Tritium Concentration in Agricultural Plants Exposed to Atmospheric HTO Vapor for Short-term

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1. Introduction

Tritium (as HTO) released from nuclear facilities is readily absorbed into plants by photosynthesis, and changes into a constituent tritium of organic compounds by metabolism. The organically bound tritium (OBT) is generally non exchangeable and remains in the tissue of a plant after the time of harvesting. Thus, the tritium level in the agricultural plants following an accidental release is essential to estimate a human ingestion dose. In spite of many studies on the movement of the tritium through the environment, additional studies are still necessary to establish the validity of the tritium models that is essential for a confident model prediction. This paper describes a dynamic compartment model for evaluating the tritium level in an agricultural plant by an acutely released tritium and its comparison to the experimental results to test the predictive accuracy of the model. Experimental results include time-series TFWT and OBT concentrations in four different agricultural plants: rice, soybean, cabbage, and radish, exposed to HTO vapor at different growth stages.

2. Model

The present model has been designed to estimate the contamination level of an agricultural plant by an acutely released tritium, without requiring excessive environmental and agricultural input data. The model calculates the time-variable concentrations of the compartments representing the atmosphere, soil, and plants of four categories; leafy vegetables, root vegetables, grain and tuber plants. The latter three plants consist of the body and the fruits (ear, pod, tuber, and root). All parts of a plant are subdivided into OBT and HTO components. The model takes account of a time-dependent growth equation of a plant so that it can predict the contamination level of the tritium depending on the growth stage of the plant.

Transfer rates of the tritium activity between the compartments can be generally described as

$$\frac{dA_i}{dt} = \sum_{k=1}^{m} K_{k,i} A_k - \sum_{i=1}^{n} (K_{i,j} + \lambda_d) A_i \qquad (1)$$

with constraints of A_i=0 at t=0, and A_a=A_{ao} for $0<t<t_{rel}$ where A_i (Bq m^{-2}) is the tritium activity of a compartment ***i***, $K_{k,i}$ is the transfer rate constant of the tritium from compartment ***k*** to ***i***, and λ_d (h^{-1}) is the decay constant of the tritium (6.44×10^{-6}). At an initial time, the activity of all the compartments is zero. Tritium activity in air (A_a) is assumed to be fixed to A_{ao} during the time of release (t_{rel}). The fixed air activity provides a source to other compartments.

3. Experimental

Plants were grown in plastic pots outdoors. Rice seedlings (*Oryza sativa* L. var.) were transplanted on 26 May, ear-emergence was observed on 14 August, and harvest was done on 10 October. Soybean (*Glycin max* L.) was sown on 22 May, and flowered on 6 July. Pods were presumed to grow from about 20 July until their harvest on 5 October. Both of the cabbage (*Brassica pekinensis* Rupr.) and radish (*Raphanus sativus* L.) cultivars were sown on 24 August, sprouted around 30 August and harvested on 13 November. Biomass data of the plants were measured according to the stage of the development.

Each plant was independently exposed to the atmospheric HTO vapor for one hour from 10:00 a.m. in a transparent plastic box at several different times according to the stages of the development. The surface of pot soil was covered by an absorbent paper lined with a polyethylene film during the whole time of an exposure to prevent a direct soil deposition, and thus the soil deposition of tritium occurred after the end of an exposure. After the end of the exposure, the contaminated plants were sampled with a proper interval of time to measure concentrations of the tissue free water tritium (TFWT) and organically bound tritium (OBT) in the samples.

4. Results and Discussion

Model performance was evaluated through the concentration prediction of the compartments for the exposure case of bean-1 (Fig. 1). Concentrations of HTO in air fell instantaneously to a level less than 0.01% of the HTO concentration of the air moisture during the exposure. During the exposure of tritium, soil layers were free from tritium since the surface soil was covered with an absorption paper. Removing the absorption paper gave rise to the exchange of tritium between the surface soil and air compartments. Consequently, the tritium level in the surface soil compartment started increasing just after the end of

the exposure. Around ten hours after the end of the exposure, the air concentration became lower than the surface soil concentration. Simultaneously, the tritium balance of the surface soil compartment changed into a negative, i.e. the loss of tritium by a root uptake and to a deeper soil became larger than the incoming flux from the air compartment, and thus the concentration of the surface soil was again decreased. For the soil layer 2 and 3 compartments, similar concentration profiles were predicted but there was a slower rise and lower peak for the latter soil due the time-lag effect of the migration. Concentrations of HTO in the soil compartments did not exceed 0.01% of C_a^o over the whole period, reflecting no direct soil deposition.

Concentrations of the HTO concentration in the plant body rose quickly by the direct deposition during the exposure and dropped rapidly due to the exchange of water vapor with air in which the tritium concentration falls to a background level due to a loss from the local atmosphere by a dispersion. The subsequent rate of the loss was decreased more slowly due to the presence of a continued uptake from the contaminated soil. The model predicted that concentrations of HTO in the pods were almost the same as those in the body. This result was made from the assumptions that the exchange rate between the pods and body was rapid (the effective half-life of tritium loss from fruit HTO to body HTO compartment was 2 hours), and that the ratio of the specific concentrations of the compartments was 1 at an equilibrium.

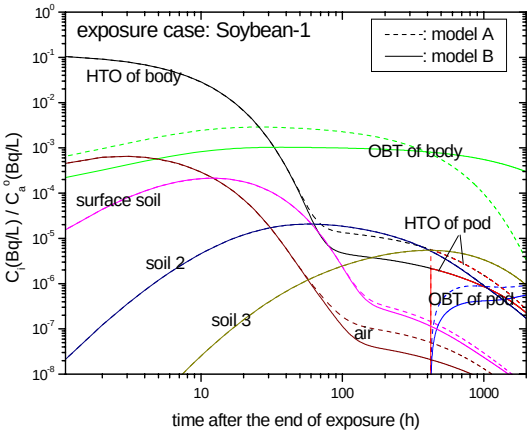

Fig.1 Simulation results of exposure case bean-1

Fig. 2 shows the comparison results of the predicted TFWT and OBT concentrations with those observed at harvest for the Chinese cabbage. The TFWT concentration was increased as the exposure approached harvest time since the loss time of HTO from the leaves by a transpiration was relatively shorter. For all the exposure cases of cabbage, the model predictions for TFWT concentrations agreed well with those observed. The OBT concentrations showed a small variation for all the exposure cases irrespective of the different exposure date. It follows from this that there was little actual loss of tritium from the OBT of the plant body once a translocation had taken place into the organic part. The observed OBT concentrations of the leaves agreed well with those predicted by model B. However, model A led to some deviation when the cabbage was exposed to the HTO vapor at an early growth stage.

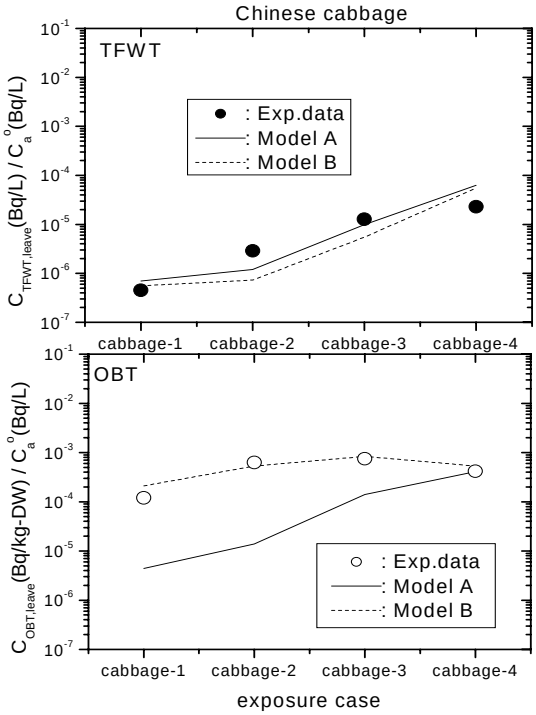

Fig.2 Comparison of model predictions for TFWT and OBT concentrations in cabbage at harvest to those observed

5. Conclusion

Model predictions were on the whole in good agreement with the observed TFWT and OBT concentrations of rice, soybean, cabbage and radish exposed to HTO vapor at different growth stages although there were some deviations for some exposure cases. Considering high variations in the growth of single plants, even under the same growth conditions, the comparison results suggest that the present model could be used with a good predictive accuracy for the prediction of the contamination level of an agricultural plant and consequently the human ingestion dose.