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Radiological Concentration Distribution of ^{134}Cs and ^{137}Cs Due to a Hypothetical Accident of TRIGA Research Reactor

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Abstract

The assessment of the radiological concentration of ^{134}Cs and ^{137}Cs owing to hypothetical accident of TRIGA Mark-II research Reactor at AERE, Savar, Bangladesh is presented here in this work. The concentration of ^{134}Cs and ^{137}Cs was estimated in different pathways consisting of the ingestion of plants, milk, and meat. The highest air concentration has been determined at 65 m distance from the core of the reactor. The maximum concentration passed off without delay simply after the accident in various directions. Local meteorological information such as average wind velocity and wind frequency were analyzed. Considering all directions, the highest concentration has been observed in the "S" direction. The concentrations of ^{134}Cs and ^{137}Cs were determined in ground, vegetation, milk and meat. The concentration of ^{137}Cs is investigated to be higher than the ^{134}Cs. The concentration of ^{134}Cs and ^{137}Cs was found to be lower in vegetation, milk, and meat than that of ground concentration. Overall, in this study, the concentration in meat has been investigated to be lower. In case of a reactor accident, the concentration assessment due to the ingestion of vegetables, milk, and meat will be a valuable guide for insuring radiological protection across the research reactor at AERE, Savar, Bangladesh.

Keywords

Concentration, Hypothetical Accident, Pathway, Radiological Protection, TRIGA Mark-II

1. Introduction

Atmospheric dispersion modeling and radiation concentration calculations for

hypothetical or probable release of radio nuclides are crucial for background radiation information and licensing necessities for the choice of a site prior to nuclear activities which includes nuclear facility. The reactor operation license is executed as per global selected criteria by means of the local regulatory authorities [1]. It's been shown that nuclear research reactors, under their normal operation, release no massive quantity of radioactivity to the surroundings. However, under accidental situations with severe core damage to the nuclear reactor, some meaningful quantity of radio nuclides may be released into the atmosphere. Radio nuclides that are genuinely anticipated to be emitted through the stack can bring about direct radiation exposure to the population and the atmosphere in downwind distance and that also be deposited on ground and vegetation [2] [3].

In the event of a release of radioactive substance into the atmosphere, the dispersion takes place relying on climate situations, resulting in deposition in-ground and other environ mental media such as vegetables, meat, and milk and finally accumulated in human beings. The dispersion additionally depends upon several parameters inclusive of the release condition (release height from the ground, the leak rate), topography (soil, presence of boundaries), and nature of the source. In this work, we focus on the behavior of ground deposition, vegetation, milk, and meat because radio nuclides are predictable to be released considering hypothetical accident of TRIGA Mark-II research reactor, Atomic energy research establishment (AERE), Savar, Dhaka, Bangladesh. When cattle (cows, oxen, and so on) are fed vegetation, their milk and meat turn out to be contaminated. The radioisotopes along with ^{134}Cs and ^{137}Cs just after the accident show the maximum severe risks [2]. To evaluate doses, it's no doubt to make up the concentration of radio nuclides is important. Various methodologies and assumptions have been taken to determine concentration suggesting the necessity of site-precise meteorological information. In this regard, IAEA generic methodologies to evaluate the radiological consequence due to the discharge of radioactive substances in the environment have been taken into consideration [4] [5]. A computational code has been developed to predict the concentration of ^{134}Cs and ^{137}Cs based on methodologies and hypothetical accidental scenario. In this work, 40% of radioactive cesium was considered to be released from the core of the reactor to the surrounding environment [5].

2. Source Term and Accident Scenario

The source term represents the amount of the radioactive materials which are released to the containment. Source term is a very important term to determine the radioactive concentration in a nuclear research reactor. An approximate principle giving activity $A_i(t)$ of an isotope i at time t after the beginning of irradiation ($t = 0$) whose fission yield is γ and its decay constant be λ_i irradiated for a time period T in P (megawatts off thermal power) can be written [5] as:

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

The Release rate is the exhaust rate from the stack. It is an essential factor that has to be determined in the case of assessing air concentration. The equation can be represented by [5]:

$$Q_1(\tau) = F_P F_B A_i(t) \frac{\lambda_1}{\lambda_1 + \lambda_r}\left[1 - e^{-(\lambda_1+\lambda_r)\tau}\right], \quad (2)$$

where F_P is the fraction release the fuel to building, F_B is the fraction remaining airborne and available to be released from the building to the atmosphere, A_i is the Activity term, λ_1 is the lake rate parameter, $\sec^{-1}$, and λ_r is the radioactive decay constant, $\sec^{-1}$.

Some logical assumptions have been noted for solving the calculation of the present work. These assumptions are: 1) the reactor was operated at full power, *i.e.* 3 MW (t); and considered the irradiation time of 10 days with continuous operation at full-powered. 2) The release of radio nuclides from the reactor stack to the atmosphere was considered 4 hours after the accident. 3) Two radio nuclides such as ^{134}Cs ($T_{\frac{1}{2}} = 2.0652$ y) and ^{137}Cs ($T_{\frac{1}{2}} = 30.17$ y) were considered for radiological concentration assessment. 4) Fraction release of Cesium was considered 40% to develop an inventory. Leak rate parameter is considered, $\lambda_1 = 1.157 \times 10^{-7}\ \sec^{-1}$, *i.e.*, 1%/day [4].

Considering the above assumptions, the activity of cesium ^{134}Cs and ^{137}Cs were by using of Equation (1). The estimated activity and release rate of radio cesium along with their uncertainty for 10 days continuous operation at 3 MW (t) power level is given in Table 1.

3. Atmospheric Dispersion and Radiological Concentration Calculation Model

For estimating downwind concentrations of airborne material released into the atmosphere, the Gaussian Plume Model (GPM) is the maximum widely used method. Inside the utility of this version, which has been validated under widely different kinds of meteorological conditions. It's assumed that the plume will spread each laterally and vertically in accordance with a Gaussian distribution.

For a continuous release from an elevated point source under consistent diffusion conditions (*i.e.* wind route, wind velocity, and atmospheric balance) and taking into account plume reflection at ground level, the concentration $x(x, y, z)$ is given by means of [3].

Table 1. Inventory of ^{134}Cs and ^{137}Cs for 10 days operation at 3 MW (t) power level.

Radionuclide	Fission Yield	Total activity in core (C_i)	Released rate (Bq/sec)	Released rate (C_i/hr)
^{134}Cs	1.33×10^{-7}	$2.53 \times 10^{-3} \pm 3.59 \times 10^{-5}$	$1.03 \times 10^{1} \pm 1.48 \times 10^{-1}$	$2.77 \times 10^{-10} \pm 3.99 \times 10^{-12}$
^{137}Cs	6.22×10^{-2}	$8.17 \times 10^{1} \pm 1.27$	$3.33 \times 10^{5} \pm 5.68 \times 10^{3}$	$8.99 \times 10^{-6} \pm 1.53 \times 10^{-7}$

$$x(x,y,z)=\frac{\varrho_i}{2\pi\cdot\sigma_y\cdot\sigma_z\cdot\upsilon_a}\exp\left(\frac{-y^2}{2\sigma_y^2}\right)\left\{\exp\left[-\frac{(z-h)^2}{2\sigma_z^2}\right]+\exp\left[-\frac{(z+h)^2}{2\sigma_z^2}\right]\right\} \quad (3)$$

where, $x(x, y, z)$ = air concentration (Bq/m^3) at a point with co-ordinates x, y, z, x= downwind distance (m), y = crosswind distance (m), z = height above the ground (m), Q = release rate (Bq/s), σ_y, σ_z = diffusion parameters (m) which are a function of downwind distance, x, and atmospheric stability, h = effective release height (m).

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

$$x=\frac{Q}{\pi\upsilon\sigma_y\sigma_z}\exp\left(-\frac{h^2}{2\sigma_z^2}-\frac{y^2}{2\sigma_y^2}\right) \quad (4)$$

The average concentration for release that happens over a time period can be calculated by making use of the above equation. If the radiological substance has a massive exit velocity (or if it's far at a high temperature), it's going to move up to a higher stage than the actual stack height. Hence the effective stack height may be written as [6]

$$H_{eff}=H+D\left(\frac{v}{u}\right)^{14}\left(1+\frac{\Delta T}{T}\right) \quad (5)$$

wherein D = 0.26 m, is the outlet stack diameter, v = 16.15 ms^{-1}, is the exit speed, ΔT is the distinction between ambient and effluent gas temperature, T is the absolute temperature of the effluent on the other hand for a research reactor like a TRIGA Mark-II at AERE, Savar, the temperature distinction, ΔT can be considered to 0 due to energetic operation of the ventilation system. Here, u = 1.56 ms^{-1}.

It is vital to convert the velocity into an effective stack height implementing the subsequent formula [3]

$$u=u_z\left(\frac{H_{eff}}{z}\right)^m, \quad (6)$$

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.

Currently, there's no meteorological station in the AERE complex and as such, all of the data have been collected from The Bangladesh Meteorological Department (BMD), Dhaka Station located approximately at a distance of 40 km from the actual site. Wind velocity and frequency have been analyzed based on the raw data collected from the BMD, Dhaka. The percentage of average wind frequencies and average wind speed for various directions are shown in **Figure 1** and **Figure 2**, respectively. It is able to be located from **Figure 1** that the average frequency in the SSE direction is dominated across the reactor site. The BMD, Dhaka has provided wind speed at 10 m height which has been converted as at effective stack height, *i.e.* 32.36 m (**Figure 2**). For higher wind velocity, the

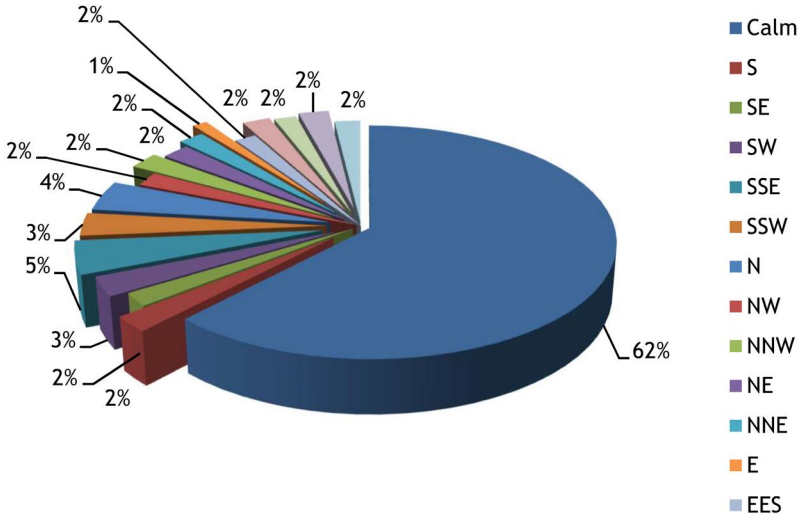

Figure 1. The percentage of average wind frequencies for various directions.

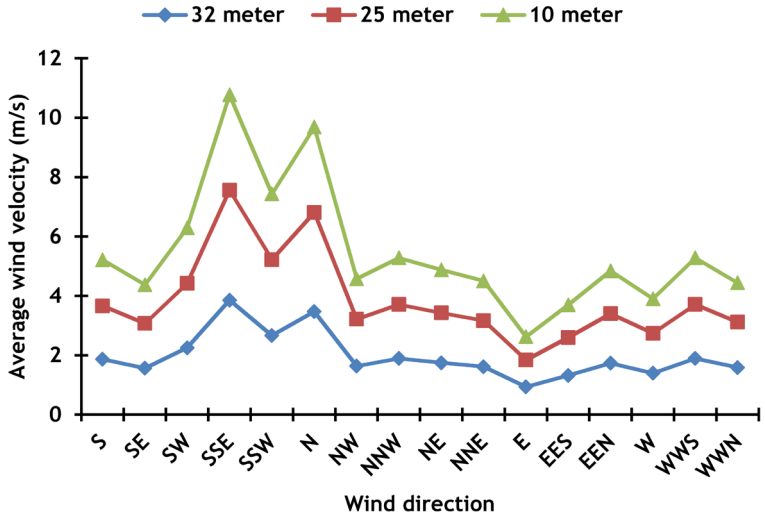

Figure 2. The percentage of average wind frequencies for various directions.

dispersion is expected to follow to a protracted distance depending on the stability class around the site and release height. Then again, air concentration can be high in a path if the wind frequency is excessive in that path. From this result, the leading stability class of the site is discovered to be "A" in keeping with the Pasquill-Gifford stability category. Parameters required for radiological concentration assessment need to be taken for this stability class.

The strategies offered in this phase to be used in instances that don't include building wake outcomes.

In this case, the arena averaged from of the GPM may be used with the following simplifying assumptions:

1) For each air concentration calculation, a single wind velocity and frequency are to be taken.

2) A single long-term average wind speed for every route.

3) An impartial atmospheric stability class (Pasquill-Gifford stability class (A)

[3].

Based on the above assumptions, the version for atmosphere dispersion may be represented via the equation [4]

$$C_A = \frac{P_P F Q_1}{U_a} \exp\left(-\lambda_i \frac{x}{u_a}\right), \tag{7}$$

where C_A is the ground level concentration at downwind distance x in sector p (Bq/m^3), P_P is the fraction of the time during the year 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, F is the Gaussian diffusion factor appropriate for the height of release H and the downwind distance x being considered (m^{-2}), Q_i is the annual average discharge rate for radionuclide i (Bq/s).

$$F = \frac{12}{\sqrt{2\pi}^3} \times \frac{\exp\left[-\left(H^2/2\sigma_z^2\right)\right]}{x\sigma_z} \tag{8}$$

where σ_z is the vertical diffusion parameter (m). σ_z can be calculated on the basis of the relationship [3]

$$\sigma_z = P_z \cdot x^{qz}. \tag{9}$$

where P_z and x^{qz} are two parameters depending on the stability class and on the effective stack height, and x is the downwind distance.

Here for stability class "A", $P_z = 0.151$ and $q_z = 1.291$ [3]. The relationship between gaussian plume diffusion factor and downwind distance for a given release height (H) is shown in **Figure 3**.

4. Radiation Concentration Calculation

The concentration calculation methodologies using GPM are described elsewhere [7]. The methodologies of concentration calculation in pathways are given in the following segments.

4.1. Ground Deposition

Activity concentrations of radio nuclides on the ground may be calculated certainly

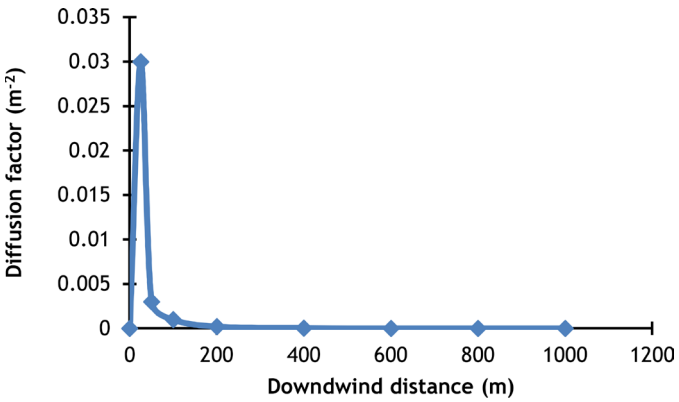

Figure 3. Relationship between gaussian plume diffusion factor and downwind distance for a given release height (H).

with the aid of the use of ratios representing the quantity of activity deposited on the ground per unit time and the ground level air concentration. These ratios are known as deposition velocities or, better, deposition coefficients because their physical meaning isn't always that of speed. For generic evaluation purposes, the following relationship is used

$$d_i = \left(V_d + V_w\right) C_A \tag{10}$$

where d_i is the total daily average deposition rate on the ground of a given radionuclide *i* from both dry and wet processes, including deposition either on to impervious surfaces or on to both vegetation and soil (Bq·m^{-2}·d^{-1}); v_d is the dry deposition coefficient for a given radionuclide (m/d); v_w is the wet deposition coefficient for a given radionuclide (m/d). $v_T = v_d + v_w$, total deposition coefficient. v_T = 1000 m/d is considered which is found in radiocesium at the Chernobyl nuclear power station in 1986 [4]. The deposition rate may be used to calculate the radionuclide concentration on vegetation because of direct contamination and the concentration of radionuclide in dry soil. The ground concentration specifically depends on the ground deposition in the earlier section. It also depends on the effective rate constant and period of the discharge of the radioactive material. The ground concentration can be calculated by using the equation [4].

$$C_{gr} = \frac{d_i \left[1 - \exp\left(-\lambda_{E_i^S} t_b\right)\right]}{\lambda_{E_i^S}} \tag{11}$$

where, d_i is the total ground deposition rate (Bq·m^{-2}·d^{-1}); $\lambda_{E_i^S}$ is the effective rate constant for reduction of the activity in root zone of soils (d^{-1}); $\lambda_{E_i^S} = \lambda_i + \lambda_s$, λ_s is the rate constant for reduction of soil activity owing to processes other than radioactive decay; λ_i = radio decay constant t_b is the duration of the discharger of radioactive material (d). The default value of $\lambda_s = 0.00014\left(\mathrm{d}^{-1}\right)$, $\lambda_i\left(^{134}\mathrm{Cs}\right) = 9.22\times10^{-4}\left(\mathrm{d}^{-1}\right)$, $\lambda_i\left(^{134}\mathrm{Cs}\right) = 6.33\times10^{-5}\left(\mathrm{d}^{-1}\right)$ and $t_b = 1.1\times10^{4}\left(\mathrm{d}\right)$ [4].

4.2. Concentration Is Vegetation

Radio nuclides intercepted by using and retained on vegetation may additionally result from fallout, washout, and irrigation with infected water or deposition of resuspended matter external deposits can be taken up by means of foliar absorption into plants. Radio nuclides can also be included with the aid of uptake from the soil through roots, observed by way of internal redistribution of radio nuclides in the plant. Techniques that may lead to the reduction of radionuclide concentrations in vegetation consist of radioactive decay, growth dilution, wash-off of externally deposited radio nuclides, leaching, and soil fixation. In addition, removal of radioactive material from vegetation may additionally occur because of grazing, harvesting, etc. For situations of extended deposition, together with from discharges, the subsequent equation may be used to estimate the concen-

tration $C_{v,i,1}$ due to direct infection of nuclide Cs in and on vegetation,

$$C_{v,i,1} = \frac{d_i \alpha \left[1 - \exp\left(-\lambda_{E_i^v} t_e\right)\right]}{\lambda_{E_i^v}} \tag{12}$$

$C_{v,i,1}$ is measured in Bq/kg dry matter for vegetation consumed by grazing animals and Bq/kg fresh matter for vegetation consumed by humans. d_i is the deposition rate of radionuclide *i* onto the ground (Bq·m^{-2}·d^{-1}) α is the fraction of deposited activity intercepted by the edible portion of vegetation per unit mass. $\lambda_{E_i^v}$ is the effective rate constant for reduction of the activity concentration of radionuclide from crops (d^{-1}), where $\lambda_{E_i^v} = \lambda_i + \lambda_w$. $\lambda_w = 0.05$ d^{-1} [4], t_e is the time period that crops are exposed to contamination during the growing season (d). $t_e = 60$ (d) [4], λ_w is the rate constant for reduction of the concentration of material deposited on the plant surfaces owing to processes other than radioactive decay (d^{-1}). λ_i is the rate constant for the radioactive decay of radionuclide *i* (d^{-1}).

The concentration of radionuclide in vegetation resulting from indirect processes from uptake from the soil and from soil adhering to the vegetation—is

$$C_{v,i,2} = F_v \times C_{s,i} \tag{13}$$

where $C_{v,i,2}$ is measured in Bq/kg dry matter for vegetation consumed by grazing animals and Bq/kg fresh matter for vegetation consumed by humans. F_v is the concentration factor for uptake of the radionuclide from the soil by edible parts of crops (Bq/kg plant tissue per Bq/kg dry soil), $C_{s,i}$ is the concentration of radionuclide *i* in dry soil (Bq/kg), $C_{s,i}$ is defined by

$$C_{s,i} = \frac{d_i \left[1 - \exp\left(\lambda_{E_i^s} t_b\right)\right]}{\rho \lambda E_i^s} \tag{14}$$

$\lambda_{E_i^S} = \lambda_i + \lambda_s$, λ_s is the rate constant for reduction of soil activity owing to processes other than radioactive decay; λ_s is the great constant for reduction of the concentration of material deposited in the root zone of soils owing to process other than radioactive decay (d^{-1}), t_b is the duration of the discharger of radioactive material (d), ρ is a standardized surface density for the effective root zone in soil (kg/m^2, dry soil). $\rho = 260$ [3].

The total concentration of the radionuclide on the vegetation at the time of consumption is

$$C_{v,i} = \left(C_{v,i,1} + C_{v,i,2}\right) \exp\left(-\lambda_i t_h\right) \tag{15}$$

where $C_{v,i,1}$ and $C_{v,i,2}$ is measured in Bq/kg dry matter for vegetation consumed by grazing animals and Bq/kg fresh matter for vegetation consumed by humans. t_h is a decay (hold-up) time that represents the time interval between harvest and consumption of the food (d). $t_h = 14$ d [4].

4.3. Concentrations in Animal Feed

The concentration of radionuclide *i* in animal feed is calculated with the aid of

$$C_{a,i} = f_p C_{v,i} + \left(1 - f_p\right) C_{p,i} \tag{16}$$

$C_{a,i}$ is the concentration of radionuclide i in the animal feed (Bq/kg, dry matter); $C_{v,i}$ is the concentration of radionuclide i for pasture, the calculated using Equations (12)-(15) with t_h = 0 (Bq/kg, dry matter), $C_{p,i}$ is the concentration of radionuclide in stored feeds (Bq/kg, dry weight), calculated using Equations (12)-(15), and substituting $C_{p,i}$ for $C_{v,i}$ with t_h = 90 d [4], f_p is the fraction of the year that animals consume fresh pasture vegetation. f_p = 0.7 [4].

4.4. Concentrations in Milk

The concentration of a radionuclide in milk relies upon without delay the radioactivity concentration of the feed consumed with the aid of the lactating animal. With the value of $C_{a,i}$ calculated with Equation (16), and the concentration in drinking water $C_{w,i}$ calculated in, the concentration of radionuclide i in milk is predicted as

$$C_{m,i} = F_m \left(C_{a,i} Q_m + C_{w,i} Q_w\right) \exp\left(-\lambda_i^t m\right) \tag{17}$$

where $C_{m,i}$ is the concentration in the milk of radionuclide i (Bq/L), F_m is the fraction of the animal's daily intake of the radionuclide that appears in each liter of milk at equilibrium (d/L). For Cs F_m = 0.3 [4], $C_{a,i}$ is the concentration of radionuclide i in the animal feed (Bq/kg, dry matter); $C_{w,i}$ is the concentration of radionuclide i in water (Bq/m^3), Q_m is the amount of feed (in dry matter) consumed by the animal per day (kg/d). Q_m = 16 kg/d (dry weight) [4], Q_w is the amount of water consumed by the animal per day (m^3/d), Q_w = 0.06 (m^3/d) [4], t_m is the average time between collection and consumption of milk, t_m = 1 [4].

4.5. Concentrations in Meat

The radionuclide concentration in meat is calculated in the same way as the concentration in milk. The same constraints exist.

$$C_{f.i} = F_m \left(C_{a.i} Q_f + C_{w,i} Q_w\right) \exp\left(-\lambda_i^t f\right) \tag{18}$$

where, $C_{f.i}$ is the concentration of radionuclide i in animal flesh (Bq/kg), F_m is the fraction of the animal's daily intake of the radionuclide that appears in each liter of milk at equilibrium (d/L). For Cs F_m = 0.3 [4], $C_{a,i}$ is the concentration of radionuclide i in the animal feed (Bq/kg, dry matter); $C_{w,i}$ is the concentration of radionuclide i in water (Bq/m^3), Q_f is the amount of feed (in dry matter) consumed by the animal per day (kg/d). Q_f = 12 kg/d (dry weight) [4], Q_w is the amount of water consumed by the animal per day (m^3/d).

Q_w = 0.06 (m^3/d) [4], λ_i is the rate constant for radioactive decay of radionuclide i (d^{-1}), t_f is the average between slaughter and human consumption of meat—a default value is 20 days [4].

5. Result and Discussion

To evaluate the concentration of each radionuclide a computational code has

been developed using Math-CAD professional software program to find out mathematical expressions. Source term and concentration distribution were evaluated using the developed code. The meteorological parameters such as wind velocity and wind frequency were estimated for calculating concentration. For different food-stuffs such as vegetation, milk, and meat owing to the accidental release of radiocesium from the TRIGA Mark-II reactor at AERE, Savar, Dhaka, Bangladesh was considered. The air concentration was estimated with respect to downwind distance. Concentration in vegetation, milk, and meat was evaluated for 8 cardinal directions as the function of time. Concentration was found to be higher in the south ("S") direction.

Table 1 shows the inventory (source-term) with statistical uncertainty for ^{134}Cs and ^{137}Cs. Both the activity in the core and corresponding release rate are found to be higher for ^{137}Cs than that of ^{134}Cs. The meteorological parameters such as wind frequency and wind velocity are presented in Figure 1 and Figure 2, respectively. The highest air concentration has been investigated at a 65 m distance from the core of the reactor and it was observed to be maximum towards the "S" direction shown in Figure 4 and Figure 5. The concentrations of ^{134}Cs and ^{137}Cs have been calculated in the ground. The maximum ground concentration appeared simply after the accident in various media and is depicted in Table 2. Maximum ground concentration was found in the "S" direction. With the passes of time, the ground concentration is found to be reduced exponentially due to radioactive decay. The radioactive materials move via ingestion to

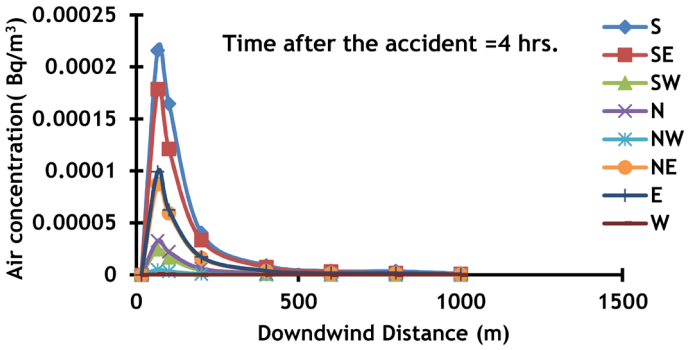

Figure 4. Air concentration as a function of downwind distance for ^{134}Cs.

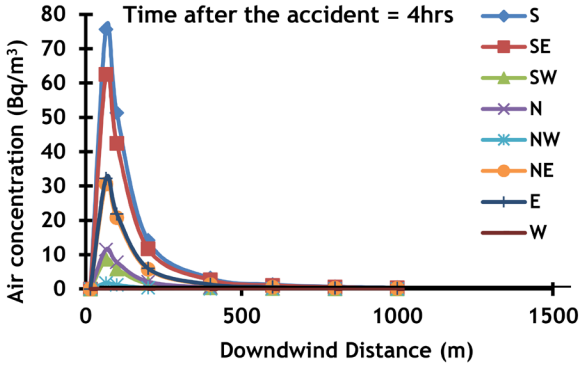

Figure 5. Air concentration as a function of downwind distance for ^{137}Cs.

plants and then to meat and milk.

In vegetation, the activity concentration takes place because of the direct deposition of air-born radio nuclides on the edible chunk of the vegetables and uptake from soil. In vegetation, the concentration of ^{134}Cs and ^{137}Cs are shown in Table 3. The concentration of vegetation of ^{134}Cs is lower owing to its short half-life in contrast the concentration of vegetation of ^{137}Cs is higher for its long half-life. It's also found that concentration in vegetation is decreased with time after occurring the accident. The sequence of concentration in the vegetation of cesium is $C_{veg}{}^{137}Cs > C_{veg}{}^{134}Cs$.

The radio nuclides in milk are seen owing to the consumption of contaminated feed by the lactating animal and the concentration in milk depends directly upon the radioactivity concentration of the feed consumed by the lactating animal. The concentration of ^{134}Cs and ^{137}Cs in milk in different directions is shown in Table 4. The concentration in milk at t = 0 is highest after the accident. The concentration in milk to be decreased and the sequence of the concentration of cesium in milk is $C_{milk}{}^{137}Cs > C_{milk}{}^{134}Cs$.

Table 2. Maximum ground concentration for different directions at time $t = 0$ (*i.e.* just after the accident).

Direction	Ground concentration (Bq/m^2)	
	^{134}Cs	^{137}Cs
S	203.231	3.323×10^8
SE	168.046	2.748×10^8
SW	23.136	3.783×10^7
N	30.862	5.047×10^7
NW	4.709	7.7×10^6
NE	82.291	1.36×10^8
W	86.951	1.416×10^8
E	0.502	8.205×10^5

Table 3. Maximum concentration in vegetation for different directions at time $t = 0$ (*i.e.* just after the accident).

Direction	concentration in vegetation (Bq/kg)	
	^{134}Cs	^{137}Cs
S	1.266	1.061×10^8
SE	1.046	8.775×10^7
SW	0.144	1.208×10^7
N	0.192	1.612×10^7
NW	0.029	2.459×10^6
NE	0.512	4.297×10^7
E	0.539	4.522×10^7
W	3.125×10^{-3}	2.62×10^5

Table 4. Maximum concentration in meat for different directions at time $t = 0$ (*i.e.* just after the accident).

Direction	concentration in meat (Bq/kg)	
	^{134}Cs	^{137}Cs
S	1.519	271.883
SE	1.256	224.812
SW	0.173	30.951
N	0.231	41.287
NW	0.035	6.3
NE	0.615	110.088
E	0.647	115.849
W	749×10^{-3}	0.67

Table 5. Maximum concentration in milk for different direction at time $t = 0$ (*i.e.* just after the accident).

Direction	concentration in milk (Bq/L)	
	^{134}Cs	^{137}Cs
S	2.025	1.698×10^{8}
SE	1.674	1.404×10^{8}
SW	0.231	1.933×10^{7}
N	0.307	2.578×10^{7}
NW	0.047	3.934×10^{6}
NE	0.82	6.875×10^{7}
E	0.863	7.235×10^{7}
W	4.999×10^{-3}	4.192×10^{5}

By depending so on the consumption of contaminated food, the concentration in meat occurs in the same way as the concentration in milk occurred. The concentration in meat shows in Table 5 just after the accident in 8 dominant directions. And again, the maximum concentration in milk was found in the same "S" direction. The concentration is decreased with time. As a result, we have got the sequence of concentration in meat in this paper for cesium is $C_{meat}{}^{137}Cs > C_{meat}{}^{134}Cs$.

6. Conclusion

In this study, concentrations in different pathways such as ground, vegetation meat and milk were investigated and based on atmospheric dispersion phenomena due to release of radio cesium from the TRIGA Mark-II research reactor at Savar in Dhaka, Bangladesh. The meteorological parameters such as wind velocity and wind frequency have also been analyzed. The air concentration was found to be highest at 65 m distance from the core of the reactor. The maximum magnitude of air concentration of ^{134}Cs and ^{137}Cs was observed in south ("S")

direction in contrast the minimum value has been examined in west ("W") direction. Though the air concentration was calculated with respect to downwind distance from the core of the reactor, the other concentration such as ground concentration, concentration in milk, vegetation and meat was determined as a function of time. The amount of concentration of radio cesium is found to be higher in ground than other pathways. On the other hand, concentration was observed to be lower in meat than other pathways. In all cases of concentrations, the highest concentration is possessed by ^{137}Cs. Due to its long half-life, there should be an awareness and caution about plants of vegetables grown in reactor site. This study obviously provides a proper guideline for nuclear research reactor on radiological safety measures that have to be considered for radiation protection from nuclear reactor site at AERE in case of radiological accident.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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