THE ABSORPTION AND EVAPORATION OF TRITIATED WATER VAPOR BY SOIL AND GRASSLAND

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Abstract. The absorption and loss of tritiated water (HTO) vapor at bare soil and grass surfaces were studied in laboratory and field experiments. The exchange involves turbulent mixing in the air and diffusion within the soil.

In short exposures it was found that uptake by moist soil was controlled by atmospheric mixing and was described by an exchange velocity of about 1 cm s⁻¹. The exchange velocity was a little smaller for air-dried soil and grass surfaces. For exposure times exceeding a few minutes re-evaporation reduced the rate of net uptake, but the total amount deposited continued to increase as the HTO diffused deeper into the surface. The diffusion coefficient for HTO in soil was investigated in the laboratory and a simple equation was derived to predict the effective diffusion coefficient.

Tritiated water, absorbed during a brief exposure, evaporated during several weeks. Its behavior was described by the diffusion equation, but unexplained discrepancies were found in apparent diffusion coefficients in field conditions. Rain washed the activity into the soil and impeded evaporation.

Most of the HTO vapor interacts with the surface within two or three days following a low level release. The effect of the surface exchange on the distribution of dose following a release of HTO vapor may be large, but will depend on the weather over a period of weeks and is difficult to foresee.

Notation

(Numbers in parentheses indicate the equation in which each symbol is defined or first appears.)

\[ C, C_i \] concentration of HTO per unit volume of soil (Bq cm⁻³ = 2.7 × 10⁻¹¹ Ci cm⁻³)
\[ D \] The effective diffusion coefficient of HTO in soil (cm² s⁻¹) (5)
\[ D_v, D_{oa} \] vapor phase diffusion coefficient for HTO in soil and free air respectively (cm² s⁻¹) (4)
\[ D_t \] the diffusion coefficient of HTO in water (cm² s⁻¹)
\[ F \] net flux of HTO to the ground (Bq cm⁻² s⁻¹)
\[ H \] relative humidity in surface soil or stomatal cavity
\[ M, M_4 \] total HTO deposit per unit area of ground surface (Bq cm⁻²)
\[ S_n, S_1 \] the fraction by volume of air and water in soil
\[ t \] time after start of exposure to HTO vapor (s)
\[ t_1 \] time scale for the distribution of HTO in soil (s) (7)
\[ u_s \] the friction velocity (cm s⁻¹)
\[ v(z) \] exchange velocity for HTO or water at the surface (cm s⁻¹) (1)
\[ v_{HTO} \] the apparent exchange velocity for an exposure of finite time (cm s⁻¹) (2)
\[ v_{HTO} \] effective exchange velocity for the evaporation of water from soil (cm s⁻¹) (19)
\[ y \] depth below the surface (cm)
\[ y_1, y_2 \] length scales describing the distribution of HTO in soil (cm) (6)
\[ z \] height above the soil surface (cm)
\[ z_0 \] the roughness length (cm)
1. Introduction

Tritium (T), a fission product and activation product, is present in all nuclear reactors and reprocessing plants. The T may be present in a number of chemical forms, but frequently a large fraction occurs as tritiated water (HTO). This material is found in the gaseous and liquid effluent streams of many nuclear installations.

As an isotope of H, T readily gains access to food chains and is efficiently transferred through the chain to man. If the radiological consequences of the release of HTO to the environment are to be evaluated, it is necessary to know the rates of transfer between the major components of the environment. In particular the processes of exchange of HTO between the atmosphere and soil and crops must be evaluated. The rate of transport of HTO vapor to water droplets and its deposition in rain has been studied previously (Booker, 1965; Chamberlain and Eggleton, 1964). The present study concerns the vapor phase transport between the atmosphere and soil and plant surfaces.

Experiments were carried out on the exchange of HTO at grass and soil surfaces in a wind tunnel and in field conditions. Section 2 of this report summarizes theoretical aspects of the exchange; Section 3 describes the laboratory experiments on the diffusion of HTO in soil; Section 4 is devoted to wind tunnel experiments and other laboratory studies of the rate of uptake of HTO vapor by soil surfaces and Section 5 concerns the field experiments on uptake and loss of HTO vapor by soil and grass.

2. Theory

Tritiated water is frequently used to trace the movement of water in natural systems, but there may be transfer of HTO by diffusion even when there is no bulk movement of water. In some circumstances (as indicated below) the bulk movement of water is negligible compared to diffusion and it is this condition that is treated here. The effect of bulk movement of water will be discussed empirically in Section 5.

The exchange of HTO between the air and the surface can usually be described as a one-dimensional problem, assuming horizontal uniformity. The exchange involves transport through the air to the surface, and diffusion within the soil. Uptake is