Nuklear Malaysia* on 28 September 2006. The purposes of the establishment were to generate new products and technologies through research and innovation based on nuclear energy .

2.5.5 Previous works on this area

Table 2.5 Previous research that related to HYSPLIT modelling

AUTHORS	YEAR	LOCATION	TITLE	METHOD	KEY FINDINGS
Pirouzmand A. et al.	2018	Bushehr	Atmospheric dispersion assessment of radioactive materials during severe T accident conditions for Bushehr nuclear power plant using HYSPLIT code	HYSPLIT code	The maximum dose for 4, 12, 24, and 48-h long emission at different points of Bushehr city is calculated and compared with the allowable dose limits.
Begy R.Cs a,b et al.	2017	Romania	^{137}Cs contamination over Transylvania region (Romania) after Chernobyl Nuclear Power Plant Accident	γ spectrometric measurements on soil samples collected from 153 locations.	Sampling points with eastern slope exposure received the highest average (27.8 ± 0.5 kBq m− 2), while southern, north-western and north-eastern ones received less than 8 kBq m− 2. Two hotspots are reported are detected
Saeed, I. M. M. et al.	2020	Baiji	The radiological assessment, hazard evaluation, and spatial distribution for a hypothetical nuclear power plant accident at Baiji potential site	HYSPLIT code	The overall individual dose intake by the population residing near the probable site from the hypothetical disaster surpassed 1 Sv, exceeding the International Commission on Radiological Protection's permissible dosage limits (ICRP).
Elizabeth K. C. et al.	2020	Mexico	Projected Cancer Risks to Residents of New Mexico from Exposure to Trinity Radioactive Fallout	BEIR VII dose-response models	provide estimates of the ranges of excess cancer cases from exposure to Trinity fallout to residents of New Mexico alive in 1945.
Stein A. F., et al.	2015	Not fixed	NOAA'S HYSPLIT ATMOSPHERIC TRANSPORT AND DISPERSION MODELING SYSTEM	HYSPLIT code	General information about HYSPLIT code
Zali A. et al.	2017	Bushehr	Public member dose assessment of Bushehr Nuclear Power Plant under normal operation by modeling the fallout from stack using the HYSPLIT atmospheric dispersion model	HYSPLIT model & dose calculation	The results children and infants' doses are higher in comparison with adults, although they are less than 1 mSv. Ingestion dose percentage in the total dose is less than 0.1%.
Bagheri, R. et al.	2019	Iran	Chemo-isotopes (^{18}O& ^{2}H) signatures and HYSPLIT model application: Clues to the atmospheric moisture and air mass origins	HYSPLIT code	Trajectory analysis by HYSPLIT modeling allowed the association of moisture sources with the iso- topic compositions of the precipitation.
Monroy-Colín, A. et al.	2020	SW Spain	HYSPLIT as an environmental impact assessment tool to study the data discrepancies between Olea europaea airborne pollen records and its phenology in SW Spain Alejandro	Pollen sampling & HYSPLIT configurations	By combining HYSPLIT system with mapping, it is helpful for achieving a full under- standing of some of the discrepancies between pollen content and phenology.
Jeong et al.	2013	Seoul, South Korea	Radiological risk assessment caused by RDD terrorism in an urban area	HYSPLIT	According to Monte Carlo simulations, the 95 percent confidence interval for morbidity was 2.40×10^{-5} to 8.55×10^{-5}, and the 95 percent confidence interval for death was 3.53×10^{-5} to 1.25×10^{-4}.

CHAPTER 3

METHODOLOGY

3.1. Introduction

This chapter explained on how to carry out the procedure to find atmospheric dispersion and dose assessment of both ^{131}I and ^{137}Cs that were released from hypothetical nuclear reactor in Southeast Asia. This study determined the dispersion of radionuclides Cesium and Iodine in Southeast Asia region. These chapter consists of HYSPLIT model configurations selection of possible study area, spatial distribution time-series , accident scenario selection, accidental release rate , effective dose measurement and risk estimation.

3.2. Study locations

There are several factors that caused nuclear accident which are categorized into external and internal factor. Some examples of external factors are flood, tsunami and earthquake. Some examples of internal factors are loss of coolant and human-made failures. In this section, some possible locations were selected to simulate nuclear accidents based on the potential of its position and project provided by government.

3.2.1 Ninh Thuan, Vietnam

Firstly, this study focused on the highest potential site to build the nuclear power plant (NPP) within the area of southeast Asia region. Based on the previous research in chapter 2, Vietnam was chose as the study area or nominated site. In Vietnam, the construction of a nuclear reactor which is located at Ninh Thuan (11.69 N 109.175 E) is already began and planned to operate on September 2020. Figure 3.1 shows the location of Ninh Thuan's reactor site. However, there are some restrictions that caused the authority to stop the operation. In November 2016, the National Assembly decided to suspend all nuclear development until 2030 and the construction of the nuclear reactor has been stopped due to safety and financial of constructions concern. Due to this condition, this study focused on the highest potential location for nuclear power plant in Southeast Asia region.

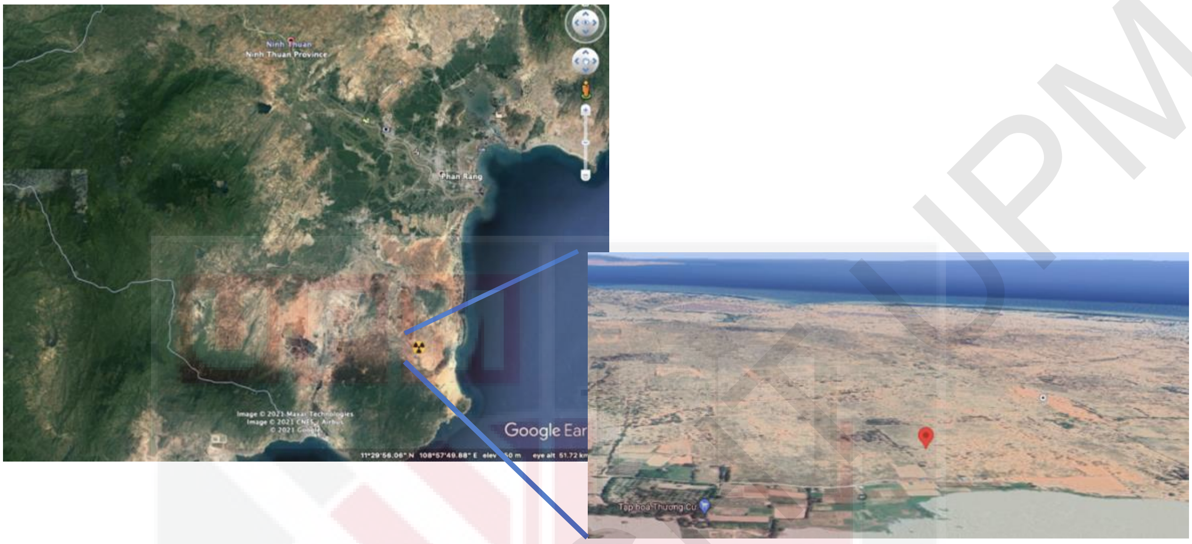


Figure 3.1 The Ninh Thuan potential site's location image from Google maps

There are 3 steps in the procedure to determine the suitable location for the NPP which are determination and evaluation of site suitability, site assessment and stage before start the operation. The selected time is at the end of 2020 as it is the year where the NPP should start operating and this study focused on the consequences of the nuclear reactor's explosion in southeast Asia region.

Ninh Tuan reactor (11.69 N,109.175 E) is built near to the sea and it is important to analyse the humidity, daily average temperature and also wind speed and direction frequency in year 2020. Based on the meteorological data, these parameters were recorded and represent in a graph point to display it. All of the parameters are selected because it can influence the particle dispersion at the potential site.

Based on the objectives of this study, one of it is to determine whether the radionuclides of ^{134}Cs and ^{137}Cs is able to reach other countries in Southeast Asia such as Malaysia and also to determine amount of effective doses from the accident. Then, the calculation of the risk assessment is calculated within a specific region.

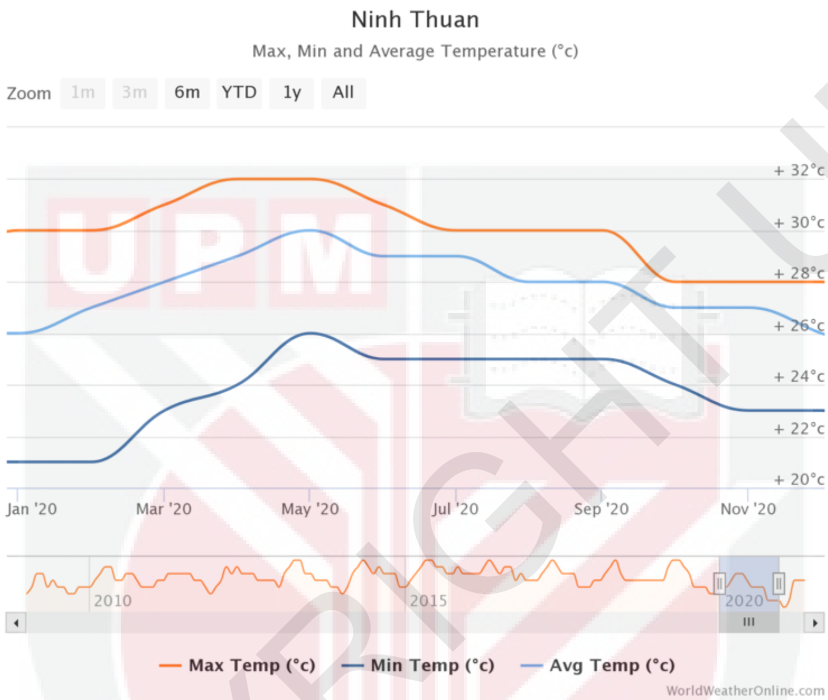


Figure 3.2 The monthly average temperature at Ninh Thuan potential site in 2020

There are some important parameters that need to be analysed and insert into the HYSPLIT model configurations such as humidity, temperature, time release and also timeline. In 2020, the Ninh Thuan nominated site is influenced by the same weather conditions as the temperature between this region is varies between 20℃ and 32℃ and the humidity per month is within the range of 70% - 75%.

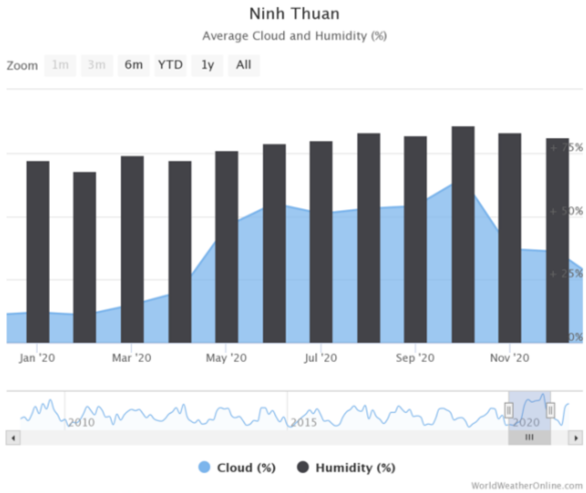
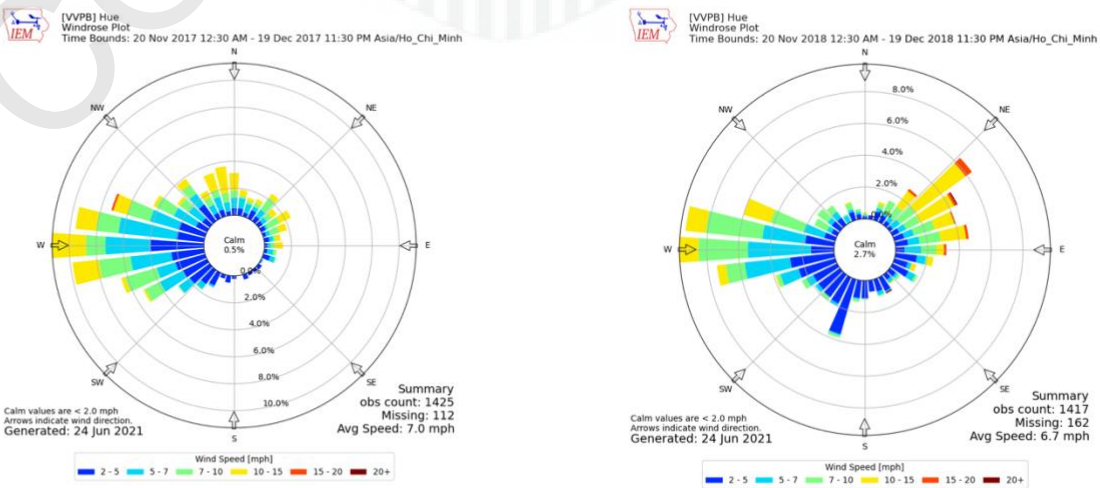
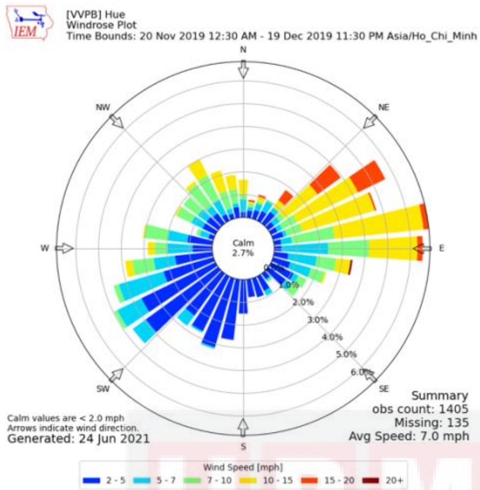


Figure 3.3 The monthly average humidity at Ninh Thuan potential site for the year 2020

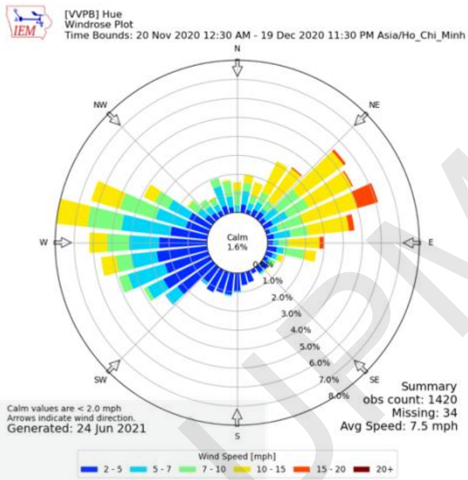
The wind direction and speed are another meteorological factor that impacts particle dispersion at a possible site. Figure 3.4 shows the wind-roses of location 8 km from Ninh Tuan from 2017 until 2020 which is at Hue city. It represents a comparison of wind speed and direction at first week of December for years 2017 until 2020. Based on the data of wind rose, it provided rough display and realistic estimation on the concentration of Cesium isotopes that disperse from the accident. As a result, authority organisation can determine some places that is safe to protect their people from the radionuclides released from the accidental nuclear reactor if the accident occur. It also can be compared to the output that be produced by the HYPLIT model.



(a) (b)



(c)



(d)

Figure 3.4 The wind-rose and wind direction at Ninh Thuan potential site between 20 November until 30 December in (a)2017, (b)2018, (c)2019 and (d)2020

To measure or evaluate the time-series of the spatial distribution for the Cesium's isotope dispersion over the cities in the other countries, some selected cities need to be prioritized according to the number of population. For each countries, capital of the country was chose in this study. Specific locations for each cities will be recorded by stating the latitude and longitude. Number of population and also distance from the selected sites, which is Ninh Thuan is shown in Table 3.1.

Table 3.1 Five selected cities nearly to the first simulation nuclear reactor in 2020

Location	Latitude	Longitude	Distance from Ninh Thuan's site (km)	Population (1000)
Nui Chua	11.6809° N	109.1751° E	49.4	30
Hanoi	21.0278° N	105.8342° E	1082.11	4,678
Bangkok	13.7563° N	100.5018° E	963.78	10,539
Kuala Lumpur	3.1390° N	101.6869° E	1312.48	1,774

3.2.2 Bangi, Malaysia

For the second reactor, the study is located within the area in Malaysia country. Even though Malaysia does not has any intention to build nuclear reactor before 2030, but it can be useful to the authority of safety in Malaysia for emergency preparedness data. The location of the simulation of accident is located at Bangi near to the research centre of nuclear energy in Malaysia, *Malaysia Nuclear Agency* (2.9156 N, 101.783 E) as shown in Figure 3.5. Then, the similar steps is used as previous nuclear reactor which are list the variable such as humidity, average temperature and also wind rose of the location in the location of simulation reactor. For wind rose figure at this site, the reference point is selected at Kuala Lumpur because of the limited resources. The distance from Bangi to Kuala Lumpur is about 28.22 km, so it is assumed that the direction and speed of wind at Bangi is quite similar with Kuala Lumpur.

Figure 3.5 Nuclear reactor selected site's location image in Bangi area from Google maps

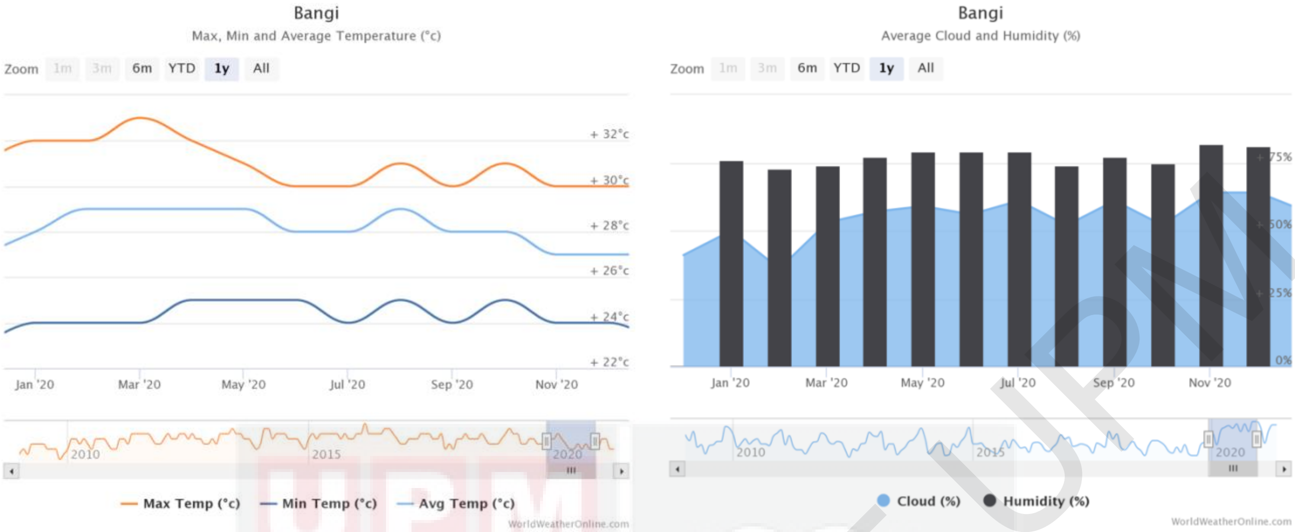


Figure 3.6 The monthly average temperature and humidity at Bangi selected site in 2020

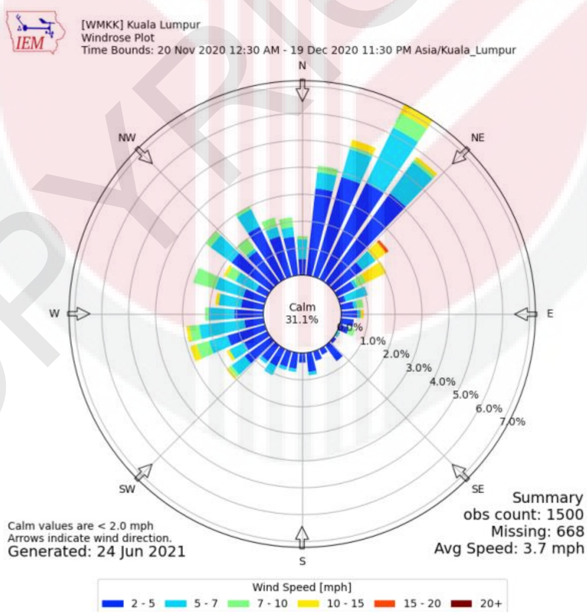


Figure 3.7 The wind-rose of wind speed and direction frequency between 20 November until 30 December of 2020 at Kuala Lumpur

Based on the recorded data from *Department of Statisitics Malaysia*, 5 cities that has highest population in 2020 in Selangor state are *Petaling*, *Hulu Langat*, *Klang*, *Gombak* and *Kuala Langat*. As previous sample or variable, some variables need to be determined in order to compute desired output from the HYSPLIT modelling system. Table 3.2 shows the detail about 5 cities that has highest number of population in Malaysia.

Table 3.2 Five selected cities with high population density nearly to the second simulation nuclear reactor in 2020

Location	Latitude (N/S)	Longitude (E/W)	Distance from Bangi' site (km)	Population (1,000)
Klang	3.0449° N	101.4456° E	40.00	879
Kuala Lumpur	3.1390 ° N	101.6869° E	28.22	1,453
Kota Bharu	6.1248° N	102.2544° E	363.10	1,460
Kampung Baru Subang	3.1293° N	101.5221° E	37.38	834
Subang Jaya	3.0567° N	101.5851° E	27.07	708

3.3. HYSPLIT software

In this section, it is focusing more to the explanation about the general part of HYSPLIT installation and also all required software that are important in computing required output. HYSPLIT software requires certain kind of software to convert the binary input into output that can be understood by public. Based on HYSPLIT tutorial that be refer in this link : https://www.ready.noaa.gov/documents/Tutorial/html/index.html.

3.3.1 Tcl/Tk

Firstly, HYSPLIT required Tcl/Tk scripts which is not included in HYSPLIT installation. Only GUI script that already equipped after HYSPLIT installation. 'Tcl' is stand for Tool Command Language and it is a very powerful but easy dynamic programming language. Tcl is suitable for a very wide range of uses, including web and desktop applications, administration, networking, testing and others. Tk is a graphical user interface toolkit that takes developing desktop applications to a higher level than conventional approaches. Tk is the standard GUI not only for Tcl, but for many other dynamic languages, and can produce rich, native applications that run unchanged across Windows, Mac OS X, Linux and more. For windows and Mac OS X, there are different files that should be downloaded, thus user need to choose it appropriately to download it (Refer figure 3.8).

Figure 3.8 Tcl/Tk download websites

3.3.2 ImageMagick & Ghostscript

The capability to convert the Postscript graphics to other graphical formats is enabled within the GUI through ImageMagick, which normally requires the prior installation of Ghostscript. However, on MAC systems Ghostscript is not required because the Preview function can be used to export the Postscript file to a select number of other formats. ImageMagick can then be used to convert these files to unsupported formats. There are many features that ImageMagick capable to do such as:

- create a GIF animation sequence from a group of images.
- add shapes or text to an image.

- apply a mathematical expression to an image, image sequence, or image channels.
- extract features, describe shapes, and recognize patterns in images.
- accurately represent the wide range of intensity levels found in real scenes ranging from the brightest direct sunlight to the deepest darkest shadows.

ImageMagick is a free software that is useful to run a binary distribution that enable users to use copy, modify, and distribute to display it properly in an image.

3.3.3 Specification

In HYSPLIT system, there are about 4 sections that is provided on the main tabs which are meteorology, trajectory, concentration, and advanced. Meteorology tab provides several steps to enter meteorological data files thus process it to perform dispersion calculations and trajectory of pollutants or radionuclides. Trajectory tab is selected to setup trajectory simulation, run the calculation and display the results. Concentration tab has similar sub menus to trajectory calculation but the difference is number of trajectories that is calculated in a period of time. Concentration tab calculation is followed by thousands of trajectories in a same time while trajectory only once. Lastly, advanced tab is used to prepare additional model parameters that is applied to further control or customization to either trajectory or concentration calculation.

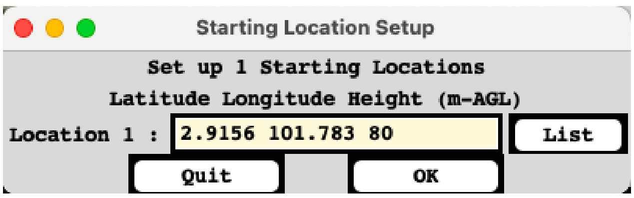


Figure 3.9 Coordinate setup in HYSPLIT system

In HYSPLIT, there are three main steps that are used to compute the trajectory and dispersion calculation in a simulated scenario. Firstly, is “Setup Run” which means the user need to configure data for the simulation with specific coordinates as shown in Figure 3.9 and save the information into a file. Next, file be copied to a file named CONTROL to be read and executed by the system. Lastly, is the Display menu called a program to read the model output file and created a Postscript graphics file. By graphics file that is produced, data such as dose’s dispersion with exact amount also can be computed and recorded.

The aim of this section is to simulate the dispersion of materials or radionuclides emitted to the air. By using HYSPLIT modelling, important data such as wet and dry deposition, chemical transformations and radioactive decay can be determined. HYSPLIT model configured according to radionuclide properties and available data on the release rate of radionuclides to the atmosphere during assumed accidents. The simulation was conducted for atmospheric dispersion of ^{131}I and ^{137}Cs. In HYSPLIT, both puff and particle dispersion equations are expressed in terms of turbulent velocity components which are consist of U and W. Final position of the radioactive particles or puffs can be determine by adding mean position (X) to the turbulent component such as expressed in the equation 3.1.

$$X_{final}(t+\Delta t) = X_{mean}(t+\Delta t) + U'[t+\Delta t]\Delta t G \quad (3.1)$$

HYSPLIT system includes template programs for converting meteorology to ARL/HYSPLIT format, and various output display and post-processing programs. By using this model, the new position towards (Z) direction can be calculated by using equation 3.2.

$$Z_{final}(t+\Delta t) = Z_{mean}(t+\Delta t) + W^{t}(t+\Delta t)\Delta t Z t_{op}^{-1} \qquad (3.2)$$

where the positions are given in grid and sigma units, respectively while the component of turbulent velocity are ms^{-1}. G and Z_{top} are conversion factors. The concentration distribution by each puff of mass m to a grid point increase according to equation below 3.3.

$$\Delta A = m(\pi d^{2} \Delta z) \qquad (3.3)$$

3.3.5 Configured Model

In HYSPLIT model system, polluted menu (Figure 3.8) is selected to set a value of emission rate over 24 hours for the required radionuclides (^{131}I & ^{137}Cs) depending to the accident in Fukushima. Deposition menu is selected for particulate radionuclides such as ^{137}Cs and the details about it is configured inside the menu. It is assumed that all other particulate radionuclides deposit the same way as ^{137}Cs. By referring to HYSPLIT tutorial, there are some steps that need to be followed in order to determine the concentration of Cesium isotopes in certain locations.

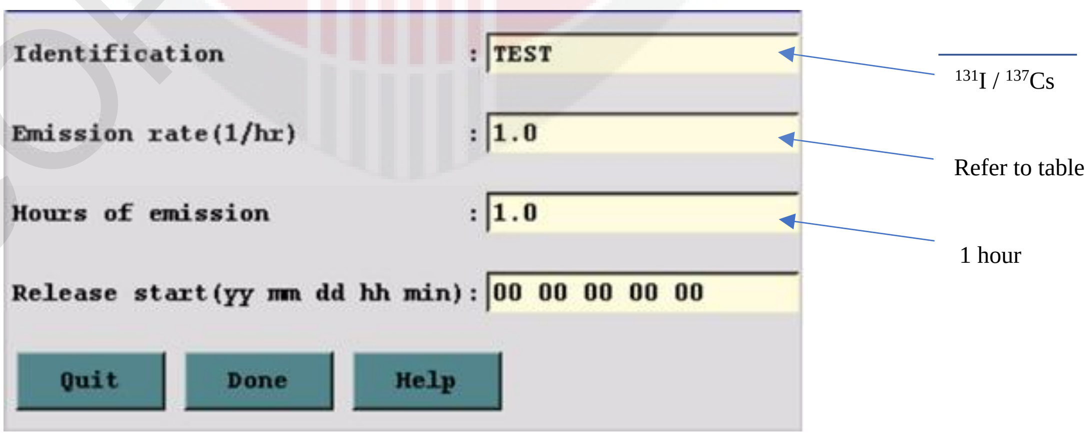


Figure 3.10 Configuration of release rate pollutants or radionuclides in HYSPLIT

Based on Figure 3.10 , the release rate of radioactive particles is set based on the data in table 2.3 . In fact, all radioactive particles have their own decay rate and also emission rate which is depend on the type of reactor. The air concentration and deposition amounts were converted to dose and the amount of the input need to be reasonable based on the assumptions. In HYSPLIT the decay process starts at the time of the particle release, however in reality the decay starts immediately after the fission product is created.

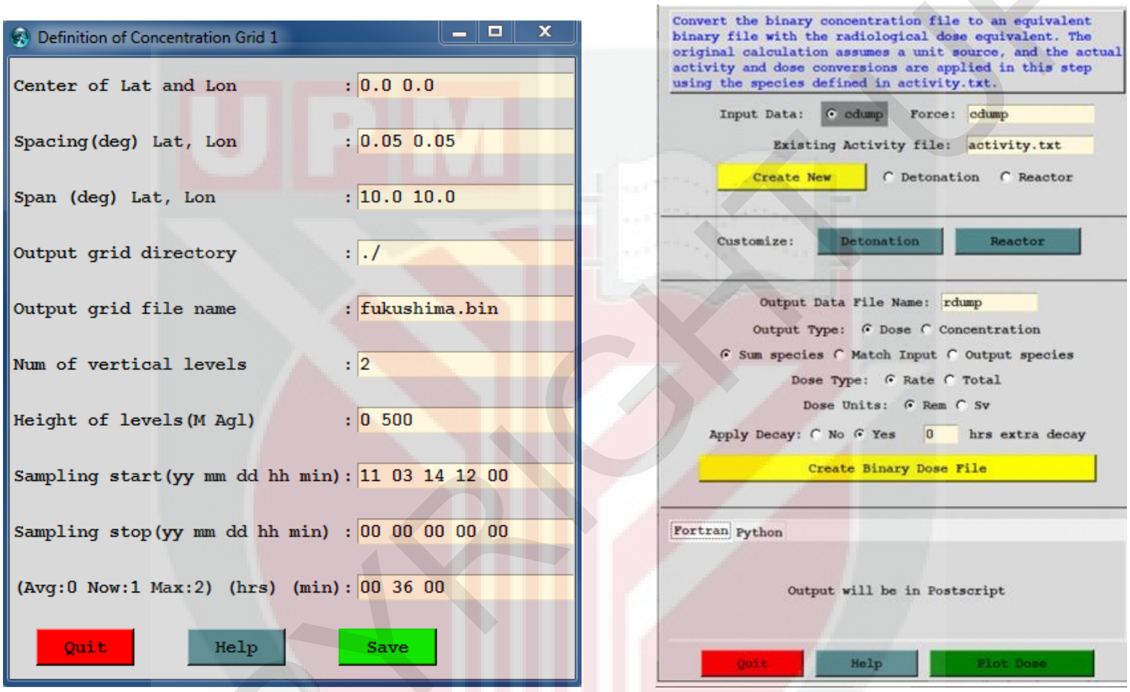


Figure 3.11 Setup of hypothetical reactor on the specific coordinate in the concentration section in HYSPLIT

Based on figure 3.11, the configuration of a 1 unit/h emission rate over 24 hours were set on **22 12 20 00 00** which means the accident is assume to be occur on 22 December 2022 at 12:00 p.m. Setting of any radioactive decay or emission were computed when simulation of the HYSPLIT system has been completed.

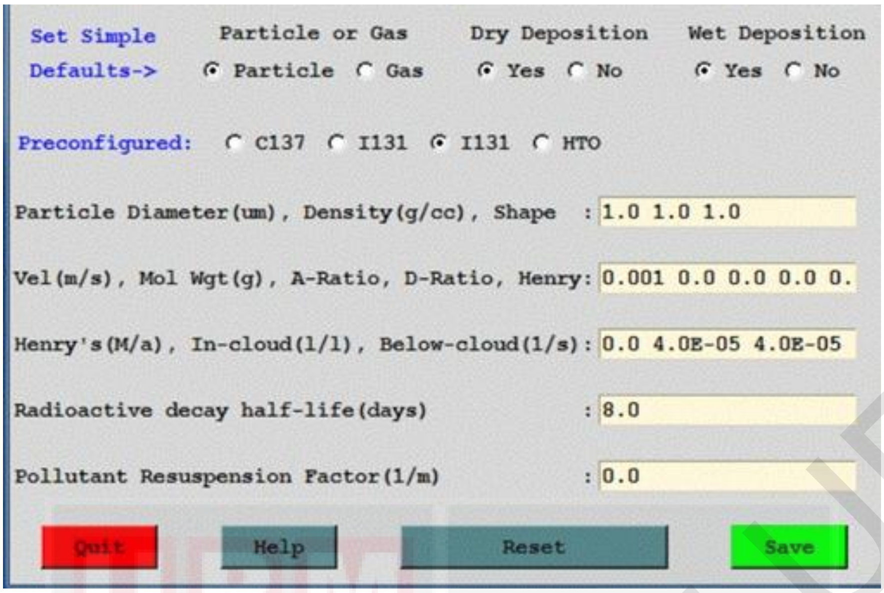


Figure 3.12 Setup of detail information about the radionuclides such as decay half-life and shape of the particles itself

There are several details that need to be specified on the ^{131}I and ^{137}Cs such as radioactive decay, and also the condition is dry or wet deposition (figure 3.12). The measurement and variable of the undesired accident were adjusted in HYSPLIT system itself then the simulation were displayed and analysed.

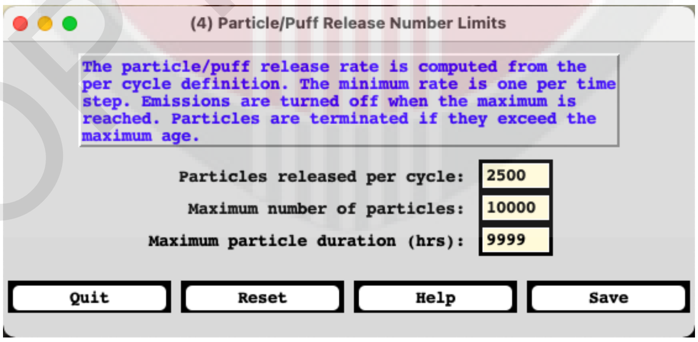


Figure 3.13 Setup for number of particles that is released from the accident simulation

After the required data has been enter into the “Setup Run” option, the data of the activity concentration with the coordinates were extracted and converted into excel form (Concentration -> Utilities -> Convert to -> ASCII -> “Execute Conversion”) as shown in figure 3.14. The data from the excel was used to calculate the activity concentration, equivalent dose and also risk of cancer fatality among the number of population.

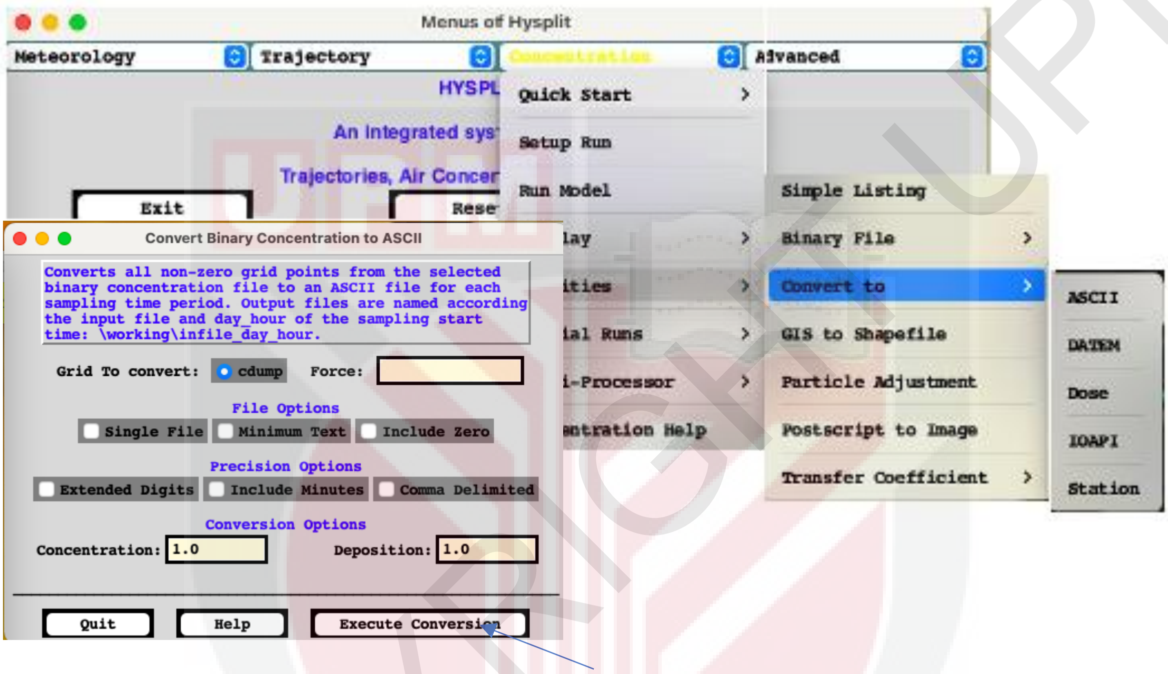


Figure 3.14 Conversion of dispersion data into Excel form

3.4. Accidental scenario selection

3.4.1 Dispersed Radionuclides

The International Nuclear and Radiological Event Scale (INES), authored by the IAEA and the OECD/NEA, classifies nuclear disasters into seven categories based on the event's cause and consequences. . It is illustrated as shown in figure 3.15. In this study, it was assumed that the accident is involving with PWR which is located in Ninh Thuan. Even though the nuclear reactor in Ninh Thuan has not be built yet, the simulation of accident is based on the same data as Fukushima's nuclear reactor accident.

Because Vietnam is located in the tropical monsoon area of the North West Pacific, it caused Vietnam to be one of the most disaster-prone countries in the southeast Asia region. There are many natural disasters such as floods, storms, landslides and also earthquake. Based on table 2.2, this study focus on accident that is caused by system loss of coolant. Then, the same emission rate of ^{131}I and ^{137}Cs from table 2.3 is sampled at the Ninh Thuan (11.69 °N, 109.175 °E) and Bangi (2.9156 °N, 101.7832 °E) to predict the consequences of the dispersion to the other countries in 2020. In this section, it is assumed that the accident scenario is caused by leaks from the reactor coolant system or it is called Loss of coolant accidents (LOCAs).

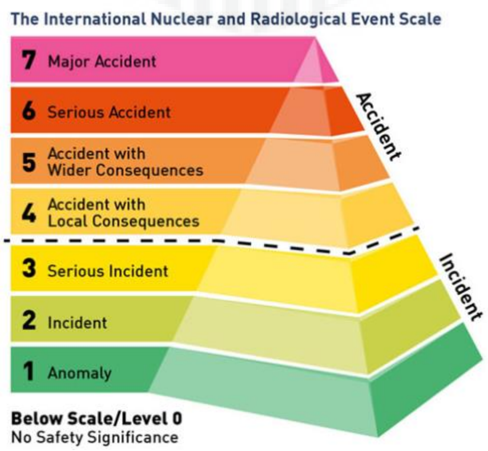


Figure 3.15 INES classification for accident level (IAEA, 2008)

According to the SOARCA research, nuclear disaster scenarios are divided into two categories: station shutdown and early containment failure. There are two types station blackout which are Long-Term station blackout (LTSBO) and Short term blackout (STSBO) . Both are differed by amount of the frequency of the initial earthquake in certain areas. Both are related with a seismic event which results in the loss of offsite power and failure of onsite emergency AC power . Time selected for the hypothetical accident is at the last week of December for 24 hours of time release.

3.4.2 Accidental release rate

In this section, several data of annual release from authorized organization such as IAEA is collected. Thus, it is compulsory to collect data from that accident to simulate it. The input data of meteorological, location, sources such as radioactive pollutants and also dispersion specifications are the variables that need to consider in analysing this simulation in HYSPLIT model. For radionuclides, the half-life, release rate, type of emitted radiation and risk group were considered for ^{131}I and ^{137}Cs isotopes.

3.5 Effective dose measurement

Dose intakes through inhalation and external exposure pathways were calculated by using equation 3.4.

$$E = e_E A t \tag{3.4}$$

where e_E is the dose rate coefficient, A is the activity concentration and t is the duration of a person being exposed to the pollutant. e_E is dependant to the altitude of the radionuclide analysis whether it is focused on ground or air. Value of A is directly obtained from the

HYSPLIT system itself and multiplied by the *External Exposure to Radionuclides in air ,water and soil* (EPA-402/R19/002 report from *EPA United States Environmental Protection Agency*) . After the amount of total effective dose is calculated for each distance, it was recorded in a table for each locations and the results are compared to the allowed dose among public people. The result after the calculation of dose conversion factor and activity concentration is rate of equivalent dose that received by adult people near to the area. Thus, by multiplying it with 3600s to determine accumulated dose in a day. This is to determine the total effective dose that received by adults on the first day of the accident occur due to the ground deposition value.

3.6 Radiation risk analysis

The calculation of cancer risks due to the exposure to a certain measure of annual effective dose equivalent from ^{134}Cs and ^{137}Cs performed by using the general formula that is authorized by ICRP organization (equation 2.6). By using calculation, the overall effective dose from the NPP in Ninh Thuan using can be recorded for various locations and directions.

$$\text{Risk of Mortality} = \text{Air concentration } [\text{Bq h/m}^3] \times \text{Breathing Rate } [\text{m}^3/\text{h}] \times \text{Mortality Coefficient } [/\text{Bq}] \qquad (3.5)$$

The probabilities of cancer risk were calculated and recorded for each 10 km distance from the source (Ninh Thuan & Bangi). Next, the probability of mortality was calculated by using equation 3.5 above (Jeong et al., 2013) by using coefficient that is suggested in *EPA Cancer Risk Coefficient for Environmental Exposure to Radionuclides* (EPA 402- R 99-001 September 1999).

CHAPTER 4

RESULTS & DISCUSSIONS

4.1 Introduction

This chapter focuses on the analysis of ^{137}Cs and ^{131}I from the simulation of accident in selected sites at Bangi, Malaysia and Ninh Thuan, Vietnam on 22 December 2020. The mean value of activity concentration (MBq/m^3) , dispersion of radionuclides, highest value of activity concentration (MBq/m^3), mean value of equivalent dose (mSv/m^3) , activity concentration (MBq/m^3) at different altitudes, activity concentration(MBq/m^3) and radiogenic cancer risk probability at certain locations were discussed separately.

4.2 Activity concentration of ^{137}Cs and ^{131}I

Activity concentration of ^{137}Cs and ^{131}I are tabulated in this section into several categories. This analysis will show how the activity concentration is differed by the wind direction of a location, type of radionuclides and also the altitude.

4.2.1 Activity concentration based on location

The mean value of activity concentration of ^{137}Cs and ^{131}I that were released from the simulation accident at Ninh Thuan are summarized in figure 4.1 and table 4.1. Meanwhile, for Bangi, it have been summarized in figure 4.2 and table 4.2. The mean activity concentrations of ^{137}Cs and ^{131}I were analysed on 22 December 2020 where the accident was assumed to be started at UTC 00:00.

Based on the table 4.1, the mean activity concentration of ^{137}Cs is determined within the period of 1 day which is in 22 December 2020. The activity concentrations of ^{137}Cs was analysed in each 1 hour on the same day. The mean activity concentrations of ^{137}Cs for Bangi, Malaysia and Ninh Thuan, Vietnam were ranged within 0.0184-13.1 MBq/m^2 (mean 1.81 ± 0.814 MBq/m^2) and 0.00398-0.385 (mean 0.073 ± 0.0263 MBq/m^2) respectively. On the other hand, for ^{131}I, the mean activity concentrations for Bangi, Malaysia and Ninh Thuan, Vietnam were ranged within 1.41 – 470 MBq/m^2 (mean 63.2 ± 27.69 MBq/m^2) and 0.235 -12.8 MBq/m^3 (mean 2.65 ± 0.88 MBq/m^2) respectively.

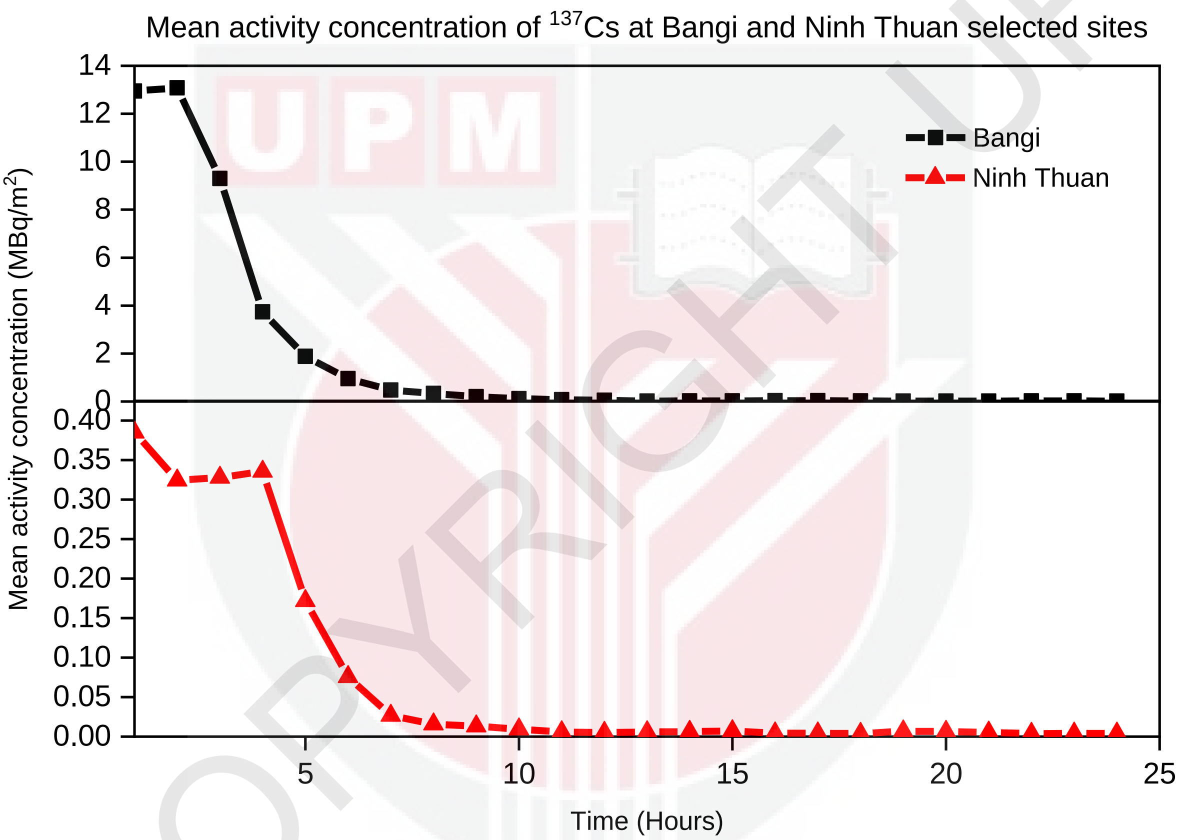


Figure 4.1 Mean activity concentration of ^{137}Cs at Bangi and Ninh Thuan nominated sites at 22 December 2020 at 00:00 UTC for ST4 scenario

The result shows that Bangi has the higher value compared to Ninh Thuan because of the geographical factors and wind direction that perhaps affecting the dispersion of radionuclides within the area. The highest value for mean activity concentration of ^{137}Cs at Bangi is between first and the second hour (UTC 01:00-02:00) after the accident occur which is 13.1 MBq/m^2.

It will then decreased gradually when the time increase as it was dispersed widely to various area. Meanwhile for Ninh Thuan, the highest value for mean activity concentration of ^{131}I during the first hour after the accident (UTC 00:00-01:00) occur which is 0.385 MBq/m^2.

Table 4.1 Summarized data for mean activity concentration of Cs-137 at Bangi and Ninh Thuan selected sites. The mean activity is divided into several period of times on the 22 December 2022 at 00:00 UTC

Time (Hours)	Mean of activity concentration of ^{137}Cs (MBq/m^2)	
	Bangi	Ninh Thuan
1	13.000 $\pm$ 6.050	0.385 $\pm$ 0.131
8	0.335 $\pm$ 0.043	0.016 $\pm$ 0.001
16	0.033 $\pm$ 0.000142	0.000419 $\pm$ 0.000103
24	0.0184 $\pm$ 0.000792	0.00398 $\pm$ 0.000112

The results from Table 4.1 observed that the average activity of ^{137}Cs is still high after 24 hours of the accident based on the high emission rate which is 1.00 x 10^{16} Bq/hr for 3 hours. For emission rate of ^{131}I in ST4 scenario, the value of emission rate is high compared to ^{137}Cs which is 6.00 x 10^{17} Bq/hr. Thus, it caused the activity concentration of ^{131}I is high compared to ^{137}Cs in the first day of accident. Figure 4.2 shows the mean activity concentration of ^{131}I at both locations. The highest value for mean activity concentration of ^{131}I at Bangi is during the first hour after the accident (UTC 00:00-01:00) after the accident occur which is 470.00 MBq/m^2. It will then decreased gradually when the time increase as it was dispersed widely to various area same as ^{137}Cs . At the same time, the highest value for mean activity concentration of ^{131}I at Ninh Thuan is during the first hour after the accident (UTC 00:00-01:00) occur which is 12.8 MBq/m^3.

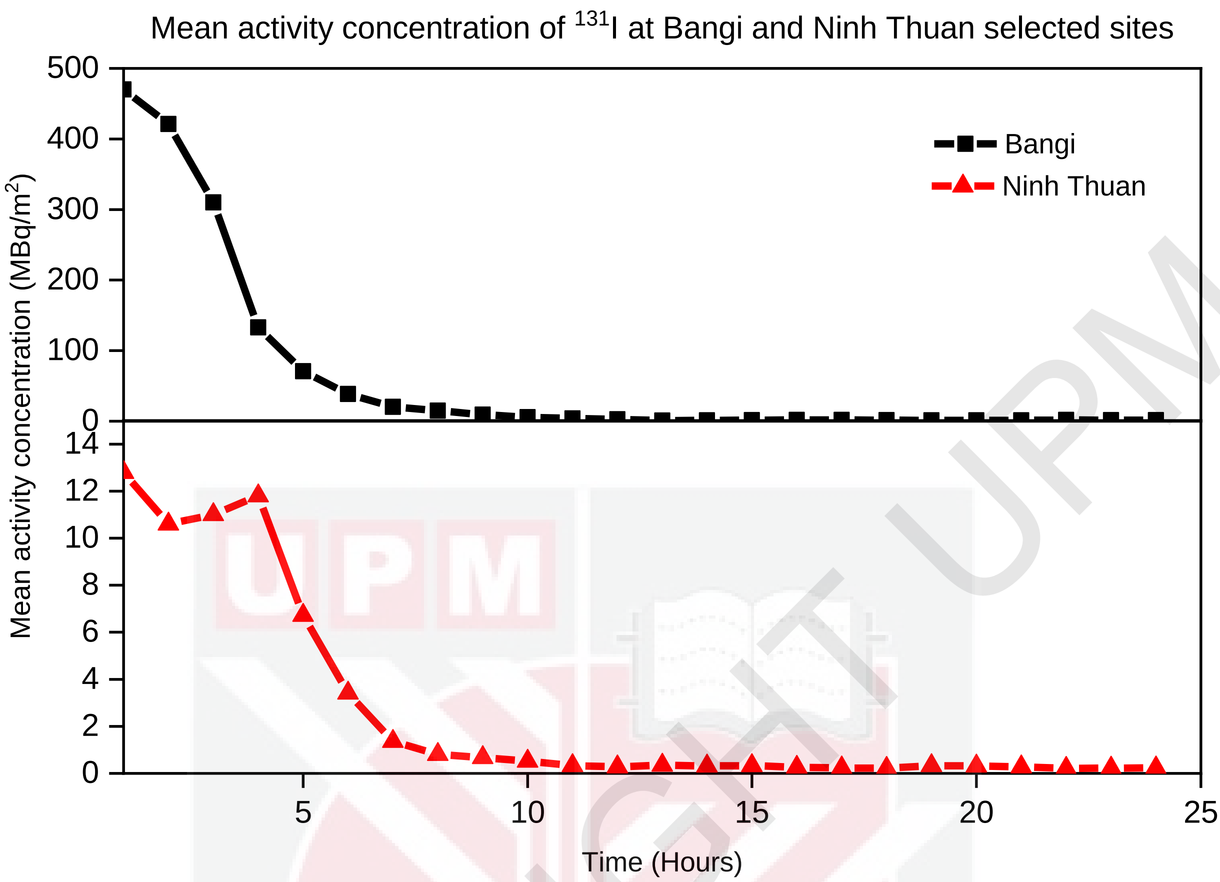


Figure 4.2 Mean activity concentration of ^{131}I at Bangi and Ninh Thuan nominated sites at 22 December 2020 at 00:00 UTC for ST4 scenario

After 24 hours of the accident, it can be observe that the activity concentration of ^{131}I is high compared to ^{137}Cs. For Bangi, the mean activity concentration of ^{137}Cs and ^{131}I is 0.0184 x 10^6 Bq/m^2 and 1.41 x 10^6 Bq/m^2 respectively while for Ninh Thuan, the mean activity concentration of ^{137}Cs and ^{131}I is 3984.59 Bq/m^2 and 2.35 x 10^5 Bq/m^2 .

Table 4.2 Summarized data for mean activity concentration of ^{131}I at Bangi and Ninh Thuan selected sites. The mean activity is divided into several period of times on the 22 December 2022 at 00:00 UTC

Time (Hours)	Mean of activity concentration of ^{131}I (MBq/m^2)	
	Bangi	Ninh Thuan
1	470.000 $\pm$ 230.000	12.800 $\pm$ 4.370
8	14.800 $\pm$ 1.904	0.804 $\pm$ 0.026
16	1.740 $\pm$ 0.0079	0.258 $\pm$ 0.0049
24	1.410 $\pm$ 0.065	0.235 $\pm$ 0.006

4.2.2 Highest Activity concentration based on location and time

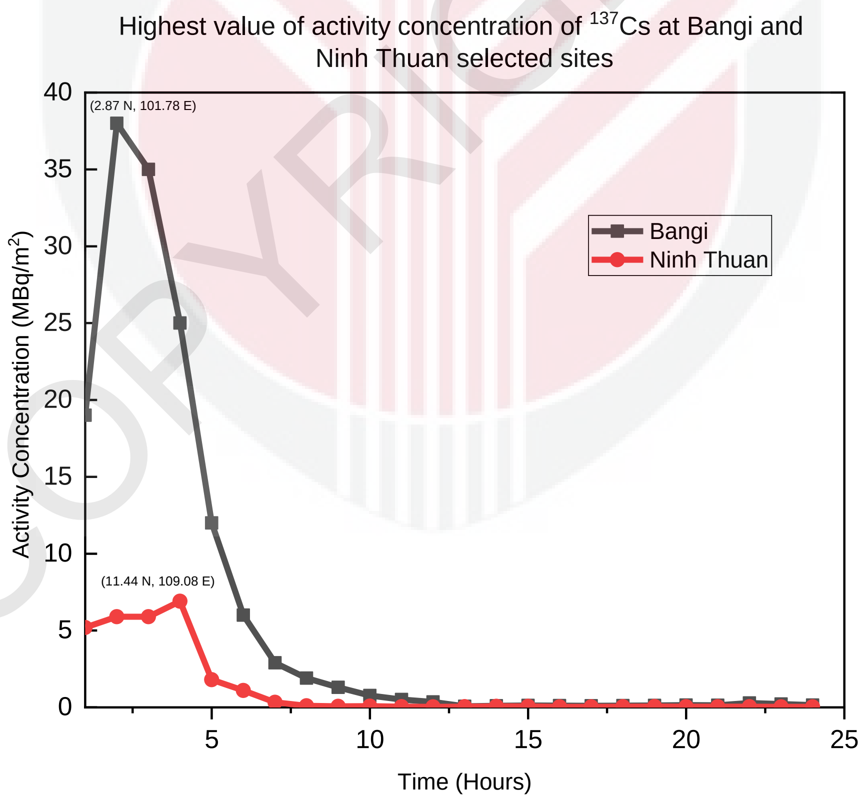


Figure 4.3 Comparison of highest value of activity concentration of ^{137}Cs at Bangi and Ninh Thuan nominated sites at 22 December 2020 starting from 00:00 UTC for ST4 scenario

Based on the figure 4.3, the highest value of activity concentration of ^{137}Cs is from UTC 01:00 until 02:00 is pointed at Dengkil (2.87 N , 101.78 E) which is near to the centre site. The value of the highest activity concentration is about 3.80 x 10^7 Bq/m^2 at ground level. There are about 90,079 of population living in the city. Thus, this accident will cause many deaths if the nearby people is not being move outside from the area within 3 hours after the explosion. Besides that, for Ninh Thuan area, the highest value of activity concentration is 6.90 x 10^6 Bq/m^2 located at the sea area (11.44 N , 109.08 E) from UTC 03:00 until 04:00. The data from figure 4.3 is summarized in Table 4.3.

Table 4.3 Summarized data for highest activity concentration of ^{137}Cs at Bangi and Ninh Thuan selected sites. The mean activity is divided into several period of times on the 22 December 2022 at 00:00 UTC

Time (Hours)	Highest value of activity concentration of ^{137}Cs (MBq/m^2)	
	Bangi	Ninh Thuan
1	19.001	5.200
8	1.900	0.098
16	0.110	0.031
24	0.150	0.033

Figure 4.4 shows the highest value of activity concentration of ^{131}I at Bangi and Ninh Thuan. The highest activity concentration of ^{131}I at Bangi is similar as ^{137}Cs which located at Dengkil (2.87 N , 101.78 E) from UTC 01:00 until 02:00 but the value is larger than ^{137}Cs as the emission rate of Iodine higher than Cesium.

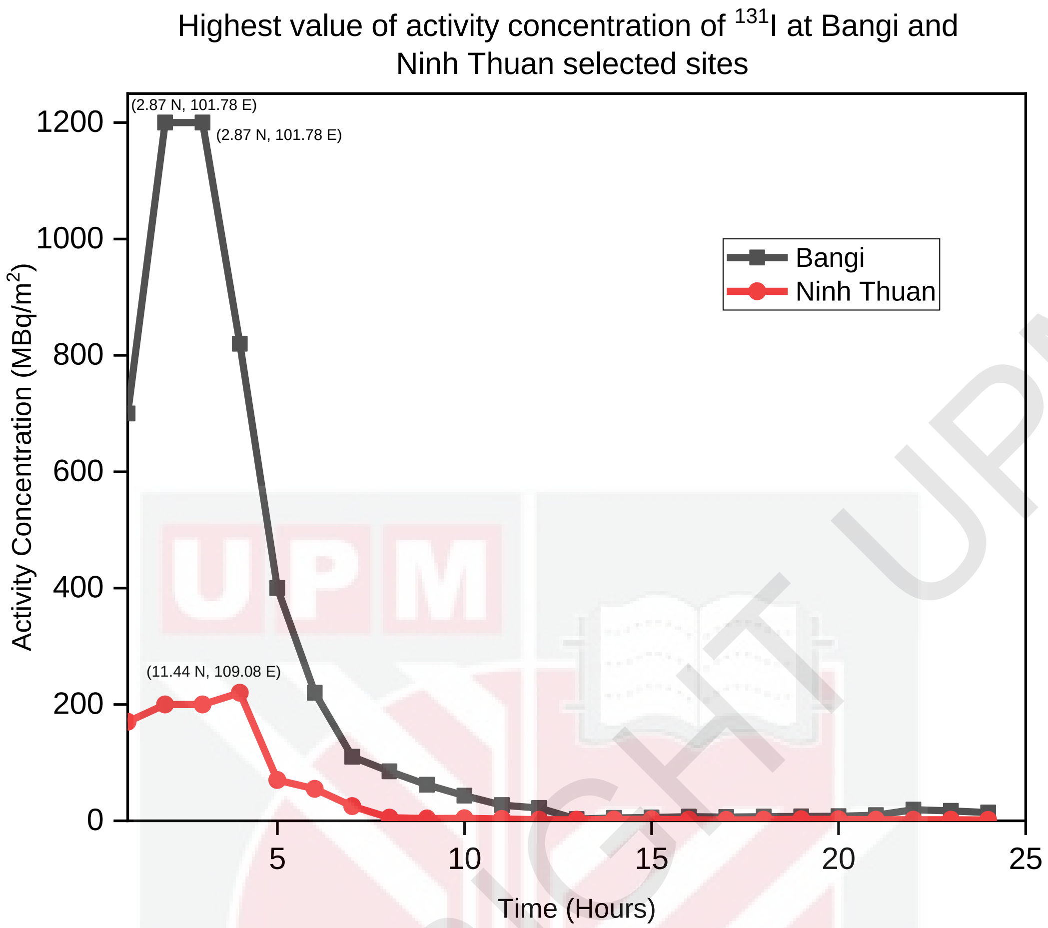


Figure 4.4 Highest value of activity concentration of ^{131}I at Bangi and Ninh Thuan nominated sites at 22 December 2020 starting from 00:00 UTC for ST4 scenario

The annual release of ^{131}I is higher compared to ^{137}Cs based on report adopted from IAEA report (McMahon et al., 2013). Thus, it caused the value of activity concentration of ^{131}I is higher than ^{137}Cs for both locations but for the long term one, ^{137}Cs will remain longer based on the half-life. People in those coordinate which are highlighted in this section need to be aware and the housing area need to be shifted into another area if the government decide to build nuclear reactor at Bangi and Ninh Thuan. Generally, Ninh Thuan's location is more safer as most of the radionuclides were estimated to move to the sea area if the accident occur.

Table 4.4 Summarized data for highest activity concentration of ^{131}I at Bangi and Ninh Thuan selected sites. The mean activity is divided into several period of times on the 22 December 2022 at 00:00 UTC

Time (Hours)	Highest value of activity concentration of ^{131}I (MBq/m^2)	
	Bangi	Ninh Thuan
1	700.00	170.00
8	85.00	5.40
16	6.90	1.70
24	14.00	1.50

4.2.3 Activity concentration of ^{137}Cs and ^{131}I based on different altitudes

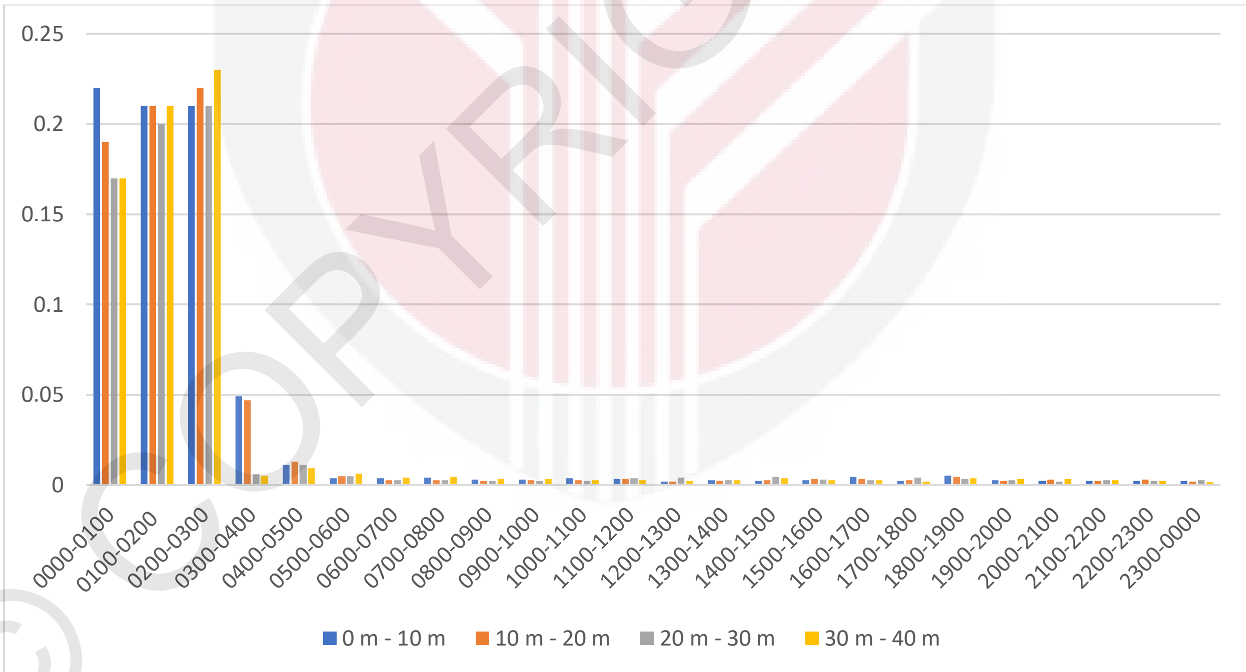


Figure 4.5 Highest value of activity concentration of ^{137}Cs at 4 different levels of altitude at Ninh Thuan

Based on figure 4.5, it can be observed that the value of activity concentration of ^{137}Cs at each levels of altitude are decreased sharply after 3 hours from the accident. The highest activity concentration of ^{137}Cs is at the altitude 30 m – 40 m on UTC (02:00-03:00) for Ninh Thuan. On the other hand, the highest activity concentration of ^{137}Cs is at the altitude 0 m – 10 m on UTC (00:00-01:00) for Bangi.

Table 4.5 Summarized data for highest activity concentration of ^{137}Cs at Ninh Thuan selected sites. The mean activity is divided into several period of times on the 22 December 2022 at 00:00 UTC

Time (Hours)	Highest values of activity concentration for different layer of altitude (MBq/m^3)			
	0 m – 10 m	10 m – 20 m	20 m – 30 m	30 m – 40 m
0000-0100	0.2200	0.1900	0.1700	0.1700
0800-0900	0.0029	0.0022	0.0024	0.0035
1600-1700	0.0044	0.0032	0.0027	0.0027
2300-0000	0.0022	0.002	0.0025	0.0016

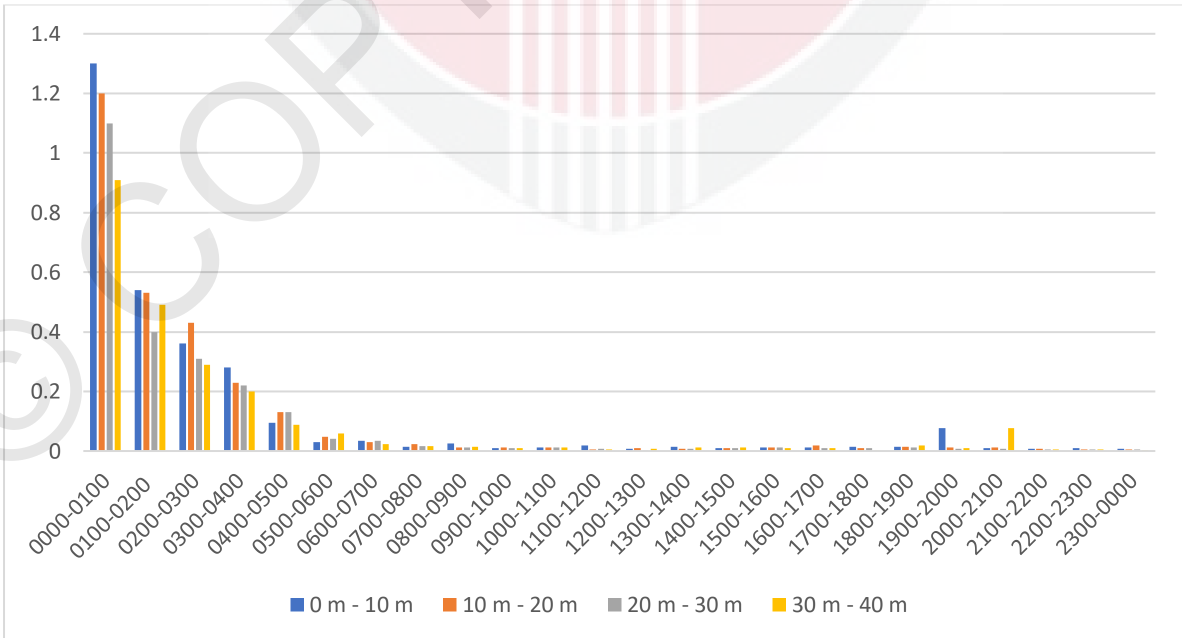


Figure 4.6 Highest values of activity concentration of ^{137}Cs at 4 different levels of altitude at Bangi

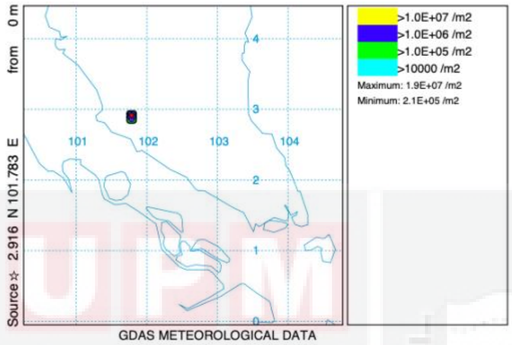
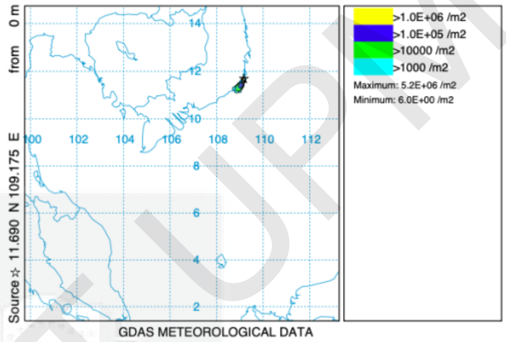
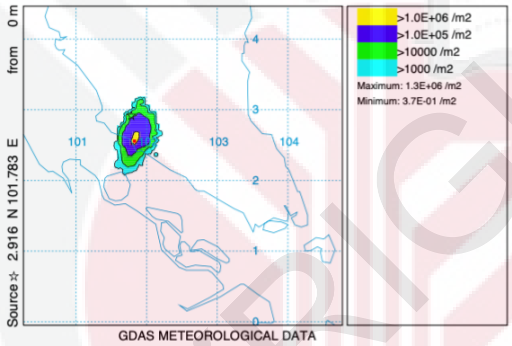
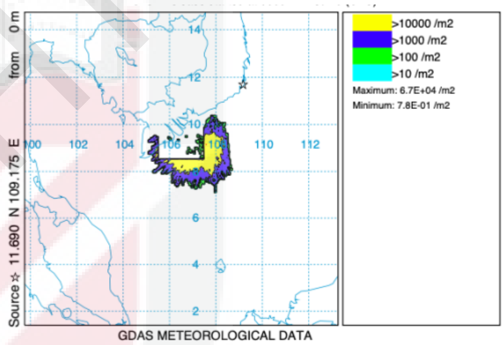
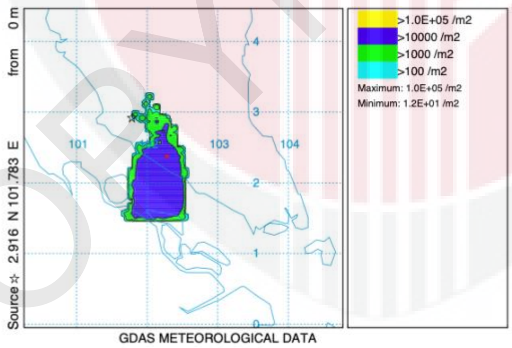
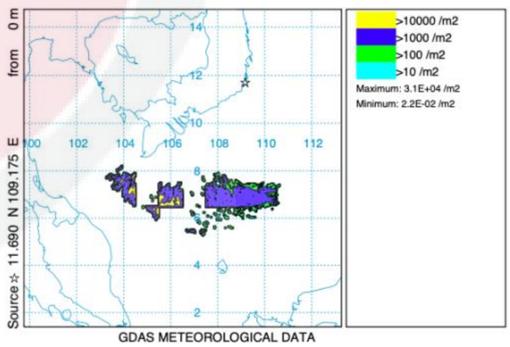
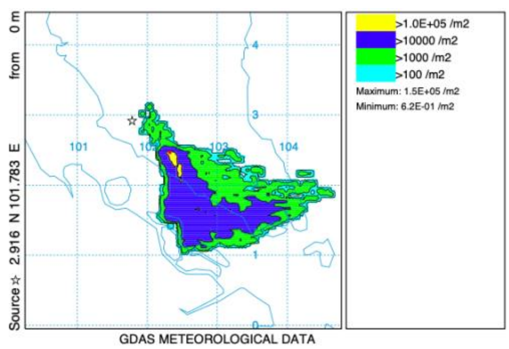
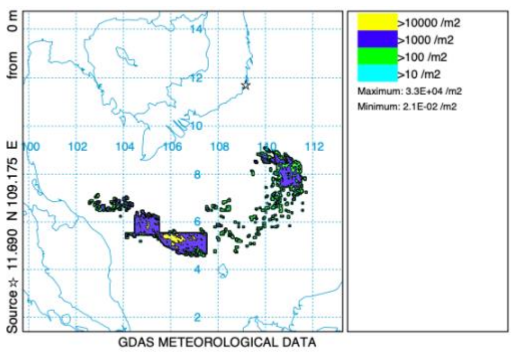
Table 4.6 Summarized data for highest activity concentration of ^{137}Cs at Bangi selected sites. The mean activity is divided into several period of times on the 22 December 2022 at 00:00 UTC

Time (Hours)	Highest value of activity concentration for different layer of altitude (MBq/m^3)			
	0 m - 10 m	10 m - 20 m	20 m - 30 m	30 m - 40 m
0000-0100	1.300	1.200	1.100	0.910
0800-0900	0.025	0.013	0.011	0.015
1600-1700	0.012	0.018	0.0097	0.01
2300-0000	0.0072	0.006	0.0048	0.0028

4.3 Dispersion of radionuclides ^{137}Cs and ^{131}I at 0 m altitude

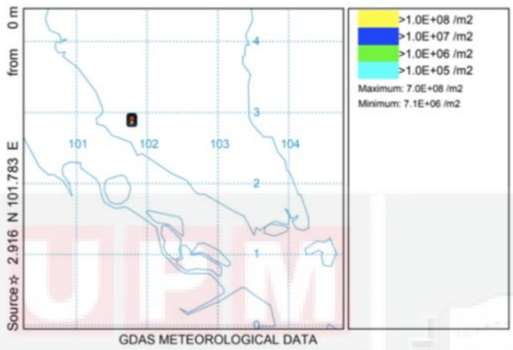
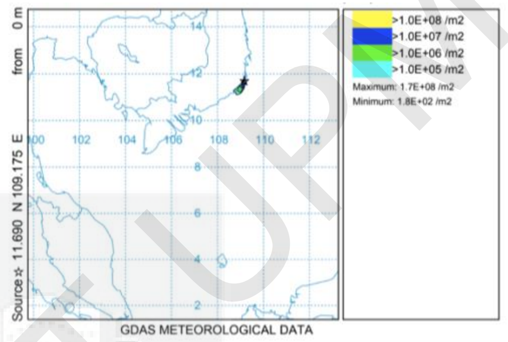
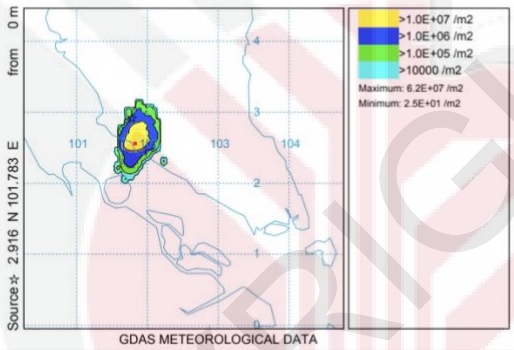
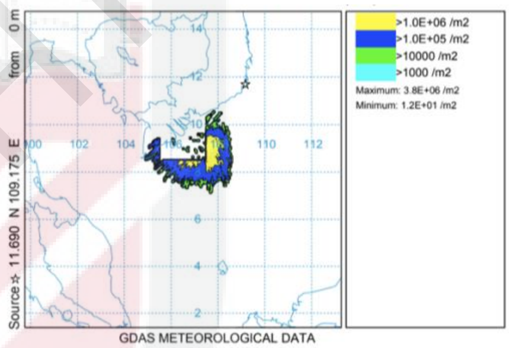
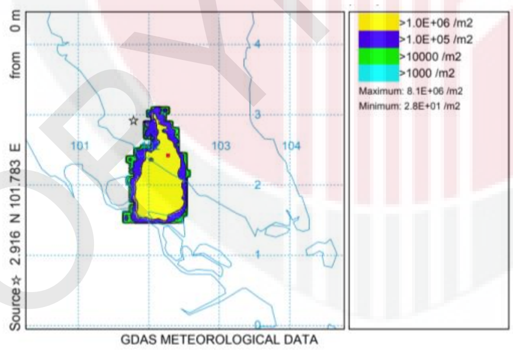
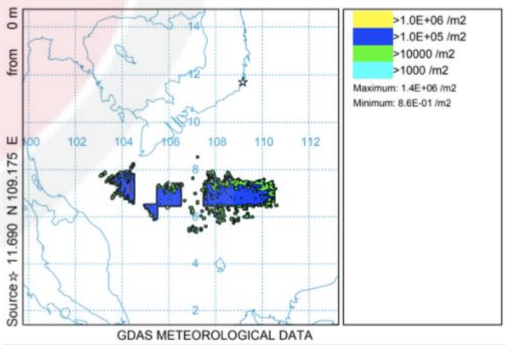
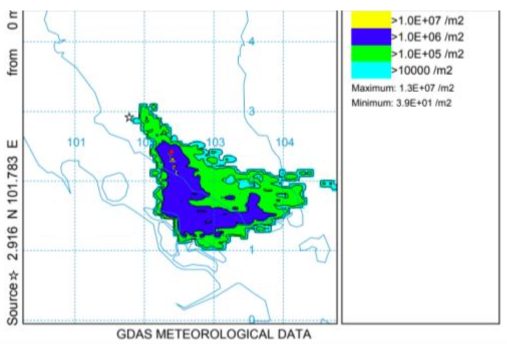
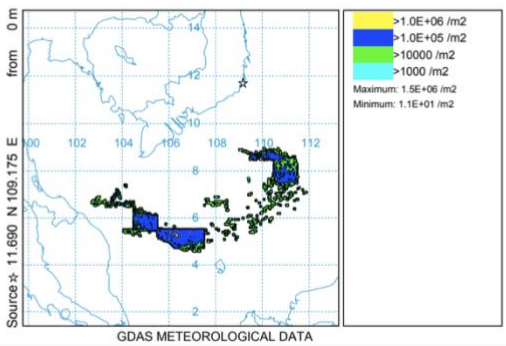
In this research, the dispersion of ^{137}Cs has been evaluated from UTC 00:00 to UTC 23:59 at specific locations using HYSPLIT software at the ground level. The main purpose of the 0m altitude is to evaluate the value that is significant to human being. The type of accident that is selected is (ST4) which is started from internal event such as loss of coolant. Table 4.7 and 4.8 displays atmospheric contours and magnitudes of ^{137}Cs and ^{131}I for an accidental release. The hypothetical accident (ST4) is run for 24 hours at second week of December.

Table 4.7 Dispersion of ^{137}Cs at both locations Bangi and Ninh Thuan at 22 December 2020, UTC 00:00 with the value of activity concentrations at ground level

Time	Dispersion of ^{137}Cs radionuclide for a hypothetical accident at the ground level	
	Bangi	Ninh Thuan
0000-0100		
0800-0900		
1600-1700		
2300-0000		

For Ninh thuan simulated reactor, figures in table 4.7 shows the movement of radioactive plume ^{137}Cs was dispersed during the accident. One of the city that was affected by the simulation of accident in the first day is Nui Chua. However, for Bangi, ^{137}Cs radionuclide was moved to the West country in Malaysia which includes Johor, Negeri Sembilan and also Malacca. This assumption should be useful in any emergency preparedness strategies for any unexpected event. In addition, some precautions area may be highlighted if the reactors will be built in these regions. Safety in this field can took action to estimate the time that is minimum to move people outside from the high possibility region that might be harmful and killed some people due to the inhalation of radionuclides that is dangerous to people. In Bangi, it took around 20 hours to reach Johor Bharu and Segamat which the highest activity concentration is around 26527.88 Bq/m^3 and 21507.88 Bq/m^3 respectively.

Table 4.8 Dispersion of ^{131}I at both locations Bangi and Ninh Thuan at 22 December 2020, UTC 00:00 with the value of activity concentrations at ground level

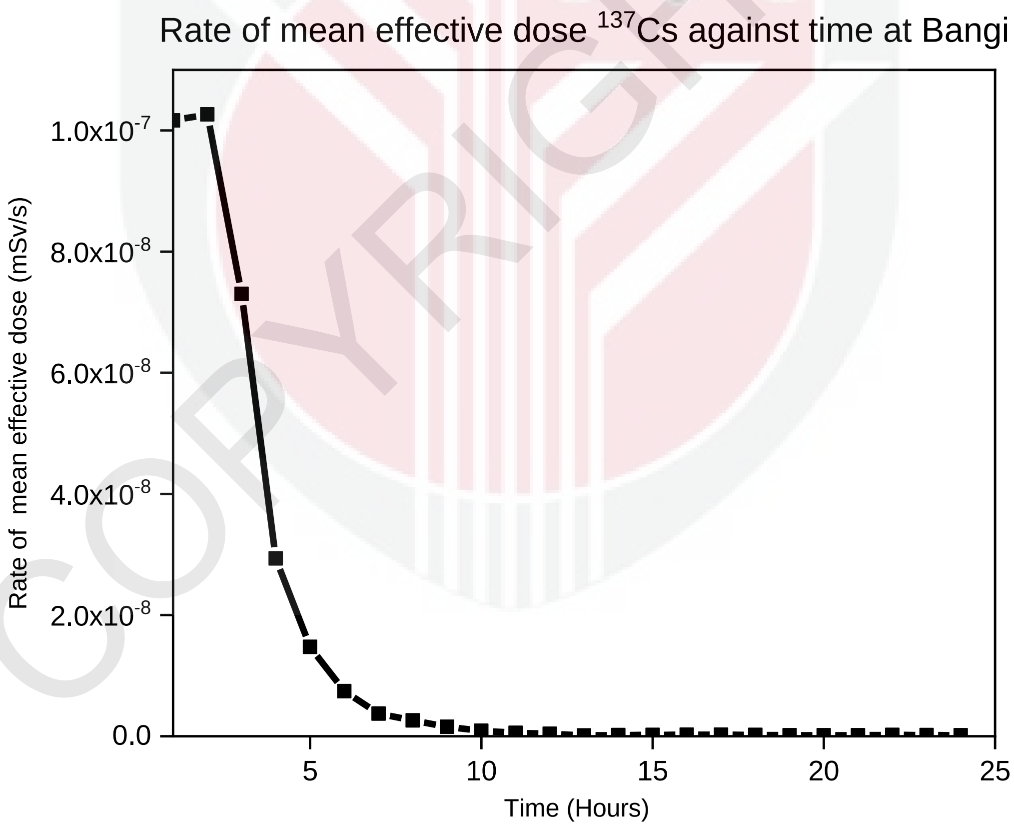
Time	Dispersion of ^{131}I radionuclide for a hypothetical accident at the ground level	
	Bangi	Ninh Thuan
0000-0100		
0800-0900		
1600-1700		
2300-0000		

Based on the table 4.8, there are few differences of the dispersion of ^{131}I especially in term of magnitude. For Ninh Thuan, the direction of wind in the fourth week of December is tend to East region so it effected the movement of radionuclides into that area.

4.4 Effective dose of ^{137}Cs and ^{131}I at selected sites

The amount of effective dose is calculated and tabulated in this section. It have been analysed with different time and altitudes. There are two types of effective dose that are focused on this section which are mean effective dose and highest effective dose on certain locations.

4.4.1 Rate mean effective dose of ^{137}Cs and ^{131}I



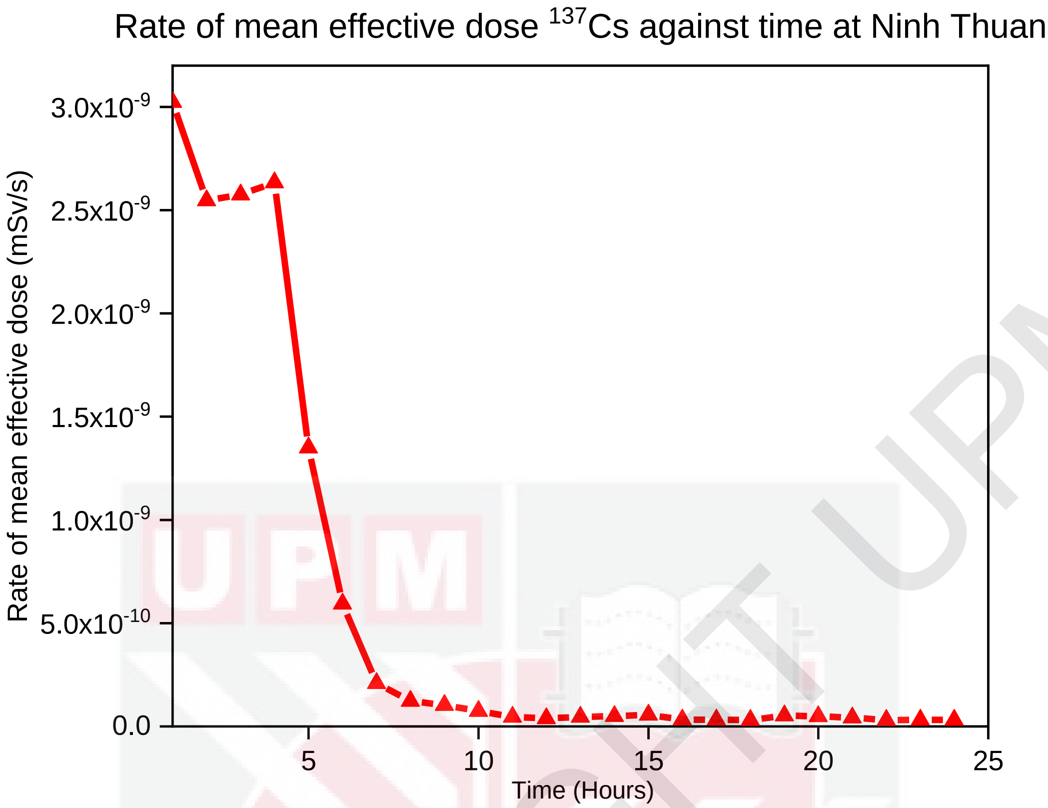


Figure 4.7 Rate of mean effective dose of ^{137}Cs against time at both at Bangi and Ninh Thuan

From the activity concentration of radionuclides determined from HYSPLIT system, it enable this research to find the rate mean of effective dose for both ^{137}Cs and ^{131}I for the first day of simulation accident. For ^{137}Cs radionuclide, the person effective dose rate coefficients for ground surface for adult is 7.85 x 10^{-18} Sv Bq^{-1} $s^{-1}m^{2}$ to convert the activity concentration into rate of effective dose and was recorded in table 4.7 for 1 hr, 8 hr , 16 hr and 24 hr. The accumulated dose of ^{137}Cs for Bangi and Ninh Thuan are 0.001227 mSv and 4.9 x10^{-5} mSv respectively on the first day of simulation accident.

Table 4.9 Mean rate of effective dose for ^{137}Cs the first day of accident at 1 hr,8 hr,16 hr and 24 hr with the accumulated effective dose on the first day of accident

Time (hours)	**Mean rate of effective dose of ^{137}Cs (mSv/s)**	
	Bangi	Ninh Thuan
1	$(1.02 \times 10^{-7}) \pm (0.475 \times 10^{-7})$	$(3.02 \times 10^{-9}) \pm (1.03 \times 10^{-9})$
8	$(2.62 \times 10^{-9}) \pm (0.339 \times 10^{-9})$	$(1.23 \times 10^{-10}) \pm (3.925 \times 10^{-12})$
16	$(2.60 \times 10^{-10}) \pm (1.115 \times 10^{-12})$	$(3.29 \times 10^{-12}) \pm (4.239 \times 10^{-13})$
24	$(1.44 \times 10^{-10}) \pm (6.217 \times 10^{-12})$	$(3.12 \times 10^{-11}) \pm (8.792 \times 10^{-13})$
Accumulated effective dose on the first day of accident (mSv)	0.001227	4.9×10^{-5}

Based on figure 4.8 , the accumulated dose of Cesium is reaching 0.0012 mSv when the time was reaching 7 hours after the simulation of accident at Bangi. However, the accumulated dose of Cesium in Ninh Thuan is low compared to Bangi with a ratio of 1 : 25 based on the emission for the first day of the accident.

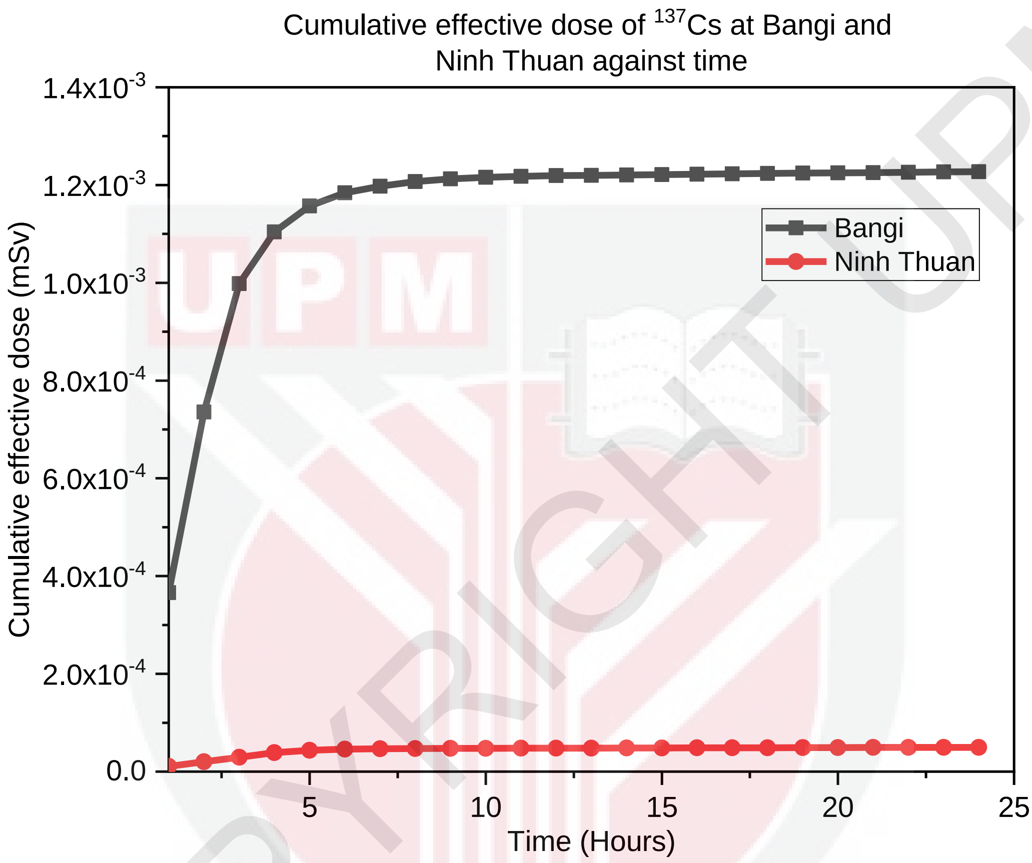


Figure 4.8 Cumulative effective dose of ^{137}Cs against time at both Bangi and Ninh Thuan

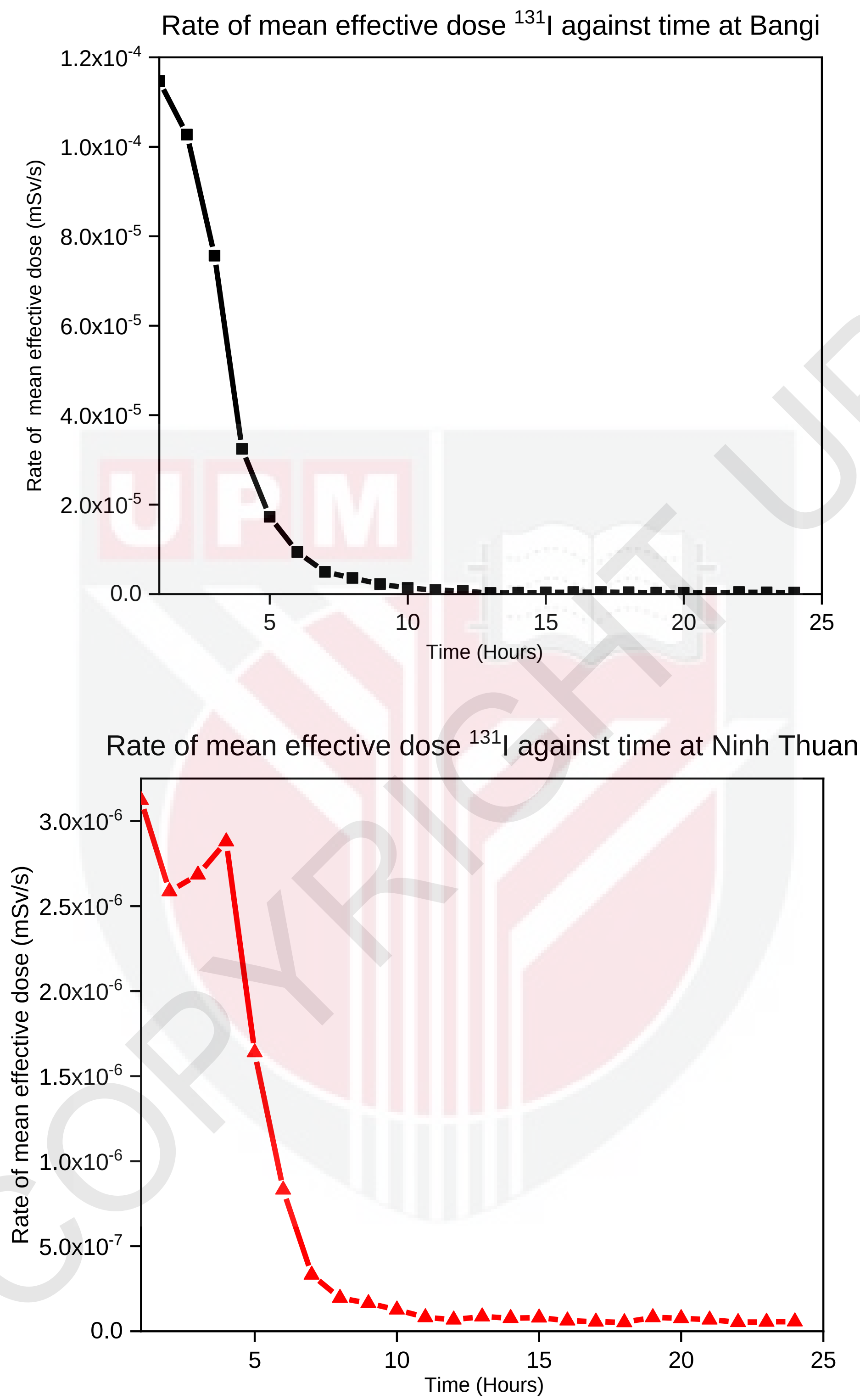


Figure 4.9 Rate of mean effective dose of ^{131}I against time at both Bangi and Ninh Thuan

For ^{131}I radionuclide, the person effective dose rate coefficients for ground surface for adult is 2.44 x 10^{-13} Sv Bq^{-1} $s^{-1}m^{2}$ to convert the activity concentration into rate of effective dose and was recorded in table 4.8 for 1 hr, 8 hr , 16 hr and 24 hr. The summarized data for results in figure 4.9 and figure 4.10 is shown in Table 4.10.

Table 4.10 Mean rate of effective dose for ^{131}I at the first day of accident at 1 hr,8 hr,16 hr and 24 hr with the accumulated effective dose on the first day of accident

Time (hours)	Mean rate effective dose of ^{131}I (mSv/s)	
	Bangi	Ninh Thuan
1	$(1.15 \times 10^{-4}) \pm (5.612 \times 10^{-5})$	$(3.12 \times 10^{-6}) \pm (1.07 \times 10^{-6})$
8	$(3.61 \times 10^{-6}) \pm (4.65 \times 10^{-7})$	$(1.96 \times 10^{-7}) \pm (6.37 \times 10^{-9})$
16	$(4.25 \times 10^{-7}) \pm (1.923 \times 10^{-9})$	$(6.30 \times 10^{-8}) \pm (1.2 \times 10^{-9})$
24	$(3.44 \times 10^{-7}) \pm (1.591 \times 10^{-8})$	$(5.73 \times 10^{-8}) \pm (1.39 \times 10^{-9})$
Accumulated effective dose in first day of accident (mSv)	1.33	0.0559

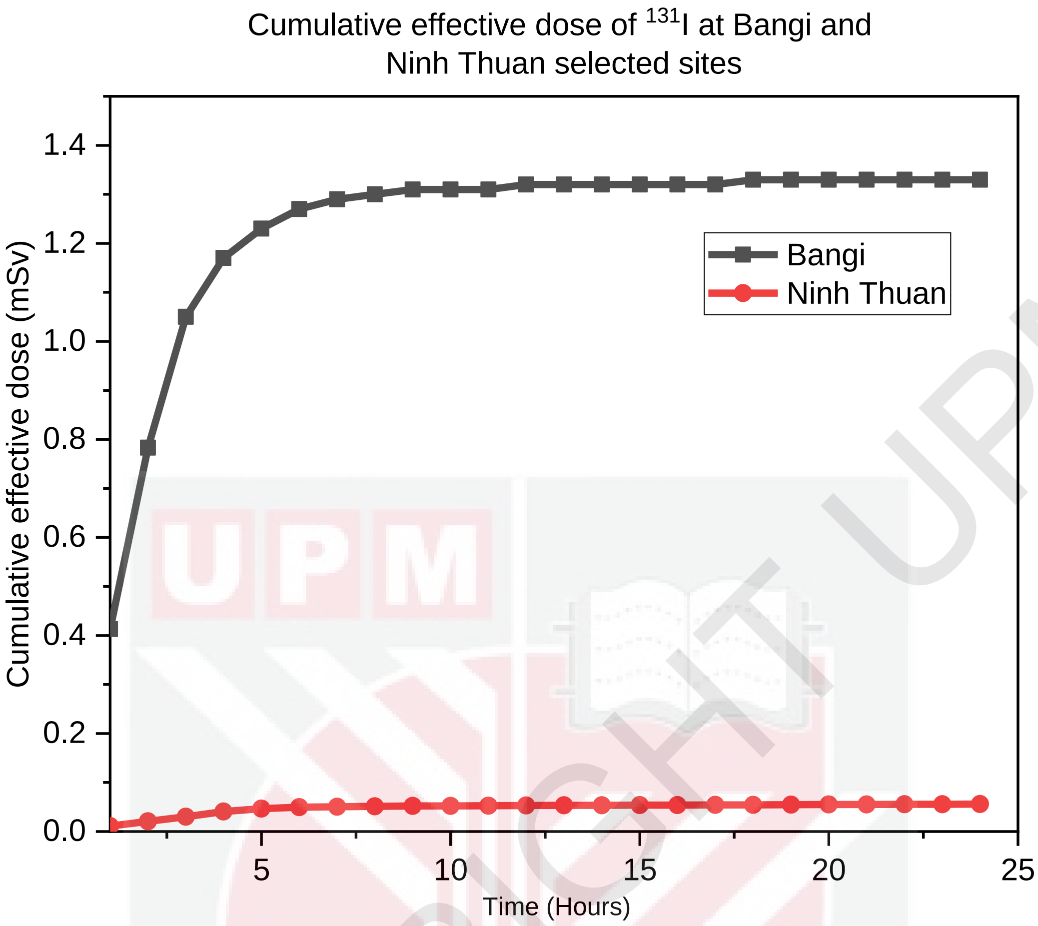


Figure 4.10 Cumulative effective dose of ^{131}I against time at both Bangi and Ninh Thuan

The amount of effective dose at any point around the selected location is determined by weather factors such as humidity, wind speed, and direction near the Nuclear Power Plant (NPP). Thus, different locations received different amount of effective dose and this study is focussing on to the effective dose generally.

4.4.2 Highest value of effective dose of ^{137}Cs and ^{131}I at different layer of altitudes

Based on Table 4.11, it shows the value of the effective dose of ^{137}Cs for each layers of altitude in Bangi area and be displayed on figure 4.11. For each layer of altitude, which is from 0 m until 40 m, the amount of effective dose increased until 1 hr of accident then it decreased due to the movement of radionuclides that is moved to the ground hypothetically by air. Due to the movement of air and mass of radionuclides, the amount of ground deposition of ^{137}Cs is gradually increase with respect to time until 210 minutes.

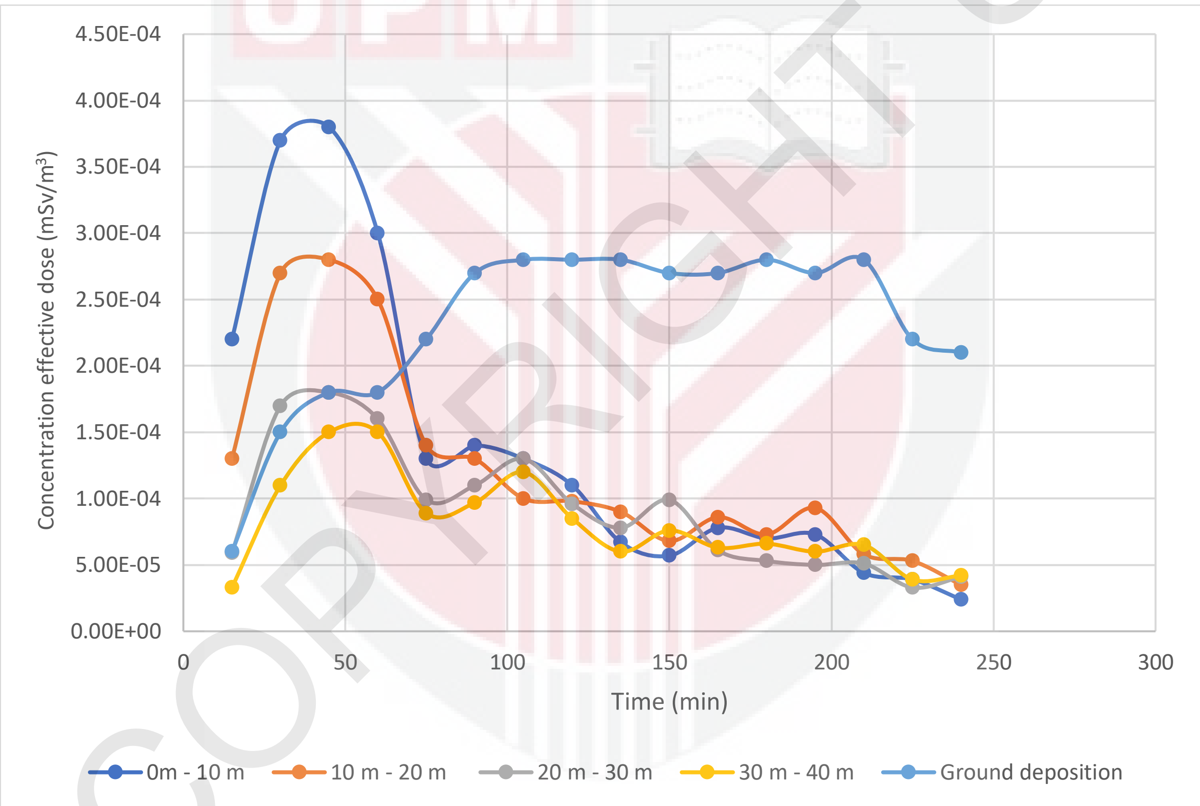


Figure 4.11 Highest value concentration of effective dose of ^{137}Cs at Bangi potential site

Table 4.11 Tabulation data of highest value of effective dose of ^{137}Cs at Bangi nominated site

Time (Minutes)	Highest value of effective dose of ^{137}Cs				
	0 m – 10 m (mSv/m^3)	10 m – 20 m (mSv/m^3)	20 m – 30 m (mSv/m^3)	30 m – 40 m (mSv/m^3)	Ground deposition (mSv/m^2)
15	2.2×10^{-4}	1.3×10^{-4}	5.9×10^{-5}	3.3×10^{-5}	6.0×10^{-5}
30	3.7×10^{-4}	2.7×10^{-4}	1.7×10^{-4}	1.1×10^{-4}	1.5×10^{-4}
45	3.8×10^{-4}	2.8×10^{-4}	1.8×10^{-4}	1.5×10^{-4}	1.8×10^{-4}
60	3.0×10^{-4}	2.5×10^{-4}	1.6×10^{-4}	1.5×10^{-4}	1.8×10^{-4}
75	1.3×10^{-4}	1.4×10^{-4}	9.9×10^{-5}	8.9×10^{-5}	2.2×10^{-4}
90	1.4×10^{-4}	1.3×10^{-4}	1.1×10^{-4}	9.7×10^{-5}	2.7×10^{-4}
105	1.3×10^{-4}	1.0×10^{-4}	1.3×10^{-4}	1.2×10^{-4}	2.8×10^{-4}
120	1.1×10^{-4}	9.8×10^{-5}	9.6×10^{-5}	8.5×10^{-5}	2.8×10^{-4}
135	6.7×10^{-5}	9.0×10^{-5}	7.8×10^{-5}	6.0×10^{-5}	2.8×10^{-4}
150	5.7×10^{-5}	6.8×10^{-5}	9.9×10^{-5}	7.6×10^{-5}	2.7×10^{-4}
165	7.8×10^{-5}	8.6×10^{-5}	6.1×10^{-5}	6.3×10^{-5}	2.7×10^{-4}
180	7.0×10^{-5}	7.3×10^{-5}	5.3×10^{-5}	6.6×10^{-5}	2.8×10^{-4}
195	7.3×10^{-5}	9.3×10^{-5}	5.0×10^{-5}	6.0×10^{-5}	2.7×10^{-4}
210	4.4×10^{-5}	5.8×10^{-5}	5.1×10^{-5}	6.5×10^{-5}	2.8×10^{-4}
225	3.9×10^{-5}	5.3×10^{-5}	3.3×10^{-5}	3.9×10^{-5}	2.2×10^{-4}
240	2.4×10^{-5}	3.5×10^{-5}	4.1×10^{-5}	4.2×10^{-5}	2.1×10^{-4}

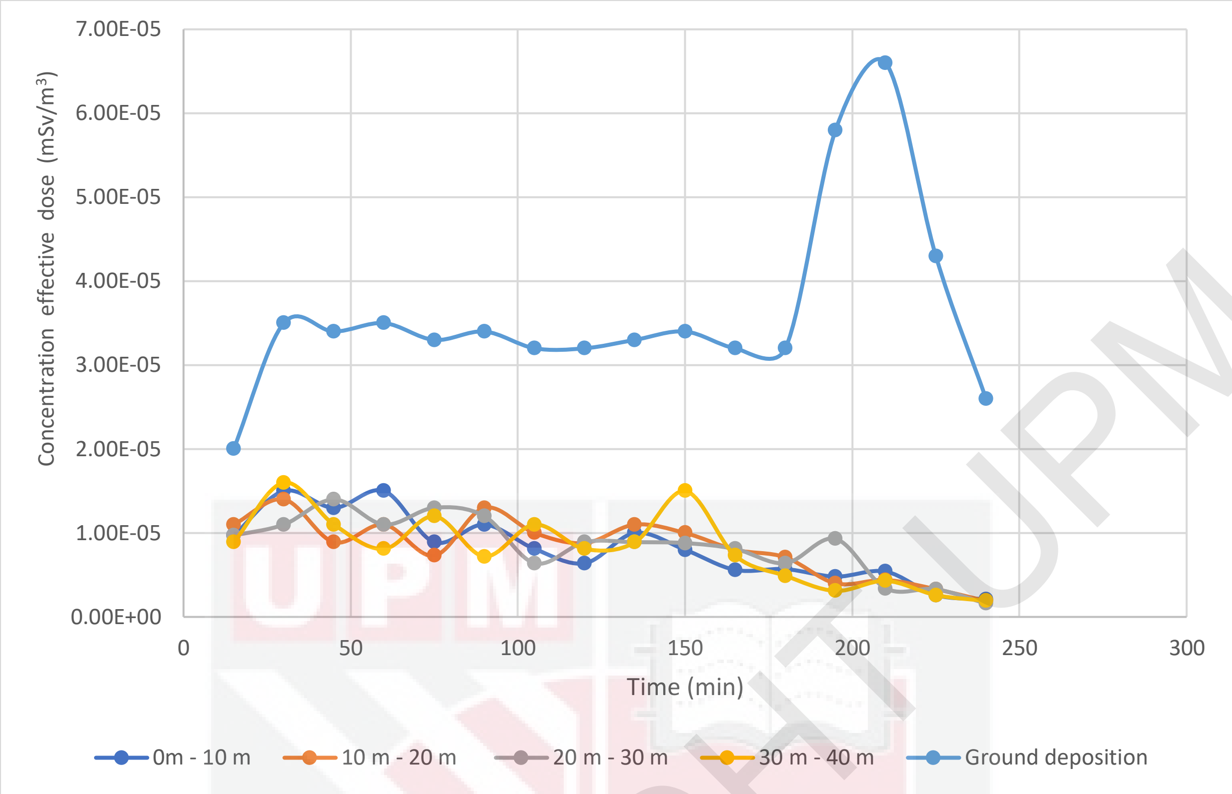


Figure 4.12 Highest value concentration of effective dose of ^{131}I at Ninh Thuan nominated site

Based on figure 4.12, it shows that ground deposition has the highest value of concentration compared to other layer of altitudes. The value of ground deposition peaked at 210 minutes and has the lowest value at the first 15 minutes after the accident occur.

Table 4.12 Tabulation data of highest value of effective dose of ^{131}I at Ninh Thuan nominated site

Time (Minutes)	Highest value of concentration effective dose of ^{131}I				
	0 m – 10 m (mSv/m^3)	10 m – 20 m (mSv/m^3)	0 m – 10 m (mSv/m^3)	30 m – 40 m (mSv/m^3)	Ground deposition (mSv/m^2)
15	9.7×10^{-6}	1.1×10^{-5}	9.7×10^{-6}	8.9×10^{-6}	2.0×10^{-5}
30	1.5×10^{-5}	1.4×10^{-5}	1.1×10^{-5}	1.6×10^{-5}	3.5×10^{-5}
45	1.3×10^{-5}	8.9×10^{-6}	1.4×10^{-5}	1.1×10^{-5}	3.4×10^{-5}
60	1.5×10^{-5}	1.1×10^{-5}	1.1×10^{-5}	8.1×10^{-6}	3.5×10^{-5}
75	8.9×10^{-6}	7.3×10^{-6}	1.3×10^{-5}	1.2×10^{-5}	3.3×10^{-5}
90	1.1×10^{-5}	1.3×10^{-5}	1.2×10^{-5}	7.2×10^{-6}	3.4×10^{-5}
105	8.1×10^{-6}	1.0×10^{-5}	6.4×10^{-6}	1.1×10^{-5}	3.2×10^{-5}
120	6.4×10^{-6}	8.8×10^{-6}	8.9×10^{-6}	8.1×10^{-6}	3.2×10^{-5}
135	1.0×10^{-5}	1.1×10^{-5}	8.9×10^{-6}	8.9×10^{-6}	3.3×10^{-5}
150	8.0×10^{-6}	1.0×10^{-5}	8.8×10^{-6}	1.5×10^{-5}	3.4×10^{-5}
165	5.6×10^{-6}	8.0×10^{-6}	8.1×10^{-6}	7.3×10^{-6}	3.2×10^{-5}
180	5.7×10^{-6}	7.1×10^{-6}	6.4×10^{-6}	4.9×10^{-6}	3.2×10^{-5}
195	4.8×10^{-6}	4.0×10^{-6}	9.3×10^{-6}	3.1×10^{-6}	5.8×10^{-5}
210	5.4×10^{-6}	4.4×10^{-6}	3.4×10^{-6}	4.3×10^{-6}	6.6×10^{-5}
225	2.6×10^{-6}	3.3×10^{-6}	3.3×10^{-6}	2.6×10^{-6}	4.3×10^{-5}
240	2.1×10^{-6}	1.9×10^{-6}	1.6×10^{-6}	1.9×10^{-6}	2.6×10^{-5}

4.5 Activity concentrations of ^{137}Cs and ^{131}I at the nearby cities from simulation nuclear reactor

4.5.1 From Ninh Thuan

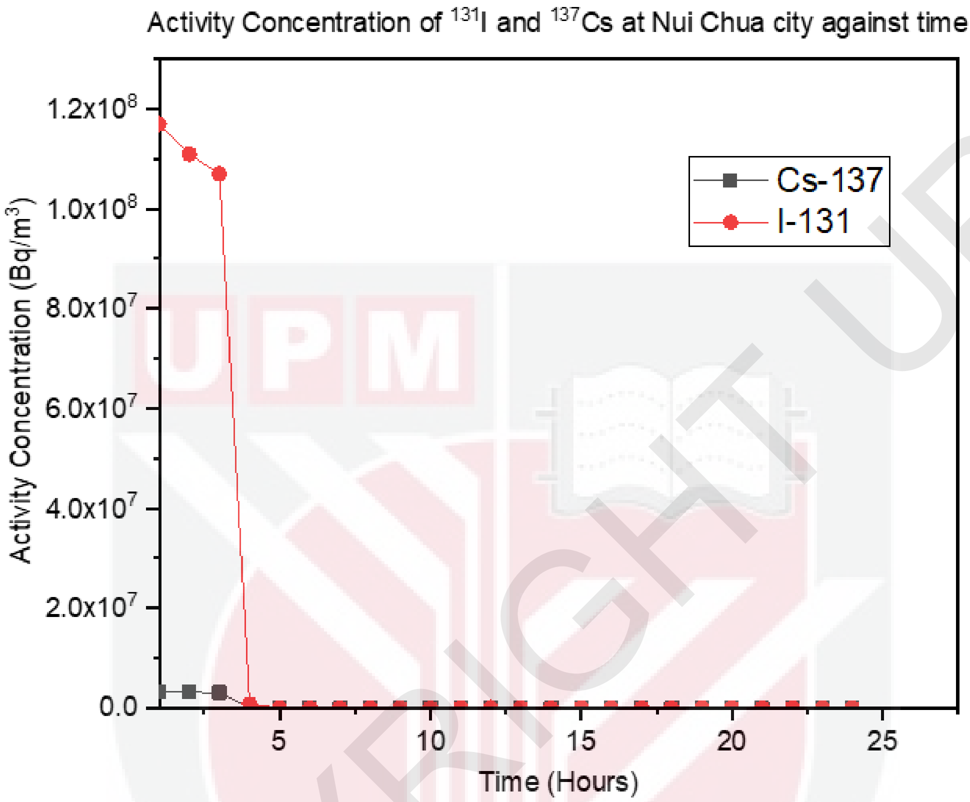


Figure 4.13 Amount of activity concentration of ^{137}Cs and ^{131}I at Nui Chua, Vietnam from accident at Ninh Thuan, Vietnam

From accident at Ninh Thuan , one of the city that is affected by the releasing of radionuclides is at Nui Chua city . Based on figure 4.13, the highest amount of activity concentration of ^{131}I in this city is 1.17 x 10^8 Bq/m^3 while for ^{137}Cs is 3.28 x 10^6 Bq/m^3. The dispersion of these radionuclides were estimated to remain at these area about 4 hours after the accident occur. Based on the cities in the Table 3.1, the radionuclides were not able to reached all the cities that is listed. This is because of the wind direction from simulation that enhance radionuclides to move into sea area.

4.5.2 From Bangi

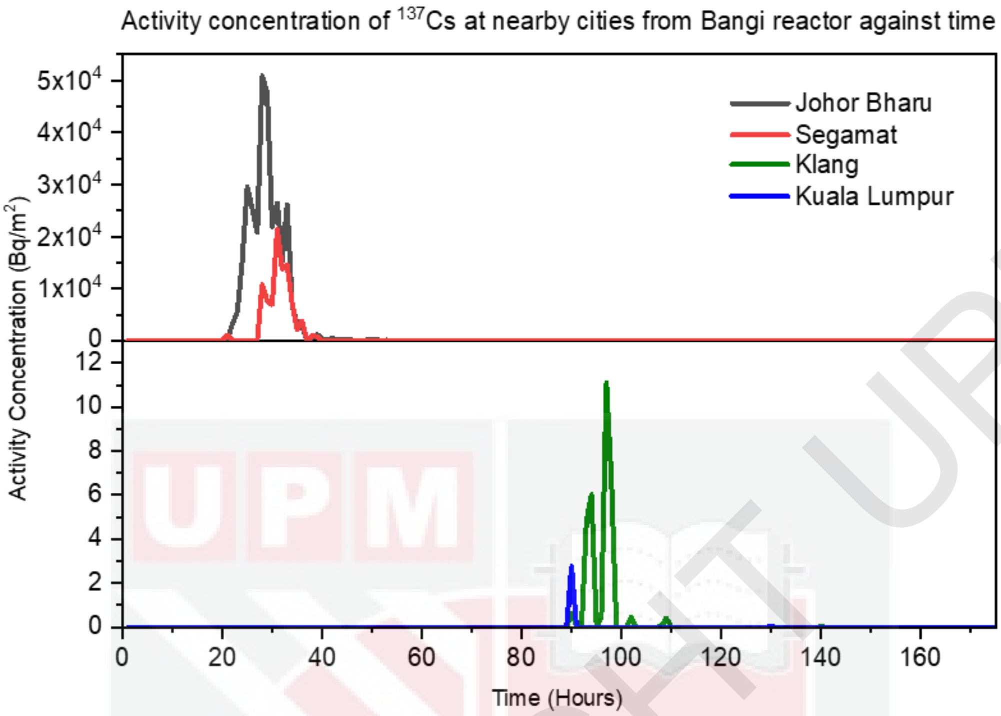


Figure 4.14 Amount of activity concentration of ^{137}Cs at 4 nearby cities from accident at Bangi, Selangor

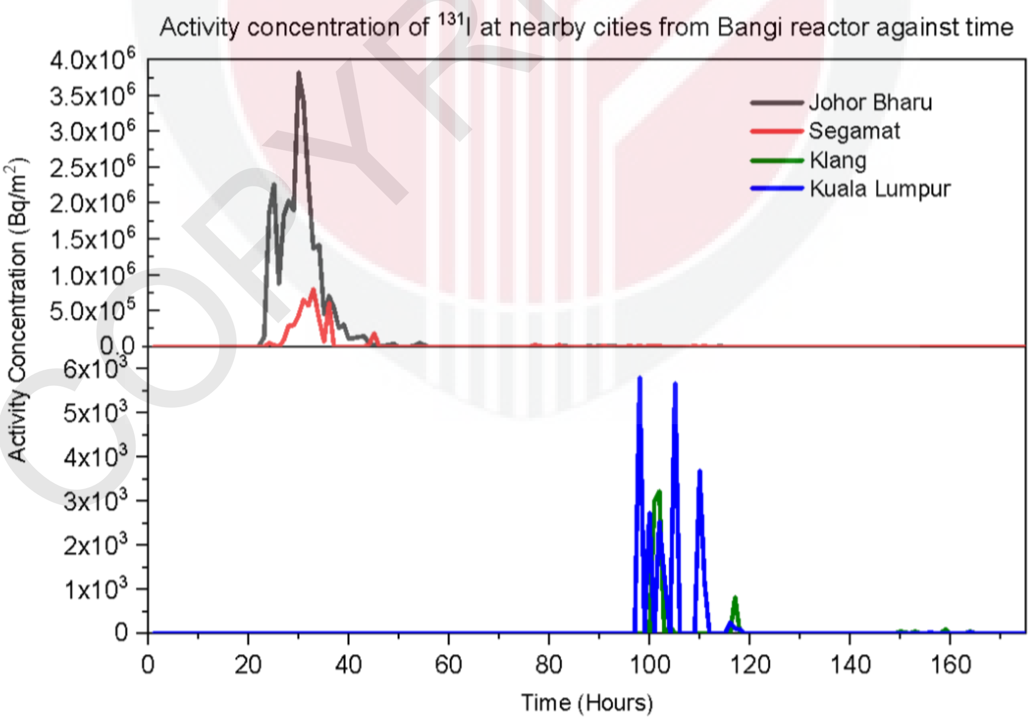


Figure 4.15 Amount of activity concentration of ^{131}I at 4 nearby cities from accident at Bangi, Selangor

Based on figure 4.15, the radioactive plume reached Johor Bharu which is one of the cities that has about 663,307 number of population within an area of 220 km^2. However, it takes more than half of a day to reach Johor Bharu for both radionuclides. Most of the radionuclides reached countries in the south region such as Johor and Negeri Sembilan because of the air movement on that season. For Johor Bharu, the highest amount of activity concentration that were dispersed by the ^{137}Cs and ^{131}I are 5.0924 x 10^4 Bq/m^3 and 2.26 x 10^6 Bq/m^3 respectively after 23 hours of the explosion.

4.6 Risk Assessment of mortality from simulation accidents

From the data in Table 4.11 and Table 4.12, this study able to calculate the amount of mortality risk by using dose-risk coefficient and average of human breathing rate obtained from *Cancer Risk Coefficients for Environmental Exposure to Radionuclides from United States Environmental Protection Agency* . This analysis is made on each altitudes and focussing more on to the inhalation exposure among the population. Based on the data in Table 4.15, it was estimated that there are about 15, 11, 10 and 9 deaths for altitude (0 m – 10 m), (10 m – 20 m), (20 m – 30 m) and (30 m – 40 m) respectively due to the inhalation of ^{137}Cs from Bangi's nuclear reactor. This results indicate that the highest probability of mortality due to the accident is at the lowest altitude compared to higher altitude.

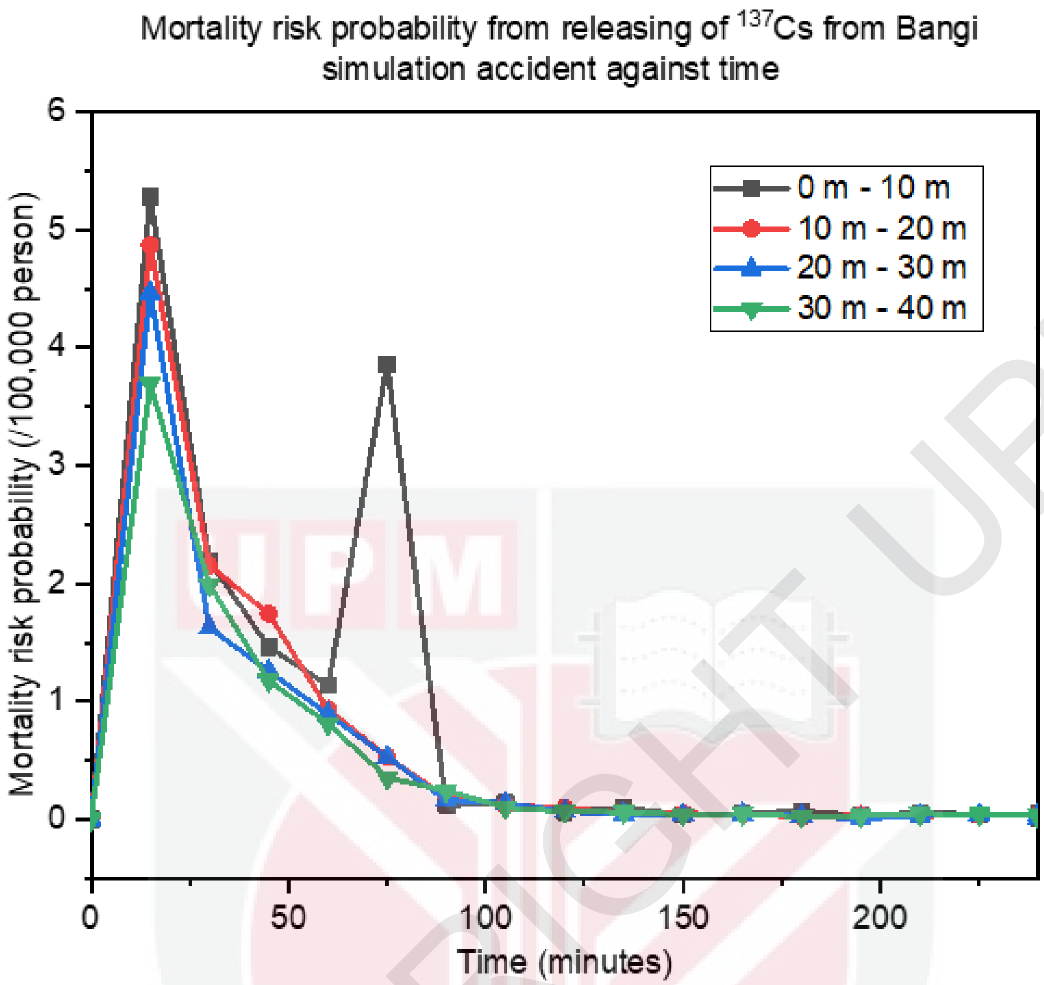


Figure 4.16 Mortality risk probability from releasing of ^{137}Cs from Bangi simulation accident for 4 hours after the accident at several layer of altitudes

Table 4.13 Mortality risk probability from releasing of ^{137}Cs from Bangi simulation accident at location with highest activity concentration

Time (Minutes)	Mortaility Risk probability from releasing of ^{137}Cs from simulation accident			
	0 m – 10 m (/100,000 population)	10 m – 20 m (/100,000 population)	20 m – 30 m (/100,000 population)	30 m – 40 m (/100,000 population)
15	5.279	4.873	4.467	3.695
30	2.193	2.152	1.624	1.990
45	1.462	1.746	1.259	1.178
60	1.137	0.934	0.893	0.812
75	3.858	0.528	0.528	0.353
90	0.122	0.191	0.162	0.244
105	0.138	0.122	0.138	0.097
120	0.061	0.097	0.069	0.069
135	0.102	0.053	0.045	0.061
150	0.038	0.049	0.037	0.041
165	0.049	0.045	0.045	0.049
180	0.073	0.022	0.027	0.025
195	0.029	0.035	0.005	0.030
210	0.057	0.030	0.034	0.049
225	0.041	0.037	0.036	0.045
240	0.049	0.045	0.045	0.041

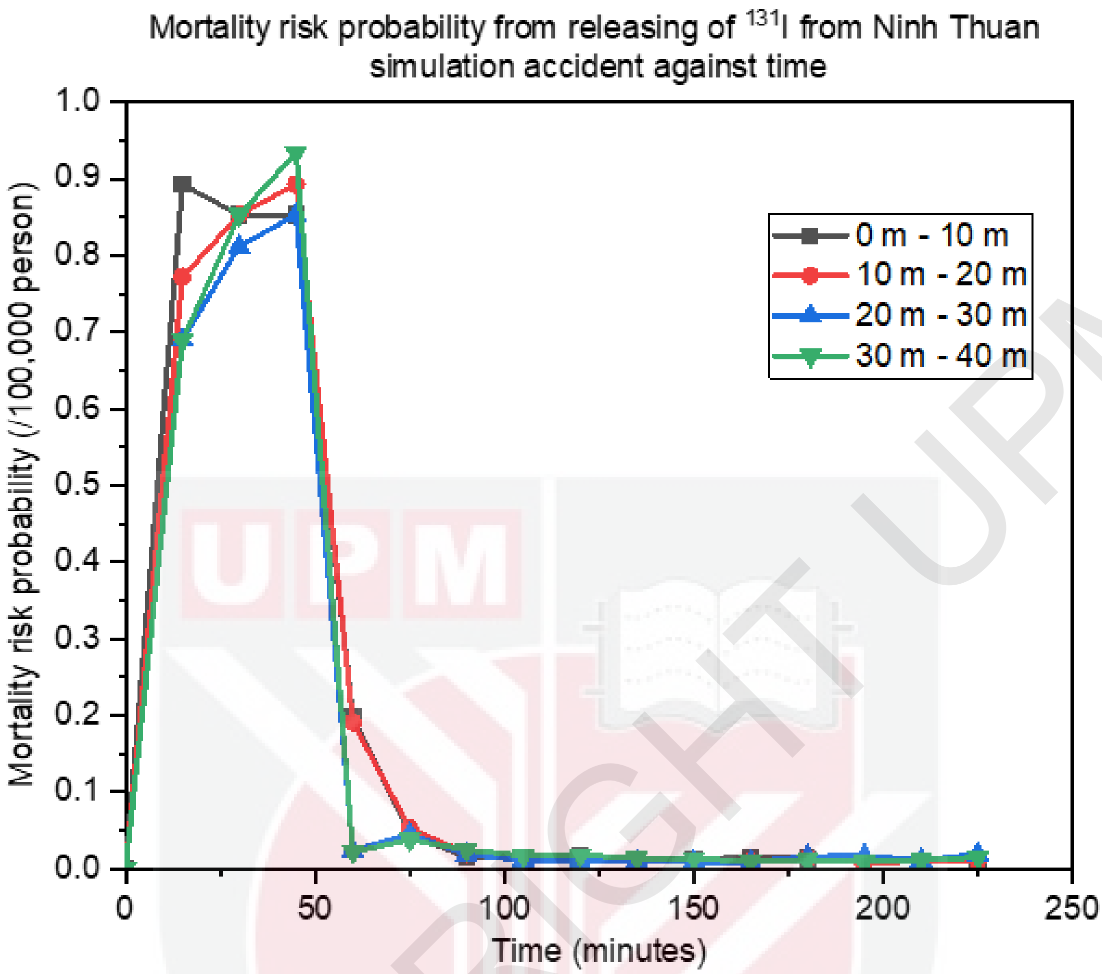


Figure 4.17 Mortality risk probability from releasing of ^{131}I from Bangi simulation accident for 4 hours after the accident at several layer of altitudes

Table 4.14 Mortality risk probability from releasing of ^{131}I from Ninh Thuan simulation accident at location with highest activity concentration

Time (Minutes)	Mortaility Risk probability from releasing of ^{131}I from simulation accident			
	0 m – 10 m (/100,000 person)	10 m – 20 m (/100,000 person)	20 m – 30 m (/100,000 person)	30 m – 40 m (/100,000 person)
15	0.893	0.772	0.690	0.690
30	0.853	0.853	0.812	0.853
45	0.853	0.893	0.853	0.934
60	0.199	0.191	0.024	0.022
75	0.045	0.053	0.045	0.038
90	0.015	0.020	0.019	0.025
105	0.015	0.011	0.011	0.017
120	0.017	0.011	0.010	0.018
135	0.012	0.009	0.010	0.014
150	0.013	0.011	0.009	0.013
165	0.015	0.010	0.009	0.010
180	0.014	0.014	0.016	0.011
195	0.008	0.008	0.017	0.009
210	0.010	0.010	0.011	0.011
225	0.010	0.011	0.019	0.015
240	0.010	0.014	0.012	0.011

Table 4.15 Estimated deaths from releasing of ^{137}Cs from Bangi simulation accident and releasing of ^{131}I from Ninh Thuan on the first 4 hours after the accident

Location	Mortality risk in each altitude / 100,000 person			
	0 m – 10 m	10 m – 20 m	20 m – 30 m	30 m – 40 m
Bangi (^{137}Cs)	15	11	10	9
Ninh Thuan (^{131}I)	3	3	3	3

Based on the data in Table 4.15, it was estimated that there are about 3 persons that were estimated to die for all layer of altitudes due to the inhalation of ^{131}I from Ninh Thuan's nuclear reactor. This results indicate that the Ninh Thuan is the preferable location compared to Bangi in order to build the nuclear reactor. Besides that, This should aid in the identification of evacuation zones around the region of the NPP. For Bangi, it is compulsory to move the people into the north regions as the radionuclides are predicted to not move into these area within one day of the accident. Meanwhile, for Ninh Thuan, it is unnecessary to move people in urgency because most of the radionuclides were predicted to move into the sea region. Lastly, the results are compared with the allowed dose such as shown in table 2.2.

CHAPTER 5

CONCLUSION

5.1 Conclusion

In conclusion, by using HYSPLIT modelling, this study able to evaluate the dispersion for both radionuclides (^{137}Cs & ^{131}I) at Ninh Thuan and Bangi. Then, it has been converted to the cumulative effective dose and risk by using the measurement of the activity concentration for different locations. From the risk assessment, this study able to predict the number of dead people for each level of altitudes and evaluate the consequences from the accidents. The health impact consequences for nuclear accident at Bangi and Ninh Thuan potential site was based on the simulation from HYSPLIT modelling and conversion from several reports to obtain the results. Based on the analysis of mean effective dose measurement, it shows that there are about 0.001227 mSv that the population in Bangi will received from the releasing of ^{137}Cs in ST4 accident and 4.9×10^{-5} mSv for Ninh Thuan's population. For the releasing of ^{131}I radionuclide, the amount of mean effective dose measurement is exceeding standard effective dose suggested by ICRP which is 1mSv for a year. For Bangi, it is about 1.33 mSv amount of effective dose that people will received if the accident occur on 22 December 2020. The outcomes of this research provide preliminary estimation on environmental and radiological effects, as well as population exposure limits. These studies could aid in the development of emergency plans to ensure that the environmental and human effects of a nuclear disaster are effectively can be handled. Thus, in term of the suitability of location that was chosen in this study, Ninh Thuan is more suitable place for a nuclear reactor compared to Bangi as the predicted movement of radionuclides for Ninh Thuan is not effected too much to the population. Besides that, this method also beneficial for a reference data to determine whether a location is suitable for building a nuclear reactor. This is based on the analysis of the effective dose and risk mortality assessment based on the available data.

5.2 Recommendations for Future Work

Since the study is made by using HYSPLIT software only, it is recommended to use several type of atmosphere modelling such as *GENII*, *CTDMPLUS*, *AERMOD and* other display software such as *ArcMap* in order to give comparisons and achieve accurate data. The analysis made on the selected locations shows that Bangi is a place that is not suitable for building a nuclear reactor. Thus, it is suggested to produce an analysis on several locations in Malaysia and produce a comparison between them. The obtained data may be useful for authorities that is responsible to establish a nuclear power plant project in the future.

This study also focussing to the short term effects after the accident and it is recommended to analyse the long term effects after the accident because Cesium-137 is an example of radionuclides that has long half-life. As a result, this study for preparedness if there are any nuclear accidents occur in the selected sites that is suggested by some authorities.

REFERENCES

Allouhi, A., El Fouih, Y., Kousksou, T., Jamil, A., Zeraouli, Y., & Mourad, Y. (2015). Energy consumption and efficiency in buildings: Current status and future trends. *Journal of Cleaner Production*, *109*, 118–130. https://doi.org/10.1016/j.jclepro.2015.05.139

Anderson, E. L. (1983). Quantitative Approaches in Use to Assess Cancer Risk. *Risk Analysis*, *3*(4), 277–295. https://doi.org/10.1111/j.1539-6924.1983.tb01396.x

ATSDR. (2004). Toxicological Profile for Cesium. *Agency for Toxic Substances and Disease Registry*, *April*.

Bagheri, R., Bagheri, F., Karami, G. H., & Jafari, H. (2019). Chemo-isotopes (18O & 2H) signatures and HYSPLIT model application: Clues to the atmospheric moisture and air mass origins. *Atmospheric Environment*, *215*(August), 116892. https://doi.org/10.1016/j.atmosenv.2019.116892

Breeze, P. (2014). Chapter 17 - Nuclear Power. In *Power Generation Technologies* (2nd ed.). Elsevier Ltd. https://doi.org/10.1016/B978-0-08-098330-1.00017-X

Breeze, P. (2017). Water-Cooled Reactors. *Nuclear Power*, 33–44. https://doi.org/10.1016/b978-0-08-101043-3.00004-3

Cahoon, E. K., Zhang, R., Simon, S. L., Bouville, A., & Pfeiffer, R. M. (2020). Projected cancer risks to residents of New Mexico from exposure to trinity radioactive fallout. *Health Physics*, *119*(4), 478–493. https://doi.org/10.1097/HP.0000000000001333

Draxler, R., Dèlia Arnold, Stefano Galmarini, Matthew Hort, Andrew Jones, S. L., Alain Malo, Christian Maurer, Glenn Rolph, Kazuo Saito, René Servranckx, Toshiki Shimbori, E. S., & Wotawa, and G. (2013). *Evaluation of Meteorological Dispersion and Deposition From the* (Issue December).

Draxler, R. R., & Hess, G. D. (1998). An overview of the HYSPLIT_4 modelling system for trajectories, dispersion and deposition. *Australian Meteorological Magazine*, *47*(4), 295–308.

Grabowski, D., Muszynski, W., Petrykowska, M., Rubel, B., Smagala, G., & Lada, W. (1994). *I °*. *157*, 227–229.

Hashimoto, S., Imamura, N., Kawanishi, A., Komatsu, M., Ohashi, S., Nishina, K., Kaneko, S., Shaw, G., & Thiry, Y. (2020). A dataset of 137Cs activity concentration and inventory in forests contaminated by the Fukushima accident. *Scientific Data*, *7*(1), 431. https://doi.org/10.1038/s41597-020-00770-1

IAEA. (2008). *Approaches and Tools for Se vere Accident Analysis for Nuclear Power Plants*.

IAEA. (2016). *Nuclear Accident Knowledge Taxonomy*. https://www.iaea.org/publications/10798/nuclear-accident-knowledge-taxonomy

Idris, H. N. (2012). *Iaea Bss Workshop (2012): Dose Limits & Dose Constraints*. *April*.

Jeong, H., Park, M., Jeong, H., Hwang, W., Kim, E., & Han, M. (2013). Radiological risk assessment caused by RDD terrorism in an urban area. *Applied Radiation and Isotopes*, *79*(September 1987), 1–4. https://doi.org/10.1016/j.apradiso.2013.04.018

Le, T. V. V. • T. A. N., & Duc, T. N. (2018). *6th International Conference on the Development of Biomedical Engineering in Vietnam (BME6)* (T. Vo Van, T. A. Nguyen Le, & T. Nguyen Duc (Eds.); Vol. 63). Springer Singapore. https://doi.org/10.1007/978-981-10-4361-1

Martinez-Quiroga, V., Akbas, S., Aydogan, F., Ougouag, A. M., & Allison, C. (2015). Coupling of RELAP5-SCDAPS MOD4.0 and Neutronic Codes. *International Mechanical Engineering Congress and Exposition*. http://www.asme.org/abo

McCollough, C. H., & Schueler, B. A. (2000). Calculation of effective dose. *Medical*

Physics, *27*(5), 828–837. https://doi.org/10.1118/1.598948

McMahon, C., Kelleher, K., McGinnity, P., Organo, C., Smith, K., Currivan, L., & Ryan, T. (2013). *Proposed nuclear power plants in the UK – potential radiological implications for Ireland*.

Mészáros, R., Leelossy, Á., Kovács, T., & Lagzi, I. (2016). Predictability of the dispersion of Fukushima-derived radionuclides and their homogenization in the atmosphere. *Scientific Reports*, *6*. https://doi.org/10.1038/SREP19915

Mohammed Saeed, I. M., Mohammed Saleh, M. A., Hashim, S., bin Ramli, A. T., & Al-Shatri, S. H. H. (2019). Atmospheric dispersion modeling and radiological safety assessment for expected operation of Baiji nuclear power plant potential site. *Annals of Nuclear Energy*, *127*, 156–164. https://doi.org/10.1016/j.anucene.2018.11.045

Monroy-Colín, A., Maya-Manzano, J. M., Tormo-Molina, R., Pecero-Casimiro, R., Gonzalo-Garijo, M. Á., & Fernández-Rodríguez, S. (2020). HYSPLIT as an environmental impact assessment tool to study the data discrepancies between Olea europaea airborne pollen records and its phenology in SW Spain. *Urban Forestry & Urban Greening*, *53*(November 2019), 126715. https://doi.org/10.1016/j.ufug.2020.126715

Murray, R. L. (2000). Nuclear Reactor Types. In *Kirk-Othmer Encyclopedia of Chemical Technology*. John Wiley & Sons, Inc. https://doi.org/10.1002/0471238961.1805010313211818.a01

Nakata, K., & Sugisaki, H. (2015). Impacts of the Fukushima nuclear accident on fish and fishing grounds. In *Impacts of the Fukushima Nuclear Accident on Fish and Fishing Grounds*. https://doi.org/10.1007/978-4-431-55537-7

Nuclear, U. S. A. (2019). *Issue 18 Winter/Spring 2019*. *18*.

Ochiai, S., Hasegawa, H., Kakiuchi, H., Akata, N., Ueda, S., Tokonami, S., & Hisamatsu, ichi. (2016). *Temporal variation of post-accident atmospheric 137 Cs in an evacuated* *area of Fukushima Prefecture: Size-dependent behaviors of 137 Cs-bearing particles*. https://doi.org/10.1016/j.jenvrad.2016.09.014

OECD. (2003). Chernobyl: Assessment of Radiological and Health Impacts. In *Proceedings of the 31st World Nuclear Association Annual Symposium, 2006* (Vol. 2006). OECD. https://doi.org/10.1787/9789264184879-en

Pre-Feasibility Study on the Establishment of Nuclear Power Plant in ASEAN. (2018). ASEAN Centre for Energy. https://aseanenergy.org/pre-feasibility-study-on-the-establishment-of-nuclear-power-plant-in-asean/

Saeed, I. M., Saleh, M. A. M., Hashim, S., Hama, Y. M. S., Hamza, K., & Al-Shatri, S. H. (2020). The radiological assessment, hazard evaluation, and spatial distribution for a hypothetical nuclear power plant accident at Baiji potential site. *Environmental Sciences Europe*, *32*(1), 6. https://doi.org/10.1186/s12302-020-0288-8

Sentian, J., Jemain, M. A., Gabda, D., Franky, H., & Wui, J. C. H. (2018). Long-term trends and potential associated sources of particulate matter (PM10) pollution in Malaysia. *WIT Transactions on Ecology and the Environment*, *230*, 607–618. https://doi.org/10.2495/AIR180571

Shuryak, I. (2021). Quantitative modeling of radioactive cesium concentrations in large omnivorous mammals after the Fukushima nuclear power plant accident. *Scientific Reports*, *11*(1), 10049. https://doi.org/10.1038/s41598-021-89449-0

Sowby, F. D. (1981). Annals of the ICRP. *Annals of the ICRP*, *6*(1), 1. https://doi.org/10.1016/0146-6453(81)90127-5

Steinhauser, G., Brandl, A., & Johnson, T. E. (2014). Comparison of the Chernobyl and Fukushima nuclear accidents: A review of the environmental impacts. *Science of the Total Environment*, *470–471*, 800–817. https://doi.org/10.1016/j.scitotenv.2013.10.029

Vítor, A. C., Huertas, P., Legube, G., & De, A. and S. F. (2020). *Sci-Hub | Studying DNA*

Double-Strand Break Repair: An Ever-Growing Toolbox. Frontiers in Molecular Biosciences, 7 | 10.3389/fmolb.2020.00024. https://sci-hub.st/10.3389/fmolb.2020.00024/full

Wada, T., Konoplev, A., Wakiyama, Y., Watanabe, K., Furuta, Y., Morishita, D., Kawata, G., & Nanba, K. (2019). Strong contrast of cesium radioactivity between marine and freshwater fish in Fukushima. *Journal of Environmental Radioactivity*, *204*(April), 132–142. https://doi.org/10.1016/j.jenvrad.2019.04.006

Webster, S. C., Byrne, M. E., Lance, S. L., Love, C. N., Hinton, T. G., Shamovich, D., & Beasley, J. C. (2016). Where the wild things are: Influence of radiation on the distribution of four mammalian species within the Chernobyl Exclusion Zone. *Frontiers in Ecology and the Environment*, *14*(4), 185–190. https://doi.org/10.1002/fee.1227

Zali, A., Shamsaei Zafarghandi, M., Feghhi, S. A., & Taherian, A. M. (2017). Public member dose assessment of Bushehr Nuclear Power Plant under normal operation by modeling the fallout from stack using the HYSPLIT atmospheric dispersion model. *Journal of Environmental Radioactivity*, *171*, 1–8. https://doi.org/10.1016/j.jenvrad.2017.01.025