

# Participation of Natural Radionuclides in Chemical Processes in Green Vegetation

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## Abstract

The rate of decrease of molecular hydrogen formation with an increase in the concentration of CO<sub>2</sub> is observed during the radiolysis of mixtures of H<sub>2</sub>O with CO<sub>2</sub>. The rates of formation of all products (H<sub>2</sub>, CO, CH<sub>4</sub>, and relatively heavy hydrocarbons) increase with increasing absorbed dose and amount of organic matter in mixtures with stable concentrations of CO<sub>2</sub>, H<sub>2</sub>O, and <sup>40</sup>KCl. There is a decrease in the rate of formation of H<sub>2</sub> and CH<sub>4</sub>, and an increase in the rate of elementary reactions of the transformation of light radiolysis products (H<sub>2</sub>, CO, CH<sub>4</sub>) into relatively heavy products (C<sub>6</sub>, C<sub>7</sub>, C<sub>8</sub>) with an increase in CO<sub>2</sub> concentration. The results obtained show the expediency of taking into account the contribution of ionizing radiation from radionuclides present in the environmental components, when considering multistage biochemical mechanisms of photosynthesis, in order to explain the initiation of energy-intensive processes of CO<sub>2</sub> and H<sub>2</sub>O decomposition. The analysis showed the presence of natural radionuclides in all samples of water, soil, vegetation and livestock products. The development of green vegetation in fertile soils is directly proportional to the concentration of microelements and natural radionuclides, in the range of concentrations of microelements formed in the soil cover of the planet. The high development of vegetation, green cover and trees in fertile areas is explained by the stimulation of photosynthesis process by relatively high concentrations of microelements and natural radionuclides.

## Keywords

Natural Radionuclides, H<sub>2</sub>O-CO<sub>2</sub> Mixtures, Fertile Soil, Plant Mass, Hydrocarbons

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## 1. Introduction

The main part of the soil is formed by chemical compounds in the form of various

minerals. Soil is the upper layer of the lithosphere exposed to living organisms and the atmosphere. The study of various forms of the presence of chemical elements in minerals, organic residues, soil colloids and determination of the amounts of oxides, hydroxides, carbonates, bicarbonates, nitrates, nitrites, sulfates and phosphates in soil samples allows us to estimate the ecological state of the soil [1] [2].

Radioactive elements and heavy metals along with non-metals and light metals in the tables of chemical elements are distinguished and characterized by high density (more than  $5 \text{ g/cm}^3$ ), biological activity, toxicity, ability to migrate in the habitat of living organisms through food chains “atmosphere—wind—rain—soil—plants—animals—humans” and accumulate in environmental objects and organisms [2] [3].

Heavy metals participate as catalysts in numerous redox reactions, isomerization, hydration, and dehydration processes occurring in environmental objects [4]-[6].

Depending on the magnitude of their concentration in the body, microelements can have a “threatening, deficient, physiological, toxic and lethal” effect on the body [5]-[14].

It has been established by systematic studies that all environmental objects (water, soil and vegetation) contain natural radionuclides, including  $^{40}\text{K}$  and  $^{22}\text{Na}$  isotopes [15].

The study of the influence of natural radionuclides on the processes occurring in environmental objects, the role of ionizing radiation from radionuclides in the course of complex multistage processes in the vegetation cover are important sources of arguments for the predictability of possible changes in the habitat of living organisms [8]-[16].

## 2. Experimental Part

The experiments were carried out under static conditions, by irradiating glass ampoules filled with the studied mixtures. The filling of ampoules with carbon dioxide, as well as the purification of water from dissolved gases, were carried out using an experimental vacuum installation. The installation consists of a vacuum part, glass volumes for storing initial liquids and gases, and a measuring part (pressure gauges) that allows working up to pressures of  $2 \times 10^5 \text{ Pa}$ . A schematic diagram of a vacuum installation designed to pump out gases dissolved in liquid water is given in previously published works [17] [18].

The glass ampoules intended for filling with the studied mixtures were previously connected to the vacuum outlet of the installation and pumped out to  $10^{-2} \div 10^{-3} \text{ Pa}$  (for 30 minutes at  $T \geq 500 \text{ K}$ , and then for another 30 minutes at room temperature), after which they were disconnected from the vacuum installation and filled with the studied systems:  $\text{H}_2\text{O}$ ,  $\text{H}_2\text{O}-\text{CO}_2$ ,  $^{40}\text{KCl}-\text{H}_2\text{O}-\text{CO}_2$ ,  $^{40}\text{KCl}-\text{H}_2\text{O}-\text{CO}_2$ -“organic matrix”. Repeatedly washed with distilled water various amounts (1.0, 5.0 and 10.0 g) of green leaves of the olive tree (*Olea europaea* L.) were chosen as the organic matrix.

Water purification from dissolved gases was carried out by pumping using a vacuum unit equipped with glass vessels, vacuum lamps, traps, oil and mercury manometers. Water purification was carried out repeatedly (4 - 5 times) according to the cycle “freezing—vacuuming—pumping—thawing of ice—slow pumping of dissolved gases” at a temperature of 293 K [17] [18].

Qualitative analysis of the studied components was carried out using a gas chromatograph GC-2010 (Shimadzu, Japan) at a temperature of 398 K, with a flame ionization detector (FID) connected to a SupelcoNucol capillary column (30 m × 0.32 mm). Helium (99.995%) was used as a carrier gas. The radiolysis products (H<sub>2</sub>, CO, CH<sub>4</sub>) were analyzed by chromatography at room temperature on a “Gas-oChrome 3101” gas analyzer equipped with a thermochemical detector and a packed column (3 m × 3 mm) filled with activated carbon at the factory. The flow of atmospheric air forced by the factory mini-pump of the device was used as a carrier gas. Hydrocarbons were analyzed also, on an Agilent 7890A chromatograph (Agilent, USA) equipped with two detectors for operation in two modes: for the analysis of hydrocarbons at a temperature of 398 K with a FID connected to a capillary column (30 m × 0.32 mm) GC-Gaspro, as well as for hydrogen analysis at room temperature with a katharometer connected to a capillary column (30 m × 0.53 mm) SupelcoCarboxenTM. Helium (99.995%) was used as a carrier gas in both modes.

Irradiation of glass ampoules filled with test mixtures was carried out with ionizing gamma radiation from <sup>60</sup>Co sources of a powerful gamma installation “YK-120000”. The dose rate absorbed in the irradiation zone was 6.6 kRad/hour (0.066 kGy/hour).

The soil samples taken were treated with distilled water, weak solutions of acid and alkali with periodic mixing and filtration, isolation of sparingly soluble particles in a centrifuge with further evaporation to obtain minerals, heavy metals and radionuclides. After radiometric measurements, the obtained dry mineral was analyzed by analytical chemistry, X-ray fluorescence, gamma, beta and atomic absorption spectroscopies and electron microscopy. Radiometric measurements were carried out using the InSpector-1000 and Radiagem-2000 radiometers (manufactured by Canberra and equipped with alpha, beta and gamma detectors) and the radiometer Identifier (Thermo Scientific). In the process of physical-chemical analysis of minerals obtained by evaporation of aqueous, weakly acid and weakly alkaline extracts of soil samples by treatment of plant samples by nitric acid's solution and heat treatment were use gamma spectrometer with HP-Ge detector manufactured by Canberra, Electronic Microscope “SEM “(manufactured by Carl-Zeiss with an electron tube), atomic absorption AA-6800 spectrometer (manufactured by Shimadzu), Expert-3L and XRF X-ray fluorescence spectrometers [14]-[16].

### **3. The Results Obtained and Their Discussion**

The employees of our laboratory conducted observations and studies of regions of our country, fertile soils, green vegetation and determined geometric dimensions

and biological parameters for further comparative studies. The common concentrations of inorganic components in fertile soil samples are 7.62 - 10.19 g/kg and common concentrations of components in other non fertile soil samples are 5.47 - 7.15 g/kg.

The value of the radioactive background in fertile soils is 0.03 - 0.15  $\mu\text{Sv}/\text{hour}$  and the intensity of alpha radiation is 0 - 0.03  $\text{Bq}/\text{cm}^2$ . The value of the radioactive background in other non fertile soils is 0.08  $\mu\text{Sv}/\text{hour}$  and the intensity of alpha radiation is 0 - 0.01  $\text{Bq}/\text{cm}^2$ . The common activity of all natural radionuclides in soil samples taken from fertile areas is 7.3 - 10  $\text{Bq}/\text{kg}$  and common activity of all natural radionuclides in soil samples taken from other non fertile soil areas is 5.3 - 6.7  $\text{Bq}/\text{kg}$ . A comparative analysis of the concentrations of mineral components and natural radionuclides shows that fertile soils are characterized by relatively high concentrations of the studied components.

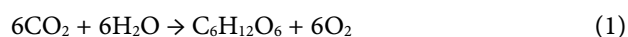
The energy of gamma rays (1.45 MeV) of  $\text{K}^{40}$  isotope is many times higher than the value of the binding energy of hydrogen with a hydroxyl group in water molecules (5 eV). In addition,  $\text{K}^{40}$  isotopes were found in all samples without exception taken from the environment, and the geometric dimensions of the studied vegetation specimens were directly proportional to the activity (concentration) of  $\text{K}^{40}$  detected in them.

The high energy of  $\text{K}^{40}$  gamma rays and the relatively high content of this isotope in vegetation are the cause of an increase in the concentration of radicals in plants, which is equivalent to the acceleration of the high-barrier endothermic process of splitting off hydrogen atoms from water molecules.

The analysis of numerous samples of water, soil, vegetation and livestock products showed the presence of  $\text{Na}^{22}$  and  $\text{K}^{40}$  radioisotopes in all samples, without exception. A comparative analysis carried out using physical chemistry methods shows that the fertile soils are characterized by relatively high concentrations of mineral components and natural radionuclides.

Conducted analyzes of the mineral composition and appearance of vegetation in different areas of green plants, as well as a comparison of the appearance of green spaces grown in experimental areas (on soil with a natural activity of  $^{40}\text{K}$  0.8  $\text{Bq}/\text{kg}$  and on soil impregnated with an aqueous solution of  $^{40}\text{KCl}$  salt with an activity of  $^{40}\text{K}$  brought to 2.5  $\text{Bq}/\text{kg}$ ) showed a relatively high growth rate of vegetation in soil areas containing high concentrations of  $^{40}\text{KCl}$  (see **Figure 1**).

The course of photosynthesis is described by the overall equation:



The high endothermicity (3080 kJ/mol) of this reaction is due to the high values of the dissociation energy of the O-H bond (485 - 498 kJ/mol or 5.0 - 5.2 eV/molec.) in the water molecule and the C=O bond (799 kJ/mol or 8.3 eV/molec.) of carbon dioxide molecule [11] [12]. Low energies of visible light (below 5 eV/quantum) are not sufficient to break the C=O bond. However, the high energies of gamma radiation quanta from the  $^{40}\text{K}$  isotope easily explain the dissociation of carbon dioxide and water molecules into the corresponding radicals and ions. The



(a)



(b)



(c)

**Figure 1.** Appearance of sunflower (*Helianthus annuus* L.), corn (*Zeamays*) and coriander (*Coriandrum sativum*) grown on ordinary soil with natural activity  $^{40}\text{K}$  0.8 Bq/kg (picture (a)/area on the left/and picture (b) and on soil impregnated with an aqueous solution of chloridesalt  $^{40}\text{K}$  with activity brought up to 2.5 Bq/kg (picture (a)/area on the right/and picture (c).

presence of  $^{40}\text{K}$  isotopes in all environmental objects (in water, soil and vegetation), relatively high growth rates of plants in soil areas containing relatively high concentrations of  $^{40}\text{KCl}$ , the presence of photosynthesis variants on the cytoplasmic membrane of extreme halobacteria or in the absence of chlorophyll and oxygen, in the depths of large lakes and seas of the planet in the presence of long-wavelength infrared radiation (from volcanic lava) testify in favor of the expediency of taking into account the role of ionizing radiation from  $^{40}\text{K}$  at the initial energy-intensive stage of photosynthesis, i.e. dissociation of  $\text{CO}_2$  and  $\text{H}_2\text{O}$  molecules [11].

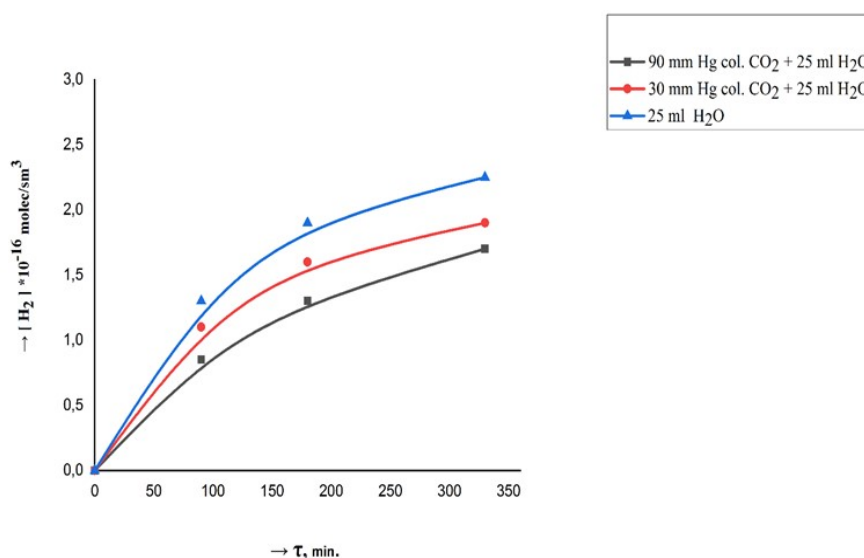
The kinetics of the formation of radiolysis products in the systems  $\text{H}_2\text{O}$ ,  $\text{H}_2\text{O}-\text{CO}_2$ ,  $^{40}\text{KCl}-\text{H}_2\text{O}-\text{CO}_2$ ,  $^{40}\text{KCl}-\text{H}_2\text{O}-\text{CO}_2$ -“organic mass” under the influence of ionizing gamma radiation were studied in order to study the course of chemical processes in a mixture of water with carbon dioxide in the presence of mass green vegetation. Repeatedly washed with distilled water different amounts (1.0, 5.0 and 10.0 g) of green leaves of olive trees (*Olea europaea* L.) were chosen as the organic matrix. Conducted radiometric measurements showed that the activity of radiation from 5.0 gr.  $^{40}\text{KCl}$  salt in one ampoule was 40 Bq. Filled with the indicated mixtures ampoules before irradiation at a powerful gamma installation were stored for 30 days around a vessel containing a weak source of gamma radiation (filled with  $^{40}\text{KCl}$  salt) with an activity of 1000 Bq. **Figures 2-6** show the kinetics

of the formation of radiolysis products of the studied mixtures irradiated at the high-power gamma installation YK-12000.

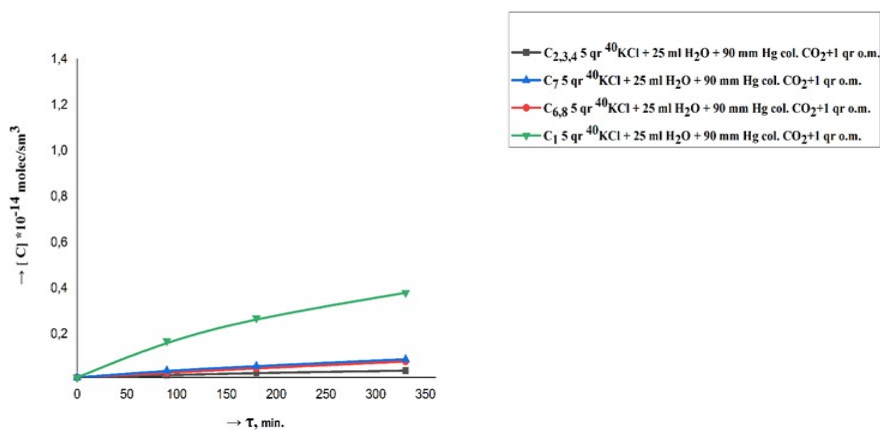
Hydrogen formation was not observed during chromatographic analysis in ampoules filled with water and a mixture of water with carbon dioxide, which were stored for a month around a weak source with an activity of 1000 Bq.

However, the presence of a trace amount of hydrogen was detected in ampoules containing multi-component systems stored for 30 days near a weak radiation source. This amount  $((0.1 - 0.2) \times 10^{14}$  molecules/cm<sup>3</sup>) was many times (more than  $10^6$  times) lower than the values of the hydrogen concentration (indicated on the kinetic curves in **Figure 4**) formed in the ampoule under the action of ionizing radiation from the powerful gamma installation YK-120000.

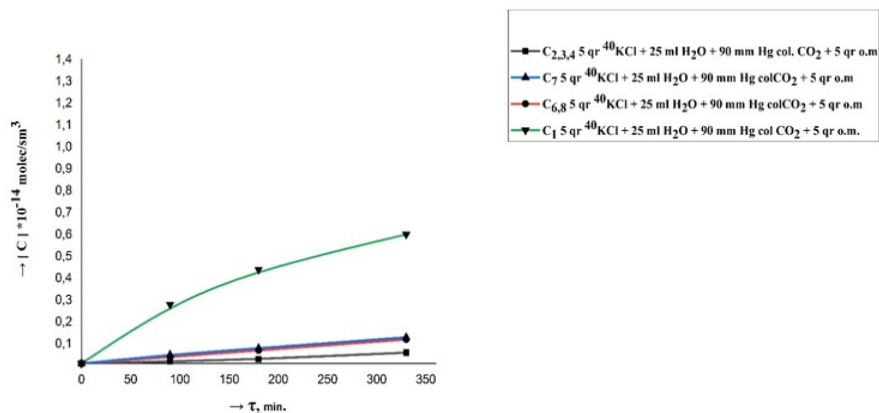
The energy of a gamma quantum from <sup>40</sup>K is 1.45 MeV. The radiation-chemical yield of hydrogen formation from water is 0.3 - 1.0 molecules/100 eV [12].



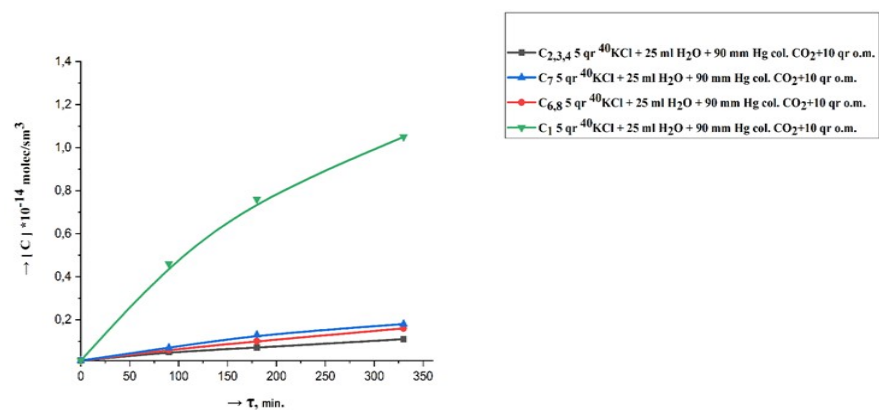
**Figure 2.** Kinetics of hydrogen production during radiolysis of water and mixtures of water with carbon dioxide.



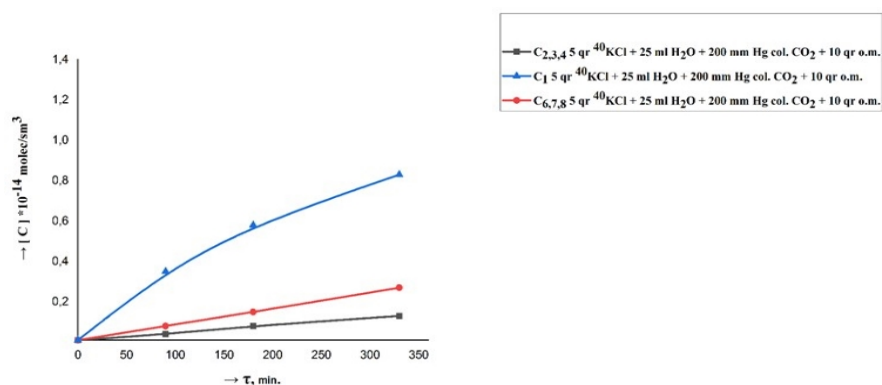
**Figure 3.** Kinetics of hydrocarbon formation upon radiolysis of mixtures "5 g <sup>40</sup>KCl - 25 ml H<sub>2</sub>O - 90 mm.Hg.col. CO<sub>2</sub> - 1 g organic mass".



**Figure 4.** Kinetics of hydrocarbon formation upon radiolysis of mixtures “5 g  $^{40}\text{KCl}$  - 25 ml  $\text{H}_2\text{O}$  - 90 mm.Hg.col.  $\text{CO}_2$  - 5 g organic mass”.



**Figure 5.** Kinetics of hydrocarbon formation upon radiolysis of mixtures “5 g  $^{40}\text{KCl}$  - 25 ml  $\text{H}_2\text{O}$  - 90 mm.Hg.col.  $\text{CO}_2$  - 10 g organic mass”.



**Figure 6.** Kinetics of hydrocarbon formation upon radiolysis of mixtures “5 g  $^{40}\text{KCl}$  - 25 ml  $\text{H}_2\text{O}$  - 200 mm.Hg.col.  $\text{CO}_2$  - 10 g organic mass”.

Gamma rays emitted by a source with an activity of 1000 Bq emit a total energy over 30 days of  $1000 \times 30 \times 24 \times 3600 \times 1,450,000 \text{ eV} = 3.8 \times 10^{15} \text{ eV}$ , which corresponds to the formation of no more than  $0.4 \times 10^{14} \text{ H}_2$  molecules from pure water in an ampoule during 30 days. The formation (radiation-chemical yield) of hydrogen during the radiolysis of organic matter is approximately ten times

higher, which corresponds to the formation of no more than  $4.0 \times 10^{14}$  molecules or  $0.1 \times 10^{14}$   $\text{H}_2/\text{cm}^3$  molecules in the ampoule, taking into account that the volume of the ampoule is  $40 \text{ cm}^3$ .

The value obtained by calculation explains the detected "dark effect of the formation of trace amounts of hydrogen" in ampoules containing mixtures of " $^{40}\text{KCl}-\text{H}_2\text{O}-\text{CO}_2$ -organic mass".

The study of the kinetics of the formation of products during the radiolysis of the above systems led to the following conclusions:

- the rate of CO formation increases with an increase in the concentration (pressure) of  $\text{CO}_2$  in the  $\text{H}_2\text{O}-\text{CO}_2$  mixture, the rate of  $\text{H}_2$  formation decreases and the formation of hydrocarbons is not observed in this case. The formation of hydrocarbons during the thermal catalysis of the  $\text{H}_2\text{O} - \text{CO}$  mixture in the presence of ionizing rays is considered in [11];

- the rate of formation of CO with an increase in the concentration (pressure) of  $\text{CO}_2$  from 30 to 200 mm.Hg.col. in mixtures "5 g  $^{40}\text{KCl} - 25 \text{ ml H}_2\text{O} - \text{CO}_2 - 1.0, 5.0$  and  $10.0 \text{ g organic matrix}$ " increases, and the rates of formation of  $\text{H}_2$  and  $\text{CH}_4$  decrease. At the same time, the total amount of formed relatively heavy hydrocarbons (C2-C8) does not change significantly;

- an increase in the rate of formation of  $\text{H}_2$ , CO,  $\text{CH}_4$  and relatively heavy hydrocarbons (C2-C8) is observed with an increase in the amount of organic matter in mixtures "5 g  $^{40}\text{KCl} - 25 \text{ ml H}_2\text{O} - 90 \text{ mm.Hg.col. CO}_2 - \text{organic matrix}$ ";

- the rate of formation of molecular products with an increase in the absorbed dose of radiation in the system "5 g  $^{40}\text{KCl} - 25 \text{ ml H}_2\text{O} - 30 \text{ mm.Hg.col. CO}_2 - 10 \text{ g organic matrix}$ " do not change significantly and the accumulation of products is observed in proportion to the value of the absorbed dose.

The revealed regularities well explain the observed high growth rates of vegetation in soil areas containing high concentrations of  $^{40}\text{KCl}$ , which are microsources of ionizing radiation that create relatively higher doses than in similar soil with vegetation (with relatively low growth rates) containing relatively low concentrations of  $^{40}\text{KCl}$ . The rapid growth and maturation of fruits of figs (*Ficus carica L.*), white mulberries (*Morus alba L.*), after a certain growth phase, the accumulation of glucose and fructose in them during summer days and nights confirms this version.

The formation of heavier hydrocarbons and carbohydrates in the studied multicomponent systems under the influence of ionizing rays can be explained by the mechanism of formation of heavy molecules, described in detail in [13] [14], which consists of a sequence of numerous elementary reactions with a number of values of their rate constants indicated.

#### 4. Conclusions

The content of mineral components and natural radionuclides in fertile soils is high. These results are in good agreement with the higher degree of development of green cover, vegetation and trees observed in areas with fertile soils, which is

explained both by the high fertility of the soil and by the participation of microelements and natural radionuclides in the acceleration of photosynthesis processes.

The considered and obtained data (the presence of  $^{40}\text{K}$  isotopes in all environmental objects, the efficiency of the process of assimilation of  $^{40}\text{K}$  from water by plants, the relatively high rates of plant development in soil areas containing high concentrations of  $^{40}\text{KCl}$ , the presence of photosynthesis in the absence of chlorophyll and oxygen, on the cytoplasmic membrane of extreme halobacteria, in the depths of large lakes and seas of the planet in the presence of long-wavelength infrared radiation/from volcanic lava/, qualitative changes in the composition of fruits of figs /*Ficus carica* L./, white mulberries /*Morus alba* L./both in summer days and at night, the high value of the C=O bond energy in carbon dioxide molecules, which is much higher than the energy of visible light quanta) indicates the expediency of taking into account the role of ionizing radiation from  $^{40}\text{K}$  at the initial energy-intensive stage of initiating the dissociation of molecules ( $\text{CO}_2$ ,  $\text{H}_2\text{O}$ , etc.) when considering traditional multistage biochemical mechanisms of photosynthesis.

### Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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