SOIL-PLANT RELATIONSHIPS AND ECOLOGICAL FORECAST OF HUMAN INTERNAL DOSES FROM LONG- LIVED RADIONUCLIDES. DOSE "COST" OF THE TRANSFORMATION OF RADIONUCLIDES BIOAVAILABILITY

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Summary

Soil pathway of radionuclides pollution of agricultural production becomes the main one at the recovery stage of postaccidental period. For this stage dynamics of the human foodstuffs cleaning and rate of internal dose due to consumption are results of the interaction of three main factors, namely, the rate of the decrease of soil contamination, structure of soil use and transformations of bioavailability of radionuclides. Representation of these ideas in quantitative form, documentation and analysis of the main ecological causes that determine the intensity of the radionuclides mobility in the biological cycle is essential increase the accuracy of the long-term forecast of human dose formation and promote the development of adequate strategies for countermeasures. General formal model and practical method of the ecological forecast of human internal doses has been proposed and used for estimation.

1.Introduction

Modern radiological situation in Ukraine resulting from Chernobyl accident has some specific particularities. This is, in the first place considerable levels of pollution with long-lived radionuclides in agricultural lands. Due to the immense area it was not possible to stop agricultural use. Secondly, this is the high diversity of the ecological characteristics of polluted agrocenosis, what results in different rates of the pollutant transfer into the biological cycle. Cost and success of the countermeasures are directly dependent of the adequate retrospective dose estimations and forecast of their accumulation, which reflects the conditions of their formation mentioned above. For practical purposes the necessity for the development and improvement of diverse methods of estimation and forecast of the internal exposure from the ingestion of contaminated food stuffs arose.

2. Materials and methods

The general model described below is based upon the registration of ecological variability of transfer factor soil-plant for different plant and soil types.

Phenomenological model

Considering the situation when inner pollution of the human organisms with radionuclides is a result of consumption of polluted product of j-type with the level of pollution A_{2j}. In the case of its plant origin this product is connected directly by transfer factor k_{ij} with agricultural land, which has i - soil type and A_{1i} - level of pollution. In the case of its animal origin this product is connected with link soil-plant as common source for all trophycal chains (without exceptions) over a few intermediate stages (plant-fodder-animal-meat; plant-fodder-animal-milk) and transfer factor is a complex coefficient.

Because of complex processes that occur in the system soil-plant following the deposition of the radionuclides, the values of kij, A1i and A2j accordingly change with time and are functional parameters.

$A_1i(t)$ is the level of radionuclides pollution of the soil of the i-th type(Bq/m2); A2j(t) is the level of radionuclides pollution of j-th food component (Bq/kg or Bq/l);

Kij- transfer factor from the soil of the i-th type to the food component j-th type.These parameters in general case are functional and dynamic characteristics. Then interconnection between these parameters may be represented as:

$$\grave{A}_2j(t) = Kij(t) * A_1i(t) \qquad (1)$$

Here and further we taken into account in dose calculation only locally grown foodstaffs.

Vjn -is the consumption rate (kg/day or year) of j -food component in the diet of members of group n and Qjn- is rate of radioactivity intake by members of n-th age group due to consumption of the j-th food component .

$$Qjn\ (t) = Vjn * \grave{A}_2j(t) \qquad (2)$$

If to take into account eqn. 1, eqn 2 may be rewritten as:

$$Qijn\ (t) = Vjn*Kij(t)*A_1i(t) \qquad (3)$$

Thus eqn. 3 reflects that intake of radioactivity due to consumption of jth diet component has been determined by the level of pollution and type of soil where trophycal chains begin.

If the structure of ration is known, we can estimate the general rate of radionuclides consumption for n-age group, the so- called intake function- Qin.

Intake of radioactivity due to consumption of all or main diet components which grow in the i-th soil type is:

$$Qni(t) = \sum_{1}^{j} Qnji(t) = \sum_{1}^{j} Vjn*Kij(t)*A_1i(t) \quad (4)$$

The eqn.4 determines the flow of radionuclides for the total diet or its main part for the conditions when trophycal chains begin from soil i-type.Thus eqn. 1-4 reflect in direct form that the level of pollution of the diet components, all ration and rate of radionuclides consumption are functions of the level of radionuclides pollution of agricultural lands, type of the soil and structure of their use and accordingly - the value of soil-plant transfer factors.If intake function Qin is known, the corresponding committed effective dose D due to radionuclides intake up during period T for members of age group n may be calculated

$$Din = Kn \sum_{0}^{T} \sum_{1}^{J} Vjn*Kij(t)*A_{1}i(t) = Kn \sum_{0}^{T} Qni(t) \qquad (5)$$

Where Kn ($SvBq^{-1}$) ingested is the effective dose coefficient for age group n
The presentated intake function in such a form gives some possibility:

-to take into account in calculation and forecast the dose dynamic phenomenon of the ration purification due to natural decay of radionuclides, their migration into soil (A1i alteration); radionuclides fixation and loss of the biological availability (Kij alteration)

- estimation of possibility and significance of the different form of countermeasures, which influence the doses decrease by means of the alteration level of soil pollution (A1i) or biological availability of radionuclides and structure of agricultural soil use (Kij(t)) or structure of the ration (Vjn).

This model is the basis of the development of the practical method of the calculation and forecast of internal doses in dynamic and heterogenetic conditions of radionuclides soil- plant transfer.

Calculation has been realised as a complex computer dynamic model of the radionuclides migration and spreadsheet form using LOTUS 123.
For dose forecast the whole capacity of radioecological and radiobiological information was taken into account, which has been used in elaboration of the preceding steps of algorithm (Kravets, *et al.*, 1994,1996).

Three mechanisms of the alteration of the initial levels of lands pollution (A1(t)), such as natural decay of radionuclides, infiltration, diffusion and two mechanisms of the alteration of pollution bioavailability, such as "hot" particles destruction and insert of ^{137}Cs -pollution into crystal lattice of the soil minerals have been taken into account.

All modern radioecological, radiohygienic and radiobiological numerical information concerning the:

- initial level of superficial lands pollution
- radionuclides "soil- plants" transfer factors for different plant production and soil type
- transfer factors for the following trophycal links (milk, meat)
- structure of human ration and its age modification
- age-dependent biokinetic models of the doses formation from intake of ^{137}Cs and ^{90}Sr
- risk assessment coefficients

- age - dependent doses coefficients

were united in the spreadsheets.

Additional numerical estimation, namely calculation of dynamics of pollution level has been realised with one dimensional transport equation describing the migration of radionuclides in soil as porous solid matrix united with the equation describing the alteration of the solubility of pollutants: 'hot' particles destruction and insert of ^{137}Cs into crystal lattice of the soils minerals :

$$dA_m/dt = D' dA_2^2/d^2x - V' dA_2/dx + k_{32}A_3(t,x) - (\beta + \lambda)A_2(t,x) \quad (6)$$
$$dA_s/dt = -(k_{32} + \lambda - \beta)A_3(t,x);$$

where λ-index of radioactive decay, A_2 (t)-partial radioactivity of soil solution, A_3(t)-partial radioactivity of the solid pollution ("hot" particles, for example);

D'=D/R - actual rate diffusion, coefficient is in interval $3*10^{-8}$-$1.8*10^{-6}$ cm s^{-1} for ^{137}Cs and 1.6-0.7*10^{-7} cm^2 s^{-1} for ^{90}Sr (Frid, Grakovskiy, 1988, Prister, Perepelytnikova et. al,1993, Levchuk,1995);

V'=V/R -actual rate of infiltration, coefficient is in interval 0.1*10^{-9}-2*10^{-7} cm s^{-1} for ^{137}Cs and in interval 1*10^{-9}-1*10^{-6} cm s^{-1} for ^{90}Sr (Prister,Perepelytnikova, et.al.,1993,Levchuk ,1995)

R=1+rKd/Q - the retardation factor, accounts for the slower movement of radionuclide due to matrix sorption than the water; Q-moisture content of the bulk soil, r- the density of dry soil;

K_{32} -rate of "hot" particles destruction. K_{32}=1*$10^{-9}$$s^{-1}$ for ^{137}Cs; K_{32}= 5*$10^{-9}$$s^{-1}$ for ^{90}Sr (Sobotovich, Dolin, 1995);

β- rate of ^{137}Cs insertion into crystal lattice of the soil minerals for the soils of different type in the interval 10^{-7} -10^{-8} s^{-1} (Ivanov,Shagalova et. al.,1976);

Forecast of the alterations of the soil-plant transfers factor (Kn(t)) have based on such real suppositions. It is known, a plant absorb mobile fraction of radionuclides (Am(t)), that is

$$Ap(t) = k\, Am(t) \quad (7)$$

Ap(t)- radioactivity of the plant tissues, k – numerical coefficient .

Transfers factor (Kij) has been determined as ratio between radioactivity of the plant biomass and general radioactivity of soil, that is

$$A1(t) = Am(t) + As(t) \quad (8)$$

and

$$Kij = Ap \backslash A1 = k\, Am(t) \backslash (As(t)+Am(t)) \quad (9)$$

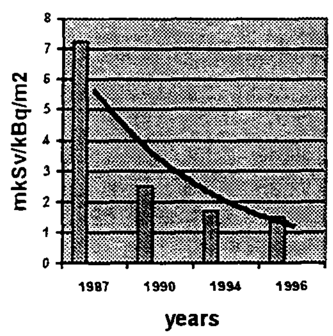
If we use system (6) for determination As(t) and Am(t), a gereral picture of the dynamic soil- plant transfers factor will be obtained.

Numerical decision of the system of equations (6-9) has been realised with two FORTRAN-language programs. The results of decision of dynamic models of radionuclides migration have been inserted into the spreadsheets and taken into account in calculation of change of pollutant content with time in the upper, ploughed soil layer, decrease of Cs bioavailability and, accordingly, the levels of the agricultural production pollution.These theoretical estimations were supported by direct measurements which were conducted at 29 farms of the Ukrainian Polessye (NRU,1996).

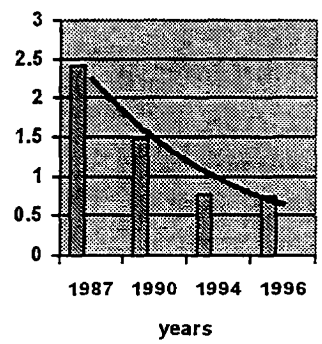
3. Result and discussion

The results of our calculation indicate that decrease soil- plant tranfer factor due to decrease of bioavailability of ^{137}Cs leads to essential decrease of the level annual internal committed dose for different soil type.

sod- podzoloc sandy loam soil



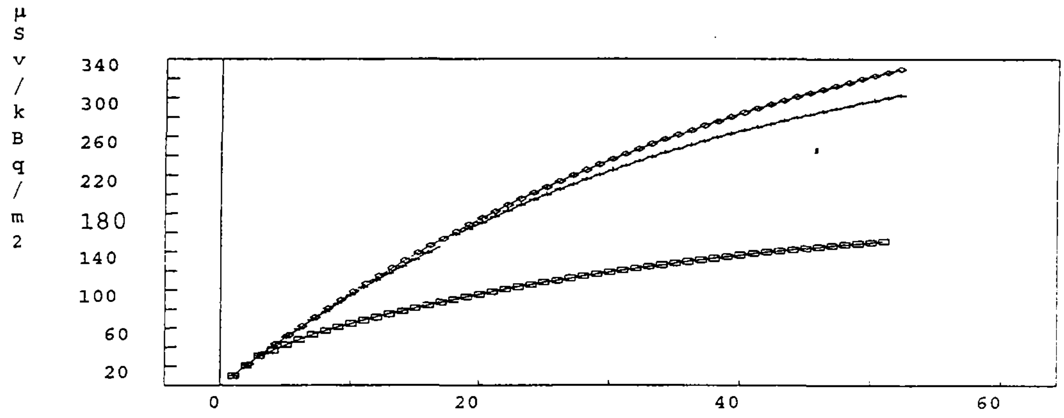
Grey forest soil



For peaty soil these levels are : 1987 - 10.7μSv/ kBq/m2, 1990 - 6.4μSv kBq/m2, 1994 - 4.7μSv kBq/m2

For sod-podzolic sandy loam soil : 1987 – 7.2 μSv kBq/m2, 1990 – 2.5μSv/ kBq/m2, 1994- 1.7 μSv/ kBq/m2

For gray forest soil these values are:1987 – 2.4μSv/ kBq/m^2, 1990 - 1.5 μSv/ kBq/m^2,1994-0.8μSv/kBq/m^2. For black soil (chernozem) our calculation give such values: 1987-0.67μSv/ kBq/m^2, 1990- 0.40μSv/kBq/m^2, 1994-0.35μSv/ kBq/m^2.



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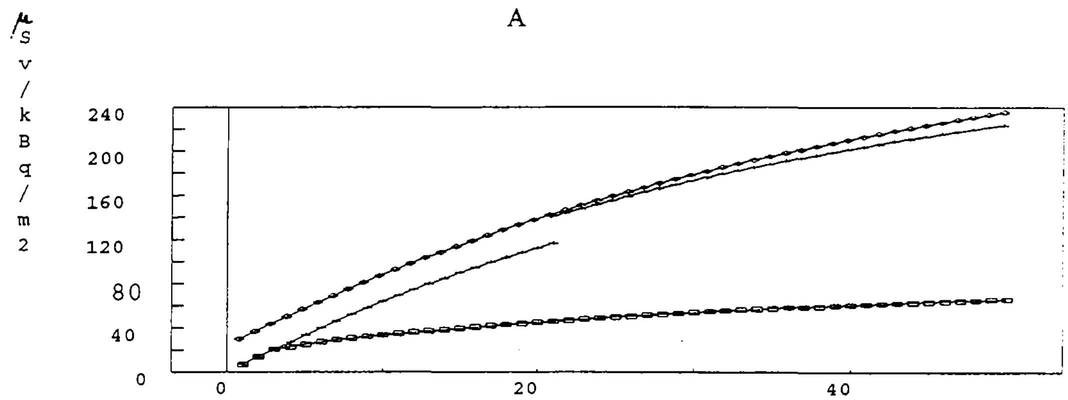

B

Fig 2. Forecast of dynamic internal doses for adult individuals for three variants of calculation

Position A –sod-podzolic sandy loam soil;B- grey forest soil
From top to bottom: forecast take into account only natural radionuclides decay; forecast take into account all forms of the vertical radionuclides migration; forecast take into account radionuclides vertical migration and the alteration of bioavailability.

The alteration of the bioavailability 137Cs has considerable influence on the process of the dose accumulation. Comparison of the our three variants of the calculation (Fig 2) have demonstrated that due to decrease of the bioavailability dose economy compose 50% , whereas due to vertical migration this meaning is nearly 5-7%.

Our results have demonstrated that namely decrease of radionuclides bioavailability – natural or artificial – is the most efficient approach in a system the countermeasures.

4.References

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