V. Mezentsev

the World of Isotopes

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IN THE WORLD OF ISOTOPES

FOREIGN LANGUAGES PUBLISHING HOUSE
Moscow 1959

TRANSLATED FROM THE RUSSIAN
BY G. YANKOVSKY

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1. ON THE THRESHOLD OF A NEW ERA

Many scientific discoveries make their way into everyday life gradually and unnoticed. It wasn't so long ago that the researches of scientists in atomic physics seemed far removed from practical life. But it was precisely here that science harnessed the most powerful force of nature and opened up vast potentialities for perfecting the whole pattern of present-day technology.

Scientists made their first acquaintance with atomic energy at the turn of the century when special, radioactive, substances were discovered. The atomic nuclei of these substances disintegrate spontaneously, releasing a very large quantity of energy. But the energy of radioactive decay is given up in small portions over a long period of time, and there is no way to accelerate the process.

Science was confronted by a tempting problem, that of finding a way to harness the colossal energy stored up in the atomic nucleus. And physicists solved it.

The discovery of ways to obtain atomic energy is not the invention of any one scientist or of the scientists of any one country. Success was achieved after years of studying the atom and its nucleus in many countries. Soviet scientists also made a significant contribution to this big and noble end.

Atomic energy is now "liberated" in so-called "atomic piles" or nuclear reactors. In these plants energy is released, during the fission of atomic nuclei, in the form of heat which may be used for different purposes, one of which is to move a steam or gas turbine that rotates an electric generator, thus converting atomic energy into electricity.

Yet another peace application of atomic energy has to do with the radiations of radioactive substances. Radioactive substances, or, to use the more common term, radioactive isotopes, belong to the "non-energy" field of atomic engineering which is beginning to find a broad and diverse application in industry, agriculture, medicine and scientific research.

Radioactive radiations have great penetrating power which is something that offers extremely intriguing possibilities. The invisible radiations of radioactive isotopes are becoming a means for control and automation in industry; they act as catalysts in chemical processes, and are a powerful factor in biology and medicine. Finally, these same radiations may be used for making small-size, long-lived sources of electric current.

The radioelements open up one more remarkable possibility. They enable scientists to follow the movement of invisible particles of matter, to see the paths taken by individual atoms and molecules, to distinguish individual atoms of a chemical element from other atoms of the same element. No matter where the radioactive atoms are, they reveal their hiding place by radiation. This property or "label" enables us to detect them anywhere.

Special instruments called counters are used to detect such "tagged" atoms. In this way it is possible to count the number of radioactive atoms that, for example, enter an organism. Also, the radiation of tracer atoms affects a photographic plate much as the rays of visible light do. Such atoms make their presence known by "signing" on the plate.

Besides, in all kinds of chemical transformations the radioactive isotopes of an element behave the same way as their non-radioactive brothers do. By observing how the radioactive atoms "travel" during chemical reactions, scientists determine the behaviour of the atoms of different substances. Tracer atoms enable us to "look into" the processes and follow the doings of chemical elements in all sorts of materials.

The tracer method is gaining recognition in the most diverse fields of life. Tracer atoms have become one of the branches of atomic engineering and are a remarkable instrument of investigation wherever the problem is to detect a substance or to study the processes of its transformation and motion.

In 1907, Marie Curie Sklodowska, who discovered the natural radioactive elements of radium and polonium, made a present of one gramme of radium to the Paris Institute. At that time this was an exceedingly valuable gift, costing several hundreds of thousands of rubles. Plants processing ores that contained radioactive substances did not obtain more than several grammes of radium a year. It is obvious that at that time there could be no question of utilizing the atomic energy of radioactive substances on a large scale.

Now, radioactive isotopes are obtained artificially, mostly in nuclear reactors, these "alchemistic" furnaces of our age. They are obtained as by-products in the production of atomic energy and in such quantities as were only dreamed of twenty years ago.

A real possibility appeared for applying the energy of radioactive substances wherever it is needed. Radioactive atoms are beginning a new life as man's best helpers.

2. "FACTORIES OF RADIOISOTOPES"

The centuries-long attempts of alchemists to transform one element into another ended in failure. What the alchemists of the Middle Ages were not able to do, was accomplished by the physicists of the 20th century.

It turned out that radioactive decay accomplishes exactly what the "makers of gold" had at one time attempted, the transmutation of one element into another. And this is not surprising since, roughly speaking, chemical elements differ from each other as to the magnitude of electric charge of the atomic nucleus. By way of illustration, the atoms of mercury differ from those of gold only in one respect: in gold the charge of the nucleus is one elementary unit less than that of the atomic nucleus of mercury. It is sufficient to change the charge of the nucleus of the atoms of a chemical element for it to become another element. These are precisely the changes that take place in the natural disintegration of radioactive elements.

When radioactive substances decay the atomic nuclei emit three main types of rays. One type, alpha rays, consists of a flow of particles with a positive electric charge. The second group of radioactive rays is a stream of fast electrons that carry a negative electric charge. These are called beta rays.* The third type of radiation, gamma rays, is very much like X-rays. Thus, if alpha or beta rays are ejected from a nucleus, its charge changes and the nucleus of one element is then converted into the nucleus of another.

The question naturally arises: is it not possible to produce this transformation artificially? The answer is yes. Scientists now find no difficulty in transforming one element into another. Gold may be obtained from mercury just as was dreamed of by the alchemists of the Middle Ages. However, such gold costs much more than that extracted in gold mines.

In 1934, two well-known French physicists, Irene and Frédéric Joliot-Curie, obtained artificial radioactive atoms (isotopes) of such ordinary stable elements as nitrogen,

* In decaying, certain artificially obtained radioisotopes eject not electrons, but positively charged elementary particles, so-called positrons.

phosphorus and others by "bombarding" various substances with beams of microparticles.

Since that time scientists have studied hundreds of different nuclear transformations which give birth to "chemical twins," or isotopes. Chemically their properties are the same, the only difference is that, unlike their stable brothers, they are radioactive.

Many hundreds of different radioactive isotopes have been obtained in this way. But even these radioactive substances were very expensive before the atomic pile became a component part of atomic engineering. Though the primary purpose of the pile is to produce atomic energy, it has at the same time become a "factory of radioactive isotopes," where the latter may be produced in large quantities. Gold, copper, iron and phosphorus placed in a nuclear reactor come out radioactive.

Let us examine one of these unusual "factories" of radioactive substances.

A two-hour ride from Moscow will take you to the town of Maloyaroslavets. Near by, surrounded by forests, is the first Soviet atomic power station. The main three-story building of the station bears a certain resemblance to a school. Only a high chimney mars the effect. But no smoke emerges from the chimney. The impression one gets at first is that the station is not working. Everything is quiet. But this is not so, the station is working and is producing electricity.

The station is housed in three buildings. The atomic pile of the station is a reactor with a graphite moderator. The main building contains the heart of the nuclear power station—the reactor together with the control board, the heat exchangers, pumps and other equipment connected with the reactor or used for scientific research. In the second building is the steam turbine and electric generator, and also electric and other apparatus and equipment. The third building houses the ventilation system that keeps the rooms clear of dangerous radioactive gases produced by the reactor.

In this case, the nuclear reactor plays the part of the steam boiler in conventional steam power stations. It contains the "atomic fuel" or, as it is usually called, the "nuclear fuel," which at present is chiefly the heavy silverish metal uranium. When the fuel "burns," the atomic nuclei of uranium are split into fragments. The process continues without interruption. This "burning" of nuclear fuel in the atomic pile can be controlled—accelerated or retarded.

The heat generated in the reactor raises the temperature of the water circulating in the pipes that pass through the core of the pile. The water transfers the heat from the reactor to the steam generators, producing live steam which in its turn rotates the power generator. This, in general outline, is how the station works.

When in operation, the nuclear reactor produces streams of radioactive radiations (gamma rays and elementary particles called neutrons). During the fission of atomic-fuel nuclei, neutrons are released in huge quantities. Nearly 60,000,000 million neutrons pass through a cross section of one square centimetre every second in the pile.

Radioradiations are dangerous to human beings. For this reason, atomic piles have a massive protective shield made of materials such as concrete, special grades of steel, lead, water, etc., that stop radiations.

In addition to this, the nuclear reactor of the first Soviet atomic power station is enclosed in a hermetically sealed steel cylinder. Outside, it is surrounded by a metre-thick layer of water and a concrete wall three metres in thickness. On top there is also a steel cover and a thick plate of cast iron. All of this provides for the maintenance personnel of the station sufficient protection from harmful reactor radiations.

Artificial radioactive substances are usually produced in the following way. The protective shielding of the atomic reactor has special channels into which chemical elements are inserted at varying depths. When the reactor is in operation these elements are subjected to a powerful "bombardment" by neutrons flying out of the pile and become radioactive. Cobalt becomes radiocobalt, nitrogen is converted into radiocarbon, chlorine is transformed into a radioactive isotope of sulphur, etc. In this way, it is possible to obtain large numbers of artificial radioactive isotopes of different elements in Mendeleyev's Periodic Table.

At present, there are over 1,000 radioactive isotopes (both natural and artificial), which have different half-lives, different radiation and different energies. Radioisotopes which are easily produced and which have half-lives that are not too short are finding extensive application.

The majority of the more important radioisotopes are obtained in the reactor as described above. However, there is also another way. During the operation of a nuclear reactor a peculiar "ash" accumulates. This is "unburnt nuclear fuel" and is very valuable. Artificial radioactive isotopes of certain elements are produced as a result of the fission of uranium nuclei; among them we find, for example, the valuable radioisotopes of cesium and europium, which are being used in many ways.

It must be added that artificial radioactive isotopes may also be obtained in so-called accelerators, which are machines that produce powerful beams of alpha particles, protons, deuterons (the nuclei of heavy hydrogen atoms) and neutrons. Artificial radioisotopes may be obtained by using these particles to "bombard" different elements of the Periodic Table. One of the most widespread machines of this type is the cyclotron. However, the chief supplier of artificial radioactive isotopes is the nuclear reactor.

3. "RADIOEYES"

Radioactive atoms open up great possibilities for control and automation of production processes.

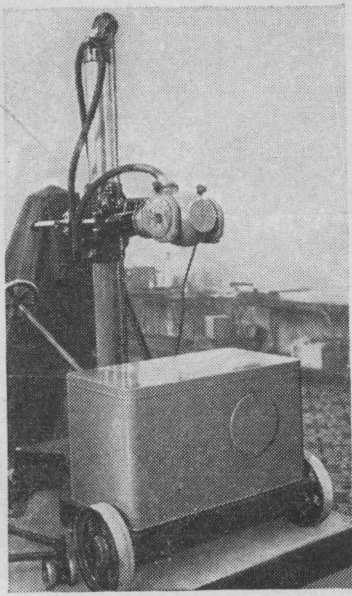
X-rays and the magnetic method have been used for a rather long time to detect internal flaws in metal parts. However, these methods cannot be used to inspect very thick parts since X-rays cannot penetrate more than two or three centimetres of metal. And besides, the equipment is cumbersome and expensive.

Now, a radioactive isotope of cobalt (cobalt-60) and also certain other radioelements are being used to inspect the quality of steel. Cobalt-60 can "see" through 30 and more centimetres of metal.

Here is the way it is done. The part to be examined is placed between the source of radioradiation and a photographic film. The gamma rays pass through the metal and are absorbed to a less extent in places where there are cavities and cracks. This leaves a trace on the film. In this way, invisible cracks in machines or pits in metal billets are easily detected, and the quality of welded seams may be determined. This is the gamma-ray test method. The inspection of parts by this method is much more rapid and accurate, and, what is most important, it can be done directly in the factory since the required apparatus is relatively simple.

Gamma-ray test techniques are used in our industry. The State Inspection of the U.S.S.R. requires that all welded boilers, bridges, ship hulls, gas pipelines, etc., be tested with radioactive isotopes. The Soviet Union is building thousands of kilometres of new gas pipelines, and every line will pass through the strict and cheap "atom control."

A radioactive level gauge for liquids in closed vessels is used to measure the level of molten steel during continuous casting. The principle of control here is very simple. A source of radioactive radiation is placed on one side of the crystallizer, on the other side of which is a counter. Radioactive radiation passes through the walls of the crystallizer and is detected by the counter. But all of a sudden the counter stops. This means that the liquid metal in the crystallizer has blocked the rays coming from the radioactive source.



Industrial gamma-ray unit for testing metals

In the same way it is possible to determine the level of molten iron in cupola furnaces. In power stations, the "radioeye" follows the water-level in the steam boilers. Radioactive level gauges are widely used in Soviet factories.

Radioactive radiation makes possible the automatic control of the thickness of materials in the process of production. One of these methods of control consists in the following: gamma rays (or beta rays) are sent through a strip of metal, rubber or paper during its manufacture. The thicker the strip the greater the absorption of radioactive radiations. The gamma radiation that passes through the strip is measured by a counter. If it is connected to an automatic device, it is possible to maintain one and the same thickness of the strip during production. In this way the thickness of parts may be measured and adjusted without interrupting the production process.

Radioactive thickness gauges are in use in Soviet factories, for example at the Leningrad Metal Works,