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Estimation of air-to-grass mass interception factors for iodine

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ABSTRACT

Air-to-grass mass interception factors for radionuclide are important basic input parameter for the estimation of radiation dose to the public around a nuclear power plant. In this paper, we present the determination of air-to- grass mass interception factors for iodine using a 2 m × 2 m × 2 m (l × b × h) size environmental chamber. The temperature, humidity, and rainfall inside the environmental chamber was controlled to required values to simulate different environmental conditions. Grass (*Pennisetum purpureum*, Schum), grown in pots, was kept inside the environmental chamber and stable iodine in elemental form was sublimed quickly inside the chamber to simulate an accidental release of iodine to the environment. The concentration of iodine in the air was measured periodically by drawing air through a bubbling setup, containing 1% sodium carbonate solution. The mass interception factor for dry deposition varied in the range of 0.25–7.7 $m^2\ kg^{-1}$ with mean value of 2.2 $m^2\ kg^{-1}$ with respect to fresh weight of grass, and that due to wet deposition varied in the range of 0.6–4.8 $m^2\ kg^{-1}$ with mean value of 2.3 $m^2\ kg^{-1}$. The mass interception factor was inversely correlated with the total iodine deposited through dry deposition as well as with the rainfall.

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1. Introduction

During the short initial phase (0–2 months) of release of radioactivity from a nuclear power plant, ^{131}I ($T_{1/2} = 8$ days) is the most important radionuclide as it rapidly transfers to milk, leading to significant thyroid dose to those consuming the milk, especially infants (Karunakara et al., 2012). This is because radioiodine released to the environment is intercepted by vegetation, which is grazed by cattle. The ingested radioiodine is completely absorbed in the gut of the cattle and rapidly transfers to the milk. Hence, from a radiological viewpoint, considerable attention should be paid to the levels and behaviour of radioiodine in the environment.

Air-to- grass radionuclide transfer parameters such as dry and wet deposition velocities and mass interception factors are important basic inputs for the estimation of radiation dose to the public around a nuclear power plant. Therefore, site-specific data on air-to- grass transfer is important for a quick evaluation of the environmental contamination, during both normal and abnormal operational phases of a nuclear facility. With this objective, a detailed study on air-to- grass and grass-to- cow milk transfer of iodine was carried out in Kaiga (14°51′ 08″N, 74°26′40″E), situated in the valley of the Western Ghats of India, about 60 km inland from coastal town Karwar where a nuclear power plant with 4 reactors of 220 MWe each is operating. A site specific study was essential for the Kaiga region because of several important features of this region. It has a unique topography as it is bounded by steep hills with dense forest, which is a natural habitat for a variety of plants that play a significant role in the environmental transport of radionuclides (Joshi et al., 2011). The annual rainfall is well over 4000 mm y^{-1} and this rainfall is higher when compared with the rainfall received by other nuclear power stations of India.

In the earlier publications, the soil-to- grass and grass-to- milk transfer coefficient (F_m) for iodine, ^{137}Cs, and ^{90}Sr for equilibrium situation as well as for a hypothetical emergency situation for Kaiga

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region (Karunakara et al., 2013a,b; Ujwal et al., 2012a,b,c; Geetha et al., 2014a,b) was reported. In this paper, result of laboratory experiments on air-to- grass mass interception factors are presented. Experiments were carried out by exposing grass to sudden release of iodine concentration in a walk-in type environmental chamber.

2. Materials and methods

Majority of the reported studies on deposition velocity and mass interception factors of ^{131}I on grass were carried out during the period of nuclear weapon testing (during 1950s and 1960s) or after the Chernobyl accident (IAEA, 1994; Chamberlain and Chadwick, 1966). Recently, in France, measurements of deposition rates of ^{131}I on grass due to the Fukushima accident were reported (Parache et al., 2011).

Under normal operational conditions of a nuclear power station, iodine radioisotopes are not present in measurable concentrations in the environmental matrices around the power station. This makes it difficult to estimate the mass interception factors of radioactive isotopes of iodine in field conditions. Hoffman et al. (1992) conducted field experiments by releasing radioactive iodine in elemental form over a grass field in order to estimate the deposition velocity and mass interception factors. The other option to evaluate air-to- grass transfer was to conduct experiments under simulated conditions using an environmental chamber (Singhal et al., 2004).

In the present study, a walk-in type environmental chamber of 2 m × 2 m × 2 m size (l × b × h) was designed and fabricated. The chamber, made of stainless steel, has facilities for (i) controlling temperature and humidity, (ii) exposing plants grown in pots to controlled levels of iodine concentrations, (iii) producing artificial rainfall, and (iv) ports for air sampling, injection of iodine vapours, etc.

The grass species, *Pennisetum purpureum,* Schum, commonly known as Napier grass and used as fodder grass in the milk dairies of the region, was grown in pots and kept inside the chamber, wherein environmental parameters such as humidity and temperature were controlled for required values. Stable iodine in elemental form was then sublimed quickly inside the chamber to generate known concentration of iodine in the air. This simulated an accidental release of iodine to the environment. The experimental arrangement for exposing the grass to iodine inside the environmental chamber is shown in Fig. 1. The concentration of iodine was measured periodically by drawing air sample from the chamber through a bubbling setup (consisting of three bubblers connected in series) containing 1% sodium carbonate solution (100 ml) at a flow rate of 3 L m^{-1} for 15 min (Fig. 2). After the sampling, the sodium carbonate solution was mixed with 2 ml hydroxylamine hydrochloride ($NH_2OH.HCl$) and acidified with 1:1 nitric acid (HNO_3). From this, iodine was extracted to the organic phase using toluene and mixed with sodium nitrite ($NaNO_2$). The concentration of iodine in the organic phase was measured based on the optical absorption of the solution at wavelength 518 nm using a Ultra violet-visible (UV–Vis) spectrophotometer (Karunakara et al., 2012). The exposure time of grass inside the chamber varied between 3 and 4 h. The concentration inside the chamber was monitored for every 30 min and the mean value of concentration was considered for the estimation of deposition velocity and mass interception factor.

The grass exposed to iodine was sampled, air dried and subjected to alkaline fusing and dissolution using a fusion mixture (Na_2CO_3+$NaNO_3$+NaOH). The extract was then treated similar to the air sample, and iodine was extracted with toluene, and the concentration was measured using a UV–vis spectrophotometer.

To estimate the iodine deposition velocity on the ground surface, experiments were performed by placing stainless steel trays, of known surface area, on the floor of the chamber. At the end of the experiment, the iodine deposited on the tray was collected by washing it with sodium carbonate solution and the concentration was measured as mentioned earlier. From the obtained inventory (mg m^{-2}), the deposition rate on the ground was estimated as follows:

$$d_i = C_d / T \quad (1)$$

where, d_i is the deposition rate (mg m^{-2} s^{-1}), C_d is the total deposited iodine concentration per unit area of tray (mg m^{-2}), and T is the time duration of deposition.

The deposition rate of iodine on grass was determined by considering the surface area of both sides of the grass leaves available for deposition. For the grass species used for this study, the mean surface area of the leaves per unit mass was found to be 46.4 m^2 kg^{-1} (w.r.t. fresh weight) and 9.9 m^2 kg^{-1} (w.r.t. dry weight). The deposition velocity (m s^{-1}) is the coefficient of dry/wet deposition rate and elemental concentration in air (mg m^{-3}) and it was determined as follows (Chamberlain and Chadwick, 1966; Hoffman et al., 1989):

$$V_d = d_i / C_a \quad (2)$$

where, V_d is the deposition velocity (dry or wet), d_i is the deposition rate (mg m^{-2} s^{-1}), and C_a is the iodine concentration in air (mg m^{-3}).

The mass interception factor (α) (m^2 kg^{-1}) is the fraction of total concentration of radionuclide deposited on the ground by the dry/wet deposition process, intercepted by the unit mass of grass. It was estimated by the following expression (Karunakara et al., 2012):

$$\alpha = C_g / C_d \quad (3)$$

where, C_g is the concentration in grass leaves (mg kg^{-1}) and C_d is the total iodine concentration deposited per unit area of ground/tray (mg m^{-2}).

For wet deposition measurements, grass grown in pot was kept inside the chamber and iodine was injected in to the chamber as outlined above. After ensuring uniform mixing of iodine inside the chamber, artificial rainfall was simulated at different intensities for 10 min. The iodine concentration in air, grass, and rain water was analyzed as outlined earlier in this section for the estimation of wet deposition velocity and mass interception factor.

3. Results and discussion

The range and mean values of dry and wet deposition rates, deposition velocities and mass interception factors for iodine with respect to grass for a simulated emergency situation are presented in Table 1. The dry deposition velocity with respect to grass surface varied in the range of 0.5×10^{-5}–3.3×10^{-5} m s^{-1} with mean value of 1.6×10^{-5} m s^{-1}. The mean value of wet deposition velocity was higher by an order of magnitude when compared to the dry deposition velocities. The mass interception factors for grass are presented with respect to fresh weight and dry weight separately in the table. The mass interception factors varied in the range of 0.25–7.7 m^2 kg^{-1} with mean value of 2.2 m^2 kg^{-1} (fresh weight) for dry deposition. The mean values of mass interception factors for dry and wet depositions were similar.

Experiments were also carried out to estimate the dry and wet deposition rates and deposition velocities of iodine with respect to the ground surface. In these experiments, stainless steel trays were kept on the floor of the environmental chamber and iodine was

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