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Dose Distribution of ^{131}I, ^{132}I, ^{133}I, ^{134}I, and ^{135}I Due to a Hypothetical Accident of TRIGA Mark-II Research Reactor

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Abstract

An attempt has been made in the work to assess radiological dose due to the deposition of ^{131}I, ^{132}I, ^{133}I, ^{134}I, and ^{135}I on ground, vegetation, milk and meat considering a hypothetical accident of TRIGA Mark-II research reactor at AERE, Savar, Bangladesh. Contribution of dose from ingestion of vegetation due to ^{131}I has been found to be dominant (62.96%). Also found that contribution of ^{132}I from immersion is higher (53.67%) and contribution of ^{133}I in meat is higher (45.64%). The contribution due to ^{134}I in both from immersion (46.13%) and from ground deposition (47.19%) was dominant while the contribution of ^{135}I from ground deposition (30.11%), inhalation (26.77%) and immersion (25.92%) were higher. Final result says that the vegetation is the dominant contributor (66.91%) for iodine.

Keywords: *Dose rate, Fission yield, Pathway, Source term, Ventilation.*

1 Introduction

Atmospheric dispersion and radiation dose calculations for accidental releases of radioactive gases are an important contribution to licensing requirements for the selection of site for a nuclear reactor. The reactor-operating license is obtained from local regulatory authorities in accordance with internationally adopted criteria [1].

Nuclear reactors, especially research reactors, do not release any significant quantity of radioactive material to the atmosphere under normal operating conditions. However, a significant fraction of the radionuclide inventory in the core may be released to the atmosphere under accident conditions with severe core damage. In the case of a hypothetical accident of research reactor, radionuclides that are anticipated to be released through the stack, can cause direct radiation exposure of the public in the downwind direction and can also be deposited on the ground and vegetation resulting in exposure through different pathways such as external irradiation, inhalation, ingestion etc. [2, 3], when cows eat

vegetation, milk and meat become contaminated. Immediately after an accident, isotopes of iodine such as ^{131}I, ^{132}I, ^{133}I, ^{134}I, and ^{135}I presents the most serious radiological hazards [4]. The main doses concerns are those to thyroid due to external irradiation, inhalation and ingestion of radioiodines.

Attempts have been made in this work to assess radiological dose in vegetation, milk and meat due to deposition of ^{131}I, ^{132}I, ^{133}I, ^{134}I, and ^{135}I considering hypothetical accident of TRIGA Mark-II research reactor at AERE, Savar, Bangladesh. Radionuclides can be deposited on soil either by direct deposition from the atmosphere or from the use of surface water for irrigation.

Different assumptions and methodologies have been taken into account for assessing radiological dose suggesting the necessity of site-specific data. Recently IAEA published generic methodologies for use in assessing the radiological consequence due to the releases of radioactive materials in the environment, [5, 6]. A computational code has been developed based on these methodologies and in this work, we have calculated only the release of radioactive iodine which is volatile, and 40% release fraction was considered. The input parameters like wind speed and frequency at different directions have been collected from Bangladesh Meteorological Department for the AERE site. Other essential parameters needed in the calculation have been taken from elsewhere [5].

2 Source Term and Accident Scenario

2.1. Source Term Calculation

The radiological source term describes the amount of the nuclides which are released to the containment. An approximate formula giving activity $A_i(t)$ of an isotope i at time t after the start of irradiation (t=0) whose fission yield is γ and its decay constant is λ_i irradiated for a time period T in P (megawatts of thermal power) can be written [6] as:

$$A_i(t) = 0.82\gamma P\left(1 - e^{-\lambda_i T}\right) \times e^{-\lambda_i (t-T)} \tag{1}$$

Radiological doses outside the reactor facility can be caused only by radionuclides with a high degree of mobility and considerable amount of radionuclides can be released from the stack of the reactor building.

2.2. Release rate calculation

Source analysis addresses the problem of deriving the source terms that determine the rate at which residual radioactivity is released into the environment (release rate). The release rate of the radionuclides from stack is determined by the source term.
The total activity of isotope i released over time τ, $Q(\tau)$, is obtained from the equation [6] as:

$$Q_i(\tau) = F_P F_B A_i(t) \frac{\lambda_l}{\lambda_l + \lambda_r} \left[1 - e^{-(\lambda_l + \lambda_r)\tau}\right] \tag{2}$$

where F_P is the fraction released from fuel to building, F_B is the fraction remaining airborne and available to be released from the building to the atmosphere, λ_i is the source term, λ_l is the leak rate parameter, sec^{-1}, and λ_r is the radioactive decay constant, sec^{-1}.

2.3. Assumptions Made in the Calculation

The radiation received by the population around the TRIGA reactor facility is directly dependent on the source term. Some realistic assumptions have been made for doing the calculation of the present work. These are given below:

- ✓ The reactor was operated at full power: 3 MW (t);
- ✓ Time after the start of irradiation: 10 days;
- ✓ Continuous operation at full power: 10 days;
- ✓ Radionuclide release time into the atmosphere from stack: 2 hours after the accident;
- ✓ Radionuclides considered for radiological concentration assessment into the environment around the reactor building: ^{131}I ($T_{1/2}$= 8.04 days), ^{132}I ($T_{1/2}$=2.30 hr.), ^{133}I ($T_{1/2}$=20.8 hr.), ^{134}I ($T_{1/2}$=0.876 hr.) and ^{135}I ($T_{1/2}$=6.61hr.);
- ✓ Fraction release [7] : Iodine: 40% of the equilibrium radioactive iodine (^{131}I, ^{132}I, ^{133}I, ^{134}I, ^{135}I) inventory developed from maximum fuel power operation of the core are immediately available for leakage to the reactor building in the direct proportion to percent of fuel failure [7];
- ✓ Leak rate parameter, $\lambda_1 = 1.157 \times 10^{-7}\ sec^{-1}$. i.e., 1%/day [5].

Considering the above assumptions, the activities of iodine (^{131}I, ^{132}I, ^{133}I, ^{134}I and ^{135}I) were calculated considering the above assumptions and using Eq.1. The fission yields of the corresponding radionuclides were obtained as the fission fragment of the total product by neglecting the filter and shielding efficiency. A constant reactor power of 3 MW (t) is an acceptable approximation for the irradiation. The calculated activity released rate of radioiodines for 10 days operation at 3 MW(t) power level are given in Table 1.

Table 1. Calculated fission product inventory for 10 days operation at 3 MW (t) power level

Radionuclide	Fission yield	Total activity in core (C_i)	Released rate (Bq/sec)
^{131}I	0.0289	4.074×10^{4}	6.965×10^{7}
^{132}I	0.054	6.06×10^{4}	8.960×10^{7}
^{133}I	0.026	5.982×10^{4}	1.008×10^{8}
^{134}I	0.047	2.376×10^{4}	2.812×10^{7}
^{135}I	0.050	9.973×10^{4}	1.622×10^{8}

3 Atmospheric Dispersion and Radiological Dose Calculation Models

3.1. The Gaussian Plume Model (GPM)

The dispersion of radioactive plume to the atmosphere depends strongly on the atmospheric conditions such as temperature, wind frequency, direction, speed and humidity of the atmosphere. Gaussian plume model is widely applied to calculate atmospheric dispersion in

the atmospheric environment. This model assuming that a Gaussian distribution in both lateral and vertical directions can be described as [6]

$$\chi(x,y,z) = \frac{Q_i}{2\pi.\sigma_y.\sigma_z.u_a}.\exp(\frac{-y^2}{2\sigma_y^2})\{\exp[-\frac{(Z-H)^2}{2\sigma_z^2}] + \exp[-\frac{(Z+H)^2}{2\sigma_z^2}]\} \quad (3)$$

where $\chi(x,y,z)$ is the radionuclide concentrations at point (x,y,z) (Bq/m^3); Q_i is release rate (Bq/s), u_a is the wind speed(m/s) at the actual stack height H(m), σ_y and σ_z are the lateral and vertical dispersion parameters (m), depending on stability class.

For radiological concentration assessment ground level concentration is required and therefore, z can be assumed to be zero and equation (3) can be written as

$$\chi(x,y,z) = \frac{Q_i}{\pi.\sigma_y.\sigma_z.u_a}.\exp(\frac{-y^2}{2\sigma_y^2})\left\{\exp\left[-\frac{H_{eff}^{\ 2}}{2\sigma_z^2}\right]\right\} \quad (4)$$

The average concentration for release that occurs over a period of time can be calculated by applying the above equation.

3.2. Effective Stack Height (ESH)

If the effluent gas has a significant exit velocity (or if it is at a high temperature), it will rise to a level higher than the actual stack height. Therefore the effective stack height can be written as [8]

$$H_{eff} = H + D(\frac{v}{u_a})^{1.4}(1 + \frac{\Delta T}{T}) \quad (5)$$

Where D is the outlet stack diameter (m), *v* is the exit effluent velocity (m/s), ΔT is the difference between ambient and effluent gas temperatures, T is the absolute temperature of the effluent but for a research reactor like a TRIGA Mark-II at AERE, Savar, the temperature difference, ΔT can be considered to zero because of active operation of the ventilation system.

3.3. Average Wind Speed at ESH

This speed needs to be converted into an effective stack height applying the following relationship [3, 9] as $u = u_z(\frac{H_{eff}}{z})^m$ (6)

where u_z is the speed at ground level at a height z =10 m and *m* is the wind coefficient depending on underlying surface and diffusion category.

3.4. Meteorology of the TRIGA Reactor Site

Presently, there is no meteorological station within the AERE complex and as such all the data have been collected from Bangladesh Metrological Department, Dhaka Station located approximately at distance of 40 km from the actual site.

3.4.1. Wind Speed, Frequency and Direction

Wind velocity and frequency have been collected from Dhaka Metrological Department for last 21 years, i.e. (1987-2007). The percentage of average wind frequencies and average wind velocity for various directions are shown in Figs. 1 and 2, respectively. It can be observed from Fig. 1 that the average frequency of wind flow in South direction is dominant (about 28.66%) around the reactor site and the possibility of radionuclide dispersions to the different directions readily depend on the respective wind frequencies. The metrological department has provided wind velocity at 10m height which has been converted as at effective stack height, i.e. 32.36m height (Fig. 2). In general, the wind velocity of the corresponding direction is responsible for determining the dispersion of radionuclides as a function of downwind distance. For higher wind velocity, the dispersion is expected to follow to a longer distance depending on the stability class around the site and release height. On the other hand, air concentration will be high in a direction if the wind frequency is high at that direction. Consequently the concentrations of radionuclides will be decreased with increasing downwind distance. Relying on these facts, the environmental sampling location can be identified during wide area environmental monitoring around a nuclear facility. This may be useful for identifying the undeclared activities in a declared facility and in the Gaussian plume equation, Pasquill-Gifford stability classification has been employed to consider stability class around the reactor site. They defined six weather categories, designated from A to F in order of increasing atmospheric stability. Using the meteorological data for the last 21 years (1987-2007), the percentages of frequency and speeds in 16 cardinal directions have been calculated which is shown in Fig. 2. From this result, the dominant stability class of the site is found to be “B” according to Pasquill-Gifford stability classification. Parameters required for radiological dose assessment must be taken for this stability class.

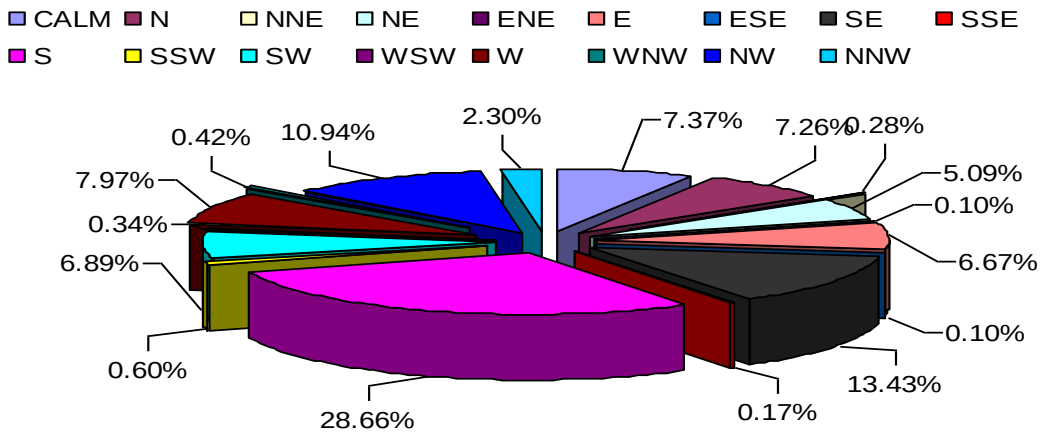

Fig. 1: The percentage of average wind frequencies for various directions.

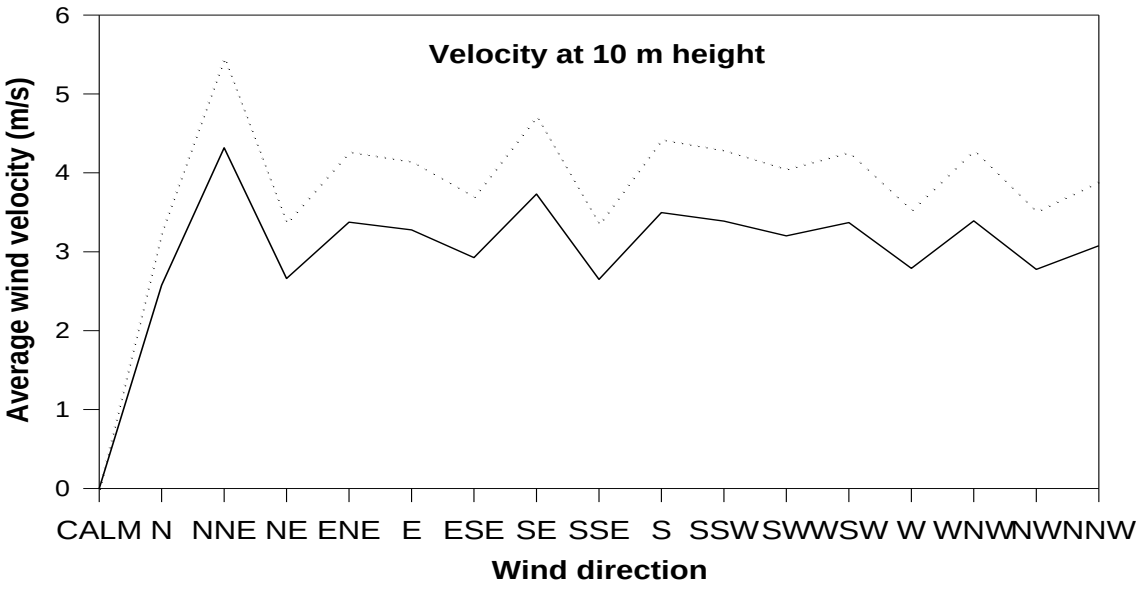

Fig. 2: The percentage of average wind velocity for various directions.

3.5. Air Concentration of Radionuclides and Gaussian Diffusion Factor

In this case the sector averaged form of the GPM may be used with the following simplifying assumptions:

a) A single wind direction and frequency for each air concentration calculation,
b) A single long term average wind speed for each direction, and
c) A neutral atmospheric stability class (Pasquill-Gifford stability class B) [5].

Air concentration of a radionuclide can be calculated based on the above mentioned assumptions by using the equation [5],

$$C_A = \frac{P_P F Q_i}{u_a} \exp(-\lambda_i \frac{x}{u_a}) \tag{7}$$

where C_A is the ground level air concentration at downwind distance x in sector p (Bq/m^3); P_p is the fraction of the time that the wind blows towards the receptor of interest in sector p; u_a is the geometric mean of the wind speed at the height of release (m/s); F is the Gaussian diffusion factor, appropriate for the height of release H_{eff} and the downwind distance x being considered (m^{-2}); Q_i is the average annual discharge rate for radionuclide *i* (Bq/s); λ_i is the rate constant for radioactive decay of radionuclide *i*.

The Gaussian diffusion factor F as a function of downwind distance x for a fixed value of H_{eff} can be estimated using the 22.5^o sector averaged form of the Gaussian plume model,

that is $$\mathbf{F} = \frac{\mathbf{16}}{\sqrt{2\pi^3}} \times \frac{\exp\left[-\left(\frac{\mathbf{H_{eff}}^2}{2\sigma_z^2}\right)\right]}{x\sigma_z} \tag{8}$$

Where σ_z is the vertical diffusion parameter (m).
The territory is assumed to be covered with pastures, forests and small villages. The value of σ_z can be calculated on the basis of the relationship [5],

$$\sigma_z = E \cdot x^G \tag{9}$$

where E and G are the two parameters depending on the stability class and on the effective stack height, and x is the downwind distance.
Here for stability class "B" E = 0.127 and G = 1.108 for release height of 32.36m at various downwind distance x [10-12m] was considered.

4 Radiation Dose Calculations

The radiation doses in different environmental media depend on the concentration of radionuclide of that media. The concentration calculation methodologies using GPM are described elsewhere [12]. The methodologies of dose calculation in pathways are given in the following segments.

4.1. External Doses from Immersion

The annual effective dose from immersion in the atmospheric discharge plume E_{im} is given by [7],

$$E_{im} = C_A DF_{im} Q_f \tag{10}$$

where C_A is the annual average concentration of nuclide i in air (Bq/m^3), DF_{im} is the effective dose coefficient for immersion (Sv/nr per Bq/m^3), and Q_f is the fraction of the year for which the hypothetical critical group member is exposed to this particular pathway.

4.2. Internal Doses from Inhalation

The internal dose following an intake of radioactive material into the body by inhalation is prolonged in time after the intake. The effective dose coefficient from intake will depend on the metabolism, age and life expectancy of the individual as well as the physicochemical behavior of the radionuclide concerned. Dose coefficients are usually evaluated using representative 'reference' values for the various factors, such as those related to metabolism and are therefore averages either for complete populations or for particular subgroups in a population.
The annual effective dose from inhalation E_{inh} is given by the following equation [7],

$$E_{inh} = C_A R_{inh} DF_{inh} \tag{11}$$

where C_A is the radionuclide concentration in air (Bq/m^3), R_{inh} is the inhalation rate (m^3/yr); and DF_{inh} is the inhalation dose coefficient (Sv/Bq).

4.3. External Doses from Ground Deposition

The annual effective dose from ground deposition E_{gr} is given by [7],

$$E_{gr} = C_{gr}.DF_{gr}.Q_f \tag{12}$$

where DF_{gr} is the coefficient for exposure to ground depositions (Sv/yr per Bq/m^3), Q_f is the fraction of the year which the hypothetical critical group member is expressed to this particular pathways, and C_{gr} is the deposition density of radionuclide i (Bq/m^3) which is obtained from the ground deposition rate d_i .

4.4. Internal Dose from Food Ingestion

Internal dose from food ingestion depend on the radionuclide concentration in food chain. The internal dose for food ingestion dose to human can be calculated using the general equation [7],

$$E_{ing,p} = C_{p,i}.H_p.DF_{ing} \tag{13}$$

where $E_{ing,p}$ is the annual effective dose from consumption of nuclide i in foodstuff p μv/hr), $C_{p,i}$ is the concentration of radionuclide i in food staff p at the time of consume (Bq/kg), H_p is the consumption rate for foodstuff p (kg/yr) and the values of H_p for different food stuff have been taken from elsewhere [7], and DF_{ing} is the dose coefficient for ingestion of radionuclide i (Sv/Bq) which have been taken from elsewhere [7]. As radionuclides can be deposited in various pathways, aforesaid equation can be represented in case of individual doses of foodstuff which are given below.

4.5. Internal Dose from Milk ingestion

The internal doses from milk ingestion cam be calculated using the equation [7],

$$E_{ingm} = C_{m,i}H_{pm}DF_{ing} \tag{14}$$

where $E_{m,i}$ is the concentration of radionuclide i in milk at the time of consume (Bq/L), H_{pm} is the consumption rate for vegetable (L/yr) and the value of H_{pm} is considered as 140 L/yr [7], and DF_{ing} is the dose coefficient for ingestion of radionuclide i (Sv/Bq) which is 2.2×10^{-8} Sv/Bq, 2.9×10^{-10} Sv/Bq, 4.3×10^{-9} Sv/Bq, 1.1×10^{-10} Sv/Bq and 9.3×10^{-10} Sv/Bq for radionuclides ^{131}I, ^{132}I, ^{133}I, ^{134}I, and ^{135}I, respectively [7].

4.6. Interval Dose from Meat ingestion

The internal dose for meat ingestion can be calculated using the following equation [7],

$$E_{ingmeat} = C_{meat,i} H_{pmeat} DF_{ing} \quad (15)$$

where $C_{meat,i}$ is the concentration of radionuclide i in milk at the time of consume (Bq/L), H_{pmeat} is the consumption rate for vegetable (kg/yr) and the value of H_{pmeat} is considered as 55kg/yr [7], and DF_{ing} is the dose coefficient for ingestion of radionuclide i (Sv/Bq) which is mentioned above for different radio nuclides [7].

4.7. Total Dose

The total dose for individual radionuclide to the human is obtain by adding all possible pathway contributions such as ingestion dose (i.e. from vegetables, milk and meat), inhalation dose and external dose from immersion and ground deposition [7],

$$E_{total} = E_{im} + E_{inh} + E_{gr} + E_{ingv} + E_{ingm} + E_{ingmeat} \quad (16)$$

where E_{total} is the total dose for individual radionuclide (µSv/hr), E_{im} is the external dose from immersion (µSv/hr), E_{inh} is the internal dose from inhalation (µSv/hr), E_{gr} is the external dose from ground deposition (µSv/hr), E_{ingv} is the internal dose from ingestion of vegetation (µSv/hr), E_{ingm} is the internal dose from ingestion of milk (µSv/hr), and $E_{ingmeat}$ is the internal dose from ingestion of meat (µSv/hr).

4.8. Total Dose for radioiodine around the TRIGA Mark-II Research Reactor

Total dose for ^{131}I, ^{132}I, ^{133}I, ^{134}I, ^{135}I and total (^{131}I+ ^{132}I+ ^{133}I+ ^{134}I +^{135}I) were found out after summing up the contribution from all the pathways, i.e. external doses for immersion and ground deposition, internal doses from inhalation and ingestion of vegetable, milk and meat (Eq.16). The total dose rates for radioiodine, as a function of time (up to 100days) for eight directions are shown in Fig. 3. It is obvious that dose rates are maximum at time t = 0 and disappear after 80 days in all the directions. Highest dose rate for different pathways at t = 0, were found in S-direction which are 178.99 µSv/hr, 1.336 µSv/hr, 69.06 µSv/hr, 0.568 µSv/hr, 3.623 µSv/hr and 253.578 µSv/hr for ^{131}I, ^{132}I, ^{133}I, ^{134}I, ^{135}I and total (^{131}I+ ^{132}I+ ^{133}I+ ^{134}I +^{135}I), respectively.

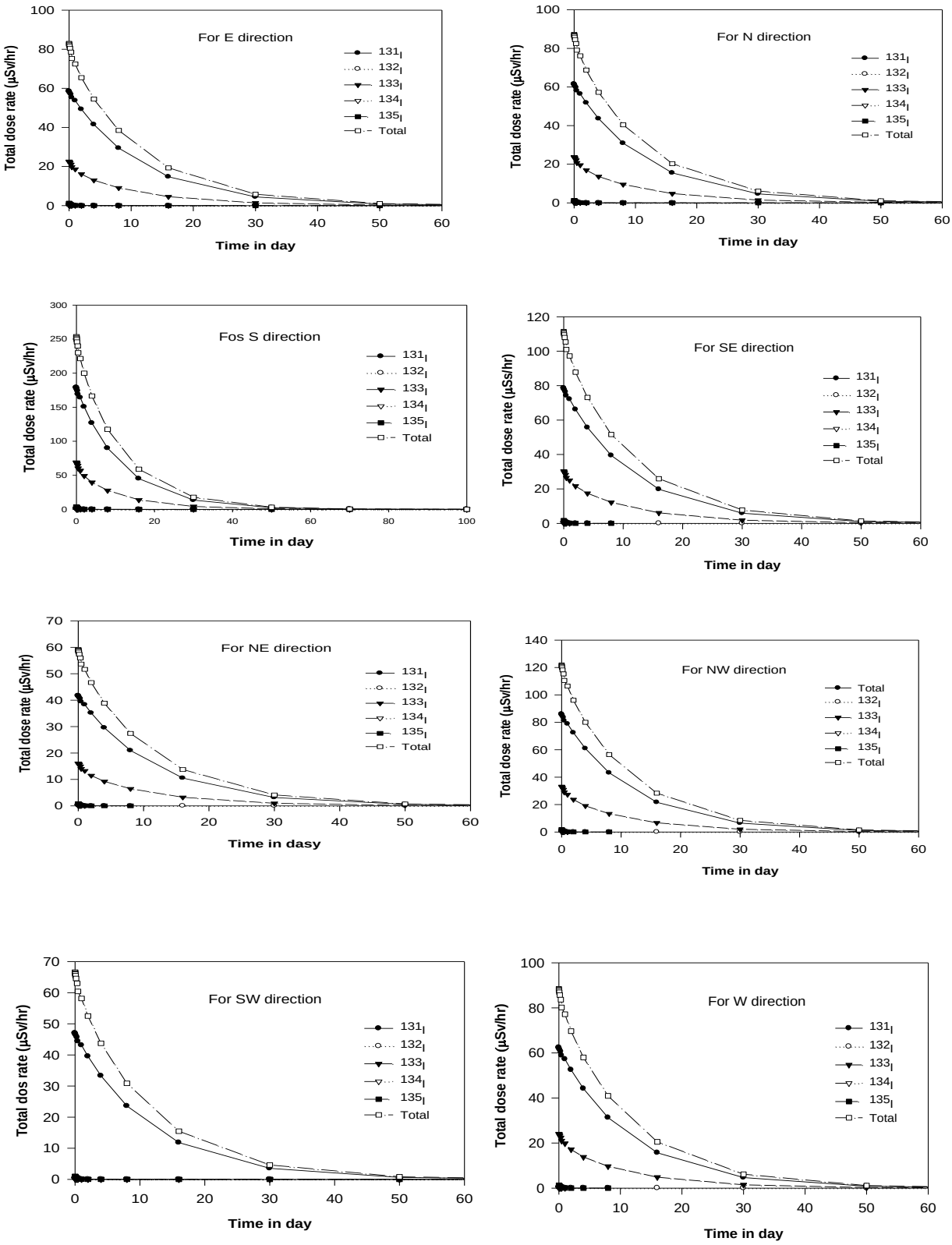

Fig. 3: Total dose rate (µSv/hr) as a function of time (day) for directions E, NE, NW, S, SE, SW, W and N.

5 Results and Discussion

A computational code has been developed to solve the mathematical expressions in order to calculate the dose of each radionuclide of interest. The code is simple, user friendly and has been developed using MathCAD Professional Software. The code consists of two parts. Source-term can be calculated using the first part and concentration as well as doses in different environmental media can be calculated using the second part of the code. The input parameters were measured for the TRIGA Mark-II reactor site, at AERE, Savar, Dhaka. The radiological dose was estimated in different foodstuff due to accidental release of radioiodine through the stack of the 3 MW TRIGA Mark-II research reactor. The results of the measurements are given in the following segments.

5.1. Dose Contribution (%) to Each Pathway

Dose to the human in different pathways such as, food ingestion, inhalation and immersion has been calculated in the present work.

The dose contribution corresponding to each pathway computed in S-direction for the isotopes of iodine and total are presented in Figs. 4, 5, 6, 7, 8, and 9 respectively. Similar nature of variation is found in all other directions as it does not depends on direction, but depends mainly on air concentration, ground concentration, concentration in milk and meat along the specific erection. It is apparent from the Fig. 4 that total dose from vegetation is the dominant contributor (62.96%) in total dose to the human due to ^{131}I compared to the doses from other pathways. Form Fig. 5 it is found that the dose due to ^{132}I from immersion is the main contributor (53.67 %) in total dose. Fig. 6 predicts that meat and milk are the principal pathways in dose contribution (45.64%) and 30.44%, respectively) for ^{133}I compared to other pathways. Fig. 7 shows that the main pathways in dose contribution due to ^{134}I are ground deposition and immersion (47.89%) and 46.13%, respectively), while from Fig. 8 it is observed that ground, inhalation, and immersion are the major pathways in dose contribution of ^{135}I (30.11%, 26.77%, and 25.92%, respectively). Fig. 9 depicts that vegetation is the dominant dose contributor (66.91%) due to total iodine compared to other pathways.

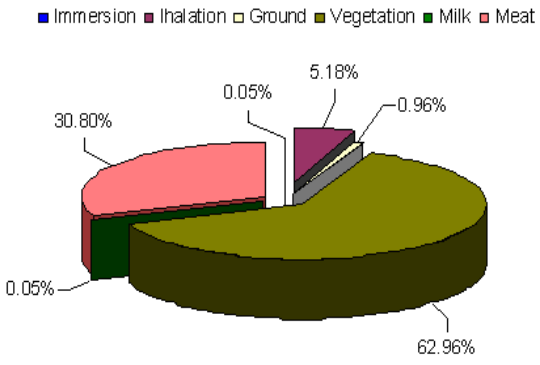

Fig. 4: Dose contribution (%) of ^{131}I in variety of pathways in S-direction.

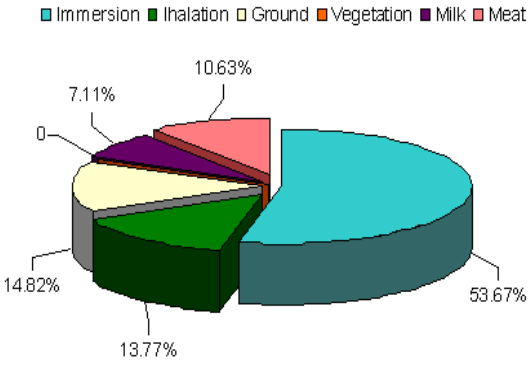

Fig. 5: Dose contribution (%) of ^{132}I in variety of pathways in S-direction.

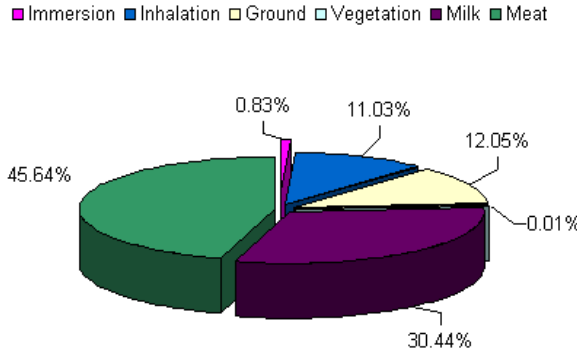

Fig. 6: Dose contribution (%) of ^{133}I in variety of pathways in S-direction.

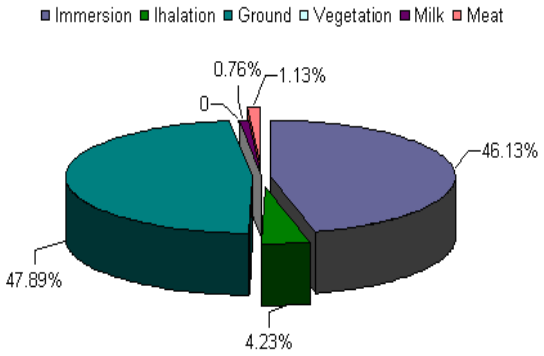

Fig. 7: Dose contribution (%) of ^{134}I in variety of pathways in S-direction.

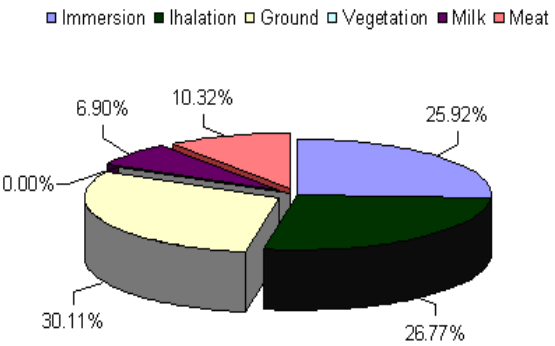

Fig. 8: Dose contribution (%) of ^{135}I in variety of pathways in S-direction.

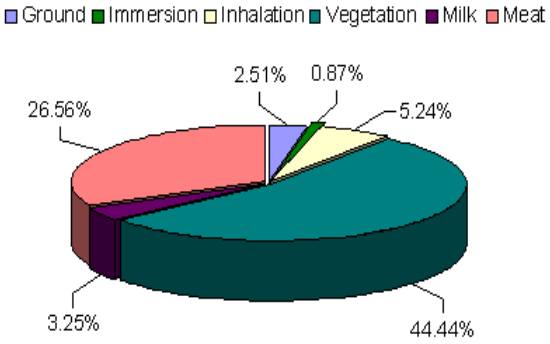

Fig. 9: Dose contribution (%) of Iodine (^{131}I, ^{132}I, ^{133}I, ^{134}I, ^{135}I) in different pathways in S-direction.

5.2. Relation between Air Concentration and Collective Dose for Different Pathways

In this work a hypothetical accident has been considered in which the radionuclides were ejected through the stack into the environment. So a perceptible amount of radionuclides would be concentrated in the air. This concentrated radionuclide will be exposed externally and internally to the human through different pathways. Hence air concentration is a key factor in measuring the total dose rate. It is important to know the relationship between air concentration and total dose for different pathways. Air concentration of ^{131}I, ^{132}I, ^{133}I, ^{134}I, and ^{135}I for eight directions with varying downwind distance was calculated and then corresponding total dose for different pathways for each concentration has also been calculated. Finally total dose and air concentration are plotted which has been shown in Fig. 10. From this figure it is clear that the total doses in different pathways are directly proportional to the air concentration. The relations between total dose rate and air concentration in different directions for ^{131}I, ^{132}I, ^{133}I, ^{134}I, and ^{135}I are given in Table 2. The table indicates that the constant of proportionality for ^{131}I in all the directions are nearly equal and for ^{132}I, ^{133}I, ^{134}I, and ^{135}I are also separately equal. Thus it can be concluded that the general relation between the total dose for different pathways and air concentration for ^{131}I, ^{132}I, ^{133}I, ^{134}I, and ^{135}I are given by:

$$\text{Total Dose} = 0.13699 \times \text{Air concentration for } ^{131}\text{I} \quad (17)$$

$$\text{Total Dose} = 0.00076 \times \text{Air concentration for } ^{132}\text{I} \quad (18)$$

Total Dose = 0.03512 × Air concentration for ^{133}I (19)
Total Dose = 0.00104 × Air concentration for ^{134}I (20)
Total Dose = 0.00111 × Air concentration for ^{135}I (21)

There general equations could be applied to the calculation of total dose rate (μSv/hr) for different pathways from air concentration (Bq/m^3) around the reactor facility.

6 Conclusions

In this present work, a computational code was developed valid only for radioisotopes of iodine, such as ^{131}I, ^{132}I, ^{133}I, ^{134}I, and ^{135}I using MathCAD software for the assessnebt of radiological dose around the TRIGA Mark-II research reactor facility. Before dose calculation, site specific data-mainly the meteorological parameters such as wind speed, wind frequency, wind direction were analyzed. Using the measured site characteristics data, radiological consequences including the activity concentrations as well as probable doses to the member of the public in different pathways (immersion, inhalation, ground deposition, and ingestion from vegetation, milk and meat) for the above mentioned isotopes of iodine were also estimated. The relationship between air concentration and total dose of different pathways has also been established in this work.

Table 2: Relationship for total dose for different pathways and air concentration

Direc-tions	**Relation for ^{131}I**	**Relation for ^{132}I**	**Relation for ^{133}I**	**Relation for ^{134}I**	**Relation for ^{135}I**
N	Total Dose = 0.13699 × Air Concentration	Total Dose = 0.000766 × Air Concentration	Total Dose = 0.035127 × Air Concentration	Total Dose = 0.001041 × Air Concentration	Total Dose = 0.00115 × Air Concentration
NE	Total Dose = 0.136995 × Air Concentration	Total Dose = 0.000767 × Air Concentration	Total Dose = 0.035126 × Air Concentration	Total Dose = 0.001038 × Air Concentration	Total Dose = 0.00115 × Air Concentration
E	Total Dose = 0.13699 × Air Concentration	Total Dose = 0.000766 × Air Concentration	Total Dose = 0.035091 × Air Concentration	Total Dose = 0.00104 × Air Concentration	Total Dose = 0.00115 × Air Concentration
SE	Total Dose = 0.136995 × Air Concentration	Total Dose = 0.000766 × Air Concentration	Total Dose = 0.035124 × Air Concentration	Total Dose = 0.001043 × Air Concentration	Total Dose = 0.00115 × Air Concentration
S	Total Dose = 0.136947 × Air Concentration	Total Dose = 0.000766 × Air Concentration	Total Dose = 0.035127 × Air Concentration	Total Dose = 0.001041 × Air Concentration	Total Dose = 0.00115 × Air Concentration
SW	Total Dose = 0.136993 × Air Concentration	Total Dose = 0.000766 × Air Concentration	Total Dose = 0.035124 × Air Concentration	Total Dose = 0.00104 × Air Concentration	Total Dose = 0.00115 × Air Concentration
W	Total Dose = 0.142167 × Air Concentration	Total Dose = 0.000765 × Air Concentration	Total Dose = 0.035125 × Air Concentration	Total Dose = 0.001043 × Air Concentration	Total Dose = 0.00150 × Air Concentration
NW	Total Dose = 0.09932 × Air Concentration	Total Dose = 0.000555 × Air Concentration	Total Dose = 0.025466 × Air Concentration	Total Dose = 0.000756 × Air Concentration	Total Dose = 0.00083 × Air Concentration

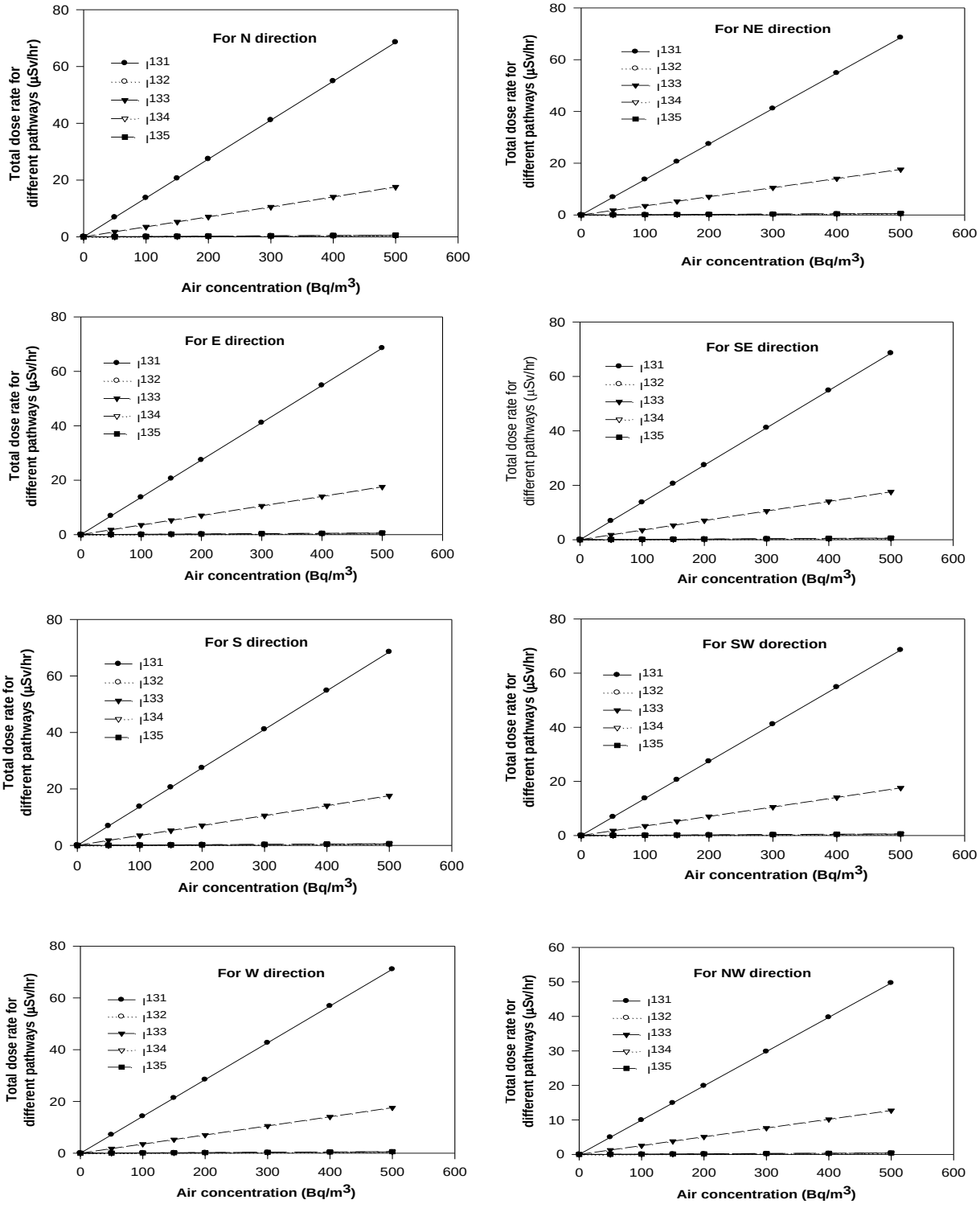

Fig. 10: Total dose rate for different pathways (µSv/hr) as a function air concentration (Bq/m^3) for directions N, NE, E, SE, S, SW, W and NW.

Doses for immersion in radioactive plum, inhalation of radioactive gas, ground deposition, and dose for ingestion of vegetation, milk and meat for ^{131}I, ^{132}I, ^{133}I, ^{134}I, and ^{135}I were measured in different pathways. Contribution of dose from ingestion of vegetation due to ^{131}I

has been found to be dominant (62.96%) than all other pathways. It was also found that contribution of ^{132}I from immersion is higher (53.67%) than that of other pathways while the contribution of ^{133}I in meat is higher (45.64%) than that of other pathways. The contribution due to ^{134}I in both from immersion (46.13%) and from ground deposition (47.19%) was dominant compared with other pathways while the contribution of ^{135}I from ground deposition (30.11%), inhalation (26.77%) and immersion (25.92%) were higher than that of other pathways. Finally, it was found that the vegetation is the dominant contributor (44.44%) for iodine ($^{131}I+^{132}I+^{133}I+^{134}I+^{135}I$) compared with other pathways.

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