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Radioactive Isotopes and Ionizing Radiations in Agriculture, Physiology, and Biochemistry

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Volume 12

RADIOACTIVE ISOTOPES AND IONIZING RADIATIONS IN AGRICULTURE, PHYSIOLOGY, AND BIOCHEMISTRY

PREFACE

The Proceedings of the International Conference on the Peaceful Uses of Atomic Energy are published in a series of 16 volumes, as follows:

Volume Number	Title	Sessions Included
1	The World's Requirements for Energy; The Role of Nuclear Power	2, 3.2, 4.1, 4.2, 5, 24.2.
2	Physics; Research Reactors	6A, 7A, 8A, 9A, 10A.1.
3	Power Reactors	10A.2, 3.1, 11A, 12A, 13A, 14A.
4	Cross Sections Important to Reactor Design	15A, 16A, 17A, 18A.
5	Physics of Reactor Design	19A, 20A, 21A, 22A, 23A.
6	Geology of Uranium and Thorium	6B, 7B.
7	Nuclear Chemistry and the Effects of Irradiation	8B, 9B, 10B, 11B, 12B, 13B.
8	Production Technology of the Materials Used for Nuclear Energy	14B, 15B, 16B, 17B.
9	Reactor Technology and Chemical Processing	7.3, 18B, 19B, 20B, 21B, 22B, 23B.
10	Radioactive Isotopes and Nuclear Radiations in Medicine	7.2 (Med.), 8C, 9C, 10C.
11	Biological Effects of Radiation	6.1, 11C, 12C, 13C.1.
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13	Legal, Administrative, Health and Safety Aspects of Large-Scale Use of Nuclear Energy	4.3, 6.2, 17C, 18C.
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15	Applications of Radioactive Isotopes and Fission Products in Research and Industry	21C, 22C, 23C.
16	Record of the Conference	1, 24.1, 24.3.

These volumes include all the papers submitted to the Geneva Conference, as edited by the Scientific Secretaries, The efforts of the Scientific Secretaries have been directed primarily towards scientific accuracy. Editing for style has been minimal in the interests of early publication. This may be noted especially in the English translations of certain papers submitted in French, Russian and Spanish. In a few instances, the titles of papers have been edited to reflect more accurately the content of those papers.

The editors principally responsible for the preparation of these volumes were: Robert A. Charpie, Donald J. Dewar, André Finkelstein, John Gaunt, Jacob A. Goedkoop, Elwyn O. Hughes, Leonard F. Lamerton, Aleksandar Milojević, Clifford Mosbacher, César A. Sastre, and Brian E. Urquhart.

The verbatim records of the Conference are included in the pertinent volumes. These verbatim records contain the author's corrections and, where necessary for scientific accuracy, the editing changes of the Scientific Secretaries, who have also been responsible for inserting slides, diagrams and sketches at appropriate points. In the record of each session, slides are numbered in numerical order through all presentations. Where the slide duplicates an illustration in the submitted paper, appropriate reference is made and the illustration does not appear in the record of the session.

Volume 16, "The Record of the Conference," includes the complete programme of the Conference, a numerical index of papers and an author's index, the list of delegates, the records of the opening and closing sessions and the complete texts of the evening lectures.

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ISOTOPES IN MEDICINE, BIOLOGY AND AGRICULTURE

LIST OF PAPERS

The Utilization of Radioactive Isotopes in Biology and Agriculture in the USSR

By A. L. Kursanov, USSR

The production of isotopes in the USSR has provided new and broad possibilities for scientific research in biology and agriculture. Artifically produced radioactive isotopes and also stable isotopes have now become available means of research extensively used by scientific workers in our country, who strive to perfect the methods used for nutrition of cultivated plants and to improve their economic qualities. At the present time biologists and agronomists are using radioactive isotopes, mainly as "labelled," or "tagged," atoms. This method, better than any other, permits one to investigate the processes that take place in the soil, the ways in which plants consume nutritive elements, the movement of various compounds in plant tissues, and, finally, the most intimate metabolic reactions in plant cells.

There is no doubt that the application of tagged atoms (as well as any other method, for that matter) calls for the careful appraising of the results obtained. For instance, the extreme sensitivity of the isotopic method sometimes forces the experimenter to forget the principal mass of the substance which he investigates and to consider secondary phenomena, comprising but a small part of the general process. In other cases, biologists have to take into consideration the possibility of direct incorporation of radioactive atoms in the substance, as a result of non-biological isotopic exchange. These phenomena should not be confused with the true course of biological transformations. In spite of certain peculiarities of the tracer method it remains extremely important.

The possibility of directly applying the energy of radioactive disintegration to stimulate, or in some cases to retard, the development of plants, which is done without injury to man, is also of great interest to agriculture. Serious attention is also given to the problem of applying the energy of radioactive disintegration to make more radical changes in the structure and heredity of organisms.

In the Soviet Union, where agriculture is largely mechanized, there are extensive possibilities for a rapid practical application of new methods of introducing fertilizers and cultivating plants, provided that these methods are substantiated by scientific research and checked by practice. At the present time, when extensive measures are being undertaken in our country for the further development of agriculture, there appear extremely wide possibilities for the practical application of new scientific achievements. They can be used on virgin lands, under conditions of irrigated agriculture as well as when cultivated plants are acclimatized in new districts, etc. For this reason, workers in agricultural experimental establishments are greatly interested in the possibility of applying radioactive and stable isotopes to solve the problems facing them.

It has been only recently that radioactive elements have begun to be applied in the practical work of biological and agricultural laboratories. Yet even during this short period of time, isotopic indicators have helped to disclose many new aspects of plant life. Such knowledge makes it possible to improve the nutrition and breeding of agricultural crops. Further study of plants by the application of radioactive elements will, undoubtedly, bring to light many new and unexpected aspects of plant life.

The present paper, which describes some of the more important results obtained in the Soviet Union where plants were studied with the help of labelled atoms, is, therefore, by no means a summary of all that has been achieved. It merely gives a description of the scope and the general direction of these rapidly developing investigations. In our paper we describe only the investigations carried on in the Soviet Union and will not mention investigations undertaken in other countries. The reason for this is our desire to give a fuller account of the application of isotopic tracers in the spheres of biology and agriculture which is undertaken in our own country. In giving this limited description we must not, however, forget that in other countries where the tracer method is applied many important results have already been achieved.

To provide Soviet biologists with information about the successes achieved abroad in the application of isotopes, a special magazine, "The Action of Radiations and the Application of Isotopes in Biology," is published in the USSR. It is a widely circulated journal which is of great assistance in the coordination of our work. Comparison of numerous investigations leads one to the conclusion that scientists of various countries could successfully join

Original language: Russian.

their efforts to solve urgent problems of biology and agriculture by means of radioactive isotopes.

To insure the extensive development of work on the application of radioactive isotopes in the sphere of biology and agriculture it was necessary to construct new apparatus and apply new methods. For example, some workers have suggested the use of instruments which, with the help of $C^{14}O_2$, automatically and accurately record the course of photosynthesis and respiratory metabolism in plants (V. Shirshov, V. Rachinsky and others); simple field methods for physiological experiments with radioactive carbonic acid have been worked out (V. Zholkevitch and others); various dosimeters have been designed which help to determine radioactivity on uninjured plants (S. Tselishchev) and thus make it possible to follow substances tagged by the isotope in the plant organism. The technique of radioautography and microradioautography has been thoroughly elaborated (Y. Mamul and others); this ensures fresh possibilities for visual investigation of the processes occuring in the plant as a whole and in its various tissues.

In their researches Soviet scientists are widely using the plants themselves to obtain preparations of sugar, amino acids, alkaloids, phosphoric ethers and many other substances marked by the isotopes of carbon, sulphur, phosphorus or nitrogen (V. Merenova, A. Kuzin, O. Pavlinova and others). These preparations are successfully applied in physiological observations on the movement and transformation of substances in organisms.

Finally, in more refined investigations, whose aim is the detailed study of separate biochemical reactions, one may apply chemically synthesized compounds marked with carbon or other elements in a strictly defined position (M. Shemyakin, B. Savinov, N. Melnikov, K. Bokarev, V. Baskakov and others).

Root nutrition is the most easily controlled aspect of the physiological development of plants. For this reason many scientists, in applying radioactive phosphorus, calcium, sulphur and other elements, have concentrated their attention on the problems of distribution and transformation of nutritive substances in the soil and on their assimilation by plants. By the application of radioactive phosphorus it was possible to change the previously existing opinion that only 10–12 per cent of phosphoric fertilizers were assimilated by plants. This opinion was formed as a result of the comparison of the general amount of phosphorus present in the yields of plants grown on fertilized and non-fertilized soils; however, no distinction was made between the phosphorus present in the soil itself and the phosphorus introduced with the fertilizer. But the experiments conducted by A. Sokolov demonstrated that when phosphate fertilizers marked by, say, P^{32} of the double superphosphate are introduced into the soil, wheat and other plants first of all assimilate the phosphorus of fertilizers, to the extent of 48–68 per cent. At the same time the amount of phosphorus assimilated from the soil itself is reduced. These results prove that plants assimilate much larger quantities of phosphorus fertilizer than previously supposed and they compel us to look for ways of increasing the percentage of phosphates assimilated by plants directly from the soil.

Another problem of vital importance for agriculture that can now be easily solved is the rational distribution of fertilizers in the soil to ensure a most rapid and complete assimilation of fertilizers by the roots of plants. This problem is particularly important for the granulated phosphoric fertilizers which are lately being widely applied in the USSR. If we place the granules of fertilizers labelled with radioactive phosphorus into different sections of the soil, we can easily see that the isotope appears in the leaves only 15–20 minutes after the contact of the rootlet with the source of P^{32}. This makes it possible, by observing the appearance of the first signs of radioactivity in the leaf lamina, to establish exactly the moment when the roots come in contact with the fertilizers. And by watching further increases in radioactivity we can also determine the rate at which a given fertilizer is assimilated.

For instance, employing this method in his experiments with oats, E. Ratner showed that if phosphorus labelled with the isotope is introduced into the soil and placed 3–4 cm below the seeds, "contact" between the roots and the fertilizer occurs in only 2–3 days after the germination of the seeds; but when the granules are displaced 5–6 cm sideways or placed much deeper than the seeds this "contact" is postponed to 3–4 weeks. Consequently, the beginning of phosphorus assimilation, which is so vital for young plants, is also postponed.

Similarly, at the present time radioactive phosphorus (P^{32}) is being used to test the efficiency of various methods of mechanized fertilization in planting cotton in the fields of the Tajik SSR (I. Antipov-Karatayev and I. Lipkind), in the Uzbek SSR (F. Reshetnikov) and in other districts of Central Asia. Undoubtedly, in the future isotopes will be of still greater importance when the various methods of mechanized fertilization are appraised.

By extensively employing P^{32} in their field experiments V. Klechkovsky and N. Kashirkina were able to study in every detail how different plants assimilate phosphorus fertilizers in the presence of other elements with varying soil humidity, liming and other conditions. It is quite obvious that such information can successfully be used to improve the methods of nutrition of agricultural crops. Many experimental stations in the Soviet Union are already extensively using these possibilities. Suffice it to say that in 1954 dozens of experimental stations used superphosphate marked with P^{32} in their field experiments.

The introduction into the soil of radioactive isotopes of several elements can also be utilized to observe the distribution of the root system, which was previously done by laborious and far from perfect methods of digging out roots and freeing them from earth. By introducing fertilizers tagged with radioactive isotopes into various soil strata, the researcher can easily observe the distribution of roots in different strata, without disturbing the plant structure, by simply watching for the appearance of radioactivity in the plant's leaves. In this way it is possible to study the influence of soil cultivation, of methods and time of irrigation, and of temperature and other factors on the development of root systems in plants. Such information is sometimes necessary for the proper nutrition of plants under specific conditions.

The application of radioactive phosphorus (P^{32}) to the study of the absorbing function of roots has permitted investigators to discover in this process, which seemed to be so well known, some new and interesting features which provide a theoretical basis for the application of granulated fertilizers. By experimenting with spring wheat, E. Ratner and his assistants were able to show that when a granule of phosphrus comes in contact with a single rootlet comprising only 4–5 per cent of the whole root system, the absorbing function of such a rootlet immediately becomes 20 or even 30 times stronger than ordinarily: as a result, one rootlet is capable of satisfying to a considerable degree the whole plant's requirement in this element.

Thus we no longer consider the root system to be a uniformly acting mechanism which sends water and nutritive substances to the above-ground portions of plants. The root system is a highly labile organ whose activity in different sections is rapidly changing under the influence of nutritive substances and the requirements of the plant. These peculiarities of the roots enable them to utilize easily the local deposits of nutritive substances: in particular, granulated fertilizers.

Radioactive isotopes have made it possible to study more closely the role played by soil microorganisms in the nutrition of plants. For instance, employing vitamin B_1 marked with radioactive carbon, G. Shavlovsky showed that this vitamin, as well as certain other vitamins of the B-group which microbes form in the soil, are easily absorbed by the roots of buckwheat and enhance the general development of plants. At the same time, isotopic sulphur helped to reveal that plant roots also utilize the amino acids methionine and cysteine, which microorganisms excrete into the soil.

In certain periods of their development, for example, setting of fruits, plants often become incapable of absorbing phosphorus and other nutritive elements through their roots. Yet the processes of movement and accumulation of plastic substances, which predominate at this given period, still require new stocks of nutritive salts and could be intensified if these salts easily penetrated into the plant.

Agricultural science has already solved this problem by applying the so-called non-root nutrition, which includes spraying, dusting, and sometimes even fumigation of the above-ground parts of the plants with the required nutritive substances. For example, in many parts of the USSR, non-root feeding by phosphorus raised the yields of sugar beet (Yakushkin) and of cotton (Uchevatkin); non-root nutrition with ammonium salts also raised the yields of cabbage and other vegetables, particularly in the north where low temperatures of the soil prevent normal penetration of nitrogen through the roots (Dadykin).

The application of labelled atoms in this case too resulted in substantiating this useful undertaking and in bringing order to it. For instance, when superphosphate, marked with P^{32}, was utilized as a non-root nutrient, it became possible to observe how the fertilizer penetrated through the leaves into the plant and how it was distributed in its tissues.

Radioautographs reproduce a clear picture of this distribution. On the basis of these documentary pictures, the agricultural workers can easily check the efficiency of nutrition and determine more exactly when such feeding should be done and how much nutrient should be applied.

Utilizing radioactive carbon (C^{14}), A. Kursanov, A. Kuzin, N. Krukova and co-workers discovered a new function of the root system, which consists in the following: the roots absorb carbon dioxide from the soil and bring it to the leaves and other green portions of the plant. It turned out that for synthesis of sugars and other products of assimilation, carbon dioxide of the soil can be utilized on a par with the carbon dioxide absorbed from the air, provided there is light. This fact has not only theoretical, but practical value as well. It proves the important role humus and the microbiological processes going on in the soil play in supplying carbonic acid to the plants. It also warns against the one-sided understanding of the tasks and possibilities of utilizing mineral fertilizers.

If we use plants labelled with radioactive carbon as green manure and introduce them into the soil, we can observe the degradation of organic residue by the rate at which $C^{14}O_2$ is liberated. Such observations are of great practical importance. They enable one to determine the intensity with which humus-forming processes take place in the soil under the influence of its cultivation, humidity, temperature and other factors. At the same time, when we grow plants in the soil containing radioactive organic residues, we are able to directly observe how they absorb and utilize various organic substances as well as the carbonic acid of decaying remains (V. Merenova).

Obviously, the relative role of carbonic acid received by the plant through its roots in the carbon nutrition of the plants as a whole may vary greatly; at present time this problem is being studied under field conditions.

The application of radioactive carbon (C^{14}) together with other up-to-date methods enabled us to study this new phenomenon in great detail and to determine its significance for plant life. It was shown that sugars formed in the leaves when CO_2 was assimilated from the air move downwards along the phloem and, on reaching the roots, penetrate into their thinnest and most active branchings. The speed of this descending movement, determined by means of radioactive carbon, is in the case of the sugar beet about 70 cm per hour.

In the roots, sugars undergo glycolytic disintegration with the accompanying formation of pyruvic acid. It is this acid which, by means of a special enzyme, incorporate the carbonic acid of the soil. The latter, in the form of carboxyl, combines with the pyruvic acid and transforms it into oxaloacetic acid which is easily reduced and transformed into malic acid, the first comparatively stable compound containing carbonic acid of the soil. Later on, as a result of mutual transformations of acids, malic acid is partly transformed into citric, ketoglutaric and other acids.

It is necessary to say that when CO_2 is introduced into organic acids in the capacity of the carboxyl group, we do not observe any practical increase in the free energy of the substance and, consequently, we cannot consider β-carboxylization as such to be equivalent to carbon dioxide nutrition of plants. But organic acids, formed in the roots and containing the carbonic acid of the soil, move upward and penetrate into the green fruit, growing apices and leaf laminae. The speed of this ascending movement, even in the case of herbaceous plants, is about 3 cm per minute or 2 metres per hour. Therefore it takes very little time for the carbonic acid of the soil to reach the assimilating tissues where it can be reduced in the process of photosynthesis, forming carbohydrates, proteins and other products rich in energy.

Some of the sugars thus formed are, in their turn, translocated to the roots where, during the process of glycolytic disintegration, they are transformed into pyruvic acid and accept from the soil fresh portions of CO_2 in order to transfer them to the leaves. Such is the principal cycle along which the process develops. But in addition to this, there are a number of subsidiary phenomena which condition the dependence of carbon dioxide nutrition in roots on other aspects of the physiological activity of plants.

By employing isotopes and chromatographic analysis, A. Kursanov, O. Tuyeva, A. Vereshchagin, I. Kolosov and S. Ukhina have succeeded in discovering a new and important function of the roots, which consists in the initial synthesis of a number (about 14) of amino acids. These amino acids are utilized in the root itself as well as in other portions of the plant where they participate in metabolism and the synthesis of new proteins. So it turned out that besides its absorbing function, which has been drawing the attention of scientists and practical workers for a long time, the root system fulfills another very important role connected with the protein metabolism of the entire plant.

At first it was considered that this aspect in the activity of the root system was an independent function having no connection with the absorbing function of the roots, but later on it was discovered that this is exactly the mechanism by which roots assimilate ammonium nitrate from the soil.

In this process a very important role belongs to the carbonic acid of the soil. This acid brings about the carboxylization of pyruvic acid and some other products which are initial acceptors of the nitrate of ammonium fertilizers.

At the same time it has been proved that for the functioning of this system the roots should be well provided with phosphorus, since phosphoric acid participates in a number of stages of the glycolytic process as well as in the cycle of di- and tricarboxylic acids. Therefore, when there is a shortage of phosphorus the roots lose, as a rule, the ability of accumulating organic acids (A. Vereshchagin) and, consequently, of fixing soil carbonic acid (O. Kulayeva). All this inevitably results in difficulties of nutrition of plants.

Such is the picture of one of the most important aspects of plant nutrition which we have at the present time and which it did not take long to discover by means of labelled atoms. In our opinion, this is convincing proof of the broad possibilities which the application of radioactive and non-radioactive isotopes opens up to biologists.

Our conceptions of the velocity of the processes taking place in plants have also been modified. The exact course of some of these processes has now been determined, thanks to the application of tracers; we have been compelled to reject the opinion that various processes occurring in the plant proceed very slowly. For example, F. Turchin, who used heavy nitrogen (N^{15}) which he introduced into the soil in the form of ammonium sulphate, showed that proteins of all the organs of the plant are constantly renewed and that this renewal proceeds at such a pace that a protein particle of vegetating rye sometimes lives no more than a few hours. Even the nitrogen of chlorophyll, forming the very centre of this pigment molecule, is renewed so rapidly in actively vegetating plants that sometimes in the course of 2–3 days more than half of it is already replaced.

Labelled atoms enable one to approach experimentally the problem of biosynthesis of chlorophyll and carotene in plants. Thus, in the Byelorussian Republic, T. Godnev and A. Shlik, utilizing in their experiments glycocol labelled in carboxyl with C^{14}, and also radioactive glucose, obtained new evidence on the course of chlorophyll, phytol and carotene synthesis in plants.

Now with the use of radioactive isotopes it is very easy to study in detail the movement of plastic substances in the plant, and to determine not only the direction and speed of this movement but also the composition of the moving products. If we bear in mind that proper nutrition of various portions of the plant and the accumulation in them of valuable nutritive elements depend precisely on this process, then we shall understand the great importance for biology and agriculture of the direct observations on the flow of plastic substances which have been made possible only with the aid of radioactive elements.

Employing this method, M. Turkina, E. Vyskrebentseva, and N. Pristupa, working in our laboratory, demonstrated that substances move in plants more quickly than was heretofore believed. For instance, the products of photosynthesis travel from the leaves to the roots of the sugar beet, pumpkin and some other plants at the rate of 70–100 cm per hour and even more. Somewhat slower is the movement of assimilants towards fruit and growing shoots, but even in this direction the organic substances usually make not less than 40–60 cm per hour. Therefore, in the majority of agricultural crops, it takes no more than 20–40 minutes for the products of photosynthesis to reach the growing points and organs of accumulation.

Finally, according to A. Akhromeiko's experiments, water, especially in some of the trees, moves along the xylem at 6–8 or even more metres per hour.

Labelled atoms, therefore, have shown that in plants, despite their outward immobility, physiological processes proceed at a very rapid rate. Consequently agricultural workers should take this fact into consideration so as to co-ordinate their methods of tending plants and the "rates" of plant activity.

Radioactive carbon (C^{14}) is used to study the composition of substances moving in the plant.

Thus, experiments conducted in our laboratory with sugar beet, pumpkin, cotton, and other crops, demonstrated that along the conducting tissue usually moves a mixture consisting of saccharose, glucose, fructose, hexophosphoric ethers, organic acids and amino-acids, with saccharose and hexophosphoric ethers forming the greater part of this mixture. In addition, they move faster than the other components and this leads to the conclusion that they are the basic mobile substances in plants.

However, the composition of the nutritive mixture moving in the conducting tissue differs in various plants and may change depending on the stage of development or under the influence of light and mineral nutrition.

All these data show that, using radioactive carbon as an observation method, we can approach the problem of arbitrarily changing the direction and composition of the plastic substances that move in the plant; this will provide agriculture in the nearest future with some new and still unused possibilities.

However, V. Zholkevich, who utilized the tracer method on the irrigated lands of the Trans-Volga, has already proved that assimilants, formed in wheat leaves from labelled carbonic acid, travel to the seeds far more rapidly in irrigated plants than in plants suffering from water shortage. With the aid of radioactive carbon dioxide, it was also shown that when potatoes are cultivated under the conditions of the extreme north, the products of CO_2 assimilation mainly travel from the leaves to the stems and growing apices, which results in abundant stems and leaves. The long day and low temperature of the soil caused a slow and retarded flow of nutritive substances to the tubers, and this was the reason for comparatively low content of starch in the local potatoes (Z. Zhurbitsky). At the present time agricultural workers of the north are searching for methods to combat this negative phenomenon, employing isotopic indicators to appraise the efficiency of the measures they undertake.

Radioactive isotopes enable one to observe not only the movement of organic substances but also the way nutritive salts move and are redistributed in the plant. In this respect interesting experiments are conducted in the Ukrainian SSR with fruit trees. By means of P^{32} and Ca^{45} it was possible to study in detail the picture of the distribution and redistribution of these elements in the development of trees (N. Lubinsky and K. Garnaga). Similar experiments are conducted on other woody plants, such as scoompia (*Cotynus coggygria Scop.*), eucommia (*Eucommia ulmoides*) and others (S. Slukhai). These experiments also deserve special attention, particularly if we bear in mind that our information on the mineral requirements of woody plants is far from complete.

Special chemical preparations, such as 2–4 dichlorophenoxyacetic acid, methyl ether of α-naphthylacetic acid, 4-iodophenoxyacetic acid, etc., have become widely applied in practical farming as a means of influencing growth and formation processes in plants. The biological aspect of this peculiar influence has been studied lately thanks to the utilization of labelled atoms.

Thus, for instance, if we introduce into a tomato plant a solution of 4-iodophenoxyacetic acid, marked with radioactive iodine (I^{131}), we can exactly determine its localization in plant tissues after some time has passed. The greatest part of the iodine preparation is concentrated in the flowers and fruit, thus creating a peculiar polarization: from leaves, roots and other portions of the plant nutritive substances travel to these organs ensuring their intensive growth and accumulation of nutritive products (Y. Rakitin).

But the isotopic method not only enables one to observe the movement and distribution of substances in the plant: it also helps to observe the course of further transformations.

Thus, A. Krylov, Y. Rakitin and N. Melnikov utilized as a growth stimulant the methyl ether of α-naphthylacetic acid marked in carboxyl or in other positions by radioactive carbon. They discovered that while this substance intensifies growth, the plant at the same time always strives to rid itself of this influence by splitting off carboxyl groups and by further rearrangement of the molecule of the physiologically active compound. In this way, the radioactive isotopes enable us to approach the solution of a problem which is of great importance to biology and agriculture—the detoxification of alien substances in the body of plants.

In a similar manner we can also observe the normal course of metabolic processes. For instance, A. Prokofiev, introducing a solution of saccharose marked with radioactive carbon (C^{14}) into the leaves of kok-saghyz, discovered that radioactive rubber very shortly appears in the latex of the plant. In this way it was proved once and for all that rubber originates from carbohydrates. This experiment is interesting from another point of view also, for it provides an explanation of the accumulation of rubber in kok-saghyz after harvesting. Practical workers have been interested in this problem for quite some time.

Developing these experiments on kok-saghyz, B. Savinov and his assistants utilized d-fructose, d-glucose, levulinic, pyruvic, and acetic acids marked with radioactive carbon in definite positions. In this way they were able to study more closely the processes of sugar transformation leading to rubber formation.

The isotopic method has also considerably modified our former ideas on the synthesis of saccharose in sugar beet. Utilizing C^{14}-labelled carbon dioxide and glucose and fructose also labelled with radioactive carbon, A. Kursanov and O. Pavlinova demonstrated that the tissues of the root and shortened stem of the sugar beet, which were formerly considered to be the organs capable of intensive synthesis of saccharose, actually cannot form this biose from glucose or fructose.

Further experiments prove that in sugar beet the synthesis of saccharose takes place mainly in the leaves where this biose is easily formed as the first free sugar of photosynthesis, or where it may be formed as a secondary product from glucose and fructose. From the leaves saccharose rapidly travels along the conducting tissues to reach the roots. This conclusion compels agronomists and selectionists striving to raise the sugar content in the industrial varieties of sugar beet, to pay more serious attention to the development of the leaf-system and to the processes occurring in it, while previous investigations underestimated the role played by the leaf system in the synthesis of saccharose.

Another example of successful application of the isotope method in plant physiology is furnished by interesting experiments conducted by V. Pontovich and A. Prokofiev. By means of C^{14}-labelled carbon dioxide they discovered that in the ripening fruits of poppy there occurs a metabolic cycle which is of great significance for the normal development of seeds. This process begins in the following manner: as a result of intensive respiration of young seeds, large portions of carbon dioxide are evolved into the core of the fruit. However, this gas is not accumulated here but diffuses to the green surface of the fruit walls where it is quickly reduced in the process of photosynthesis, forming sugar and other nutritive products which, through placenta, are transmitted from the walls back to the growing seeds. Thus, in the green poppy fruit this peculiar type of turnover ensures a quick removal of superfluous carbonic acid from its core, maintains a high concentration of oxygen necessary for the synthesis of fat, and results in the restoration of organic substances which the seeds use in respiration.

The tracer method opens especially broad possibilities for scientists engaged in investigating photosynthesis. Utilizing isotopes, Soviet scientists have achieved a number of successes in this sphere. The discovery of photolysis of water, made almost simultaneously in the Soviet Union (Vinogradov and R. Teis) and in some other countries, is particularly important. It enables one to understand the mechanism of photoreduction of carbonic acid.

At the present time we are approaching the solution of the problem of primary organic substances formed in the process of photosynthesis. The utilization of labelled carbon dioxide in combination with paper chromatography ensures an extreme sensitivity of such experiments and enables one to detect labelled products of photosynthesis only 0.5 seconds after irradiation. Thus, N. Doman has recently discovered two new substances of low molecular weight whose nature is now under investigation. For the time being we know only that the first of these substances does not contain phosphorus and, consequently, is not phosphoglyceric acid. These and many other investigations conducted by means of radioactive and non-radioactive elements are preliminary to the decisive step in the direction of disclosing the mystery of photosynthesis and of mastering this process, a step which probably will take place in the near future.

Since we cannot consider in detail a number of such investigations in this paper, we shall take up only the question of the direct products of photosynthesis. A. Nichiporovich, N. Voskresenskaya, T. Andreyeva, and others, utilizing radioactive carbon (C^{14}) in the form of carbon dioxide and heavy nitrogen (N^{15}) in the form of an ammonium salt, demonstrated that not only carbohydrates but proteins as well are the direct products of photosynthesis in the leaves of plants. The composition of the photosynthetic products may vary considerably under the influence of the species of the plant and its age, as well as its environmental conditions. This process is most strongly influenced by the spectral composition of light and its intensity. These factors, in combination with mineral nutrition, can considerably change the composition of the primary products formed in the leaves. Thus, carbohydrates are synthesized mainly in the red and yellow parts of the spectrum, while proteins are formed under the influence of blue light. Besides its fundamental significance for biology, this fact also provides practical possibilities to influence the development and properties of plants by changing the composition of the primary products of photosynthesis which are being formed. There is every ground for the practical utilization of this discovery under hothouse conditions where it is possible to use sources of lighting with varying spectral composition and intensity which enables the agronomist to control not only the quantitative aspect of photosynthesis but the qualitative as well.

We have already said that the present paper does not describe all the new data in the sphere of metabolism and plant nutrition obtained in the USSR by applying the tracer technique. It is our opinion, however, that this paper proves that application of the achievements of nuclear physics for studying plant life opens great possibilities for the development of biology and agriculture.

But even at the present time, when we are only beginning to discover the practical possibilities of radioactive isotopes as a method of studying plant life, we can state with satisfaction that in the USSR this method has already seriously influenced the development and improvement of practical farming methods.

For instance, it was by means of radioactive isotopes that the problem of the effective application of granulated fertilizers was finally solved: this at once ensured wide application of this method of plant nutrition, and it is now successfully used on thousands of large farms in the Soviet Union.

Radioactive elements helped to bring about a similarly radical change in the attitude to non-root nutrition, whose expediency was for a long time disputed. At the present time the non-root nutrition is successfully practised in the USSR on thousands of hectares. This method is applied to those crops and in those periods of vegetation when non-root feeding can give the greatest effect required.

Radioactive isotopes have also demonstrated the possibility of a more economical and at the same time more effective utilization of fertilizers for feeding plants. This resulted in a number of rational changes in soil cultivation, in reconstruction and improvement of sowing machines, and in other measures that are being rapidly introduced in practical farming in our country.

But all this does not exhaust those great possibilities that are opened before biologists and agronomists utilizing atomic energy for the aims of peaceful construction. Employing radioactive isotopes, we can now more profoundly study the laws of plant life, and it is our duty to show to the agricultural workers ways and means of obtaining abundant and stable yields, ways of securing a prosperous and tranquil existence for all.