ASSESSMENT OF RADIOLOGICAL INCIDENT AT POTENTIAL NUCLEAR POWER PLANT SITES IN MALAYSIA USING HYBRID SINGLE PARTICLE LANGRANGIAN INTEGRATED TRAJECTORY SIMULATION

By

AMIRUL FAKHRUDDIN BIN JAMALUDIN

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Chairman : Muhammad Khalis bin Abdul Karim, PhD
Faculty : Faculty of Science

After every nuclear-related incident, the main health threat is the radiation emitted off-site. The 2011 Fukushima Daiichi nuclear power plant incident exemplifies this, as it released radionuclides that posed health risks locally and to neighboring countries. Simulating hypothetical radiological incidents is essential for training, assessing response plans, mitigating risks, and enhancing coordination to ensure effective preparedness and response. This study simulated a scenario similar to the Fukushima incident at three potential nuclear power plant sites in Malaysia using the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model. This model tracks air parcel trajectories and atmospheric dispersion of radioactive emissions. The simulation indicated that radionuclides traveled west and northwest from the Rungkup, Perak (S1) and Jugra, Kuala Langat, Selangor (S2) sites. For the Tenggaroh, Mersing, Johor (S3) site, the dispersion was to the south. Air concentration measurements showed no radionuclide activity between 9 and 12 hours after the incident. Ground deposition results revealed that S1 and S2 covered approximately 1500 km^2 and 3025 km^2, respectively. S3 had the largest affected area of around 4537 km^2 but the lowest maximum dose reading of about 7.9 mSv within 36 hours. Mortality rates at 36 hours were highest at S2 (19.7 deaths per 1000 persons) compared to S1 (5.82 deaths) and S3 (1.31 deaths). Similarly, radiation-induced disease rates were highest at S2 (22.7 cases per 1000 persons) compared to S1 (6.72 cases) and S3 (1.52 cases). The Linear No-Threshold (LNT) model, endorsed by the International Commission on Radiological Protection (ICRP), predicts that even low radiation doses proportionately increase cancer risk. This study generally found that a hypothetical accident would contaminate areas around the three potential nuclear power plant sites in Malaysia, emphasizing the need for effective preparedness and response strategies.

Keywords: HYSPLIT, Fukushima Daiichi Nuclear Power Plant, radionuclides

SDG: GOAL 7: Affordable and Clean Energy

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Master Sains

PENILAIAN INSIDEN RADIOLOGI DI TAPAK LOJI JANAKUASA NUKLEAR BERPOTENSI DI MALAYSIA MENGGUNAKAN SIMULASI TRAJEKTOR BERSEPADU LANGRANGIAN HIBRID PARTIKEL TUNGGAL

Oleh

AMIRUL FAKHRUDDIN BIN JAMALUDIN

Mei 2023

Pengerusi : Muhammad Khalis bin Abdul Karim, PhD
Fakulti : Sains

Selepas setiap insiden berkaitan nuklear, isu utama yang mengancam kesihatan manusia ialah jumlah radiasi yang dipancarkan di luar tapak. Insiden loji janakuasa nuklear Fukushima Daiichi berikutan gempa bumi dan tsunami pada 2011 telah mengeluarkan radionuklid menimbulkan ancaman kepada kesihatan manusia kepada penduduknya serta negara jiran. Simulasi kejadian radiologi awal adalah penting untuk latihan kakitangan, menilai pelan tindak balas, mengurangkan risiko dan meningkatkan koordinasi untuk memastikan kesediaan dan tindak balas yang berkesan dalam kecemasan akibat tinggi tersebut. Dalam kajian ini, senario yang sama telah disimulasikan di tiga tapak loji tenaga nuklear yang berpotensi di Malaysia berdasarkan insiden Loji Kuasa Nuklear Fukushima Daiichi (FDNPP). Trajektori Bersepadu Lagrangian Zarah Tunggal Hibrid (HYSPLIT) ialah model komputer berdasarkan pendekatan Langrangian dan Eulerian yang digunakan untuk mensimulasikan dan menjejak trajektori bungkusan udara dan pelepasan pembelahan serakan atmosfera. Selepas insiden nuklear, HYSPLIT dapat mengkaji profil penyebaran bahan radioaktif yang dibebaskan. Data menunjukkan bahawa radionuklid bergerak ke barat dan barat laut untuk simulasi yang dijalankan di S1 (Rungkup, Perak) dan S2 (Jugra, Kuala Langat, Selangor) namun untuk S3 (Tenggaroh, Mersing, Johor) radionuklid telah tersebar ke selatan dari tapak pelepasan. Simulasi menunjukkan bahawa tiada aktiviti radionuklid hadir dalam udara antara 9 jam – 12 jam persampelan. Keputusan pemendapan tanah menunjukkan bahawa S1 dan S2 telah meliputi kira-kira 1500 km^2 dan 3025 km^2 tanah masing-masing manakala S3 menunjukkan keluasan terbesar sekitar 4537 km^2 tetapi bacaan dos maksimum terendah iaitu kira-kira 7.9 mSv dalam masa 36 jam. Pada 36 jam, bacaan tertinggi bagi S1, S2 dan S3 masing-masing ialah 5.82, 19.7 dan 1.31 kematian bagi setiap 1000 orang. Di S1, S2, dan S3 selepas 36 jam, masing-masing terdapat 6.72, 22.7, dan 1.52 kes penyakit akibat sinaran bagi setiap 1000 orang. Model Linear No-Threshold (LNT) yang telah disahkan oleh Suruhanjaya Antarabangsa mengenai Perlindungan Radiologi (ICRP) meramalkan bahawa walaupun pada dos sinaran yang rendah, risiko kanser meningkat secara berkadar. Kajian ini secara amnya mendapati kemalangan hipotesis itu akan mencemarkan kawasan sekitar tiga tapak loji janakuasa nuklear (NPP) yang berpotensi.

Kata Kunci: HYSPLIT, Loji Kuasa Nukelar Fukushima Daiichi, radionuklid

SDG: *GOAL 7: Affordable and Clean Energy*

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Muhammad Khalis bin Abdul Karim, PhD
Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Mohd Mustafa bin Awang Kechik, PhD
Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Internal Examiner)

Nurisya binti Mohd Shah, PhD
Senior Lecturer
Faculty of Science
Universiti Putra Malaysia
(Internal Examiner)

Mohd Hamzah Harun, PhD
Agensi Nuklear Malaysia
(External Examiner)

____
ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 16 May 2024

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LIST OF ABBREVIATIONS

ASEAN	Association of Southeast Asian Nations
ATDM	Atmospheric Transport and Dispersion Model
Bq	Becquerel
BWR	Boiling Water Reactor
DNA	Deoxyribonucleic acid
EPR	Emergency preparedness respond
FDNPP	Fukushima Daiichi Nuclear Power Plant
HYSPLIT	Hybrid Single Particle Lagrangian Integrated Trajectory
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
INES	International Nuclear and Radiological Event Scale
MAGNOX	Basic Gas-Cooled Reactor
MKN	Majlis Keselamatan Negara
NOAA	National Oceanic and Atmospheric Administration
NPP	Nuclear Power Plant
PWR	Pressurized Water Reactor
RBMK	Reaktor Bolshoy Moshchnosty Kanalny, high-power channel reactor
Sv	Sievert
UNCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
WANO	World Association of Nuclear Operators
WMO	World Meteorogical Organization

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Nuclear accidents are catastrophic events that can occur at nuclear power plants, research facilities, or during the transportation or handling of nuclear materials (IAEA, 2015). These accidents can have severe consequences for the environment and for the health and safety of the public. They can cause releases of radioactive materials into the air, water, or soil, which can have long-term effects on human health and the environment. Nuclear accidents can also have significant economic and social impacts, as they can disrupt the operation of a facility and lead to costly cleanup and compensation efforts. The most well-known nuclear accident is the Chernobyl disaster, which occurred in 1986 in Ukraine, but there have been several other major nuclear accidents throughout the world, including the Fukushima Daiichi disaster in 2011 in Japan and the Three Mile Island accident in 1979 in the United States.

The Fukushima Daiichi nuclear power plant accident was a disaster that occurred in Japan in 2011, following a massive earthquake and tsunami. The disaster caused serious damage to the Fukushima Daiichi nuclear power plant, leading to a series of events that resulted in radiation leaks and the release of radioactive materials into the environment (Evangeliou et al., 2014). The Fukushima Daiichi nuclear power plant accident was the worst nuclear disaster since the Chernobyl accident in 1986, and it had significant impacts on the health and well-being of people living in the surrounding area. It also had far-reaching economic consequences, as the disaster resulted in the closure of several nuclear power plants in Japan and a significant decrease in the country's reliance on nuclear energy. In the aftermath of the Fukushima Daiichi nuclear power plant accident, authorities have worked to clean up the site and to prevent similar accidents from occurring in the future. The disaster caused explosions and fires at the nuclear power plant, leading to the release of large amounts of radioactive materials into the air and water. The accident caused significant radiation contamination in the surrounding area, leading to the evacuation of over 150,000 people from their homes. Figure 1.1 shows the contamination levels of cesium-137 based on gamma ray measurements from 42-fixed wing helicopter survey flights at altitudes ranging from 150 to 700 meters.

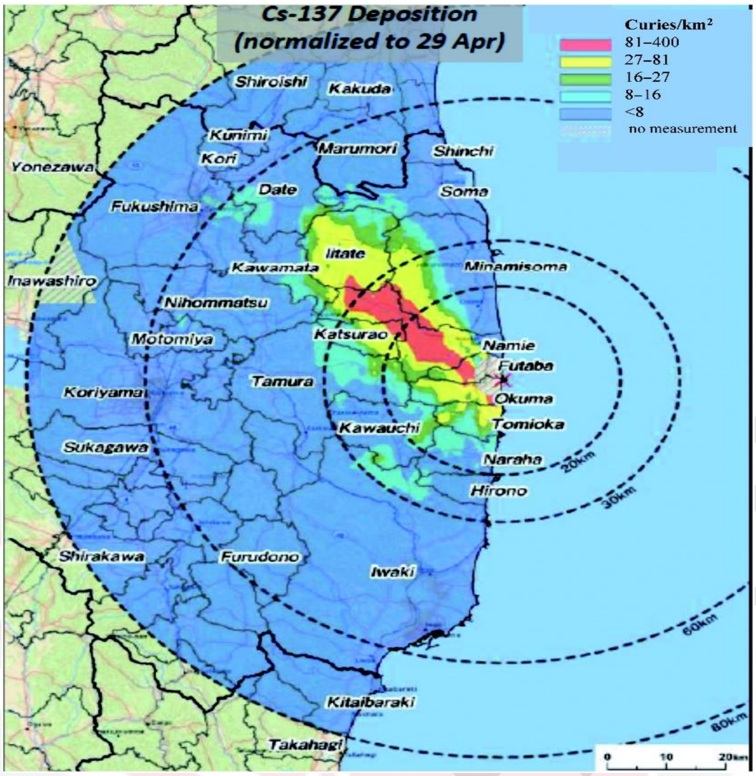

Figure 1.1: Contamination levels of cesium–137 based on gamma-ray measurements from 42 fixed–wing and helicopter survey flights at altitudes ranging from 150 to 700 meters (Hippel, 2011)

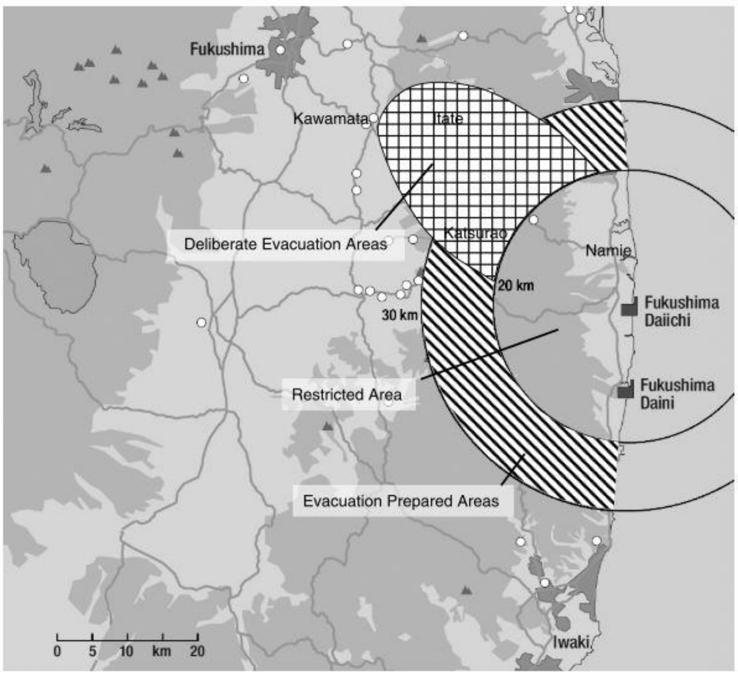

Figure 1.2: Evacuation areas near Fukushima Daiichi NPP (Thielen, 2012)

1.2 Problem Statement

A nuclear accident is a tragic occurrence that happens when a nuclear power station malfunctions or when radioactive materials are handled carelessly. These mishaps may cause the discharge of radioactive materials into the environment, which might have detrimental and long-lasting effects on the ecosystem and human health (McBride et al., 2004).

The following are brief examples of several major nuclear power plants accidents that occurred throughout the world;

1. Three Mile Island (1979): This accident occurred in Pennsylvania, USA, when a partial meltdown took place in the Unit 2 reactor. It was caused by a combination of equipment malfunctions and operator errors. Although there was a release of radioactive gases, the containment structure prevented a large-scale release into the environment. It led to significant changes in nuclear safety regulations.

2. Chernobyl (1986): The Chernobyl disaster in Ukraine (then part of the Soviet Union) is one of the most severe nuclear accidents in history. It resulted from a reactor design flaw and a series of operator errors during a safety test. The reactor experienced a massive steam explosion and fire, releasing a substantial amount of radioactive material into the atmosphere. The accident caused immediate deaths, long-term health effects, and the evacuation and relocation of nearby residents.

3. Fukushima Daiichi (2011): This accident occurred in Japan following a powerful earthquake and subsequent tsunami. The natural disaster led to the loss of cooling functions in three reactors at the Fukushima Daiichi nuclear power plant. Without proper cooling, the reactors experienced fuel melting and hydrogen explosions. A significant release of radioactive material occurred, and the surrounding areas were evacuated. The accident led to changes in nuclear safety practices and increased scrutiny of nuclear power globally.

Radiation exposure danger to persons who live or work nearby the disaster site is one issue that might result from a nuclear accident. Numerous health issues, such as cancer, genetic abnormalities, and other disorders, may result from this. Additionally, the contamination of soil and water by radioactive chemicals can cause issues for the environment and agriculture (Fesenko et al., 2020; Von Hippel, 2011).

Nuclear accidents might also cause social and economic unrest, which is a risk. Following a nuclear accident, cleanup and restoration work can be costly and time-consuming, and the surrounding community's economy may suffer significantly. Additionally, social tensions and anxiety within the afflicted population might result from the dread and uncertainty surrounding a nuclear disaster. All things considered, nuclear accidents pose a variety of issues that might have negative and far-reaching effects. It is crucial to take precautions to avoid these mishaps and to put in place measures to lessen their effects when they do happen.

In order to construct a nuclear reactor, it is crucial to make sure the location is acceptable, meaning it won't have a significant negative impact on the local population in the event of an accident(Idris & Abd. Latif, 2012). The population density and geographic location are particularly relevant to this investigation . The air movement should be taken into account as the major component that might enhance the dispersion of radionuclides to the population, hence the precise site for the reactor cannot be examined using the common radius measure alone.

1.3 Objectives

The aim of this study to simulate the dispersion of radionuclides from potential nuclear power plant sites in Malaysia based on the FDNPP incident. The specific objectives are as follows;

1) To simulate a radiological accident similar to Fukushima Daiichi Nuclear Power Plant incident at potential nuclear power plant sites in Malaysia using HYSPLIT simulation software.
2) To create a dose projection and distribution of radionuclides based on the hypothetical incident at three potential nuclear power plant sites in Malaysia

3) To analyze the health and hazard risk that may threaten the population of the contaminated and affected area.

1.4 Scope of Study

A research project's scope of study describes the breadth of the investigation that will be made. Along with the precise research questions or objectives that the study seeks to solve, it also provides the study's boundaries and restrictions. The scope of the study aids in defining the research's emphasis and establishes what will be included in or left out of the investigation.

The research issue and the resources at hand will determine how restricted or broad the study's scope is. While a broad scope could include a broader territory, several inhabitants, or a longer time period, a small scope might concentrate on a single location, population, or time period.

1.4.1 Study Area

The region or geographic area where a research study is carried out is known as the study area. It is the precise site where data gathering and research operations are carried out. The study area might be a small, narrow area, like a single neighbourhood or city, or it can be a broader, more general area, like a whole nation or continent. In this study, the study area will be focused at Malaysia’s potential nuclear power plant sites.

The study area of a research study is frequently chosen based on certain qualities that make it pertinent or indicative of a wider population or subject. The study area is a crucial component of research design since it influences the study's scope and emphasis(Basri et al., 2016; Idris & Abd. Latif, 2012). The logistics of doing research in a particular field, such as the accessibility of tools and equipment as well as any potential ethical or cultural issues, must also be taken into account.

In this study, three locations have been selected to site for simulation. Those three locations are 1) Rungkup, Hilir Perak ; 2) Jugra, Kuala Langat, Selangor and S3) Tenggaroh, Mersing, Johor. Those potential sites will be further discussed in Chapter 3.

1.4.2 Source Term

The amount and kind of radioactive material that is released into the environment as a result of an accident or release event are referred to as the "source term" in the context of nuclear energy and radiation safety. When estimating the possible effects of a nuclear accident or release on the local environment and population, the source term is crucial (Achim et al., 2014).

The term "source" can refer to a wide range of radioactive substances, including as fission products, activation products, and fuel debris. Depending on the precise nature of the discharge event, it may also comprise gases, liquids, and solids. A number of techniques, including computer modelling and examination of data made at the release location, can be used to determine the source term. It is crucial in establishing the right course of action and cleanup procedures as well as in estimating the possible effects of a nuclear catastrophe (Onda et al., 2015).

1.5 Significance of Study

The importance or relevance of the research to a certain subject or area of study is referred to as the study's significance. It serves as a means of illustrating the importance and contribution of the study to the body of information currently available on a certain topic.

Research may indicate the importance of a subject in a number of ways. One option is to demonstrate how the study fills a gap in the literature already available or solves a need in the industry. A research could, for instance, examine a subject that hasn't been studied before or offer fresh viewpoints on a problem that already exists.In general, the importance of the study is a crucial component of research since it supports the investment of time, money, and effort in the investigation. Additionally, it ensures that the study is pertinent, significant, and has the ability to advance knowledge in a given area.

1.5.1 Importance of Study for Malaysia

There are a variety of reasons why it would be important to do research on the dose projection of a nuclear catastrophe in Malaysia.

First, a nuclear accident in Malaysia may potentially have a big impact on the community and environment there. It would be feasible to understand the potential effects of the release of radioactive materials on the people and the environment and take the necessary precautions to limit or prevent these effects by undertaking research on the potential dosage projection of such an accident.

Next, in terms of emergency planning and response, study on the projected dosage of a nuclear disaster in Malaysia might be beneficial. It would be able to create backup plans and reaction methods to lessen the effects of an accident by being aware of the potential effects of a nuclear disaster.

This study will be focusing on the usage of HYSPLIT, a software developed for the purpose of simulating various real-life scenarios. HYSPLIT when compared to other type of softares, is the latest simulation available to the public. However it also has a lot limitations;

1. Simplified Atmospheric Representation: HYSPLIT assumes a simplified representation of the atmosphere, overlooking complex

atmospheric processes. This can affect the accuracy of the model in capturing dispersion patterns.

2. Limited Spatial Resolution: HYSPLIT operates on a coarse spatial resolution, which may not accurately represent local-scale variations in terrain, land use, and meteorological conditions.

3. Simplified Source Representation: HYSPLIT assumes point source releases, which may not capture the behavior of pollutants from area sources or varying emissions over time.

4. Limited Chemical and Physical Processes: HYSPLIT primarily focuses on transport and dispersion rather than detailed atmospheric chemistry and reactions.

5. Input Data Accuracy and Uncertainty: The accuracy of HYSPLIT simulations relies on the quality and accuracy of input data, which can introduce errors and uncertainties.

6. Lack of Real-Time Updates: HYSPLIT is not designed for real-time updates, limiting its ability to capture rapidly changing atmospheric conditions.

It is important to be aware of these limitations and use the model's outputs in conjunction with other sources of information and expert judgment for decision-making in situations involving pollutant dispersion.

Lastly, in terms of influencing public policy and decision-making, research on the dosage prediction of a nuclear disaster in Malaysia would be crucial. It would be feasible to inform the creation of rules and regulations pertaining to the use of nuclear energy in Malaysia by offering evidence-based information on the prospective effects of a nuclear disaster.

1.6 Thesis Overview

This thesis is broken down into five chapters ; each chapter having its own particular information. Chapter 1 explains the introduction, problem statement, background study as well as the objectives of the research. Chapter 2 contains the literature review and other resarches and studies that was refered to in the completion of this thesis. Chapter 3 is the methodology and materials that was consumed and used to simulate, extract, analyze and display data. Since this is a simulation-based study, the materials mainly used are in the form of software.

Chapter 4 and 5 are the essence of this research which are the discussion, results, summary and conclusion. They also contain further recommendations and potential studies that could be done in the future.

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