Radioactive Plume Dispersion Modeling and Estimation of Radiation Doses

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A thesis submitted to

Department of Physics

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Final Approval

It is certified that the work presented in this thesis entitled "Plume dispersion modeling and estimation of radiation doses" by **Mazzammal Hussain, Registration No. 03-FBAS/MSPHY/F10** is of sufficient standard in scope and quality for the award of degree of MS Physics from International Islamic University, Islamabad.

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Declaration

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Mazzammal Hussain

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Papers for Publications

1. Mazzammal Hussain, Salah Ud-din Khan, Waqar A. Adil Syed, ***'Estimation of Emergency Planning Zones for Nuclear Research Reactor'***, accepted for proceedings of the 20th International Conference on Nuclear Engineering, ICONE20POWER2012 July 30 - August 3, 2012, Anaheim, California, USA.
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Dedicated to;

My dear and loving Mother

For Her unfailing support and encouragement over the years, always being there, listening, caring and helping me to turn this dream into reality.

Our Lord! Forgive me and my parents, and (all) the believers on the Day when the reckoning will be established

[The Quran, chapter #14, verse #41]

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Muzammil Satti

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List of Abbreviations

EPZs	Emergency Planning Zones
GPM	Gaussian Plume Model
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
InterRAS	International Radiological Assessment System
LPZ	Long term protective action Planning Zone
MACCS	MELCORE Accident Consequence Code System
MET	Meteorological
MO	Meteorological Options
NPP	Nuclear Power Plant
PARR-1	Pakistan Research Reactor-1
PAZ	Precautionary Action Zone
PCTRAN	PC-based Nuclear Power Plant Simulator
PNRA	Pakistan Nuclear Regulatory Authority
SRDT	Solar Radiations/Delta-T
TEDE	Total Effective Dose Equivalent
UNSCEAR	United Nations Scientific Committee on Effects of Atomic Radiations
UPZ	Urgent protective action Planning Zone
USNRC	United State Nuclear Regulatory Commission
USSR	Union of Soviet Socialist Republics

Abstract

Plume dispersion modeling and estimation of off-site radiation doses for an accident at a nuclear research reactor has been modeled using one year hourly meteorological data. MELCORE Accident Consequence Code System (MACCS) has been used to model the off-site consequences of radioactive release by considering atmospheric transport, deposition, mitigative actions and dosimetry. The effect of release height, release duration and atmospheric stability class on early health effects has been studied. Considering the national regulations requirements, the early health effects modeled for different accidental scenarios are compared with 'Hotspot' and 'InterRAS' results. A good agreement of results has been found with a fluctuating trend in meteorological parameters. Further, it was found that source term, meteorology, release height, release duration and atmospheric stability class have a great influence on plume dispersion modeling. MACCS code was found a good tool for the assessment of early health effects and identification of intervention distances (emergency planning zones) for implementation of different protective actions during emergency phase.

CHAPTER 1

1. Introduction

1.1 Nuclear Energy an Overview

With exponentially increasing energy requirements, conventional and non-conventional energy resources are explored to meet the current and future energy demand. The world's energy resource includes fossil fuel (oil, gas and coal), nuclear energy and renewable energy (hydro, wind, solar, biomass and geothermal). The nuclear energy contributes more than fifteen percent to world's energy utilization with more than four hundred nuclear power plants in about thirty countries. Military use of atomic energy at Hiroshima and Nagasaki put question mark on atomic energy and the potential threat associated with it. Many concerns were raised on nuclear energy utilization and many of which still exist. Later on, utilization of atomic energy for the peaceful purpose was promoted and encouraged worldwide. The world's first nuclear power plant, Obninsk (USSR) started its operation in 1954. . International Atomic Energy Agency (IAEA) came into existence in 1956 to promote and regulate the atomic energy. The international bodies e.g. IAEA, International Commission on Radiological Protection (ICRP), United Nations Scientific Committee on Effect of Atomic Radiations (UNSCEAR) and national regulatory bodies in various countries have chalked out requirements for site selection, installation, commissioning and safe operation of nuclear facilities.

1.2 Nuclear Accident Consequences

A range of possible accidents are associated with nuclear power plants starting with minor incident to immense disaster. Nuclear power plant's accident which may affect both the site personal and public residing in the vicinity is known as general emergency. Chernobyl accident in USSR, 1986 caused major radioactive releases to the environment and posed a great threat not only to the local area but for all over the world. This disaster taught mankind to propose many improvements in the design of safety related systems, equipments, radiation protection approaches and emergency preparedness and response.

In 2011, due to earth quake followed by Tsunami in Japan, nuclear emergency occurred at Fukushima nuclear power plants due to multi-layer failures alarming local and international community for the safety of nuclear power plants. The IAEA ministerial conferences, political decision for banning on installation of new NPPs in some countries, re-evaluation of nuclear power plants design, safety systems and emergency planning zones in many countries followed by this accident.

Deterministic and probabilistic approaches are used to study the possible accidents at NPPs to improve the design and to minimize the occurrence of nuclear and radiological accidents. One of the approach used world wide at nuclear power plants and accepted by various regulatory bodies is to assess the consequences of nuclear accidents, emegency planning zones using state-of-the-art codes. Different plume dispersion models e.g. Box model, Gaussian model, Lagrangian model, Eulerian model etc are used. Indispensable factors considered for plume dispersion modeling and estimation of radiation doses are:

- The source term inventory and fraction of releases
- The heat content and plume buoyancy
- Release duration
- Release height
- Building wake affect
- Meteorological conditions (wind speed, direction, precipitation and atmospheric stability)

In case of radioactive release from a nuclear facility, arrangements are ensured to be in place to avoid exposure of ionizing radiations to the public. The arrangements for protective action depends on the amount of radioactivity released (source term), type of radionuclide (physical and chemical form), half life, meteorological condition, affected area and total population.

1.3 Regulatory Requirements for Emergency Preparedness

A nuclear facility having potential effects on the population and environment performs a detailed study on accidents and their consequences. Emergency preparedness and response arrangements ensure that all necessary resources are in place. Nuclear power plants use plume dispersion codes for different accident scenarios in various prevailing weather conditions at the site to estimate the affected area and population.

In Pakistan, Pakistan Nuclear Regulatory Authority (PNRA) is the national competent Authority to devise, adopt and promulgate national regulations for the use of nuclear energy, radioactive sources and ionizing radiation generators. The national regulations, "regulations for licensing of nuclear installation(s) in Pakistan-PAK/909" requires an emergency preparedness plan prior to introduction of nuclear material into the system [1]. The "regulations on safety of nuclear power plant operation-PAK/913" requires the licensee to establish appropriate emergency arrangements from the time the nuclear fuel is brought to the site [2]. The "regulations on management of a nuclear or radiological emergency-PAK/914" requires licensee to develop, test and put in place an infrastructure according to the hazard category as defined in these regulations for emergency preparedness and response. The licensee has to ensure "a timely managed, controlled, coordinated and effective response at the installation, in the immediate vicinity and the region affected by the nuclear or radiological emergency". Emergency preparedness plans are required to be maintained for managing accidents, mitigating their consequences, protecting site personnel, public and the environment. Emergency plans are required to be tested in an exercise before the commencement of operation and at a defined frequency thereafter [3].

1.4 Emergency Planning Zones

An important level of defense in depth concept for nuclear power plants safety is emergency preparedness and response. It is based on analyses of severe accident and calculations of radiation doses for the public.

Emergency responses for most of the accident types take place over two areas, on-site and off-site areas. The area surrounding nuclear power plant(s) within the security perimeter, fence or the other designed property marker called on-site area. This area is under immediate control of nuclear power plant(s) operators. The off-site area is not under the control of the operators. It is divided into three parts [4]:

- Precautionary action zone (PAZ)
- Urgent protective action planning zone (UPZ)
- Longer term protective action planning zone (LPZ)

The imaginary layout of emergency planning zones is shown as Figure 1.1.

1.4.1 Precautionary Action Zone (PAZ)

It is the pre-designated "area around a facility for which arrangements have been made to take urgent protective actions in the event of a nuclear or radiological emergency to reduce the risk of severe deterministic health effects. Protective actions within this area are to be taken before or shortly after a release of radioactive material or an exposure on the basis of the prevailing conditions at the facility".

1.4.2 Urgent Protective Action Planning Zone (UPZ)

It is the pre-designated "area around a facility for which arrangements have been made to take urgent protective actions in the event of a nuclear or radiological emergency to avert doses in accordance with international safety standards. Protective actions are taken on the basis of environmental monitoring or as appropriate on prevailing conditions at the facility".

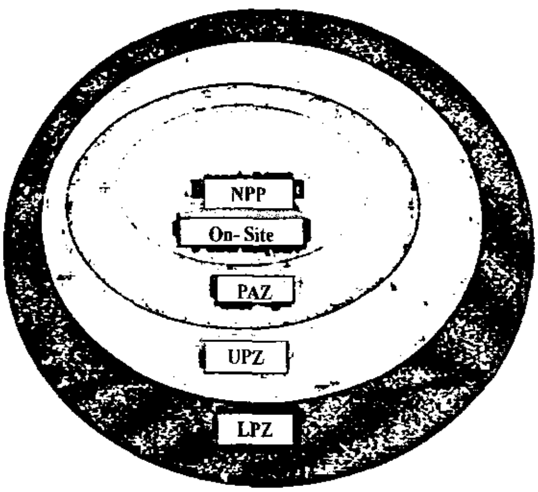

Figure 1.1 Imaginary Layout of Emergency Planning Zones (EPZs)

1.4.3 Longer Term Protective Action Planning Zone (LPZ)

It is the pre-designated area far from the installation designated to reduce the long term dose from ground contamination. Protective actions such as relocation, food restrictions and agricultural countermeasures based on environmental monitoring and food sampling are taken in this zone.

1.5 Current Research Work

Consequence analysis for a hypothetical accident at nuclear research reactor has been modeled and radiation doses at different distance are estimated. MELCORE Accident Consequence Code System (MACCS) has been used to model plume dispersion and estimate the radiation doses. An hourly meteorological data spanning over a year for city of Islamabad, Pakistan has been used for modeling.

The first two modules ATMOS and EARLY of MACCS code have been used for this study considering different accident scenarios for a nuclear research reactor. The estimated results are compared with the international published data considering national regulations and InterRAS code. InterRAS code is a Gaussian based plume dispersion code developed by IAEA. The effect of different parameters e.g. release height, heat content, release time, atmospheric stability class etc on radiation doses to be public has been analyzed.

Theoretical background of plume dispersion, MACCS code and its modeling is presented in the next chapter. The basic concept about metrology, atmosphere, consequence analysis of nuclear power plant accident and an introduction to MACCS code is discussed. Material and methods used for processing of hourly based meteorological data, estimation of atmospheric stability class and its conversion to code (MACCS) input file, and different release scenarios considered are discussed in chapter 3. The results analysis and discussion on meteorological data, MACCS output results are discussed in chapter 4. Conclusion and future recommendations are presented in final chapter 5.

CHAPTER 2

2. Theoretical Background

2.1 The Atmosphere and Meteorology

2.1.1 Composition of the Atmosphere

The whole seen around the globe composed of three features, the dry part of the land called 'lithosphere', the wet part called 'hydrosphere' and the upper envelop of air called 'atmosphere'. The advancement in engineering and technology, continuous urbanization and industrialization has significantly increased the environmental pollution which badly affects human life and environment. The pollutants are discharged to environment in the form of solid, liquid and gaseous/particulates. Atmosphere is an envelope of gases extended up to height of about one thousand kilometers. Approximately one half of the total mass of the atmosphere is concentrated in first five kilometers near the earth surface. The pollutants emitted in one part of the globe also affect the other parts of the globe. The radioactivity released in Chernobyl (USSR, 1986) and Fukushima (Japan, 2011) affected many continents and caused an increased level of radioactivity of the world.

In the atmosphere, temperature has a complex trend with the altitude. Based on the temperature profile the atmosphere is divided into four layers known as troposphere, stratosphere, mesosphere and thermosphere [5] as shown in Figure 2.1.

2.1.1.1 Troposphere

It is the lowermost layer and is characterized by the steady state average decrease in temperature at 6.5°C per kilometer. All of the pollutants are emitted into troposphere. This layer has an average altitude of fifteen kilometers however it varies for different locations. The upper boundary of the troposphere is called tropopause with temperature up to -60°C preventing the water vapors on earth.

2.1.1.2 Stratosphere

The atmospheric layer above tropopause is stratosphere. It has two regions of different temperature variation. In the lower region the temperature is independent of altitude and in upper region temperature increases with increasing altitude. The rise in temperature in upper region of stratosphere is due to the absorption of ultraviolet radiation by ozone. It provides a natural shield around the earth from harmful effects of dangerous radiation. At about fifty kilometers from the earth surface, the temperature increases to about 20°C marks upper boundary of the stratosphere called stratopause.

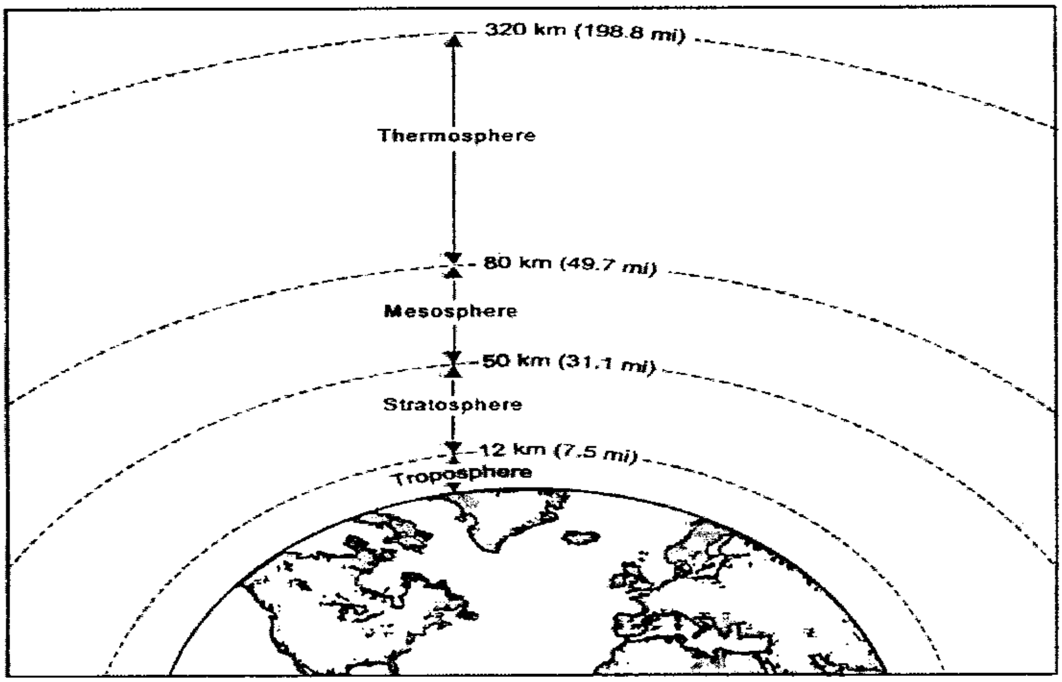

Figure 2.1 Vertical Structure of Atmosphere [5]

2.1.1.3 Mesosphere

The atmospheric layer next to the stratopause, just above fifty kilometers is known as mesosphere. The density of air and ozone concentration decreases rapidly with increasing height in this region. The temperature steadily decreases with altitude due to decrease in absorption of solar radiation by ozone, reaching to about -100°C at the upper boundary of mesosphere which is called mesopause.

2.1.1.4 Thermosphere

The region above the mesopause, extending up to eighty kilometers called thermosphere. Solar energy is converted into sensible heat in this region as concentration of gas molecules dropped less than 10^{19} molecules per cubic meter as compared to 2.5×10^{25} molecules per cubic meter at sea level. The temperature at a height of two hundred kilometers rises to 500°C and at upper boundary of thousand kilometers reaches 1225°C. Thermosphere is also known as ionosphere and it the highest layer recognized.

2.1.2 Effect of Topography on Atmospheric Motion

Topography which is a physical characteristic of earth's surface dominantly affects the air flow relatively close to the earth's surface. There are four type of topography features flat, mountain/valley, land/water and urban [5].

Topography creates turbulence in the atmosphere by two ways, one is thermal and other one is mechanical. The characteristic of differential heating, different heat observed by different objects creates thermal turbulence in the atmosphere. The wind flows over different objects creates mechanical turbulence.

2.1.2.1 Flat Terrain

The earth surface is not completely flat, some terrain may be considered to be flat for topographical purposes. Ocean and plain land are considered to be flat terrain.

2.1.2.2 Mountain/Valley

Mechanical and thermal turbulence over mountain/valley depends on size, shape and orientation of the features. Air tends to move up and over an obstacle in its path and find its way around the sides.

2.1.2.3 Land/Water

The land and water exhibit different roughness and heating properties. The plume dispersion and transport is very difficult to predict.

2.1.2.4 Urban

Urban areas have more roughness features and different thermal characteristics due to the presence of man-made elements. The thermal and mechanical components influence the atmospheric transport. Different topographical features are shown in Figure 2.2.

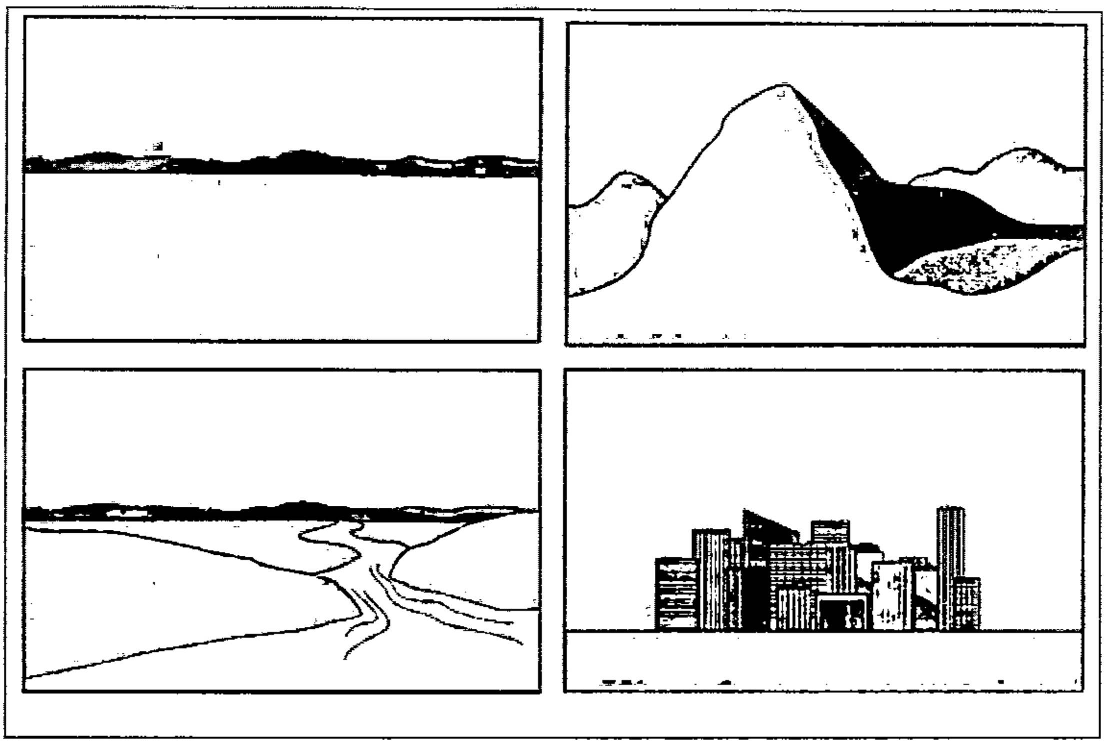

Figure 2.2 Topography [5]

2.1.3 Vertical Atmospheric Motion

Vertical motion plays an important role in plume dispersion. Vertical motion is caused by pressure difference and air lifting over terrain and convection. Followings are the basic principles related to vertical motion of the atmospheric motion.

2.1.3.1 Parcel of Air

It is defined as a well defined tiny packet of air molecules, a constant number of molecules that acts as a whole. The exchange of heat between air parcel and surrounding air is negligible and temperature within air parcel remains almost the same.

2.1.3.2 Buoyancy Factor

The warm air is less dense and lifted up over the cold air which is known as buoyancy factor. As the parcel rises, it expands and decreases temperature and cools. The rise or descend of air parcel depend on temperature difference between it and surrounding air.

2.1.3.3 Lapse Rates

The rate of change of air temperature with altitude is called lapse rate. The atmospheric lapse rate is approximately -6°C to -7°C per kilometer which varies with locality and time of the day.

2.1.3.4 Dry Adiabatic Laps Rate

The air parcel contains its heat within itself. It does not exchange heat to its boundaries and to the atmosphere. Increase or decrease of molecular activity produces temperature change within air parcel, called adiabatic process. The dry adiabatic lapse rate is a fixed rate and independent of ambient air temperature. The dry adiabatic lapse rate is -9.8°C per kilometer.

2.1.3.5 Wet Adiabatic Lapse Rate

An air parcel holding water vapors rises and cools with dry adiabatic lapse rate until reaches condensation temperature or dew point. Latent heat in the parcel is released by condensation and parcel's cooling rate decreases, which is known as wet adiabatic lapse rate.

2.1.3.6 Environmental Lapse Rate

The temperature variation of ambient air is called environmental lapse rate also known as prevailing or atmospheric lapse rate. It changes significantly with height and some time at a greater rate than dry adiabatic lapse rate. Temperature inversion occurs when temperature increases with altitude and it confines vertical air motion.

2.1.3.7 Mixing Height

The degree to which air parcel will rise or descend depends on adiabatic lapse rate and environmental lapse rate relationship. The height where air parcel cooling with dry adiabatic lapse rate crosses environmental lapse rate called mixing height. It is the maximum level of air parcel rise. When environmental lapse rate is greater than dry adiabatic lapse rate, no intersection will occur and mixing height may extend to greater height.

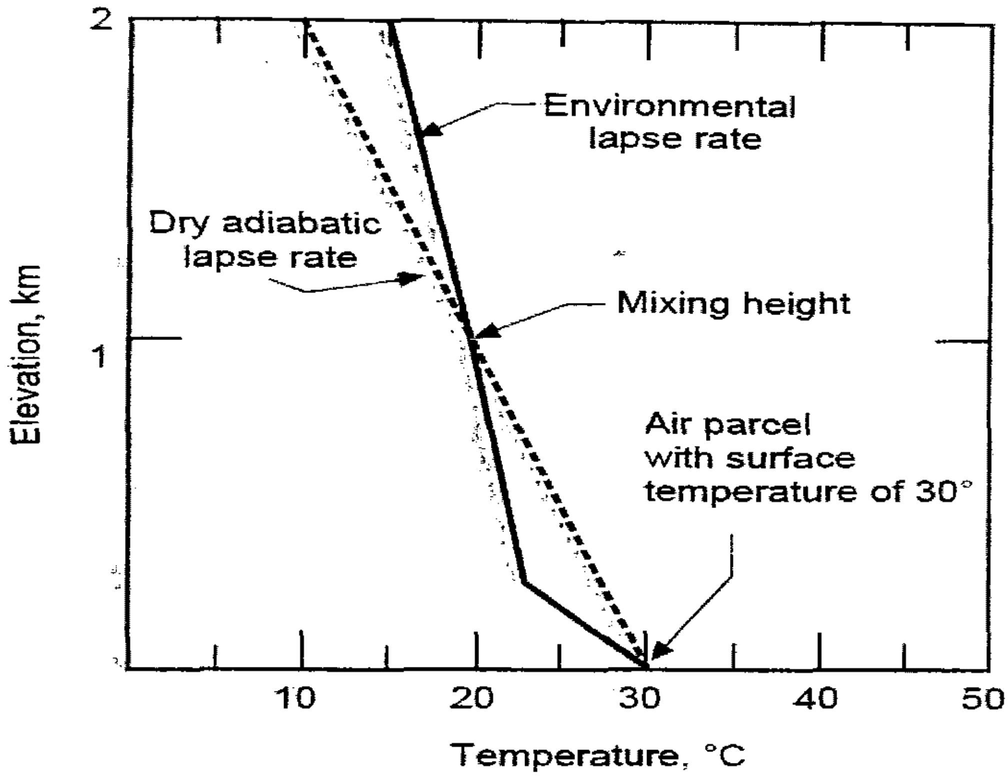

Figure 2.3 Laps Rate and Mixing Height [5]

2.1.4 Atmospheric Stability

The atmospheric stability defines atmospheric effect on the vertical motion of the air parcel.

2.1.4.1 Stable Atmospheric Condition

If the atmospheric condition is stable, the vertical motion of the air parcel is discouraged i.e. the vertical motion is not supported by the environment. A stable atmosphere corresponds to a situation in which if a puff of smoke released in the atmosphere is perturbed up or down, it will resist and tends to restore its original position. Stable atmospheric condition occurs at night with little or no wind.

2.1.4.2 Unstable Atmospheric Condition

If the atmospheric condition is unstable, air parcel tends to move upward or downward and continue that movement. It depends on the difference between environmental and dry adiabatic lapse rate. These conditions are developed mostly on sunny days with low wind speed.

2.1.4.3 Neutral Atmospheric Condition

If the atmospheric condition neither encourages nor discourages air movement, the atmosphere is said to be neutral. The neutral atmospheric condition exists when the environmental lapse rate is the same as the dry adiabatic lapse rate. This condition occurs on windy days or when there is cloud cover.

2.1.4.4 inversion

When the conditions are extremely stable, cooler air near the surface is trapped by the warmer air above it. In such a case no vertical air motion is possible. Plumes which are emitted below or above the inverted layer are trapped either below or above the inverted layer. Due to inversion, the concentration of emitted plume some time increases to dangerous level.

2.1.5 Plume Behavior and Stability

Different behaviors of plumes in different atmospheric conditions are described below.

2.1.5.1 Looping Plume

Looping behavior of plume is experienced when atmospheric conditions are highly unstable. In this case the ambient lapse rate is greater than the adiabatic lapse rate and turbulence of air itself causes the atmosphere to serve as an effective vehicle of dispersion. As a result, the plume exhibits a random behavior i.e. looping and some of the plume may even touch the ground. In the areas where conditions make looping plumes, higher stacks may be needed to prevent premature contact with the ground. The looping behavior of the plume is shown in Figure 2.4.

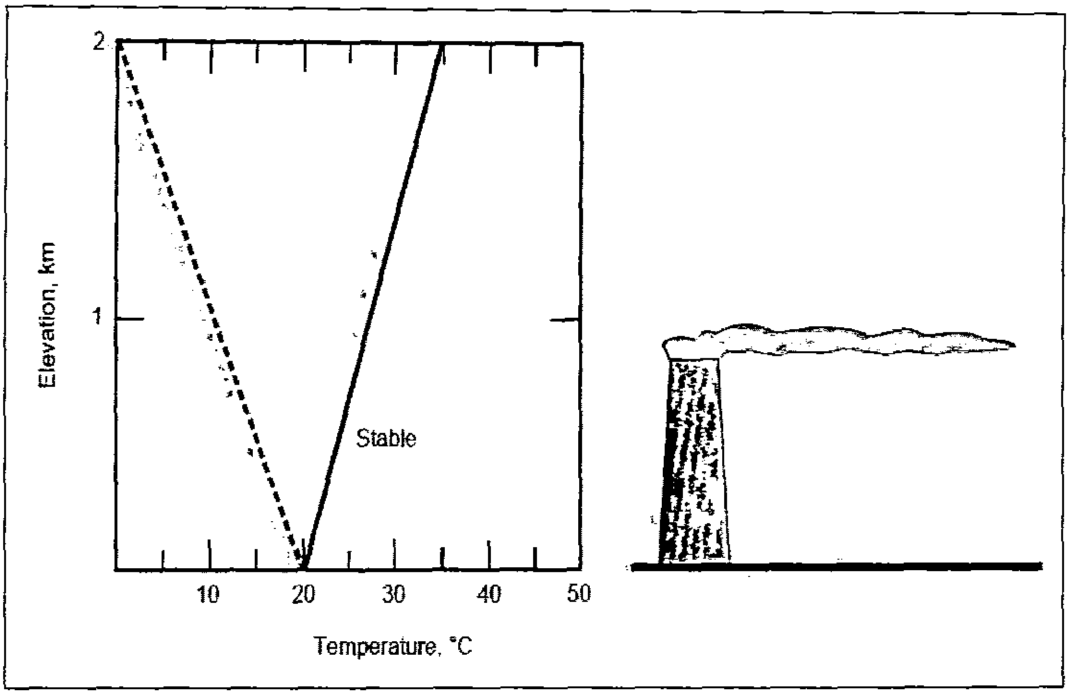

Figure 2.5 Fanning Plume [5]

2.1.5.3 Coning Plume

This behavior of plume is experienced when atmospheric conditions are neutral or slightly stable. When the ambient lapse rate is equal to or very near the dry adiabatic lapse rate, the plume issuing from a single chimney or smoke stack tends to rise directly into the atmosphere until reaches air of density similar to that of the plume itself. This type of emission is called neutral plume. However, this neutral plume tends to cone when wind is blowing in horizontal direction. This type of plume resembles a cone with a horizontal axis. This situation occurs normally on cloudy days or sunny days between the breakup of a radiation inversion and the development of unstable daytime conditions. The coning behavior of the plume is shown in Figure 2.6.

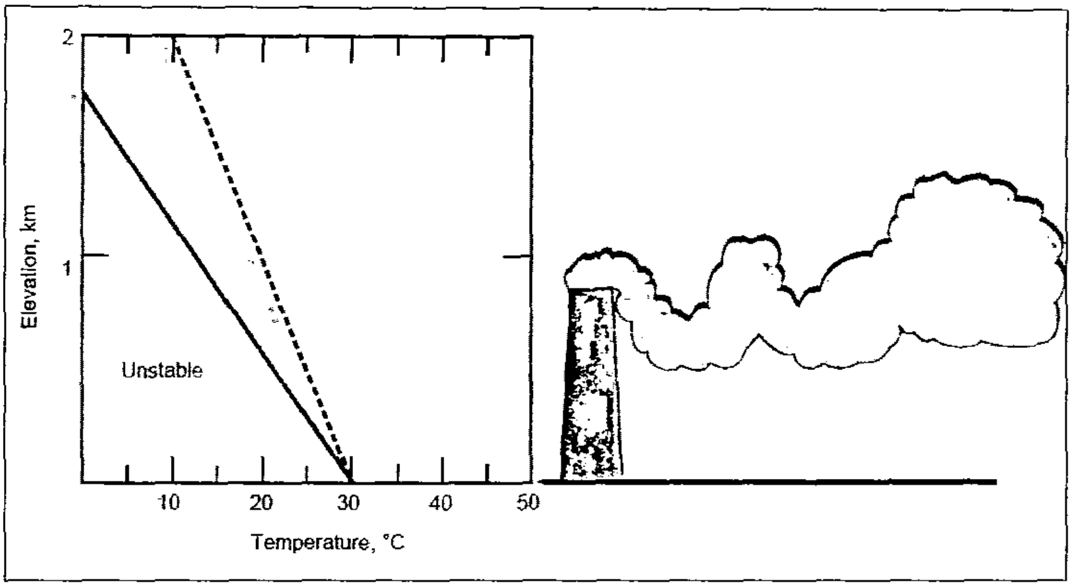

Figure 2.4 Looping Plume [5]

2.1.5.2 Fanning Plume

This behavior of plume is experienced in stable conditions. When the lapse rate is with an opposite slope compared to dry adiabatic lapse rate as in the presence of inversion, the dispersion of stake gas is minimal, because of lack of turbulence. Usually hot effluent rises initially until its temperature stabilizes a certain height from the stake. If strong fluctuating horizontal wind components are present, the plume spreads out in the horizontal plane like a fan and hence this pattern of plume is termed as fanning. In areas where radiation inversions are common, construction of stacks high enough to allow for discharges of emissions above the inversion layer is recommended. A fanning plume is not necessarily an unfavorable condition for the dispersion of effluents. The fanning behavior of the plume is shown in Figure 2.5.

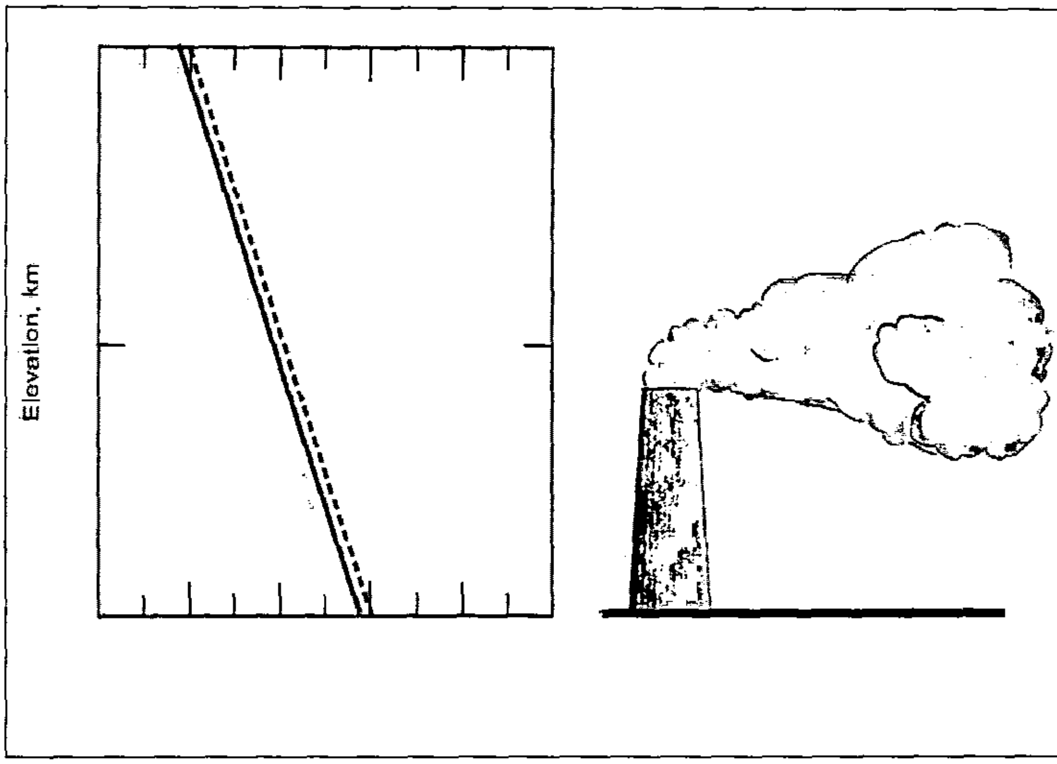

Figure 2.6 Coning Plume [5]

2.1.5.4 Lofting Plume

When the lapse rate is adiabatic above the emission source and inversion conditions exist below the source, the plume is said to be lofting. These conditions develop around sunset, as the night time radiation inversion begins to buildup. A lofting plume has minimal downwind mixing, and the pollutants are dispersed downwind without any significant ground level concentration. Thus lofting is the most favorable condition for the dispersion of effluents. Since in this case plume does not come near the ground and is dispersed at great distance over large volume of air. The lofting behavior of the plume is shown in Figure 2.7.

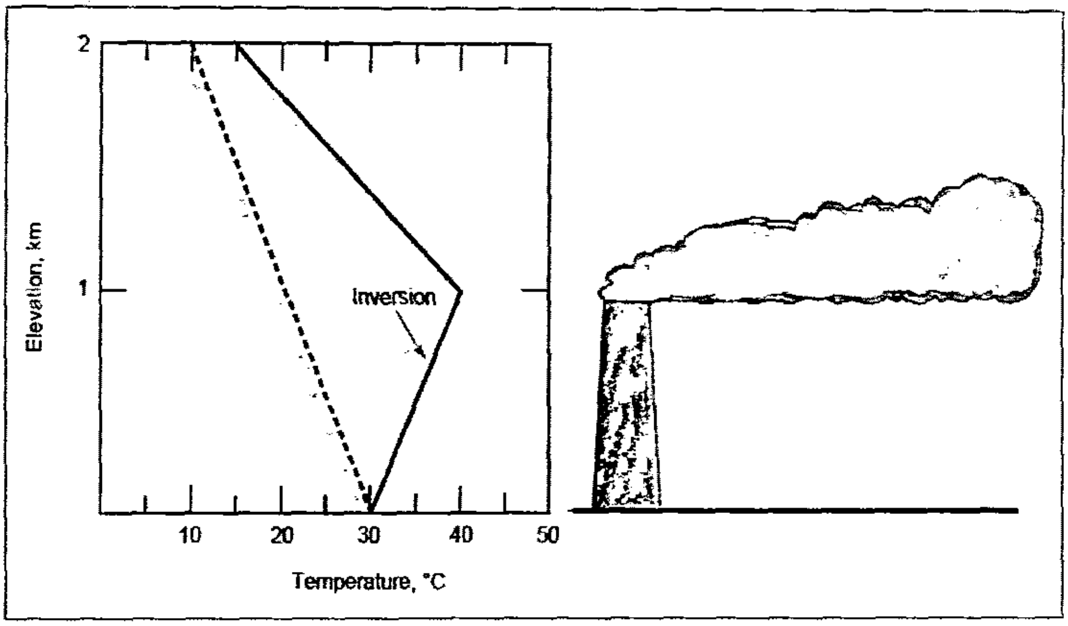

Figure 2.7 Lofting Plume [5]

2.1.5.5 Fumigating Plume

Shortly after the sun rises on a clear morning, the inversion due to the night time radiating of the earth begins to dissipate as the surface of the earth heat up. Starting at the ground level, the inversion is replaced by an adiabatic profile, which moves slowly upward. Thus an inversion layer occurs at a short distance above the plume source and adiabatic or super adiabatic conditions prevail below the stack. Effluents emitted, after this new profile is established, are confined by the inversion overhead, but can be dispersed towards the ground as the result of turbulence developed in the newly heated air. Such a condition that may lead to a high concentration of effluents at ground level is termed as fumigation. Though fumigation usually lasts only for a short period of time, it may cause high concentration of ground level. The fumigating behavior of the plume is shown in Figure 2.8.

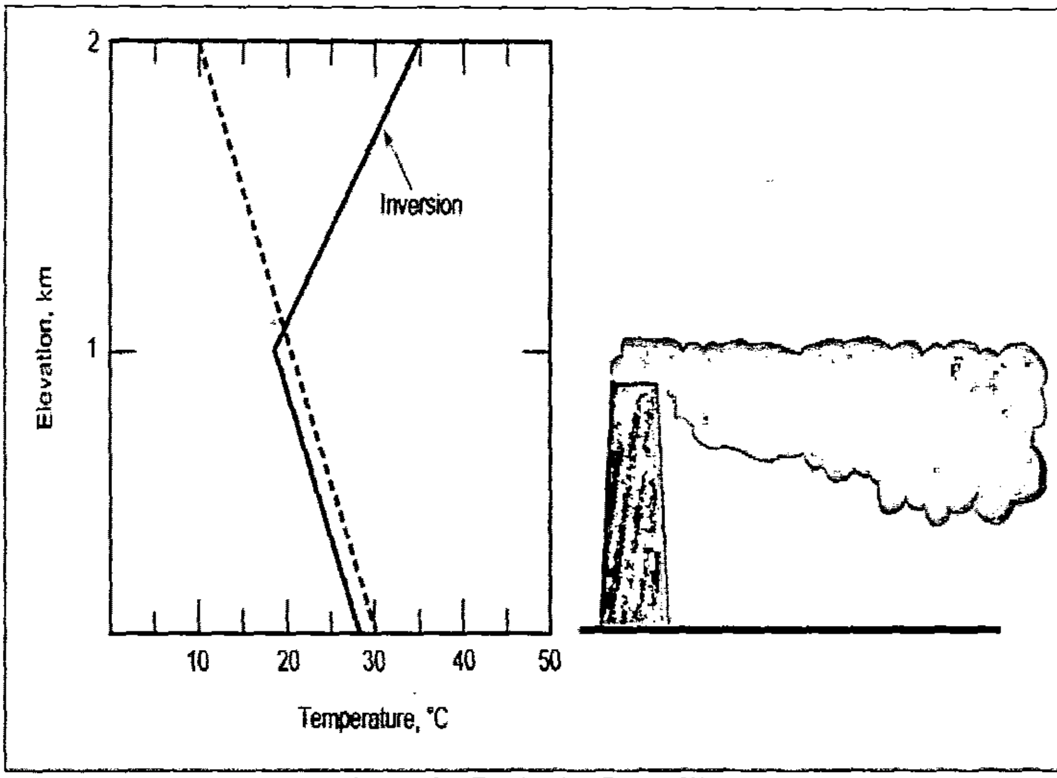

Figure 2.8 Fumigating Plume [5]

2.1.6 Methods to Estimate Atmospheric Stability Class

There are different approaches used to estimate the atmospheric stability class. Atmospheric stability in plume dispersion modeling is used to estimate lateral and vertical dispersion parameters (σ_y, σ_z) in Gaussian plume models. The stability classes represent how much atmosphere is turbulent for atmospheric dispersion. The stability classes are classified as follows [6].

Table 2.1 Types of Stability Classes

Stability Class	Letter	Phrase
1	A	Very unstable
2	B	Moderately unstable
3	C	Slightly unstable
4	D	Neutral
5	E	Slightly stable
6	F	Moderately/Very stable

Some of the methods for estimating stability classes are as follows.

2.1.6.1 Turner Method

This method was proposed by Turner to estimate atmospheric stability classes using routinely collected weather data. Following parameters are required for the estimation of stability class.

- Horizontal wind speed,
- Cloud cover,
- Ceiling height and time of observation

2.1.6.2 Solar Radiation/Delta-T (SRDT) Method

In some of the cases, the cloud cover and ceiling height data may not be available, in such a situation, SRDT method is very useful. Following parameters are required in this method to estimate the stability class.

- Surface wind speed (10m)
- Sunshine and solar irradiation intensity (during day)
- Lapse rates for different heights (during night)
- Time of observation at day and night timing

2.1.6.3 σ_E Method

Turbulence based method use standard deviation of the elevation angle of the wind in combination with mean wind speed.

2.1.6.4 σ_A Method

Turbulence based method use standard deviation of the wind direction in combination with the mean wind speed.

2.2 Plume Dispersion Modeling

Plume dispersion modeling is a numerical tool to establish a relationship between emissions, meteorology, atmospheric concentrations, deposition and other factors. It provides quantitative information on dispersion and deposition concentration at specific location and time in air and at ground level. Plume dispersion models are used in risk analysis, emergency planning, environmental impact assessment and other regulatory purposes. Plume dispersion models are useful due to their capability to assess and determine the relationship between emissions and concentrations/depositions, including the consequences of past and future scenarios. The concentration of the substances in the atmosphere is determined by release duration, release height, transport, diffusion, chemical and radioactive transformation and ground deposition. The transport of plume is characterized by the wind speed, direction, stability and precipitation.

A plume dispersion model is a computational procedure for estimating the plume transport and deposition. The emission characteristics (stake height, stake diameter, release velocity, heat contents, chemical and physical properties of the gases/particle released etc), topography features and meteorology are required for the modeling of the plume dispersion and estimation of ground and air concentration. Rapid development was made in 1950s and 1960s including major field studies to understand the structure of atmosphere.

To model plume dispersion, physics of the dispersion process and use of numerical equations and computation techniques are required. There are different types of models starting with very simple model to the most sophisticated models.

Gross Screen Models

These models require only hand held calculator, monograph or a spread sheet. These models could handle one source at a time normally. It is very useful to apply such model before using advance models for better understanding of the plume dispersion.

Intermediate Models

These models are usually PC-based which includes variable meteorology and sophisticated source information.

Advance Models

In these models, desktop PC or a workstation is required. These models could model multiple source types and dispersion at short and long range distances.

2.2.1 Plume Dispersion Models

Different approaches for dispersion modeling have been used ranging from simple box model to Lagrangian concept of atmospheric dispersion. A brief introduction of the models is as follows [7].

2.2.1.1 Box Model

This model is based on the law of conservation of mass. It is supposed that plume from the source expended to include whole area of the downwind face of the box. Average concentration of the plume is estimated using this model. A major drawback of this method is that air mass inside the box is treated as well mixed and concentration is assumed uniform. One advantage of the box models is that they are able to include detailed chemical reaction schemes.

2.2.1.2 Gaussian Plume Model (GPM)

This model is based on a single equation derived from time integration of Gaussian puff equation for continuous release. This equation is achieved by solving Fickian diffusion equation assuming homogenous turbulence and a uniform wind field. The plume width is determined by σ_y andσ_z. These are most widely used atmospheric dispersion models. These models are used to study the consequence analysis of nuclear power plant accidents, radiological and environmental impact and are recommended by national regulatory bodies and international agencies (IAEA).

2.2.1.3 Lagrangian Model

This type of model considers temporal variations in wind velocity, turbulence in modeling and provides better results than Gaussian Plume Model (GPM) for short and long range. Lagrangian model have the capability to model both homogenous and inhomogeneous conditions over flat or complex terrain. Particles could be assigned different physical and chemical properties to study the physical and chemical interactions. The release of the pollutants is represented by releasing large number of discrete particles which are advected by prevailing wind. The model determines the trajectories of each particle as it move under the wind field and particle position is stored at each time step.

2.3 Consequence Analysis of Nuclear Accidents

The consequences of nuclear accidents are studied using state-of-the-art codes. These codes are used to assess the progression of nuclear accidents (progression of different transients), estimation of source term released (inside the containment), radioactive material released to the environment, dose to the public through different means (cloudshine, groundshine, resuspension, ingestion of contaminated water and food etc), area and land affected by radioactive releases etc. The codes are also used to study the long range impact of such release over a large distance to the other countries.

Different researcher use different plume dispersion codes and techniques to analyze the nuclear power plants accident consequences. Atmospheric dispersion modeling for a radioactive explosion in a public area containing Cs-137 was performed by Hyo-Joon Jeong and co-workers using a Gaussian based plume dispersion code [8]. Atmospheric dispersion modeling for a mixture of radioactive gaseous and aerosol pollutants using Bulgarian Emergency Response System (BERS) was performed by B. Velva. It was concluded that it is a proficient tool to assess long-range atmospheric dispersion of radioactive releases [9]. A remediation assessment modeling for urban areas contaminated with dispersed radionuclides was carried out K.M. Thiessen and co-workers [10]. J. Qu presented the results of dose and cost calculation for relocation after nuclear accidents and quantifies the relationship between radiation dose and relevant parameters defining protective actions [11]. Accident dose consequences for nuclear emergency response applications and estimation of emergency planning zones using PCTRAN were studied by Yi-Hsiang Cheng. It was concluded that the software easily initiates an accident simulation, predicts the conditions of the plant, and assesses the consequences of offsite dose distributions faster than the real accident time [12]. E. Rodgers compared geographically referenced ground-based measurements of gamma and beta radiation to model predictions of particle dispersion and estimated the influence of particles size, wind speeds, and vertical and lateral turbulence on the near field fallout patterns resulting from Chernobyl's first two releases of radioactive materials. Excellent conformity between empirical measures and model predictions was found when reasonable atmospheric parameters were assigned [13]. Probabilistic risk assessment

(PRA) for long-range atmospheric transport was carried out by Bent Lauritzen and co-workers. Model parameters were estimated by comparing with the results of long-range atmospheric dispersion model calculations using one-year numerical weather prediction model data. It was found that the estimated ensemble mean provides a reasonable first approximation to the total dry and wet deposition from the one-year continuous release [14]. S. Shoaib Raza studied atmospheric dispersion modeling for accidental release from the Pakistan Research Reactor-1 (PARR-1) using Gaussian based plume dispersion model "Hotspot" and concluded that there is no increase in the potential radiological impact of PARR-1 on the public [15]. T. Haste and co-workers performed assessment of MELCOR independently using empirical data. An attempt to demonstrate a MELCOR–MACCS capability to simulate the whole plant accident sequence, including the containment response and off-site consequences arising from fission product release from the containment was made. Results were compared with observed and deduced data for the major accident signatures and rough estimates for exposure based on off-site monitoring were made. The results provided a good basis for the NPP analysis foreseen [16]. Re-evaluation of emergency planning zone for nuclear power plants was performed by Ke-Shih Chuag using MACCS2 code and concluded that the radius identified previously is a reasonable conservative value of EPZ for each of the three operating NPPs in Taiwan. C.V. Srinivas and R. Venkatesan, studied dispersion of air borne radioactive effluents during a hypothetical accidental scenario from a proposed prototype fast breeder reactor (PFBR) at an Indian coastal site, Kalpakkam, using a 3-D meso-scale atmospheric model MM5 and a random walk particle dispersion model FLEXPART. The results were also compared to the Gaussian based plume dispersion model [17]. R. Bianconi, presented the technical concepts behind the ENSEMBLE (web based system for decision support in case of nuclear emergency) system, the methodology adopted to acquire different model predictions in real time to produce multi-model predictions [18]. X.Y. Wang and co-workers used a new finite cloud method for calculating external exposure dose in a nuclear emergency. The method calculates external exposure dose over a specially constructed three-dimensional columned space. The results were compared with Gaussian plume dispersion codes [19]. Jongtae Jeong & Wondea Jung studied estimation of early health effects for different combinations of release parameters and meteorological data using MACCS code for YGN 3&4 nuclear power plants in Korea and concluded that with the same amount of radioactive material released to the atmosphere, a large difference in early health effects from case to case was observed [20]. Jongtae Jeong and Jaejoo Ha studied influence of source term release parameters on health effects for YGN 3 & 4 nuclear power plants in Korea using MACCS code and concluded that the research work will be very useful for developing strategies for reducing offsite consequences of accident management if they are combined with influence of weather conditions on off-site risk [21]. Iouli Andreev and co-workers using FLEXPART studied risk due to beyond design base accidents of nuclear power plants in Europe that could give an indication which countries are likely to profit by joining the treaties and which are not [22]. Lennart Thaning and Alexander Baklanov, consider simulated accident at a nuclear power plant that could cause a large release of radioactivity into the atmosphere. The consequence analysis was performed using two different models. A 3-dimensional meso-scale model, developed at the Kola Science Centre and some consequences for the population have been estimated by using the MACCS model [23].

Many others have studied the safety assessment and consequence modeling of nuclear power plant accidents using different plume dispersion codes and derived co-relation of different parameters by modeling the consequences of real and hypothetical accident.

2.4 MELCORE Accident Consequence Code System

MELCORE Accident Consequence Code System (MACCS) was developed by Sandia National Laboratories for the consequence assessment of severe accidents at nuclear power plants. For execution of MACCS code, input data based on two fundamental aspects for its modeling, one is the time span after start of the nuclear accident and second one is the distance from the reactor. The time after the accident has been divided into three phases, as emergency phase, intermediate phase and long term phase. The emergency phase is complementary and defined by the user. The rest of two phases are optional and subject to analysis for intermediate and long term consequences assessment. The emergency phase starts just after the accident initiation and lasts up to seven days.

For this period, exposure to population from radioactive cloud and contaminated ground is modeled. Protective actions e.g. evacuation, sheltering, KI distribution etc are considered during this phase. During intermediate phase which is followed by emergency phase lasts for many weeks, includes protective actions e.g. evacuation and decision making process for taking protective actions. During this phase, it is considered that contaminated cloud has been passed away and exposure is left only from the contaminated ground. Protective actions e.g. temporary relocations etc are considered during this phase. The long term phase starts after the intermediate phase to an infinite time and includes protective actions like decontamination, interdiction and condemnation of property etc.

The reactor is considered as the centre for specifying regions surrounding the reactor using spatial grid coordinate system. In MACCS, there is a provision of thirty five radial distances up to maximum distance of 9999 kilometers with minimum separation of 0.1kilomer between two radii. The innermost radii should not be less than 0.1km. The angular distance has been divided into sixteen directions. MACCS is organized into three modules;

ATMOS Module

This module performs the atmospheric transport and deposition portion of the calculation.

EARLY Module

This module estimates the consequences of the accident immediately after the accident usually within the first week.

CRONC Module

This module estimates the long term consequences of the accident.

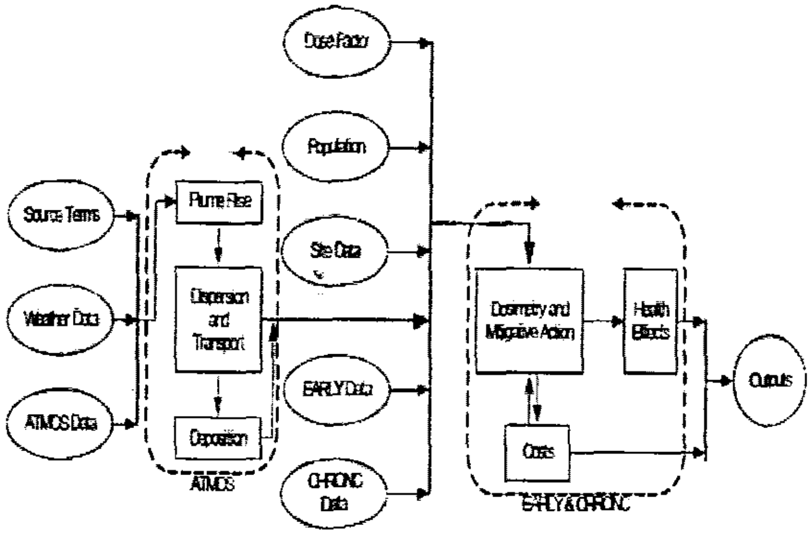

Figure 2.9 MACCS Modules

Following parameters are required for the execution of MACCS code.

- Inventory of the reactor
- Atmospheric source term released including number of plume segments, heat content, time, duration and height of release etc
- Meteorological data of the reactor site. This includes an hourly based data for one year
- Population distribution at the site
- Emergency response actions including evacuation, sheltering, post accidental relocation etc
- Long term protective actions for calculations of nuclear damage

2.4.1 ATMOS Module

In case of a severe nuclear accident, radioactive gases and aerosols are released to the atmosphere. As a first phase for consequence analysis, calculation of the downwind transport, dispersion and deposition of radioactive material is made which is treated in the ATMOS module of the MACCS code. For atmospheric transport weather data is required as input. In MACCS, there are five ways to specify the required 120 hours of weather data.

- Constant weather conditions
- User specified weather sequence
- User specified start time
- Stratified random sampling
- Structured Monte Carlo sampling

In MACCS, Gaussian plume model has been used for the study of atmospheric dispersion of radioactive material and vertical and cross wind distributions.

The plume dimensions are defined in vertical and crosswind direction by the standard deviations (σ_y, σ_z) of the normal distribution of material concentration in crosswind and vertical directions. The general form of the Gaussian plume equation is;

$$\chi(x, y, z) = \frac{Q}{2\pi \bar{u} \sigma_y \sigma_z} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \exp\left[-\frac{1}{2}\left(\frac{z-h}{\sigma_z}\right)^2\right] \quad (3.1)$$

Where, $\chi(x, y, z)$ is the time integrated air concentration (Bq-s/m^3) at the downwind location (x,y,z), Q is the source strength (Bq), $\bar{u}$ is the mean downwind speed, σ_y and σ_z are the standard deviations (meters) of the normal concentration distribution along crosswind and vertical direction and h is the release height (meters).

Equation (3.1) is not applicable when plume expands vertically and is bounded by mixing layer or by the ground. To solve this problem, ground and mixing layers are considered as totally reflecting boundaries. This is achieved by adding a mirror image sources below the ground and above the inversion layer. By considering this affect in equation (3.1), the centerline air concentration $\chi(x = 0, y = 0, z = H)$ and ground concentrations $\chi(x = 0, y = 0, z = 0)$, after time of release to the time at which the concentrations become uniform along vertical direction is given by,

$$\chi(x, y = 0, z) = \frac{Q}{2\pi\sigma_y\sigma_z\bar{u}}\left[\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right] + \sum_{n=1}^{5}\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H-2nL}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H-2nL}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z-H+2nL}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H+2nL}{\sigma_z}\right)^2\right]\right\}\right] \quad (3.2)$$

Where, $H = h + \Delta h$ is height of the plume centerline (meters), h is the initial release height of the plume before plume rise and Δh is the amount of plume rise, L is the height (meter) of the inversion layer (mixing height).

In MACCS, only first five terms are considered and rest of the terms are neglected. When a uniform vertical distribution is attained, following equation is used to calculate centerline air concentration.

$$\chi(x, y = 0, z) = \frac{Q}{\sqrt{2\pi}\bar{u}\sigma_y L} \quad (3.3)$$

The MACCs code tests the uniform distribution along the vertical direction at each spatial interval along the plume trajectory. Two conditions must be satisfied to pass the test.

1) σ_z must be larger than H and
2) The ground level centerline air concentration must be greater than the ground level centerline air concentration

2.4.2 Early Exposure Pathways

In early exposures, five exposure pathways are considered, external and internal exposure from cloudshine, exposures from groundshine, internal exposure from resuspension inhalation and skin doses from deposited material onto the skin. Acute and lifetime doses from early exposures are calculated. The dose for early exposure in a given spatial element is a product of radionuclide concentration, dose conversion factor, duration of exposure and shielding factor. The dose conversion factors for all the exposure pathways are provided in MACCS input file "MACCS Dose Conversion Factor File". The exposure depends on the exposure pathway and shielding factor. Shielding factor for various pathways and for three different groups of people (evacuees, doing normal job and in shelters) are also defined.

CHAPTER 3

3. Modeling and Methodology

This chapter is organized in two sections; the first one concerned with the processing of hourly based meteorological data for the year 2010, estimation of atmospheric stability class and its conversion to code (MACCS) input file. The second one deals with the code (MACCS) used, initial conditions, assumptions and different release scenarios considered to study the radiation doses at different distances and co-relation of different release parameters.

3.1 Metrological Data Processing

For the execution of MACCS code, the hourly based data for the year 2010 for Islamabad city (MET station SRRC) was obtained from Pakistan Metrological Department (PAKMET). The hourly data contains information about the pressure, temperature, clouds, visibility, wind, weather and sunshine. The wind velocity and directions were measured at a height of 10 meter.

3.1.1 Classification and Processing of Meteorological Data

The analysis of met data was made and required information for this research work i.e. the day of the month, hours of the day, precipitation, wind direction and wind velocity were segregated from the MET data. The data of all the 8760 hours (one year) was prepared to be used as MACCS input file. The wind velocity which was measured in Knott (unit of wind speed) was converted to meter per second and the precipitation data which was measured in millimeters was converted to inches. The wind directions which were provided in terms of North(N), North East (NE), East(E), South East (SE), South (S), South West (SW), West (W) and North West (NW) was converted to the 16 directions format as required by MACCS input file.

Following assumptions were made for processing of MET data

1. For the hours where MET data was not available, the wind speed and directions were considered similar to that of previous hour.
2. For the calm atmospheric conditions (wind speed less than 1 knot) the wind speed was considered to be 0.9 knot (0.46m/sec). The wind direction during calm hours was considered to be similar to that of previous hour.
3. The wind direction data was available for the 8 directions of the compass separated by angular distance of 45^0. This data was used for the 16 directions as required by the MACCS input file.

3.1.2 Estimation of Wind Speed at Release Height

The meteorological data (wind speed & direction) was collected from the ground station with an approximate height of ten meters. As the near surface wind speed increases with altitude, the same data if used for the stake height (61meters) will overestimate the plume rise. This could produce significant underestimation of the radiation doses. To incorporate the affect of wind speed with altitude, following theoretical formula was used to estimate the wind speed at higher altitudes.

$$u = u_o \left(\frac{z}{z_0}\right)^p \qquad (3.1)$$

Where, u is the wind speed at height z, u_o is wind speed at surface and p is the parameter (dimensionless) that varies with stability class and surface roughness.

In this study, it has been assumed that the research reactor is located in rural area, the values of p against each stability class used are presented in Table 3.1.

Table 3.1 Stability Parameter against Stability Classes

Stability Class	P(Rural Area)	P(Urban Area)
A	0.07	0.15
B	0.07	0.15
C	0.10	0.20
D	0.15	0.25
E	0.35	0.40
F	0.55	0.60

Using equation (3.1) and Table 3.1, the hourly MET data was approximated at the height of sixty one meters.

3.1.3 Estimation of Atmospheric Stability Class

From the meteorological data two parameters wind speed and sunshine were available. To estimate the atmospheric stability class, Solar Radiation Delta-T (SRDT) method for Pasquill-Gifford (P-G) stability class was used. Stability classes for different values of wind speed, solar intensity and temperature gradient are presented in Table 3.2.

Table 3.2 Estimation of Atmospheric Stability Class

Day Time- Solar Radiation-SR (W/m^2)				
Wind Speed (m/sec)	SR≥925	675≤SR<925	175≤SR<675	SR<175
v<2	A	A	B	D
2≤v<3	A	B	C	D
3≤v<5	B	B	C	D
5≤v<6	C	C	D	D
v≥6	C	D	D	D
Night Time - Vertical Temperature Gradient				
	TG<0	TG≥0		
v<2	E	F		
2≤v<2.5	D	E		
v≥2.5	D	D		

3.1.4 Solar Irradiation

The solar irradiation R_s, can be calculated with the Angstrom formula which relates solar radiation to extraterrestrial radiation and relative sunshine duration

$$R_s = \left(a + b\frac{n}{N}\right) R_a \left(\frac{MJ}{m^2.day}\right) \quad (3.2)$$

Where, n is the actual duration of sunshine (hours), N is the maximum possible duration of sunshine or daylight hours [hour], $\frac{n}{N}$ is relative sunshine duration and R_a is the extraterrestrial radiation [MJ m^{-2} day^{-1}], a is the regression constant, expressing the fraction of extraterrestrial radiation reaching the earth on overcast days (n = 0) and a + b is the fraction of extraterrestrial radiation reaching the earth on clear days (n = N).

For the measurement of solar radiation in Watt/m^2, the equation (3.2) becomes

$$R_s = \left(a + b\frac{n}{N}\right) R_a \times 27.28[\text{Watt/m}^2]$$

The day and night timing were collected from [24] for Islamabad for the year 2010.

3.1.5 Programming for Estimation of Stability Class

To estimate the stability class based on Table 3.2, excel formula was formulated using IF, AND, OR logics. The AND logic is true only if all the inputs are true and OR logic is true if any one of input logic is true. Following formula was modeled to estimate the stability class.

$$Formula =$$

$$IF(OR(AND(V < 2, SR \geq 925, NE < T < NS), AND(2 \leq V < 3, SR \geq 925, NE < T < NS), AND(V < 2,675 \leq SR < 925, NE < T < NS)), \text{"A"},$$

$$IF(OR(AND(3 \leq V < 5, SR \geq 925, NE < T < NS), AND(2 \leq V < 3,675 \leq SR < 925, NE < T < NS), AND(3 \leq V < 5,675 \leq SR < 925, NE < T < NS), AND(V < 2,175 \leq SR < 675, NE < T < NS)), "B",$$

$$IF(OR(AND(5 \leq V < 6, SR \geq 925, NE < T < NS), AND(V \geq 6, SR \geq 925, NE < T < NS), AND(5 \leq V < 6,675 \leq SR < 925, NE < T < NS), AND(2 \leq V < 3, 175 \leq SR < 675, NE < T < NS), AND(3 \leq V < 5, SR \geq 175, NE < T < NS)), "C",$$

$$IF(OR(AND(V \geq 6{,}675 \leq SR < 925, NE < T < NS), AND(5 \leq V < 6{,}175 \leq SR < 675, NE < T < NS), AND(V \geq 6{,}175 \leq SR < 675, NE < T < NS), AND(SR \geq 175, NE < T < NS), AND(V \geq 2.5, NS \leq T), AND(V \geq 2.5, T \leq NE)), "D",$$

$$IF(OR(AND(2 \leq V < 2.5, NS \leq T), AND(2 \leq V < 2.5, T \leq NE)), "E", IF(OR(AND(V < 2, NS \leq T), AND(V < 2, T \leq NE)), "F", "Error")))))$$

Where, V is the average wind speed observed during each hour (m/sec), SR is solar Radiation (W/m^2), NE is night end time (sunrise +one hour), NS is night start time (sunset-one hour) and T is representative hour for which stability will be calculated

Following assumptions were made in these calculations

1. For night, the temperature gradient was considered to be ≥0,
2. For each hour of the day, the observed and actual solar radiation was averaged over whole of the day. In this case, the solar radiation of each hour of the day remained constant.

3.2 Methodology (Modeling)

MACCS code has been used to model plume dispersion and estimate the radiation doses. In this study first two modules (ATMOS & EARLY) of MACCS code, has been used to study the radioactive plume dispersion and early dose calculations by considering different accident scenarios for a nuclear research reactor. The third module (CHRONC) of MACCS code which is used to calculate the long term radiation doses and contamination impact on human health and property has not been considered in this study.

3.2.1 Initial Conditions and Assumptions

The initial conditions and assumption used in the modeling of accident scenarios has been discussed in this section. Initial conditions and assumptions considered are summarized in tabular form as Appendix-A.

3.2.1.1 Source Term and Release Fraction

The source term for the fission product in the reactor core was taken from the international published data [15] for a postulated accidental airborne release from Pakistan Research Reactor (PARR-1), Islamabad on upgraded power of 10MW. The fractions of releases were based on USNRC document NUREG-1150. The release fractions of 1, 0.4, 0.3, 0.05 and 0.02 for noble gases, halogens, alkali metals, the tellurium group and the Ba-Sr group, respectively has been considered. Thirty radionuclide's source inventory was prepared for ATMOS input file.

3.2.1.2 Meteorological Data

One year hourly data for the year 2010 for Islamabad city was used for modeling of all the dispersion scenarios. Four different options for the meteorology at the site were used to assess the projected doses at different locations in the periphery of nuclear research reactor. The boundary weather mixing layer height was considered to be 1000 meter.

1. User Specified Weather Data

In this method, the fixed start day and time as specified in ATMOS user input file, prevailing wind speed (2m/sec) and prevailing stability class (F) has been used. For the execution of this method, a 120 hour of data is taken from MACCS input file (METIN) starting with the user specified day and time.

2. Weather Bin Sampling Method

In this method the one year meteorological data is sorted into weather bins. Weather sequences are sorted into categories and a probability to each category is assigned according to their initial condition (wind speed and stability class) and occurrence of rain (intensity and distance).

3. Constant Weather Data

In this method the constant wind speed and stability class has been used. The one year meteorological data is not required in this case.

4. **Special Case (Maximum Wind Speed)**

In this case, the maximum wind speed was used in constant weather condition method. The maximum speed of 13.38 m/sec at height of ten meters and 17.55 m/sec at height of sixty one meters has been used. The one year meteorological data is not required in this case.

3.2.2 *Release Scenarios*

Following release scenarios were considered for the estimation of radiation doses and for co-relation of different dispersion parameters.

3.2.2.1 Scenario-1

In this scenario, the releases were considered at height of sixty one meters (stake releases). The meteorological data for sixty one meters has been used in this scenario. The Total Effective Dose Equivalent (TEDE) for whole body and inhalation dose for thyroid was modeled by using four different meteorological options.

3.2.2.2 Scenario-2

In this scenario, the releases were considered at ground level (ten meters). The meteorological data for ten meters height has been used in this scenario. The TEDE for whole body and inhalation dose for thyroid was modeled by using four different meteorological options.

3.2.2.3 Scenario-3

In this scenario, the releases were considered through stake and meteorological data of ground level has been used. The TEDE for whole body and inhalation dose for thyroid was modeled by using four different meteorological options.

3.2.2.4 Comparison of Doses for Constant Weather Condition

In this scenario, the comparison of the first three scenarios was made with the scenario using the meteorological conditions at the site published in international literature [15]. The TEDE for whole body and inhalation dose for thyroid was modeled by using constant weather conditions.

3.2.2.5 Comparison of MACCS and InterRAS Codes

A comparison of MACCS code for three release scenarios using constant weather conditions has been made with InterRAS code. The InterRAS code, estimate radiation doses maximum up to 48 hours. Comparison of doses using MACCS and InterRAS codes has been made for calculation duration of 48 hours (2 days).

3.2.2.6 Effect of Plume Dispersion Parameter

The influence of plume dispersion parameters stake height, release duration and stability class has been modeled. The modeling was performed for seven days TEDE.

3.2.3 Release Duration

The release duration was considered to be 1800 sec (30mints) for all three accident scenarios.

3.2.4 Effluent Temperature (Heat Content)

The heat content of the emitted radioactive plume was considered to be zero in all three accidental scenarios.

3.2.5 Building Wake Affect

The building wake affect has not been considered in these calculations.

3.2.6 Calculation Duration

To identify the emergency planning zones and to take protective actions evacuation and iodine prophylaxis, the calculation duration was considered to be one week (seven days) and for sheltering doses was calculated for two days. The doses were compared with the intervention levels as provided in national regulations-PAK/914.

3.2.7 Protective Actions

No protective action was considered during the calculation of radiation doses

3.2.8 Distance

Distance of twenty five kilometers divided into twenty seven radii has been used to estimate the consequence of accidental release along the downwind distance. The radial distances 0.5, 1.0, 1.5, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5, 9.0, 9.5, 10.5, 11, 12.5, 15.0, 17, 17.5, 20.0, 22.5 and 25.0 kilometers respectively have been used.

CHAPTER 4

4. Results and Discussion

In this chapter, the results of meteorological data, MACCS output results for different scenarios and intervention radii identified for different scenarios have been discussed. The seven days TEDE, two days TEDE and seven days thyroid doses have been modeled for different scenarios. The results are compared with the reference level for taking different protective action. The intervention levels for different protective actions prescribed in PAK/914 are as follows.

Table 4.1 Reference Levels for Protective Actions

Protective Action	Reference Level	Time Limit
Evacuation	50 mSv	not more than seven days
Sheltering	10 mSv	not more than two days
KI Tablet	100 mGy	

4.1 Meteorological Trends

Hourly based meteorological data for the year 2010 was processed and analyzed. The percentage value of wind direction remained 3.7% in north, 8.7% in north-east, 8.4% in east, 13.8% in south-east, 10.8% in south, 38.3% in south-west, 6.4% in west and 10% in north-west respectively. Data presented in Figure 5.1 represents that dominant wind direction was south-west (38.3%) during year 2010.

Mostly the average wind speed remained 2 m/sec at the height of ten meters and sixty one meters with maximum wind speed of 13.38 m/sec and 17.55 m/sec respectively. The frequency of the stability classes was recorded as 0% stability class-A, 17.81% stability class-B, 5.71% stability class-C, 16.35% stability class-D, 1.97% stability class-E and

58.16% stability class-F. The dominant atmospheric stability class as presented in Figure 5-2 was stability class-F.

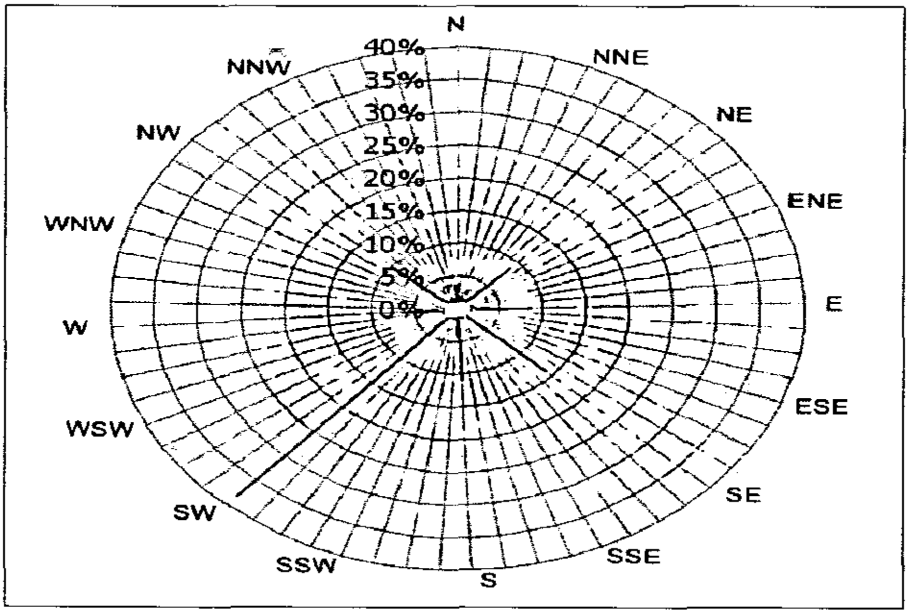

Figure 4.1 Wind Rose for sixteen directions

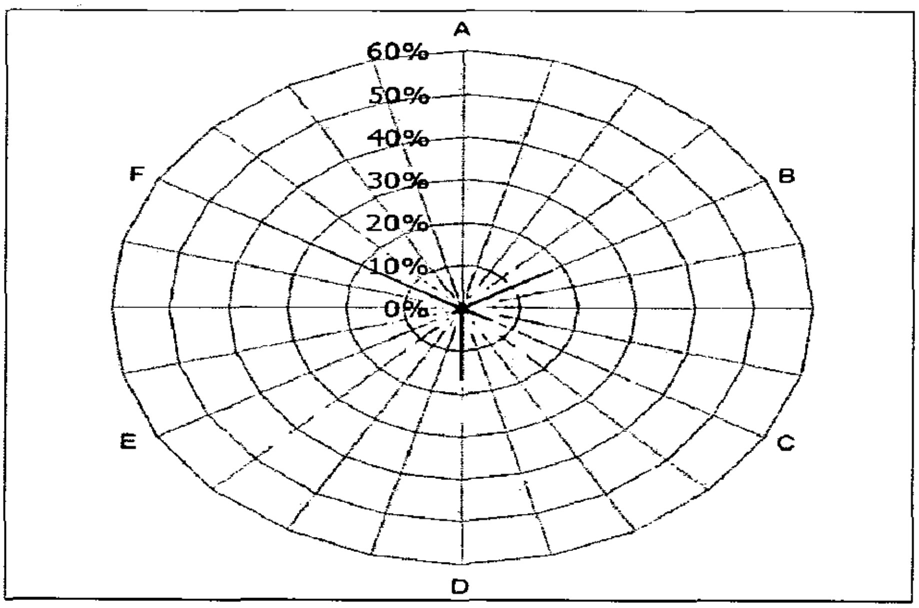

Figure 4.2 Dominant Stability Class

4.2 Trends of Radiation Doses

In this section, trends of radiation doses over the distance for different scenarios has been presented and analyzed. The output results in tabular form are also presented in Appendix B and C.

4.2.1 Mean TEDE Trends (One Week)

Mean TEDE for different release heights and meteorological conditions has been analyzed and presented in Figure 4.3 to 4.6. Through analysis, it was found that radiation doses reduce exponentially over the distance. From trend analysis the maximum dose of 1.12×10^3 mSv for scenario-1, 1.4×10^4 mSv for scenario-2, 1.76×10^3 mSv for scenario-3 and 5.85×10^3 mSv with constant meteorological conditions was estimated at a mean distance of 0.25 kilometer.

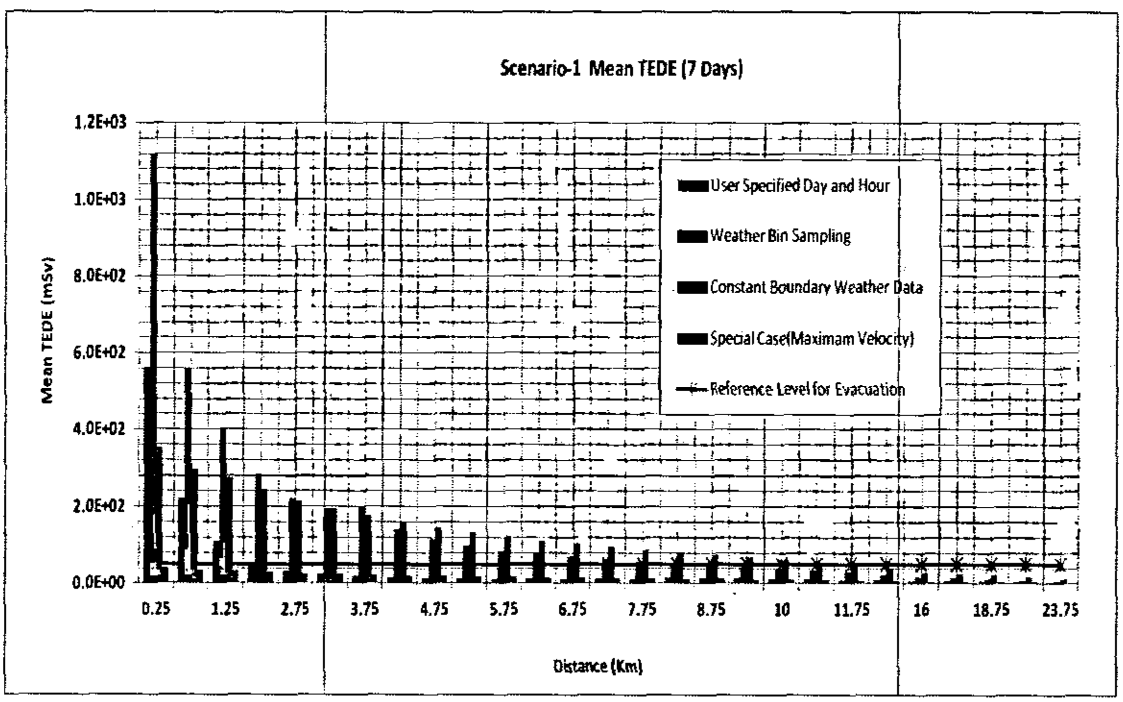

Figure 4.3 Scenario-1 Mean TEDE (7 days)

It was found that the protective action "evacuation" was required at different distances in different accident situations. The radiation doses reduces less than intervention level for evacuation at a distance of 10 kilometers for scenario-1, 3.75 kilometers for scenario-2, 7.75 kilometers for scenario-3 and 5.25 kilometers for constant weather conditions.

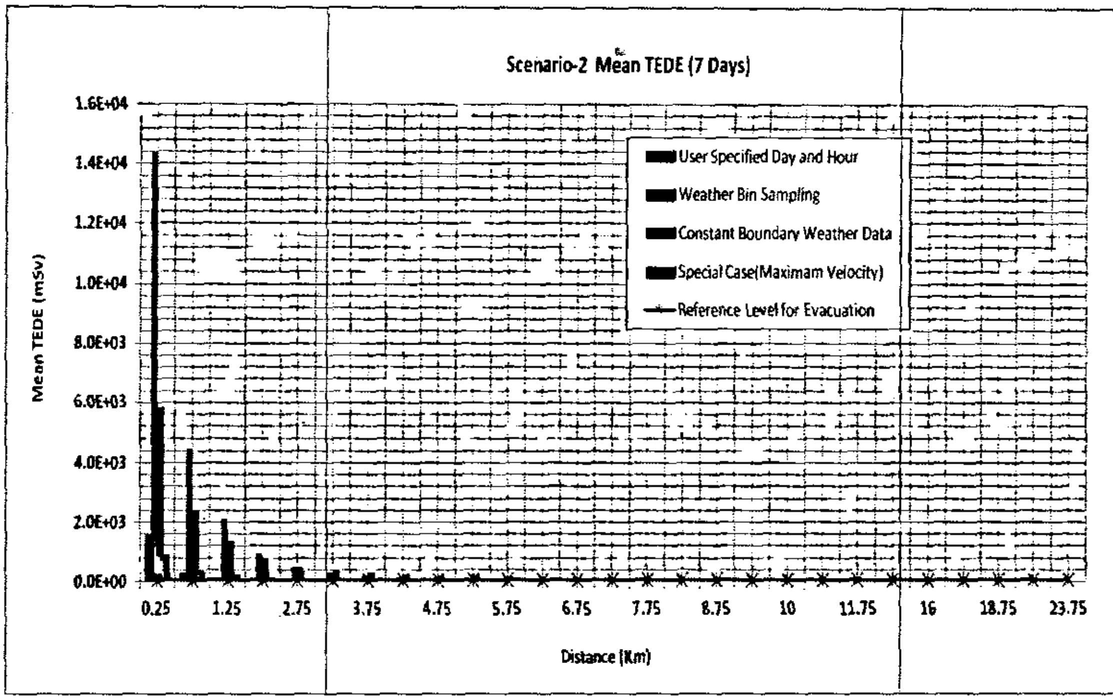

Figure 4.4 Scenario-2 Mean TEDE (7 days)

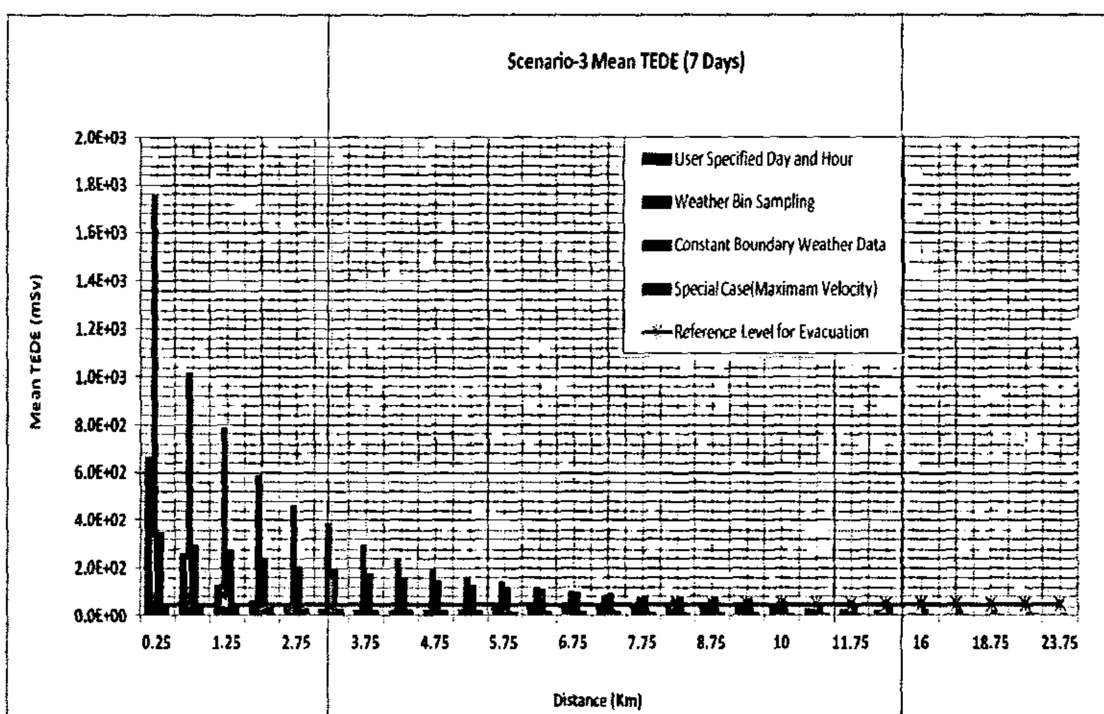

Figure 4.5 Scenario-3 Mean TEDE (7 days)

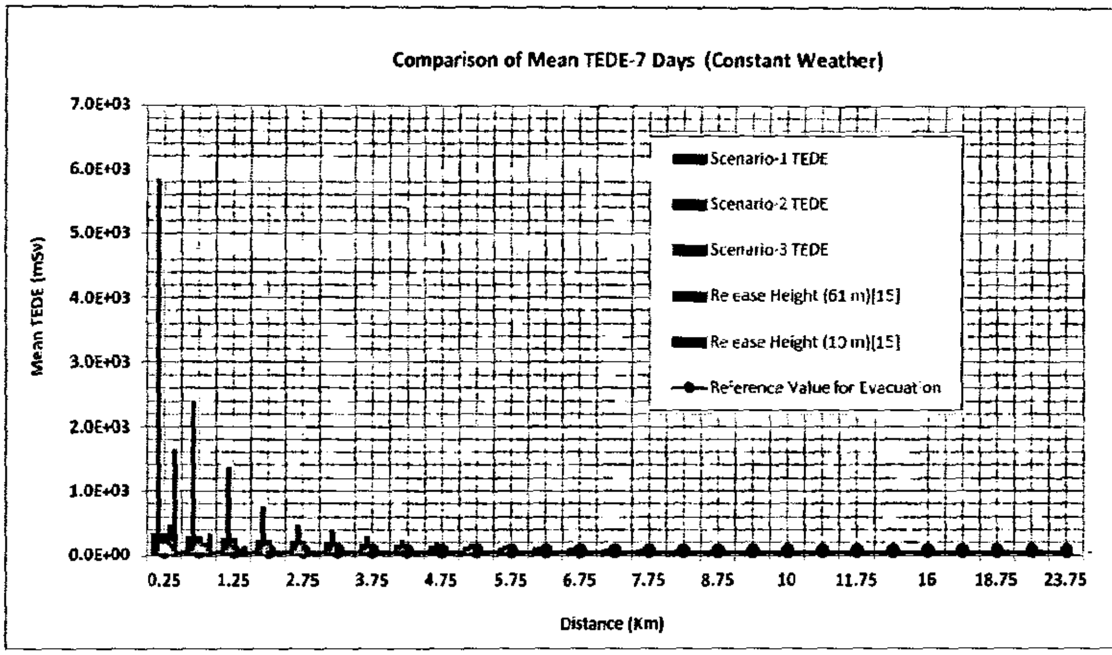

Figure 4.6 Comparison of Mean TEDE (7 days) for Constant Weather

4.2.2 Mean TEDE Trends (Two Days)

A similar trend was obtained for mean TEDE over two days and is presented in Figure 4.7 -4.10.

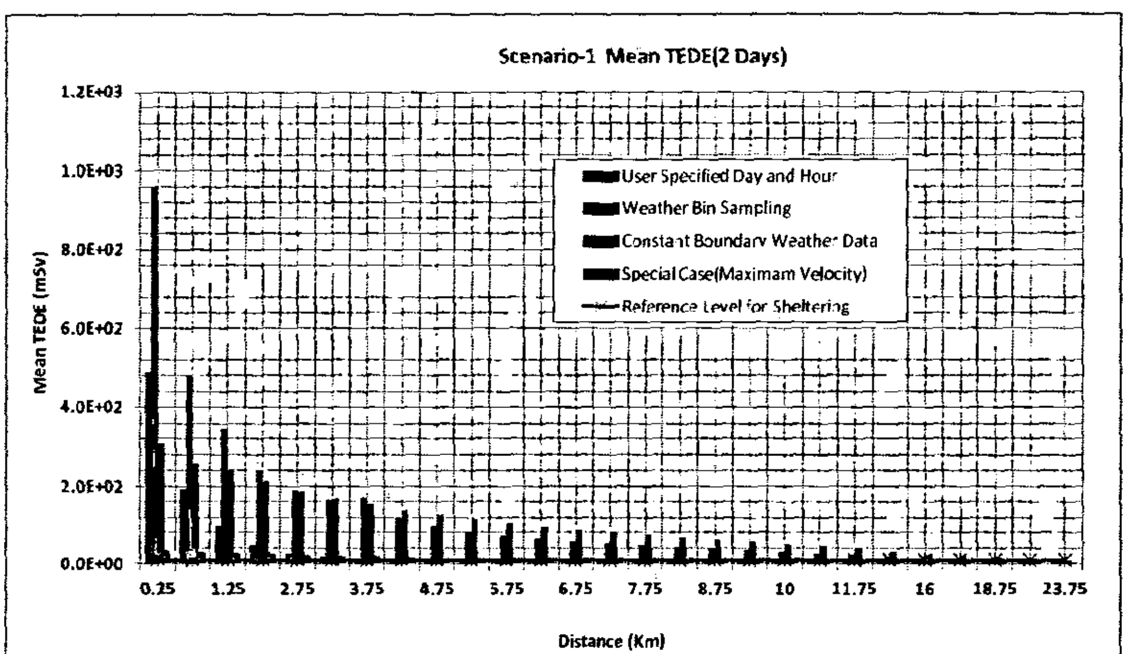

Figure 4.7 Scenario-1 Mean TEDE (2 days)

The dose reduces exponentially with mean TEDE of 0.95×10^3 mSv for scenario-1, 1.2×10^4 mSv for scenario-2, 1.76×10^3 mSv for scenario-3 and 5.1×10^3 mSv for constant meteorological conditions estimated at a mean distance of 0.25 kilometer. The distance for intervention level "sheltering" required for different accidental situation remained 12 kilometers for scenario-1, 3.75 kilometers for scenario-2, 10 kilometers for scenario-3 and 7.25 kilometers for constant weather conditions respectively.

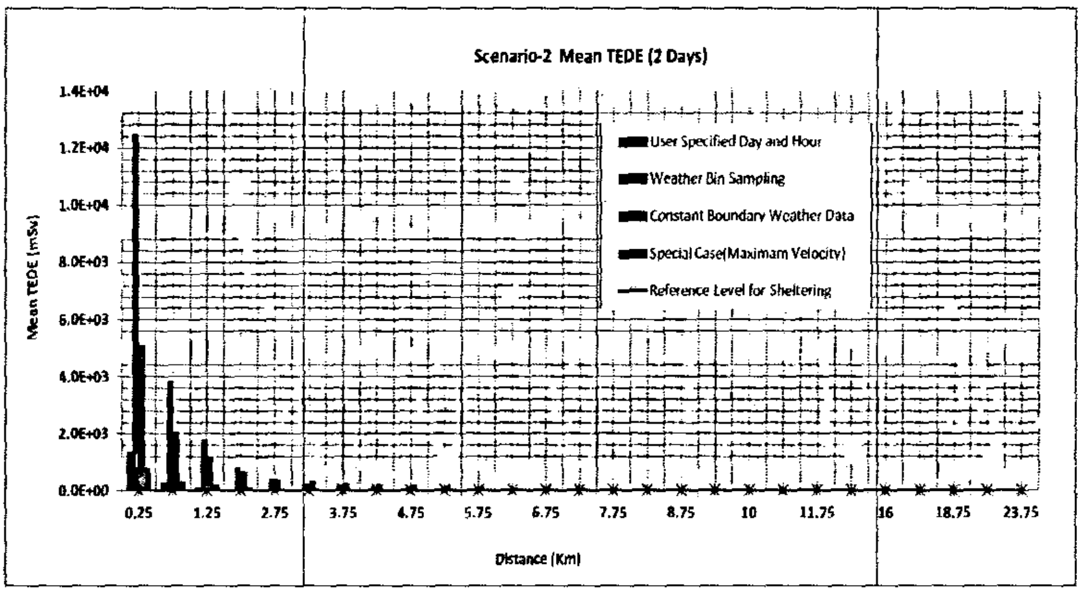

Figure 4.8 Scenario-2 Mean TEDE (2 days)

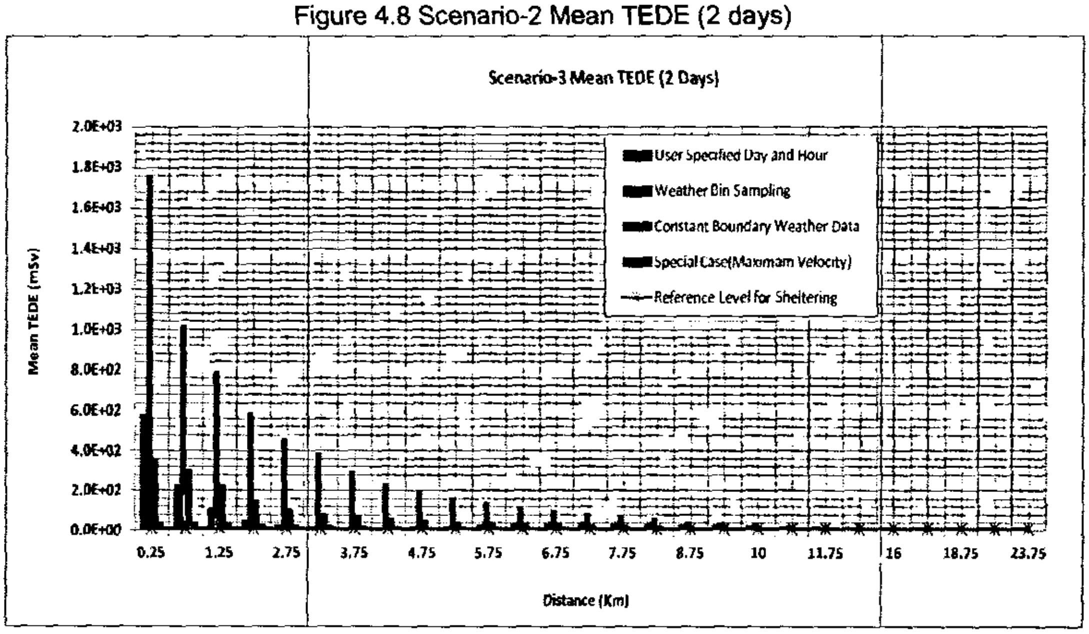

Figure 4.9 Scenario-3 Mean TEDE (2 days)

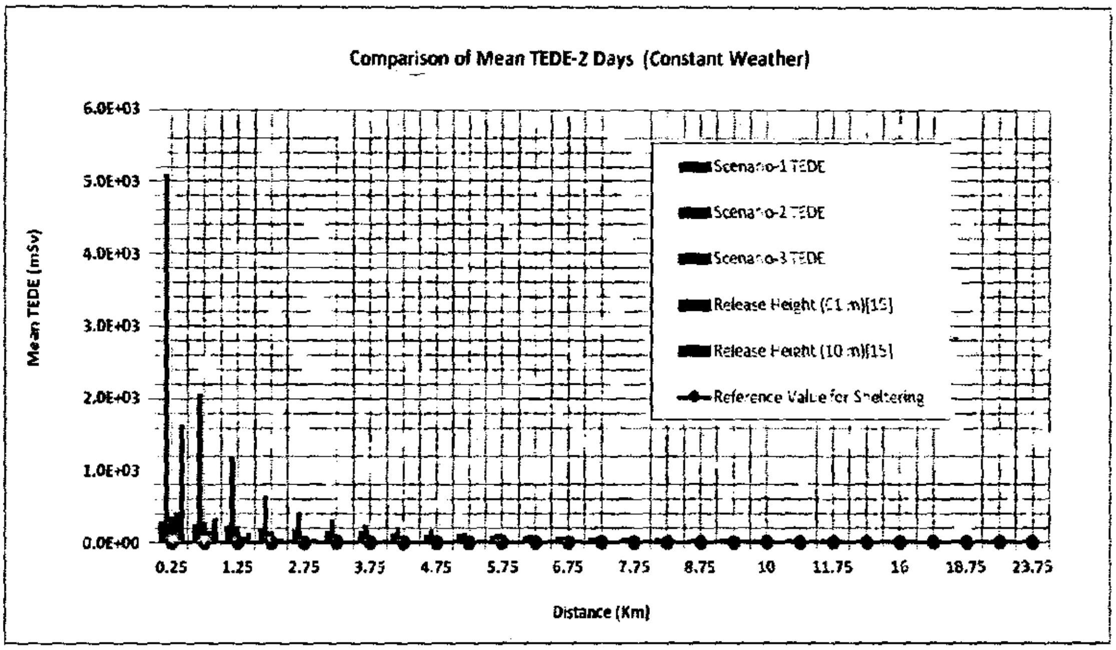

Figure 4.10 Comparison of Mean TEDE (2 days) for Constant Weather

4.2.3 Trend of Mean Thyroid Doses

An exponentially decreasing trend of thyroid doses over the distance has been observed for various accidental scenarios and presented in Figure 4.11 to Figure 4.15.

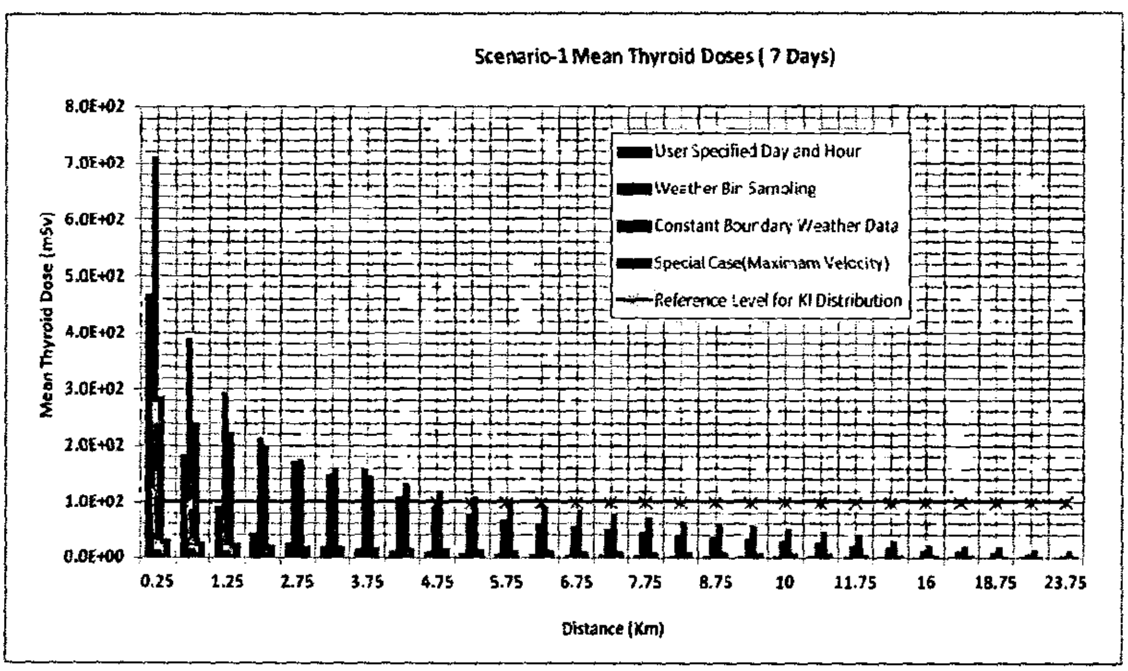

Figure 4.11 Scenario-1 Mean Thyroid Doses (7 days)

The mean thyroid dose of 7.1×10^2 mSv for scenario-1, 1.19×10^4 mSv for scenario-2, 1.14 mSv for scenario-3 and 4.92×10^3 mSv for constant weather conditions at a distance of 0.25 kilometer were recorded. The distance for intervention level "KI distribution" was approximated as 5.25 kilometers for scenario-1, 3.25 kilometers for scenario-2, 5.75 kilometers for scenario-3 and 4.75 kilometers for constant weather condition.

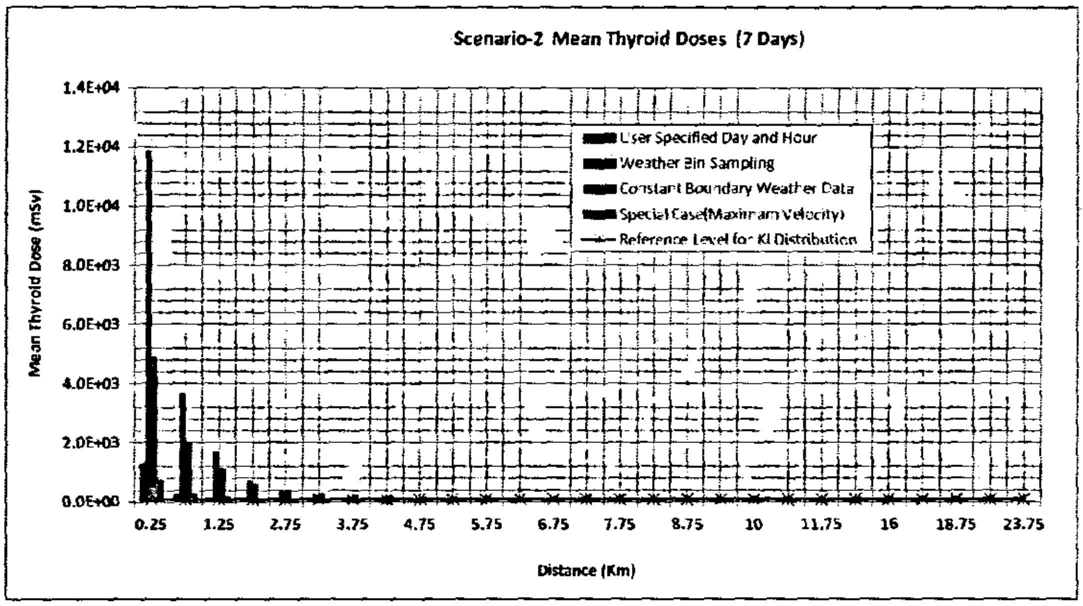

Figure 4.12 Scenario-2 Mean Thyroid Doses (7 days)

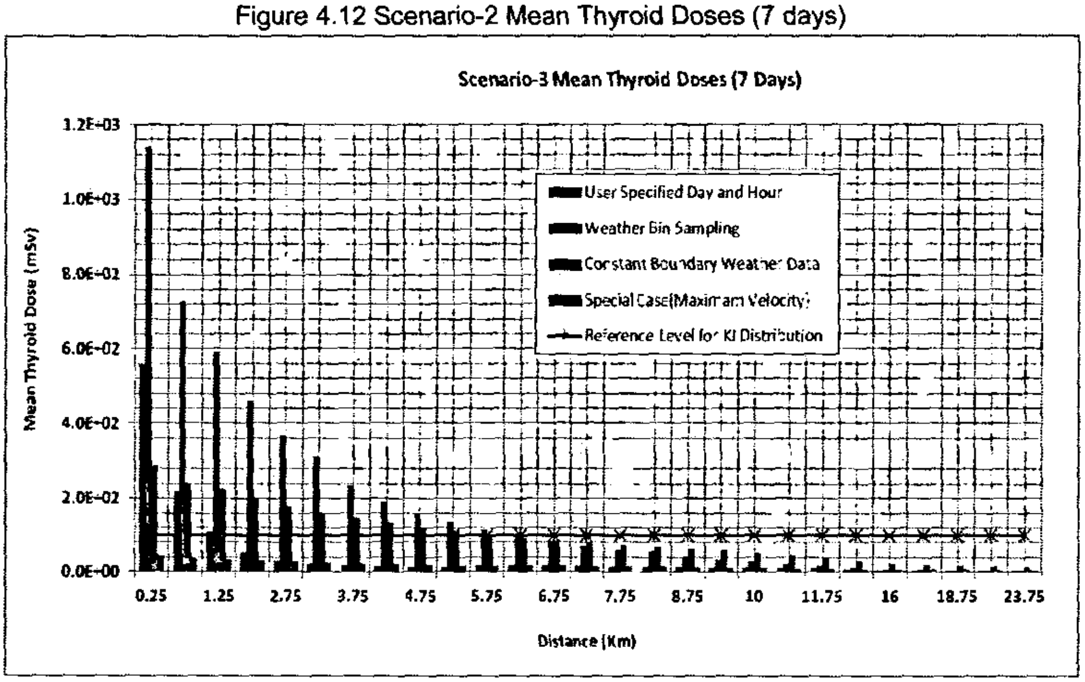

Figure 4.13 Scenario-3 Mean Thyroid Doses (7 days)

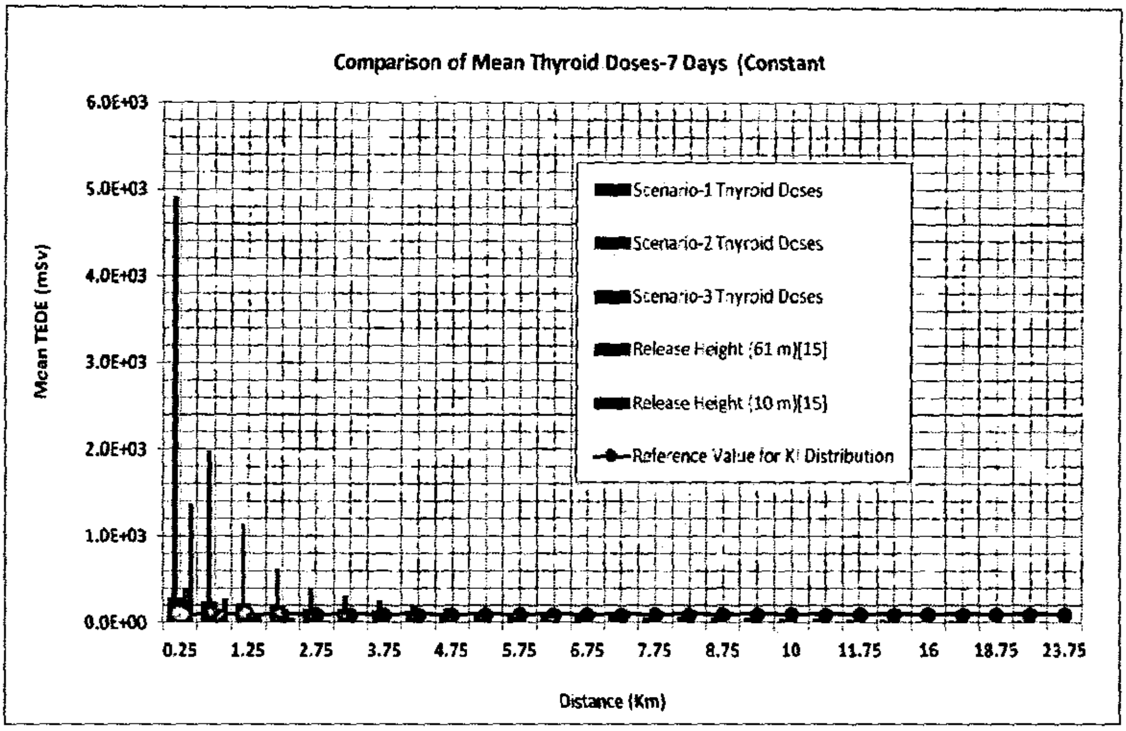

Figure 4.14 Comparison of Mean Thyroid Doses for Constant Weather

4.2.4 Effects of Plume Dispersion Parameters

The influence of plume dispersion parameters e.g. stake height, release duration and stability class has been modeled.

4.2.4.1 Effect of Release Height

The mean total effective dose equivalent to the whole body for seven days for different release heights against the distance is presented in Figure 4.15. For release height from ten meters to fourty meters, the meteorological data for the height of ten meters and for release height fifty meters to eighty meters, meteorological data for the height of sixty one meters was used for calculation purpose. Weather bin sampling method was used for the calculation of radiation doses. From the trend analysis, it is found that, at a release height of ten meters, the maximum dose of 1.44×10^4 mSv has been observed and at height of eighty meters maximum dose of 620 mSv has been observed at mean distance of 0.25 kilometers. The trend shows that with the increase in height, the doses reduce in the periphery of nuclear reactor with dispersion at the long distance.

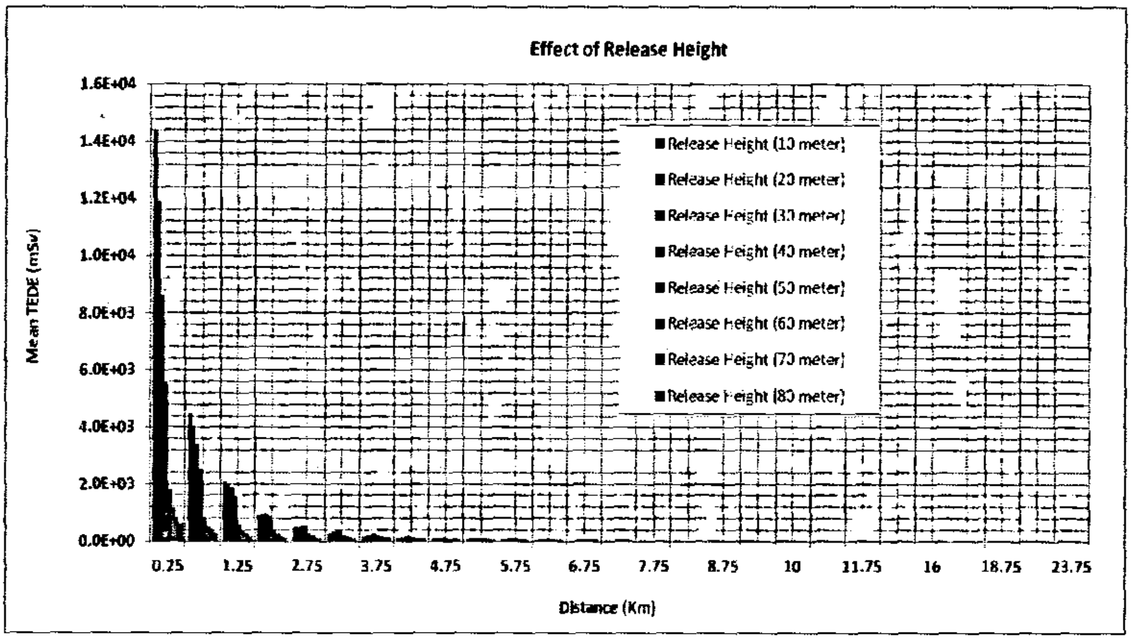

Figure 4.15 Effect of Release Height

4.2.4.2 Effect of Release Duration

The mean total effective dose equivalent to the whole body for seven days (emergency phase) for different release durations is presented in Figure 4.16.

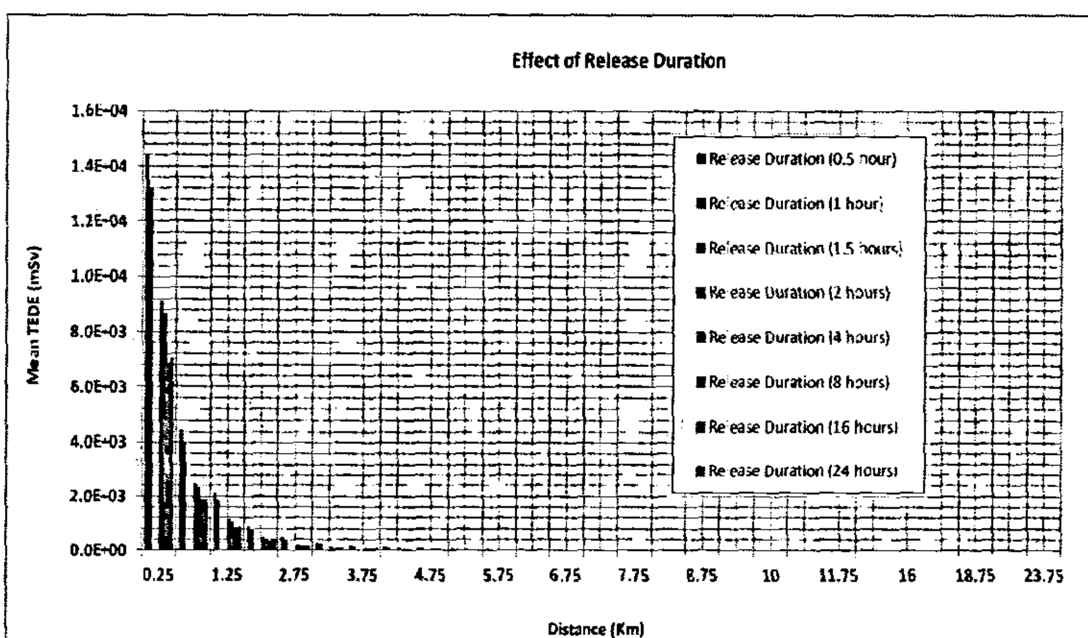

Figure 4.16 Effect of Release duration

For release height of ten meters with meteorological data at height of ten meters, the doses for different distances has been modeled for different release durations. The weather bin sampling method has been considered in the modeling. From the trend analysis, it is found that, the maximum dose of 1.44×10^4 mSv has been observed for release duration of 1800 sec (0.5 hour) and maximum dose of 7.05×10^3 mSv has been observed for release duration of twenty four hours at mean distance of 0.25km. The radiation doses decreases around the periphery of nuclear reactor with the increase is release duration.

4.2.4.3 Effect of Stability Class

The mean total effective dose equivalent to the whole body for seven days (emergency phase) for release height of ten meters and release duration of 1800 seconds for different stability classes has been modeled and presented in Figure 4.17. The constant weather condition method was used for the estimation of radiation doses. From the trend analysis, it is found that, the maximum dose of 5.86×10^3 mSv has been observed with stability class F at mean distance of 0.25km.The radiation doses increases in the periphery of nuclear reactor with the change in the stability class A to F.

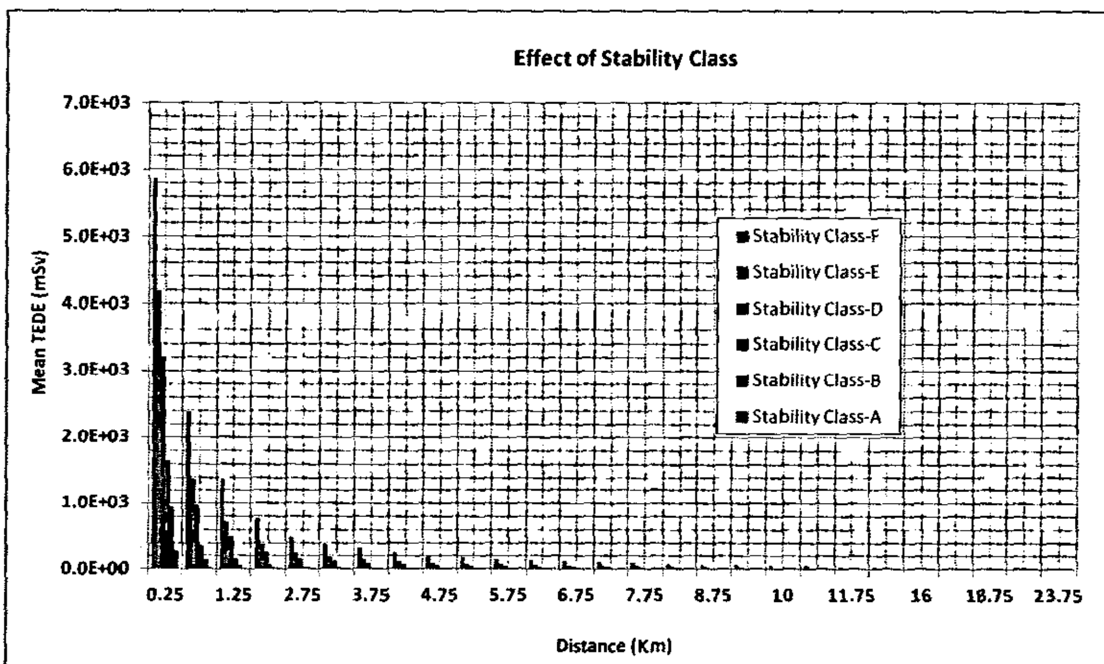

Figure 4.17 Effect of Stability Class

4.2.5 Mean Distance for Intervention Levels

The intervention level for evacuation (50mSv) was achieved at different distances for difference emergency scenarios and for different meteorological options. Mean distances (Km) for taking intervention (evacuation) for different meteorological options (MO) are presented in Table 4.2 and Table 4.2.

Table 4.2: Evacuation Intervention Distance for Different Met Options

Scenarios	Intervention (Evacuation) Distances (Km)			
	MO-1	MO-2	MO-3	MO-4
Scenario-1	2.00	7.75	10.00	0.25
Scenario-2	2.75	6.75	10.75	4.75
Scenario-3	2.75	8.75	10.00	0.25

Table 4.3 Evacuation Intervention Distance for Constant Meteorology

Scenario-4	Intervention (Evacuation) Distance
Scenario-1	10.00
Scenario-2	10.75
Scenario-3	10.00
Sixty one meters*	02.00
Ten meters*	02.75

* [15]

The intervention level for sheltering (10mSv) was achieved at different distances in different release scenarios for different meteorological options. Mean distances (Km) for taking intervention (sheltering) are presented in Table 4.4 and Table 4.5.

Table 4.4 Sheltering Intervention Distance for Different Met Options

Scenarios	Intervention (Sheltering) Distances (Km)			
	MO-1	MO-2	MO-3	MO-4
Scenario-1	2	7.75	10.75	0.25
Scenario-2	2.75	6.25	10	4.25
Scenario-3	2.75	8.25	5.25	0.25

Table 4.5 Sheltering Intervention Distance for Constant Met

Scenario-4	Intervention (Sheltering) Distances
Scenario-1	10.75
Scenario-2	10.00
Scenario-3	05.25
Sixty one meters*	02.00
Ten meters*	02.75

The intervention level for KI tablets (100mGy) was achieved at different distances in different release scenarios for different meteorological options. Mean distances (Km) for taking intervention (KI tablets) is presented in Table 4.6 & Table 4.7.

Table 4.6 KI Prophylaxis Intervention Distance for Different Met Options

Scenarios	Intervention (KI Distribution) Distances (Km)			
	MO-1	MO-2	MO-3	MO-4
Scenario-1	2	7.25	10	0.25
Scenario-2	2.75	5.75	9.25	4.25
Scenario-3	2	8.25	10	0.25

Table 4.7 KI Prophylaxis Intervention Distance for Constant Met

Scenario-4	Intervention (KI Distribution) Distances
Scenario-1	10
Scenario-2	9.25
Scenario-3	10
Sixty one meters*	2
Ten meters*	2.75

4.2.6 Comparison of MACCS and InterRAS Codes

A comparison of MACCS and InterRAS code output results (mean effective dose equivalent to whole body for two days) for constant weather conditions are presented in Figure 5-15. From the trend analysis, it is found that, the maximum of 5.10×10^3 mSv has

CHAPTER 5

5. Conclusions and Future Recommendations

5.1 Summary

- The most frequent wind direction south-west i.e. 38.3% and the prevailing stability class F i.e. 58.16%.were recorded during year 2010. These results differ from the site specific data where the most prevailing wind direction east-north-east and most prevailing stability class C were observed.
- Intervention distance for evacuation, sheltering and KI prophylaxis remained in the range 1.5 to 2.5 kilometers for user specified MET data; 5.0 to 9.0 kilometers for weather bin sampling method; 5.0 to 11.0 kilometers for constant weather data and 0.5 to 4.5 kilometers for special case.
- With site specific meteorological conditions, intervention distance range is very low i.e. 1.5 to 2.5 kilometers which is very close to the already estimated values i.e. 1 to 2 kilometers using 'Hotspot' Code. The values vary considerably for other meteorological options. The difference in intervention distance range appears due to the difference in meteorological conditions used in calculations.
- With meteorological data of a different height, doses are not correctly estimated. For better estimation of radiation doses, meteorological data of the release height must be used.
- The output results for MACCS and InterRAS code are similar and in good agreement. MACCS code could be used during the early phase of emergency for the estimation of radiation doses.
- The release height, release duration and atmospheric stability class significantly affect the plume dispersion and radiation doses. These parameters need to be handled carefully for analyzing the consequences of nuclear accident.

5.2 Conclusion

MACCS code is a very useful code for the estimation of radioactive plume dispersion and estimation of emergency planning zones (intervention distances). The source term, meteorological data, release height, release duration and atmospheric stability class should be considered carefully for better estimation of results.

5.3 Recommendations for Future Studies

- CHRONC module of MACCS code should be used to analyze intermediate and long term radiation effects.
- MACCS code could also be used to estimate the nuclear damage produced by postulated accidents at nuclear power plants.
- Different input factors used in MACCS input files are based on US study. Similar studies should be performed with local meteorological conditions and food chains to estimate better results

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Appe

Initial Conditions & Assumptions for Accident Scenarios
Scenarios (1-4)

Parameters		Release Scenarios			
		Scenario-1	Scenario-2	Scenario-3	Scenario-4
Source Term & Release Fraction		As published in international literature for nuclear research reactor (S. Shoaib Raza-2005			
Release Height		61 meter	10 meter	61 meter	61m
Met data Height		61 meter	10 meter	10 meter	61m
Release Duration		1800 Seconds			
Weather Sampling Options	1. User specified 2. Weather bin sampling 3. Constant Met data 4. Special Case (V_{max})	1-4	1-4	1-4	3 (V=2m/sec fo stability class F For PARRI (2. and 2.9 at heigl stability class C
Boundary Conditions		Wind speed (2m/sec), Stability class (F), V_{max}(10m)=13.38m/sec, V_{max}(61m)=17.55m/sec			
Heat Contents (Watts)		0 Watts			

Plume Dispersion Parameter (Scenario-5)

Parameters		Release Scenarios		
		Effect of Release Height	Effect of Release Duration	Effect o
Source Term & Release Fraction		As published in international literature for nuclear research reactor[15]		
Release Height		10m, 20m, 30m, 40m, 50m, 60m, 70m, 80m	10 meter	1(
Met data Height		10m for 10-40m release height 61m for 50m-8m release height	10 meter	1(
Release Duration		1800 Seconds	0.5 hr, 1 hr, 1.5hr, 2hr, 4 hr, 8hr, 16hr, 24hr	18
Stability Class				A
Weather Sampling Options	1. User specified 2. Weather bin sampling 3. Constant Met data 4. Special Case (V_{max})	2	2	4
Boundary Conditions		Wind speed (2m/sec), Stability class (F), V_{max}(10m)=13.38m/sec, V_{max}(61m)=17.55m/sec		
Heat Contents (Watts)		0 Watts		

Appendix-B

Output Results of Scenario-1

(7 Days TEDE)

Distance (KM)		7 Days TEDE (mSv)			
Distance Range	Mean Distance	MET Option 1	MET Option 2	MET Option 3	MET Option 4
0.0-0.5	0.25	5.63E+02	1.12E+03	3.51E+02	4.02E+01
0.5-1.0	0.75	2.23E+02	5.60E+02	2.96E+02	3.42E+01
1.0-1.5	1.25	1.12E+02	4.04E+02	2.75E+02	3.21E+01
1.5-2.5	2.00	5.51E+01	2.82E+02	2.44E+02	2.91E+01
2.5-3.0	2.75	3.26E+01	2.22E+02	2.14E+02	2.61E+01
3.0-3.5	3.25	2.46E+01	1.94E+02	1.95E+02	2.42E+01
3.5-4.0	3.75	1.93E+01	2.02E+02	1.78E+02	2.25E+01
4.0-4.5	4.25	1.56E+01	1.41E+02	1.62E+02	2.08E+01
4.5-5.0	4.75	1.38E+01	1.15E+02	1.47E+02	1.94E+01
5.0-5.5	5.25	1.34E+01	9.85E+01	1.34E+02	1.80E+01
5.5-6.0	5.75	1.31E+01	8.65E+01	1.23E+02	1.68E+01
6.0-6.5	6.25	1.30E+01	7.69E+01	1.12E+02	1.57E+01
6.5-7.0	6.75	1.27E+01	6.94E+01	1.03E+02	1.47E+01
7.0-7.5	7.25	1.28E+01	6.30E+01	9.46E+01	1.37E+01
7.7-8.0	7.75	1.33E+01	5.73E+01	8.71E+01	1.29E+01
8.0-8.5	8.25	1.37E+01	5.22E+01	8.03E+01	1.22E+01
8.5-9.0	8.75	1.41E+01	4.76E+01	7.43E+01	1.15E+01
9.0-9.5	9.25	1.39E+01	4.35E+01	6.88E+01	1.08E+01
9.5-10.5	10.00	1.29E+01	3.81E+01	6.16E+01	9.98E+00
10.5-11.0	10.75	1.19E+01	3.40E+01	5.53E+01	9.23E+00
11.0-12.5	11.75	1.09E+01	2.93E+01	4.82E+01	8.36E+00
12.5-15.5	13.75	9.08E+00	2.19E+01	3.73E+01	6.96E+00
15.5-17.0	16.00	7.55E+00	1.61E+01	2.85E+01	5.77E+00
17.0-17.5	17.25	6.85E+00	1.37E+01	2.48E+01	5.24E+00
17.5-20.0	18.75	6.13E+00	1.15E+01	2.12E+01	4.70E+00
20.0-22.5	21.25	5.15E+00	8.37E+00	1.65E+01	3.98E+00
22.5-25.0	23.75	4.36E+00	6.42E+00	1.31E+01	3.42E+00

Output Results of Scenario-1

(2 Days TEDE)

Distance (KM)		2 Days TEDE (mSv)			
Distance Range	Mean Distance	MET Option 1	MET Option 2	MET Option 3	MET Option 4
0.0-0.5	0.25	4.91E+02	9.56E+02	3.07E+02	3.51E+01
0.5-1.0	0.75	1.95E+02	4.81E+02	2.59E+02	2.99E+01
1.0-1.5	1.25	9.81E+01	3.48E+02	2.40E+02	2.81E+01
1.5-2.5	2.00	4.81E+01	2.42E+02	2.12E+02	2.54E+01
2.5-3.0	2.75	2.84E+01	1.91E+02	1.86E+02	2.28E+01
3.0-3.5	3.25	2.14E+01	1.67E+02	1.69E+02	2.12E+01
3.5-4.0	3.75	1.68E+01	1.73E+02	1.54E+02	1.96E+01
4.0-4.5	4.25	1.35E+01	1.21E+02	1.40E+02	1.82E+01
4.5-5.0	4.75	1.19E+01	9.80E+01	1.27E+02	1.69E+01
5.0-5.5	5.25	1.14E+01	8.41E+01	1.16E+02	1.57E+01
5.5-6.0	5.75	1.10E+01	7.37E+01	1.06E+02	1.46E+01
6.0-6.5	6.25	1.08E+01	6.54E+01	9.66E+01	1.37E+01
6.5-7.0	6.75	1.05E+01	5.89E+01	8.84E+01	1.28E+01
7.0-7.5	7.25	1.04E+01	5.34E+01	8.12E+01	1.20E+01
7.7-8.0	7.75	1.08E+01	4.85E+01	7.47E+01	1.13E+01
8.0-8.5	8.25	1.11E+01	4.41E+01	6.88E+01	1.06E+01
8.5-9.0	8.75	1.13E+01	4.02E+01	6.36E+01	1.00E+01
9.0-9.5	9.25	1.11E+01	3.67E+01	5.88E+01	9.45E+00
9.5-10.5	10.00	1.03E+01	3.20E+01	5.26E+01	8.70E+00
10.5-11.0	10.75	9.52E+00	2.85E+01	4.71E+01	8.05E+00
11.0-12.5	11.75	8.63E+00	2.45E+01	4.10E+01	7.29E+00
12.5-15.5	13.75	7.19E+00	1.83E+01	3.16E+01	6.07E+00
15.5-17.0	16.00	5.94E+00	1.33E+01	2.41E+01	5.03E+00
17.0-17.5	17.25	5.37E+00	1.14E+01	2.09E+01	4.57E+00
17.5-20.0	18.75	4.79E+00	9.48E+00	1.78E+01	4.10E+00
20.0-22.5	21.25	4.00E+00	6.88E+00	1.38E+01	3.47E+00
22.5-25.0	23.75	3.37E+00	5.25E+00	1.10E+01	2.98E+00

Output Results of Scenario-1

(7 Days Thyroid Doses)

Distance (KM)		**Thyroid Doses (mSv)**			
Distance Range	Mean Distance	MET Option 1	MET Option 2	MET Option 3	MET Option 4
0.0-0.5	0.25	4.69E+02	7.12E+02	2.87E+02	3.28E+01
0.5-1.0	0.75	1.84E+02	3.89E+02	2.40E+02	2.76E+01
1.0-1.5	1.25	9.17E+01	2.95E+02	2.23E+02	2.59E+01
1.5-2.5	2.00	4.45E+01	2.13E+02	1.99E+02	2.36E+01
2.5-3.0	2.75	2.62E+01	1.72E+02	1.76E+02	2.13E+01
3.0-3.5	3.25	1.97E+01	1.52E+02	1.60E+02	1.98E+01
3.5-4.0	3.75	1.55E+01	1.60E+02	1.46E+02	1.83E+01
4.0-4.5	4.25	1.24E+01	1.12E+02	1.33E+02	1.70E+01
4.5-5.0	4.75	1.02E+01	9.10E+01	1.21E+02	1.58E+01
5.0-5.5	5.25	8.58E+00	7.85E+01	1.11E+02	1.47E+01
5.5-6.0	5.75	7.29E+00	6.92E+01	1.01E+02	1.37E+01
6.0-6.5	6.25	6.27E+00	6.16E+01	9.27E+01	1.28E+01
6.5-7.0	6.75	5.25E+00	5.57E+01	8.50E+01	1.20E+01
7.0-7.5	7.25	4.58E+00	5.06E+01	7.82E+01	1.12E+01
7.7-8.0	7.75	4.32E+00	4.59E+01	7.20E+01	1.05E+01
8.0-8.5	8.25	4.08E+00	4.17E+01	6.64E+01	9.92E+00
8.5-9.0	8.75	3.85E+00	3.80E+01	6.14E+01	9.35E+00
9.0-9.5	9.25	3.64E+00	3.47E+01	5.69E+01	8.83E+00
9.5-10.5	10.00	3.35E+00	3.05E+01	5.09E+01	8.13E+00
10.5-11.0	10.75	3.10E+00	2.73E+01	4.57E+01	7.51E+00
11.0-12.5	11.75	2.80E+00	2.34E+01	3.98E+01	6.79E+00
12.5-15.5	13.75	2.32E+00	1.76E+01	3.07E+01	5.64E+00
15.5-17.0	16.00	1.90E+00	1.29E+01	2.35E+01	4.67E+00
17.0-17.5	17.25	1.71E+00	1.09E+01	2.04E+01	4.24E+00
17.5-20.0	18.75	1.52E+00	9.13E+00	1.74E+01	3.80E+00
20.0-22.5	21.25	1.26E+00	6.61E+00	1.36E+01	3.21E+00
22.5-25.0	23.75	1.05E+00	5.09E+00	1.08E+01	2.76E+00

Output Results of Scenario-2

(7 Days TEDE)

Distance (KM)		**7 Days TEDE (mSv)**			
Distance Range	Mean Distance	MET Option 1	MET Option 2	MET Option 3	MET Option 4
0.0-0.5	0.25	1.58E+03	1.44E+04	5.86E+03	9.04E+02
0.5-1.0	0.75	3.29E+02	4.48E+03	2.38E+03	3.91E+02
1.0-1.5	1.25	1.46E+02	2.10E+03	1.37E+03	2.38E+02
1.5-2.5	2.00	6.71E+01	9.23E+02	7.68E+02	1.43E+02
2.5-3.0	2.75	3.86E+01	4.76E+02	4.90E+02	9.81E+01
3.0-3.5	3.25	2.88E+01	3.03E+02	3.82E+02	7.98E+01
3.5-4.0	3.75	2.32E+01	2.03E+02	3.06E+02	6.65E+01
4.0-4.5	4.25	2.44E+01	1.46E+02	2.51E+02	5.66E+01
4.5-5.0	4.75	2.65E+01	1.10E+02	2.09E+02	4.89E+01
5.0-5.5	5.25	2.83E+01	8.35E+01	1.77E+02	4.27E+01
5.5-6.0	5.75	3.81E+01	6.66E+01	1.51E+02	3.77E+01
6.0-6.5	6.25	4.40E+01	5.32E+01	1.30E+02	3.36E+01
6.5-7.0	6.75	4.59E+01	4.25E+01	1.14E+02	3.02E+01
7.0-7.5	7.25	4.74E+01	3.48E+01	9.96E+01	2.73E+01
7.7-8.0	7.75	4.69E+01	2.87E+01	8.81E+01	2.48E+01
8.0-8.5	8.25	4.39E+01	2.41E+01	7.83E+01	2.27E+01
8.5-9.0	8.75	4.12E+01	1.81E+01	7.01E+01	2.09E+01
9.0-9.5	9.25	3.86E+01	1.52E+01	6.30E+01	1.93E+01
9.5-10.5	10.00	3.52E+01	1.22E+01	5.41E+01	1.72E+01
10.5-11.0	10.75	3.20E+01	1.01E+01	4.69E+01	1.55E+01
11.0-12.5	11.75	2.83E+01	7.72E+00	3.93E+01	1.36E+01
12.5-15.5	13.75	2.22E+01	4.93E+00	2.85E+01	1.07E+01
15.5-17.0	16.00	1.24E+01	3.44E+00	2.05E+01	8.51E+00
17.0-17.5	17.25	5.60E+00	2.94E+00	1.74E+01	7.57E+00
17.5-20.0	18.75	2.78E+00	2.45E+00	1.45E+01	6.66E+00
20.0-22.5	21.25	2.08E+00	2.03E+00	1.09E+01	5.47E+00
22.5-25.0	23.75	1.81E+00	1.48E+00	8.41E+00	4.59E+00

Output Results of Scenario-2

(2 Days TEDE)

Distance (KM)		2 Days TEDE (mSv)			
Distance Range	Mean Distance	MET Option 1	MET Option 2	MET Option 3	MET Option 4
0.0-0.5	0.25	1.38E+03	1.25E+04	5.10E+03	7.87E+02
0.5-1.0	0.75	2.88E+02	3.87E+03	2.07E+03	3.41E+02
1.0-1.5	1.25	1.27E+02	1.81E+03	1.19E+03	2.08E+02
1.5-2.5	2.00	5.85E+01	7.91E+02	6.67E+02	1.25E+02
2.5-3.0	2.75	3.36E+01	4.07E+02	4.25E+02	8.56E+01
3.0-3.5	3.25	2.51E+01	2.58E+02	3.31E+02	6.96E+01
3.5-4.0	3.75	2.01E+01	1.73E+02	2.65E+02	5.81E+01
4.0-4.5	4.25	2.06E+01	1.24E+02	2.17E+02	4.94E+01
4.5-5.0	4.75	2.20E+01	9.30E+01	1.81E+02	4.27E+01
5.0-5.5	5.25	2.31E+01	7.08E+01	1.53E+02	3.73E+01
5.5-6.0	5.75	3.12E+01	5.64E+01	1.30E+02	3.29E+01
6.0-6.5	6.25	3.59E+01	4.50E+01	1.12E+02	2.94E+01
6.5-7.0	6.75	3.71E+01	3.59E+01	9.78E+01	2.64E+01
7.0-7.5	7.25	3.80E+01	2.94E+01	8.58E+01	2.38E+01
7.7-8.0	7.75	3.74E+01	2.42E+01	7.58E+01	2.17E+01
8.0-8.5	8.25	3.49E+01	2.03E+01	6.74E+01	1.98E+01
8.5-9.0	8.75	3.26E+01	1.52E+01	6.02E+01	1.82E+01
9.0-9.5	9.25	3.05E+01	1.28E+01	5.41E+01	1.68E+01
9.5-10.5	10.00	2.76E+01	1.03E+01	4.64E+01	1.50E+01
10.5-11.0	10.75	2.50E+01	8.43E+00	4.02E+01	1.35E+01
11.0-12.5	11.75	2.20E+01	6.47E+00	3.36E+01	1.18E+01
12.5-15.5	13.75	1.71E+01	4.10E+00	2.43E+01	9.37E+00
15.5-17.0	16.00	9.57E+00	2.83E+00	1.75E+01	7.42E+00
17.0-17.5	17.25	4.32E+00	2.40E+00	1.48E+01	6.60E+00
17.5-20.0	18.75	2.27E+00	2.00E+00	1.23E+01	5.80E+00
20.0-22.5	21.25	1.72E+00	1.65E+00	9.20E+00	4.77E+00
22.5-25.0	23.75	1.49E+00	1.19E+00	7.08E+00	3.99E+00

Output Results of Scenario-2

(7 Days Thyroid Doses)

Distance (KM)		**Thyroid Doses (mSv)**			
Distance Range	Mean Distance	MET Option 1	MET Option 2	MET Option 3	MET Option 4
0.0-0.5	0.25	1.31E+03	1.19E+04	4.92E+03	7.59E+02
0.5-1.0	0.75	2.68E+02	3.67E+03	1.99E+03	3.26E+02
1.0-1.5	1.25	1.18E+02	1.72E+03	1.14E+03	1.98E+02
1.5-2.5	2.00	5.37E+01	7.51E+02	6.34E+02	1.18E+02
2.5-3.0	2.75	3.08E+01	3.81E+02	4.03E+02	8.06E+01
3.0-3.5	3.25	2.30E+01	2.39E+02	3.14E+02	6.53E+01
3.5-4.0	3.75	1.79E+01	1.59E+02	2.51E+02	5.44E+01
4.0-4.5	4.25	1.43E+01	1.14E+02	2.05E+02	4.61E+01
4.5-5.0	4.75	1.17E+01	8.43E+01	1.70E+02	3.97E+01
5.0-5.5	5.25	9.68E+00	6.38E+01	1.44E+02	3.47E+01
5.5-6.0	5.75	1.46E+01	5.05E+01	1.23E+02	3.06E+01
6.0-6.5	6.25	1.64E+01	3.99E+01	1.06E+02	2.72E+01
6.5-7.0	6.75	1.55E+01	3.15E+01	9.20E+01	2.44E+01
7.0-7.5	7.25	1.46E+01	2.55E+01	8.07E+01	2.21E+01
7.7-8.0	7.75	1.37E+01	2.09E+01	7.13E+01	2.01E+01
8.0-8.5	8.25	1.28E+01	1.74E+01	6.33E+01	1.83E+01
8.5-9.0	8.75	1.20E+01	1.30E+01	5.66E+01	1.68E+01
9.0-9.5	9.25	1.13E+01	1.09E+01	5.08E+01	1.55E+01
9.5-10.5	10.00	1.03E+01	8.64E+00	4.36E+01	1.38E+01
10.5-11.0	10.75	9.37E+00	7.00E+00	3.77E+01	1.24E+01
11.0-12.5	11.75	8.31E+00	5.37E+00	3.15E+01	1.09E+01
12.5-15.5	13.75	6.56E+00	3.43E+00	2.28E+01	8.60E+00
15.5-17.0	16.00	4.42E+00	2.39E+00	1.64E+01	6.81E+00
17.0-17.5	17.25	2.17E+00	2.02E+00	1.39E+01	6.06E+00
17.5-20.0	18.75	1.96E+00	1.74E+00	1.15E+01	5.32E+00
20.0-22.5	21.25	1.69E+00	1.48E+00	8.64E+00	4.37E+00
22.5-25.0	23.75	1.47E+00	1.10E+00	6.65E+00	3.66E+00

Output Results of Scenario-3

(7 Days TEDE)

Distance (KM)		7 Days TEDE (mSv)			
Distance Range	Mean Distance	MET Option 1	MET Option 2	MET Option 3	MET Option 4
0.0-0.5	0.25	6.69E+02	1.76E+03	3.51E+02	5.27E+01
0.5-1.0	0.75	2.64E+02	1.02E+03	2.96E+02	4.48E+01
1.0-1.5	1.25	1.33E+02	7.88E+02	2.75E+02	4.21E+01
1.5-2.5	2.00	6.49E+01	5.92E+02	2.44E+02	3.81E+01
2.5-3.0	2.75	3.82E+01	4.62E+02	2.14E+02	3.42E+01
3.0-3.5	3.25	2.88E+01	3.92E+02	1.95E+02	3.16E+01
3.5-4.0	3.75	2.33E+01	2.98E+02	1.78E+02	2.93E+01
4.0-4.5	4.25	2.48E+01	2.40E+02	1.62E+02	2.72E+01
4.5-5.0	4.75	2.71E+01	1.99E+02	1.47E+02	2.52E+01
5.0-5.5	5.25	2.90E+01	1.66E+02	1.34E+02	2.35E+01
5.5-6.0	5.75	3.91E+01	1.42E+02	1.23E+02	2.18E+01
6.0-6.5	6.25	4.51E+01	1.22E+02	1.12E+02	2.04E+01
6.5-7.0	6.75	4.71E+01	1.04E+02	1.03E+02	1.90E+01
7.0-7.5	7.25	4.87E+01	8.98E+01	9.46E+01	1.78E+01
7.7-8.0	7.75	4.82E+01	7.73E+01	8.71E+01	1.68E+01
8.0-8.5	8.25	4.51E+01	6.71E+01	8.03E+01	1.58E+01
8.5-9.0	8.75	4.23E+01	4.90E+01	7.43E+01	1.48E+01
9.0-9.5	9.25	3.97E+01	4.20E+01	6.88E+01	1.40E+01
9.5-10.5	10.00	3.61E+01	3.47E+01	6.16E+01	1.29E+01
10.5-11.0	10.75	3.29E+01	2.87E+01	5.53E+01	1.19E+01
11.0-12.5	11.75	2.91E+01	2.18E+01	4.82E+01	1.08E+01
12.5-15.5	13.75	2.28E+01	1.26E+01	3.73E+01	8.94E+00
15.5-17.0	16.00	1.28E+01	8.24E+00	2.85E+01	7.39E+00
17.0-17.5	17.25	5.76E+00	6.74E+00	2.48E+01	6.70E+00
17.5-20.0	18.75	2.84E+00	5.31E+00	2.12E+01	6.00E+00
20.0-22.5	21.25	2.12E+00	3.87E+00	1.65E+01	5.06E+00
22.5-25.0	23.75	1.85E+00	2.66E+00	1.31E+01	4.33E+00

Output Results of Scenario-3

(2 Days TEDE)

Distance (KM)		2 Days TEDE (mSv)			
Distance Range	Mean Distance	MET Option 1	MET Option 2	MET Option 3	MET Option 4
0.0-0.5	0.25	5.83E+02	1.50E+03	3.63E+02	4.60E+01
0.5-1.0	0.75	2.31E+02	8.73E+02	3.03E+02	3.92E+01
1.0-1.5	1.25	1.16E+02	6.75E+02	2.30E+02	3.68E+01
1.5-2.5	2.00	5.65E+01	5.05E+02	1.54E+02	3.33E+01
2.5-3.0	2.75	3.33E+01	3.92E+02	1.08E+02	2.98E+01
3.0-3.5	3.25	2.51E+01	3.31E+02	8.84E+01	2.76E+01
3.5-4.0	3.75	2.02E+01	2.51E+02	7.33E+01	2.56E+01
4.0-4.5	4.25	2.09E+01	2.01E+02	6.18E+01	2.37E+01
4.5-5.0	4.75	2.24E+01	1.67E+02	5.28E+01	2.20E+01
5.0-5.5	5.25	2.37E+01	1.39E+02	4.56E+01	2.05E+01
5.5-6.0	5.75	3.20E+01	1.19E+02	3.97E+01	1.91E+01
6.0-6.5	6.25	3.67E+01	1.01E+02	3.49E+01	1.78E+01
6.5-7.0	6.75	3.81E+01	8.64E+01	3.09E+01	1.66E+01
7.0-7.5	7.25	3.90E+01	7.42E+01	2.76E+01	1.56E+01
7.7-8.0	7.75	3.83E+01	6.38E+01	2.48E+01	1.46E+01
8.0-8.5	8.25	3.58E+01	5.52E+01	2.23E+01	1.37E+01
8.5-9.0	8.75	3.35E+01	4.02E+01	2.02E+01	1.29E+01
9.0-9.5	9.25	3.13E+01	3.44E+01	1.84E+01	1.22E+01
9.5-10.5	10.00	2.84E+01	2.83E+01	1.61E+01	1.12E+01
10.5-11.0	10.75	2.57E+01	2.34E+01	1.42E+01	1.04E+01
11.0-12.5	11.75	2.26E+01	1.77E+01	1.22E+01	9.38E+00
12.5-15.5	13.75	1.76E+01	1.02E+01	9.19E+00	7.79E+00
15.5-17.0	16.00	9.83E+00	6.62E+00	6.93E+00	6.43E+00
17.0-17.5	17.25	4.44E+00	5.39E+00	6.01E+00	5.83E+00
17.5-20.0	18.75	2.31E+00	4.24E+00	5.13E+00	5.22E+00
20.0-22.5	21.25	1.76E+00	3.09E+00	4.03E+00	4.40E+00
22.5-25.0	23.75	1.53E+00	2.11E+00	3.23E+00	3.76E+00

Output Results of Scenario-3

(7Days Thyroid Doses)

Distance (KM)		Thyroid Doses (mSv)			
Distance Range	Mean Distance	MET Option 1	MET Option 2	MET Option 3	MET Option 4
0.0-0.5	0.25	5.58E+02	1.14E+03	2.87E+02	4.30E+01
0.5-1.0	0.75	2.18E+02	7.27E+02	2.40E+02	3.62E+01
1.0-1.5	1.25	1.08E+02	5.91E+02	2.23E+02	3.40E+01
1.5-2.5	2.00	5.24E+01	4.61E+02	1.99E+02	3.09E+01
2.5-3.0	2.75	3.08E+01	3.67E+02	1.76E+02	2.78E+01
3.0-3.5	3.25	2.32E+01	3.12E+02	1.60E+02	2.58E+01
3.5-4.0	3.75	1.81E+01	2.37E+02	1.46E+02	2.40E+01
4.0-4.5	4.25	1.45E+01	1.92E+02	1.33E+02	2.22E+01
4.5-5.0	4.75	1.19E+01	1.61E+02	1.21E+02	2.06E+01
5.0-5.5	5.25	9.87E+00	1.35E+02	1.11E+02	1.92E+01
5.5-6.0	5.75	1.49E+01	1.16E+02	1.01E+02	1.78E+01
6.0-6.5	6.25	1.68E+01	9.94E+01	9.27E+01	1.67E+01
6.5-7.0	6.75	1.58E+01	8.47E+01	8.50E+01	1.56E+01
7.0-7.5	7.25	1.49E+01	7.28E+01	7.82E+01	1.46E+01
7.7-8.0	7.75	1.40E+01	6.28E+01	7.20E+01	1.37E+01
8.0-8.5	8.25	1.31E+01	5.46E+01	6.64E+01	1.29E+01
8.5-9.0	8.75	1.23E+01	3.97E+01	6.14E+01	1.21E+01
9.0-9.5	9.25	1.15E+01	3.39E+01	5.69E+01	1.14E+01
9.5-10.5	10.00	1.05E+01	2.78E+01	5.09E+01	1.05E+01
10.5-11.0	10.75	9.58E+00	2.29E+01	4.57E+01	9.70E+00
11.0-12.5	11.75	8.50E+00	1.74E+01	3.98E+01	8.76E+00
12.5-15.5	13.75	6.71E+00	9.93E+00	3.07E+01	7.26E+00
15.5-17.0	16.00	4.52E+00	6.42E+00	2.35E+01	5.99E+00
17.0-17.5	17.25	2.23E+00	5.19E+00	2.04E+01	5.43E+00
17.5-20.0	18.75	2.01E+00	4.13E+00	1.74E+01	4.86E+00
20.0-22.5	21.25	1.73E+00	3.02E+00	1.36E+01	4.09E+00
22.5-25.0	23.75	1.51E+00	2.08E+00	1.08E+01	3.50E+00

Output Results of Scenario-4

(7 Days TEDE)

(Using constant weather option)

Distance (KM)		7 Days TEDE (mSv)				
Distance Range	Mean Distance	Scenario-1	Scenario-2	Scenario-3	[15] (10m)	[15] (61m)
0.0-0.5	0.25	3.51E+02	5.86E+03	3.51E+02	1.65E+03	4.86E+02
0.5-1.0	0.75	2.96E+02	2.38E+03	2.96E+02	3.45E+02	1.93E+02
1.0-1.5	1.25	2.75E+02	1.37E+03	2.75E+02	1.53E+02	9.75E+01
1.5-2.5	2.00	2.44E+02	7.68E+02	2.44E+02	7.01E+01	4.79E+01
2.5-3.0	2.75	2.14E+02	4.90E+02	2.14E+02	4.03E+01	2.84E+01
3.0-3.5	3.25	1.95E+02	3.82E+02	1.95E+02	3.01E+01	2.15E+01
3.5-4.0	3.75	1.78E+02	3.06E+02	1.78E+02	2.34E+01	1.68E+01
4.0-4.5	4.25	1.62E+02	2.51E+02	1.62E+02	1.87E+01	1.36E+01
4.5-5.0	4.75	1.47E+02	2.09E+02	1.47E+02	1.53E+01	1.12E+01
5.0-5.5	5.25	1.34E+02	1.77E+02	1.34E+02	1.28E+01	9.40E+00
5.5-6.0	5.75	1.23E+02	1.51E+02	1.23E+02	1.09E+01	8.01E+00
6.0-6.5	6.25	1.12E+02	1.30E+02	1.12E+02	9.34E+00	6.91E+00
6.5-7.0	6.75	1.03E+02	1.14E+02	1.03E+02	8.12E+00	6.03E+00
7.0-7.5	7.25	9.46E+01	9.96E+01	9.46E+01	7.13E+00	5.31E+00
7.7-8.0	7.75	8.71E+01	8.81E+01	8.71E+01	6.32E+00	4.72E+00
8.0-8.5	8.25	8.03E+01	7.83E+01	8.03E+01	5.64E+00	4.23E+00
8.5-9.0	8.75	7.43E+01	7.01E+01	7.43E+01	5.08E+00	3.82E+00
9.0-9.5	9.25	6.88E+01	6.30E+01	6.88E+01	4.61E+00	3.47E+00
9.5-10.5	10.00	6.16E+01	5.41E+01	6.16E+01	4.03E+00	3.05E+00
10.5-11.0	10.75	5.53E+01	4.69E+01	5.53E+01	3.58E+00	2.72E+00
11.0-12.5	11.75	4.82E+01	3.93E+01	4.82E+01	3.12E+00	2.38E+00
12.5-15.5	13.75	3.73E+01	2.85E+01	3.73E+01	2.50E+00	1.92E+00
15.5-17.0	16.00	2.85E+01	2.05E+01	2.85E+01	2.06E+00	1.60E+00
17.0-17.5	17.25	2.48E+01	1.74E+01	2.48E+01	1.89E+00	1.47E+00
17.5-20.0	18.75	2.12E+01	1.45E+01	2.12E+01	1.72E+00	1.34E+00
20.0-22.5	21.25	1.65E+01	1.09E+01	1.65E+01	1.49E+00	1.17E+00
22.5-25.0	23.75	1.31E+01	8.41E+00	1.31E+01	1.31E+00	1.04E+00

Output Results of Scenario-4

(2 Days TEDE)

(Using constant weather option)

Distance (KM)		2 Days TEDE (mSv)				
Distance Range	Mean Distance	Scenario-1	Scenario-2	Scenario-3	[15] (10m)	[15] (61m)
0.0-0.5	0.25	3.07E+02	5.10E+03	3.63E+02	1.44E+03	4.24E+02
0.5-1.0	0.75	2.59E+02	2.07E+03	3.03E+02	3.01E+02	1.68E+02
1.0-1.5	1.25	2.40E+02	1.19E+03	2.30E+02	1.33E+02	8.51E+01
1.5-2.5	2.00	2.12E+02	6.67E+02	1.54E+02	6.11E+01	4.18E+01
2.5-3.0	2.75	1.86E+02	4.25E+02	1.08E+02	3.51E+01	2.48E+01
3.0-3.5	3.25	1.69E+02	3.31E+02	8.84E+01	2.62E+01	1.87E+01
3.5-4.0	3.75	1.54E+02	2.65E+02	7.33E+01	2.03E+01	1.47E+01
4.0-4.5	4.25	1.40E+02	2.17E+02	6.18E+01	1.63E+01	1.18E+01
4.5-5.0	4.75	1.27E+02	1.81E+02	5.28E+01	1.33E+01	9.75E+00
5.0-5.5	5.25	1.16E+02	1.53E+02	4.56E+01	1.11E+01	8.18E+00
5.5-6.0	5.75	1.06E+02	1.30E+02	3.97E+01	9.41E+00	6.96E+00
6.0-6.5	6.25	9.66E+01	1.12E+02	3.49E+01	8.07E+00	6.00E+00
6.5-7.0	6.75	8.84E+01	9.78E+01	3.09E+01	7.01E+00	5.23E+00
7.0-7.5	7.25	8.12E+01	8.58E+01	2.76E+01	6.15E+00	4.60E+00
7.7-8.0	7.75	7.47E+01	7.58E+01	2.48E+01	5.44E+00	4.09E+00
8.0-8.5	8.25	6.88E+01	6.74E+01	2.23E+01	4.85E+00	3.66E+00
8.5-9.0	8.75	6.36E+01	6.02E+01	2.02E+01	4.37E+00	3.30E+00
9.0-9.5	9.25	5.88E+01	5.41E+01	1.84E+01	3.95E+00	3.00E+00
9.5-10.5	10.00	5.26E+01	4.64E+01	1.61E+01	3.46E+00	2.63E+00
10.5-11.0	10.75	4.71E+01	4.02E+01	1.42E+01	3.06E+00	2.34E+00
11.0-12.5	11.75	4.10E+01	3.36E+01	1.22E+01	2.66E+00	2.04E+00
12.5-15.5	13.75	3.16E+01	2.43E+01	9.19E+00	2.12E+00	1.64E+00
15.5-17.0	16.00	2.41E+01	1.75E+01	6.93E+00	1.75E+00	1.37E+00
17.0-17.5	17.25	2.09E+01	1.48E+01	6.01E+00	1.60E+00	1.25E+00
17.5-20.0	18.75	1.78E+01	1.23E+01	5.13E+00	1.45E+00	1.14E+00
20.0-22.5	21.25	1.38E+01	9.20E+00	4.03E+00	1.25E+00	9.95E-01
22.5-25.0	23.75	1.10E+01	7.08E+00	3.23E+00	1.10E+00	8.80E-01

Output Results of Scenario-4

(7 Days Thyroid Doses)

(Using constant weather option)

Distance (KM)		**Thyroid Dose (mSv)**				
Distance Range	Mean Distance	Scenario-1	Scenario-2	Scenario-3	[15] (10m)	[15] (61m)
0.0-0.5	0.25	2.87E+02	4.92E+03	2.87E+02	1.37E+03	4.05E+02
0.5-1.0	0.75	2.40E+02	1.99E+03	2.40E+02	2.80E+02	1.59E+02
1.0-1.5	1.25	2.23E+02	1.14E+03	2.23E+02	1.23E+02	7.94E+01
1.5-2.5	2.00	1.99E+02	6.34E+02	1.99E+02	5.61E+01	3.86E+01
2.5-3.0	2.75	1.76E+02	4.03E+02	1.76E+02	3.22E+01	2.28E+01
3.0-3.5	3.25	1.60E+02	3.14E+02	1.60E+02	2.40E+01	1.72E+01
3.5-4.0	3.75	1.46E+02	2.51E+02	1.46E+02	1.87E+01	1.35E+01
4.0-4.5	4.25	1.33E+02	2.05E+02	1.33E+02	1.49E+01	1.09E+01
4.5-5.0	4.75	1.21E+02	1.70E+02	1.21E+02	1.23E+01	8.96E+00
5.0-5.5	5.25	1.11E+02	1.44E+02	1.11E+02	1.02E+01	7.52E+00
5.5-6.0	5.75	1.01E+02	1.23E+02	1.01E+02	8.70E+00	6.41E+00
6.0-6.5	6.25	9.27E+01	1.06E+02	9.27E+01	7.48E+00	5.53E+00
6.5-7.0	6.75	8.50E+01	9.20E+01	8.50E+01	6.51E+00	4.83E+00
7.0-7.5	7.25	7.82E+01	8.07E+01	7.82E+01	5.72E+00	4.26E+00
7.7-8.0	7.75	7.20E+01	7.13E+01	7.20E+01	5.08E+00	3.79E+00
8.0-8.5	8.25	6.64E+01	6.33E+01	6.64E+01	4.54E+00	3.39E+00
8.5-9.0	8.75	6.14E+01	5.66E+01	6.14E+01	4.09E+00	3.06E+00
9.0-9.5	9.25	5.69E+01	5.08E+01	5.69E+01	3.71E+00	2.79E+00
9.5-10.5	10.00	5.09E+01	4.36E+01	5.09E+01	3.25E+00	2.45E+00
10.5-11.0	10.75	4.57E+01	3.77E+01	4.57E+01	2.89E+00	2.19E+00
11.0-12.5	11.75	3.98E+01	3.15E+01	3.98E+01	2.52E+00	1.91E+00
12.5-15.5	13.75	3.07E+01	2.28E+01	3.07E+01	2.03E+00	1.55E+00
15.5-17.0	16.00	2.35E+01	1.64E+01	2.35E+01	1.68E+00	1.29E+00
17.0-17.5	17.25	2.04E+01	1.39E+01	2.04E+01	1.54E+00	1.19E+00
17.5-20.0	18.75	1.74E+01	1.15E+01	1.74E+01	1.41E+00	1.09E+00
20.0-22.5	21.25	1.36E+01	8.64E+00	1.36E+01	1.22E+00	9.55E-01
22.5-25.0	23.75	1.08E+01	6.65E+00	1.08E+01	1.08E+00	8.50E-01

App

Co-relation of Plume Dispersion Parameter (Effect of Release Height-RH)

Distance (KM)		7 Days TEDE (mSv)						
Distance Range	Mean Distance	RH-10	RH-20	RH-30	RH-40	RH-50	RH-60	RH-70
0.0-0.5	0.25	1.44E+04	1.19E+04	8.62E+03	5.54E+03	1.82E+03	1.17E+03	8.07E+
0.5-1.0	0.75	4.48E+03	4.07E+03	3.39E+03	2.54E+03	8.69E+02	5.83E+02	3.97E+
1.0-1.5	1.25	2.10E+03	2.04E+03	1.87E+03	1.57E+03	5.91E+02	4.19E+02	2.92E+
1.5-2.5	2.00	9.23E+02	9.52E+02	9.62E+02	9.09E+02	3.84E+02	2.90E+02	2.11E+
2.5-3.0	2.75	4.76E+02	5.14E+02	5.57E+02	5.76E+02	2.82E+02	2.28E+02	1.75E+
3.0-3.5	3.25	3.03E+02	3.34E+02	3.77E+02	4.13E+02	2.37E+02	1.98E+02	1.58E+
3.5-4.0	3.75	2.03E+02	2.26E+02	2.60E+02	2.93E+02	2.24E+02	2.04E+02	1.79E+
4.0-4.5	4.25	1.46E+02	1.65E+02	1.93E+02	2.22E+02	1.56E+02	1.43E+02	1.25E+
4.5-5.0	4.75	1.10E+02	1.24E+02	1.47E+02	1.73E+02	1.26E+02	1.16E+02	1.02E+
5.0-5.5	5.25	8.35E+01	9.53E+01	1.14E+02	1.37E+02	1.06E+02	9.95E+01	8.90E+
5.5-6.0	5.75	6.66E+01	7.62E+01	9.22E+01	1.12E+02	9.19E+01	8.72E+01	7.92E+
6.0-6.5	6.25	5.32E+01	6.11E+01	7.44E+01	9.17E+01	8.03E+01	7.73E+01	7.13E+
6.5-7.0	6.75	4.25E+01	4.90E+01	6.01E+01	7.51E+01	7.14E+01	6.97E+01	6.52E+
7.0-7.5	7.25	3.48E+01	4.01E+01	4.95E+01	6.24E+01	6.40E+01	6.32E+01	5.99E+
7.7-8.0	7.75	2.87E+01	3.31E+01	4.10E+01	5.21E+01	5.75E+01	5.75E+01	5.52E+
8.0-8.5	8.25	2.41E+01	2.78E+01	3.45E+01	4.41E+01	5.17E+01	5.23E+01	5.08E+
8.5-9.0	8.75	1.81E+01	2.06E+01	2.52E+01	3.20E+01	4.67E+01	4.76E+01	4.67E+
9.0-9.5	9.25	1.52E+01	1.73E+01	2.12E+01	2.69E+01	4.23E+01	4.35E+01	4.31E+
9.5-10.5	10.00	1.22E+01	1.39E+01	1.70E+01	2.17E+01	3.65E+01	3.80E+01	3.82E+
10.5-11.0	10.75	1.01E+01	1.14E+01	1.38E+01	1.76E+01	3.23E+01	3.39E+01	3.44E+
11.0-12.5	11.75	7.72E+00	8.66E+00	1.05E+01	1.33E+01	2.74E+01	2.91E+01	2.99E+
12.5-15.5	13.75	4.93E+00	5.42E+00	6.36E+00	7.84E+00	2.01E+01	2.18E+01	2.28E+
15.5-17.0	16.00	3.44E+00	3.74E+00	4.31E+00	5.21E+00	1.45E+01	1.59E+01	1.70E+
17.0-17.5	17.25	2.94E+00	3.17E+00	3.62E+00	4.33E+00	1.23E+01	1.36E+01	1.47E+
17.5-20.0	18.75	2.45E+00	2.63E+00	2.97E+00	3.50E+00	1.02E+01	1.14E+01	1.24E+
20.0-22.5	21.25	2.03E+00	2.15E+00	2.38E+00	2.72E+00	7.36E+00	8.29E+00	9.13E+
22.5-25.0	23.75	1.48E+00	1.56E+00	1.71E+00	1.94E+00	5.59E+00	6.35E+00	7.06E+

Co-relation of Plume Dispersion Parameter (Effect of Release Duration-RD)

Distance (KM)		7 Days TEDE (mSv)						
Distance Range	Mean Distance	RD-0.5hr	RD-1hr	RD-1.5hrs	RD-2hrs	RD-4hrs	RD-8hrs	RD-16h
0.0-0.5	0.25	1.44E+04	1.32E+04	1.18E+04	1.15E+04	9.13E+03	8.68E+03	6.90E+
0.5-1.0	0.75	4.48E+03	3.97E+03	3.46E+03	3.31E+03	2.51E+03	2.35E+03	1.87E+
1.0-1.5	1.25	2.10E+03	1.86E+03	1.63E+03	1.52E+03	1.14E+03	1.06E+03	8.55E+
1.5-2.5	2.00	9.23E+02	8.24E+02	6.88E+02	5.68E+02	4.80E+02	4.03E+02	3.68E+
2.5-3.0	2.75	4.76E+02	3.87E+02	3.20E+02	2.76E+02	2.39E+02	1.91E+02	1.87E+
3.0-3.5	3.25	3.03E+02	2.48E+02	2.11E+02	1.87E+02	1.63E+02	1.30E+02	1.29E+
3.5-4.0	3.75	2.03E+02	1.75E+02	1.49E+02	1.30E+02	1.15E+02	9.19E+01	9.24E+
4.0-4.5	4.25	1.46E+02	1.28E+02	1.09E+02	9.44E+01	8.36E+01	6.74E+01	6.83E+
4.5-5.0	4.75	1.10E+02	9.56E+01	8.04E+01	7.10E+01	6.26E+01	5.08E+01	5.17E+
5.0-5.5	5.25	8.35E+01	7.32E+01	6.11E+01	5.47E+01	4.66E+01	3.82E+01	3.96E+
5.5-6.0	5.75	6.66E+01	5.69E+01	4.78E+01	4.29E+01	3.22E+01	2.73E+01	2.99E+
6.0-6.5	6.25	5.32E+01	4.51E+01	3.84E+01	3.43E+01	2.58E+01	2.15E+01	2.39E+
6.5-7.0	6.75	4.25E+01	3.65E+01	3.12E+01	2.79E+01	2.10E+01	1.73E+01	1.95E+
7.0-7.5	7.25	3.48E+01	2.99E+01	2.57E+01	2.08E+01	1.72E+01	1.42E+01	1.40E+
7.7-8.0	7.75	2.87E+01	2.49E+01	2.01E+01	1.64E+01	1.47E+01	1.17E+01	1.06E+
8.0-8.5	8.25	2.41E+01	1.86E+01	1.54E+01	1.38E+01	1.25E+01	9.89E+00	8.86E+
8.5-9.0	8.75	1.81E+01	1.53E+01	1.31E+01	1.18E+01	1.07E+01	8.41E+00	7.50E+
9.0-9.5	9.25	1.52E+01	1.32E+01	1.13E+01	1.01E+01	8.35E+00	7.17E+00	6.38E+
9.5-10.5	10.00	1.22E+01	1.08E+01	9.21E+00	8.33E+00	6.75E+00	5.86E+00	5.18E+
10.5-11.0	10.75	1.01E+01	8.86E+00	7.65E+00	6.67E+00	5.59E+00	4.81E+00	4.24E+
11.0-12.5	11.75	7.72E+00	6.75E+00	5.66E+00	5.55E+00	4.49E+00	3.85E+00	3.36E+
12.5-15.5	13.75	4.93E+00	4.33E+00	3.78E+00	3.85E+00	3.08E+00	2.44E+00	2.55E+
15.5-17.0	16.00	3.44E+00	3.12E+00	3.00E+00	2.81E+00	2.11E+00	1.57E+00	1.75E+
17.0-17.5	17.25	2.94E+00	2.94E+00	2.51E+00	2.37E+00	1.75E+00	1.24E+00	1.42E+
17.5-20.0	18.75	2.45E+00	2.42E+00	2.10E+00	1.92E+00	1.45E+00	1.04E+00	1.12E+
20.0-22.5	21.25	2.03E+00	1.74E+00	1.48E+00	1.35E+00	1.06E+00	8.50E-01	7.73E-
22.5-25.0	23.75	1.48E+00	1.31E+00	1.13E+00	1.06E+00	8.61E-01	7.50E-01	5.92E-

Co-relation of Plume Dispersion Parameter (Effect of Stability Class-SC)

Distance (KM)		7 Days TEDE (mSv)					
Distance Range	Mean Distance	SC-A	SC-B	SC-C	SC-D	SC-E	
0.0-0.5	0.25	2.70E+02	9.32E+02	1.65E+03	3.20E+03	4.18E+03	5.
0.5-1.0	0.75	2.78E+01	1.40E+02	3.45E+02	9.56E+02	1.37E+03	2.
1.0-1.5	1.25	1.53E+01	4.88E+01	1.53E+02	4.87E+02	7.19E+02	1.
1.5-2.5	2.00	1.01E+01	1.71E+01	7.01E+01	2.50E+02	3.78E+02	7.
2.5-3.0	2.75	7.48E+00	9.82E+00	4.03E+01	1.52E+02	2.34E+02	4.
3.0-3.5	3.25	6.40E+00	8.19E+00	3.01E+01	1.17E+02	1.81E+02	3.
3.5-4.0	3.75	5.59E+00	7.15E+00	2.34E+01	9.31E+01	1.44E+02	3.
4.0-4.5	4.25	4.97E+00	6.36E+00	1.87E+01	7.59E+01	1.18E+02	2.
4.5-5.0	4.75	4.46E+00	5.74E+00	1.53E+01	6.32E+01	9.87E+01	2.
5.0-5.5	5.25	4.05E+00	5.21E+00	1.28E+01	5.34E+01	8.37E+01	1.
5.5-6.0	5.75	3.71E+00	4.77E+00	1.09E+01	4.57E+01	7.19E+01	1.
6.0-6.5	6.25	3.42E+00	4.40E+00	9.34E+00	3.96E+01	6.25E+01	1.
6.5-7.0	6.75	3.17E+00	4.08E+00	8.12E+00	3.47E+01	5.49E+01	1.
7.0-7.5	7.25	2.96E+00	3.80E+00	7.13E+00	3.06E+01	4.85E+01	9.
7.7-8.0	7.75	2.77E+00	3.56E+00	6.32E+00	2.72E+01	4.32E+01	8.
8.0-8.5	8.25	2.60E+00	3.34E+00	5.64E+00	2.44E+01	3.87E+01	7.
8.5-9.0	8.75	2.45E+00	3.15E+00	5.08E+00	2.20E+01	3.49E+01	7.
9.0-9.5	9.25	2.32E+00	2.98E+00	4.61E+00	1.99E+01	3.16E+01	6.
9.5-10.5	10.00	2.14E+00	2.76E+00	4.03E+00	1.73E+01	2.75E+01	5.
10.5-11.0	10.75	1.99E+00	2.56E+00	3.58E+00	1.52E+01	2.41E+01	4.
11.0-12.5	11.75	1.82E+00	2.34E+00	3.12E+00	1.29E+01	2.05E+01	3.
12.5-15.5	13.75	1.54E+00	1.98E+00	2.50E+00	9.63E+00	1.53E+01	2.
15.5-17.0	16.00	1.31E+00	1.69E+00	2.06E+00	7.22E+00	1.15E+01	2.
17.0-17.5	17.25	1.21E+00	1.55E+00	1.89E+00	6.25E+00	9.94E+00	1.
17.5-20.0	18.75	1.10E+00	1.42E+00	1.72E+00	5.32E+00	8.46E+00	1.
20.0-22.5	21.25	9.60E-01	1.24E+00	1.49E+00	4.17E+00	6.60E+00	1.
22.5-25.0	23.75	8.46E-01	1.09E+00	1.31E+00	3.34E+00	5.28E+00	8.