THE HISTORY OF RADIUM[1]

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THE discovery of radio-active substances followed close on the discovery of the X-rays, and was due partially to certain phenomena observed in a Crookes tube. When there is sufficient vacuum in the tube all of the glass on the cathode side becomes fluorescent, shining with a bright yellowish-green light. In 1895 Roentgen discovered that in this condition the tube emitted a radiation capable of penetrating flesh and many other substances opaque to light. He called these rays "X-rays," but they were later named "roentgen rays" in honor of their discoverer.

We now know that the roentgen rays were produced by the action of the cathode rays on the glass of the tube, but in 1896 Poincare, a French mathematician, advanced the hypothesis that the fluorescence in the tube might be the cause of the roentgen rays. From this, he reasoned that all fluorescent material, if sufficiently illuminated, would give off roentgen rays. Several scientists adopted this hypothesis as a basis for their work, among them Henri Becquerel, who was particularly qualified to carry on research of this character, since he had received special training from his father, Edmond Becquerel, one of the pioneers in the investigation of phosphorescence and fluorescence. Becquerel's starting point was wrong, since the fluorescence of uranium was entirely apart from the surprising phenomena that will be described. In fact it may be said that at the time of his investigations uranium was the only known fluorescent substance capable of producing these phenomena. His first experiment was relatively simple; he surrounded a photographic plate with black paper, placed on it a few crystals of uranium sulphate, exposed the whole to the sun, and after several hours developed the plate. A faint picture of the crystals appeared. Apparently the hypothesis had been demonstrated, and the fluorescence in the uranium illuminated by sunlight had produced roentgen rays, since the black paper had been penetrated beneath the crystals. Becquerel, naturally, was very anxious to repeat the experiment, this time interposing between the plate and crystals not only the black paper, but a copper cross 0.1 mm. thick to see if the radiation of the uranium would penetrate through the denser obstacle. Fortunately for Becquerel the sun did not shine. After keeping the plate in the dark room underneath the crystals and cross for several days, waiting for the sun to appear, he became impatient and proceeded to develop the plate. To his great surprise a vivid picture appeared. The uranium, shielded from any kind of illumination, had given off energy without appreciable change in the substance itself. By repeating the experiment several times he effectively disproved Poincare's hypothesis, but it was still necessary to determine whether uranium possessed the property of some of the phosphorescent bodies of storing luminous radiation and giving the energy back more slowly, and in a changed form. If this were true, as time went on, the action would grow weaker and weaker if the uranium were kept in a dark room. However, repeated trials demonstrated that even after several months the activity of the uranium was not diminished in the slightest. The phenomenon of radio-activity and the fact of the spontaneity of the uranium radiations were thus definitely established, and the rays emitted were called "Becquerel rays" in honor of their discoverer. The report of Becquerel's work in 1896 stimulated many others to similar research, among whom should be mentioned Elster, Giesel and Schmidt of Germany, Kelvin and Crookes of England, and Rutherford of Canada.

At about this time Marie Sklodowska of Poland (afterward Madame Curie) was a student at the University of Paris, doing

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graduate work in physics and chemistry under Becquerel and Curie. Becquerel, having the greatest respect for the accuracy of Miss Sklodowska's training and the precision and clarity of her mind, invited her to undertake the study and investigation of the Becquerel rays. Her problem in the beginning was relatively simple. She wanted "to demonstrate that radio-activity was present, not only in uranium, but in other elements as well." She hoped to find this property in other bodies, but to a lesser degree. First of all it was necessary to be able to measure accurately the radio-activity of the elements to be studied. A gold-leaf electroscope, therefore, was devised which was adaptable to her experiments. With this electroscope she conducted a systematic examination of various ores for evidence of radio-activity and found that the element thorium possessed radio-active properties of about the same degree as those of uranium. However, a short time before she published her thesis, Schmidt, of Germany, announced the discovery of radio-activity in the same metal. Undaunted by this, Madame Curie began the examination of uranium-bearing ores and also of uranium residues in order to determine their relative radio-activity as compared with uranium. Her first samples were from the mines in Joachimsthal, Bohemia, the source of the uranium which Becquerel had used in his experiments. The ore was known as pitchblende, and was a black mineral resembling hardened pitch in density and color. Chemically, it is a fairly pure oxid of uranium, although it is also known to contain many other elements in small quantities, such as lead, copper, bismuth and barium. At this time the ore was being mined for the uranium, as it contained as high as 50 per cent of this element. Madame Curie ground the ore into a dry powder, and on testing its radio-activity with her electroscope, found it to be several times as active as pure uranium, and in all cases the minerals tested showed from four to five times the activity to be expected from the percentage of uranium present.

Becquerel had previously shown that the radio-activity of uranium was an atomic property; that is, the activity observed depended only on the amount of uranium present and was not affected by its combination with other substances. Thus, the great activity of the uranium ores could only be accounted for by assuming that another substance was present which was much more active than uranium itself. Madame Curie interested her husband in her work, and they joined forces in the attempt to isolate the unknown element. Through the courtesy of the Austrian Government they secured a ton of the same kind of uranium residue that Madame Curie had previously examined. Separating pitchblende into all its constituent parts is even now an extremely difficult task, and was particularly difficult for the Curies, who were searching for an unknown element, which, as is now known, occurs in the richest ores in proportion of about one to ten million. As a guide to the separation of the radio-active substance they employed Madame Curie's electroscope to measure the ionization produced by the active body. After each chemical separation, the activities of the precipitate and the filtrate, evaporated to dryness, were separately examined; in this manner it was possible to ascertain whether the active substance had been mainly precipitated or left behind in the filtrate. This served as a rapid means of qualitative and quantitative analysis. Only a general idea of the process of extraction will be given here.

The mineral was first heated with sodium carbonate, and then dissolved in hydrochloric acid, after which it was treated with hydrogen sulphid. A black, muddy precipitate was formed from the clear solution. On separating the precipitate into its constituents, which included copper, lead and bismuth, a certain amount of radio-activity was found to accompany the metal bismuth. A radio-active element, combined with the bismuth, was isolated and

called "polonium" in honor of Madame Curie's native country. Polonium is now designated "Radium F," since it is one of the decay products of radium. Ammonia was added to the clear solution and a new precipitate containing iron and uranium formed. This precipitate was, of course, radio-active due to the presence of uranium, but the filtrate, when tested, was many times more so. Ammonium sulphid was then added to the filtrate and a non-active precipitate obtained. Finally, ammonium carbonate was added to the remaining filtrate, and this precipitate, when tested, was found to be several times more active than the original pitchblende. When examined chemically, this precipitate was found to be made up chiefly of barium. Knowing pure barium to be absolutely inactive when tested with an electroscope, it was evident that the barium from the pitchblende contained another substance so similar in chemical properties that all the chemical operations the material had undergone thus far had failed to separate them. The final separation was accomplished by fractional crystallization, a prolonged, tedious process, this being the only method found so far that will successfully separate the two elements. The radio-active barium was converted into barium chlorid, the solution evaporated to dryness, and the crystals were dissolved in boiling water. The solution was allowed to cool, and the crystals which separated on cooling were collected, and found to be more radio-active than the material from which they were made. It was evident, therefore, that associated with the barium chlorid there was a radio-active metal allied to barium which formed a chlorid less soluble than barium chlorid. This new element was called "radium" in allusion to its radio-active properties. By working on large quantities of material and by repeated fractional crystallizations, they obtained products more and more active until they at last obtained a product thirty times as active as uranium. Surely this last product, even if not pure, must at least contain a large proportion of the new element. A platinum wire was dipped into the salt and then into a Bunsen flame, and to the disappointment of the investigators, only the characteristic green color produced by barium was visible. However, when the light was analyzed spectroscopically, faint lines were present in addition to those produced by the barium. It was necessary then to persist in the crystallization. The product became more and more radio-active, and the red rays, characteristic of the new substance, began to predominate in the Bunsen flame. Finally, when the salt had been reduced to the merest pinch by the successive reductions at each separation, the spectral lines of barium could no longer be seen. Pure radium chlorid had at last been isolated at the expense of almost incredible labor and perseverance. The activity of the pure radium chlorid was amazing, even to its discoverers. The electroscope was discharged almost instantly, and a photographic plate was fogged merely by bringing it near the radium product. Its radio-activity was later found to be over two million times that of uranium.

It might be of interest to note here that radium itself was not obtained until 1910 (twelve years later), when Madame Curie and Debierne isolated the element as a pure white metal, resembling barium in its general chemical properties, and showing the radio-active properties expected. Its atomic weight, as determined by Madame Curie, was found to be 226.4. Metallic radium changes quickly when exposed to the air since it reacts with the water in the air, forming radium hydroxid.

The publication by the Curies of their thesis, in 1898, aroused great interest, and many able investigators began work on the newly discovered element. Within a few months Giesel had simplified the process of extraction, reducing the time required for fractional crystallization from three months to one month. He dissolved the radio-active barium obtained from pitchblende in hydrobromic instead of hydrochloric acid, producing the bromides of radium and

barium, which are much easier to separate by fractional crystallization. By this method Giesel succeeded in securing the largest quantity of radium bromid that has as yet been obtained from any ore (4 grains to the ton of residue). It was extracted from the pitchblende at Joachimsthal, Bohemia. Realizing the value of the radium-bearing ores in Bohemia, the Austrian Government forbade its exportation, and a world-wide hunt for radium ores was begun immediately by the French and English. Radium was found to be widely distributed throughout the earth's crust in minute quantities. Strutt, Joly, Knocke and others were able to detect it in very small quantities in volcanic rocks, in certain springs and in sea water.

Pitchblende, or uranite, was found at Cornwall, England, but in such quantities as to be of negligible value. In 1899 two French mineralogists, in search of pitchblende, came to America, where they found immense deposits of a uranium-bearing ore in Colorado and Utah. They called this ore "carnotite," in honor of Carnot, a French chemist. On analysis this ore was found to contain radium, but in considerably smaller quantities than in pitchblende. Nevertheless, since its discovery this deposit has produced over 80 per cent of all the radium in use to-day. The production of radium for the next fourteen years was on a very limited scale, as can be seen from a bulletin issued by the Bureau of Mines, Washington, D. C., in 1913, announcing that, of the estimated world's supply of radium (about 30 gm.), enough ore had been shipped to Europe from the United States to manufacture 18 gm., and that, despite this large exportation, less than 2 gm. was owned in this country.

However, shortly before this report was made, Mr. Joseph M. Flannery, the pioneer producer of Vanadium Steel and the head of the American Vanadium Steel Company, became interested in radium through the death of a sister from carcinoma. He learned that radium might have helped her, and determined to make enough of the element in this country so that it would be available in all similar cases. He withdrew from his vanadium and other interests, devoting all his time to this task. After fourteen months of preliminary work and experimentation he succeeded in extracting the first radium in this country in 1913. The field was absolutely new and unknown to anyone in America. The process of extraction was entirely different from that used in Europe, where the ores were about one hundred times as rich in radium.

The carnotite deposits which he had selected for his ore supply were located in southwestern Colorado, sixty-five miles from a railroad and in a dry, arid country. A concentration mill and supply depot were built at a point convenient to the many ore claims, as the deposits covered a region of about 800 square miles. Burros were used to carry the ore from the mines in the mountains, and to carry back to the miners the water and other supplies, for all of which they were dependent on headquarters.

Since the extraction of the first radium in 1913 the United States has become the foremost producer of radium in the world, and in 1922, out of a total of 175 gm., estimated to be the world's total available supply at this time, had produced about 120 gm. The process of radium production in this country is approximately as follows: The carnotite ore is reduced to a fine powder and sacked at the concentration mill. These sacks are transported by burros, wagons, and trucks to the railroad, and shipped to the reducing plant, where the ore is refined, using nearly the same process as did Madame Curie when she first isolated the element, but on a much larger scale. About 500 tons of the powdered ore are reduced to 500 pounds of radium barium chlorid. It is then sent to the laboratory, converted into bromids, and separated by fractional crystallization. The production of 1 gm. of radium from the carnotite ores requires from 500 to 600 tons of ore, 10,000 tons of distilled water, 1,000 tons of

coal, and 500 tons of chemicals. Practically all of the radium as made to-day is in the form of salts, of which radium bromid, chlorid, and sulphate constitute the bulk. The bromids and chlorids are soluble in water and are used chiefly in the preparation of radium emanation, whereas the insoluble radium sulphate is used mainly in the making of the various therapeutic applicators.

Recently radium has appeared on the market which has been extracted from an ore located in the Belgian Kongo, Africa. The ore had been discovered just before the Great War by a Belgian firm engaged in copper mining, but fearing an unfavorable outcome of the war they kept their discovery a secret. Only within the past year has the ore been mined on an extensive scale. It consists largely of pitchblende similar to that found in Bohemia. The ore is shipped to Belgium, where the radium is extracted. As a direct result of this, the price of radium fell from $120,000 to $70,000 a gram, and some of the American mines are temporarily closed, being unable to compete with a company having a richer grade of ore. It is not known as yet how much radium the newly found deposits will eventually yield.

THE DISCOVERY AND THE UTILIZATION OF THE PHYSICAL AND CHEMICAL PROPERTIES OF RADIUM

The development of the theory of ionization of gases by Wilson, Thompson, Rutherford and Townsend (1896-1899) proved of great value, not only in the isolation of radium, but also in the study of its radio-active properties. In 1899, as a result of the work of Giesel, Becquerel and Villard, the alpha, beta and gamma rays of radium were separated and studied. The alpha rays were found to be positively charged helium atoms shot out from the radium atom with a velocity of from 9,000 to 12,000 miles a second. They are not penetrating, and, in fact, can be stopped by a single sheet of paper. Later Madame Curie was able to demonstrate that they were the principal source of the heat emitted by radium; "thus out of a total of 136 calories, given off by a gram of radium in one hour, the alpha rays are responsible for 125 calories." The beta rays were shown to be similar to, or identical with, the cathode rays of an X-ray tube; in other words, they are negatively charged particles (electrons) traveling at a high velocity and able to penetrate from 1 to 5 mm. of aluminum, depending on their speed. More recently their velocity has been measured and found to vary from 2 to 98 per cent of the velocity of light. The gamma rays were shown to be non-electrified radiations, corresponding to the X-rays, but more penetrating. Unlike the alpha and beta rays, they cannot be deflected by a magnet and are neither refracted nor reflected. They possess ionizing, photographic and fluorescent properties, but to a lesser degree than the alpha and beta rays, the proportion being, alpha rays 10,000, beta rays 100, and gamma rays 1. However, they compensate for this by their penetrability. Recently they were detected by Failla, of New York City, behind 25 cm. of lead, although as a rule 10 cm. of lead will stop more than 99 per cent of these rays. As a comparison between the gamma rays of radium and the X-rays it has been estimated that it would require an X-ray machine of two million volts to produce X-rays as penetrating as the shortest gamma rays. In the same year that Giesel, Becquerel and Villard were carrying on this work, Rutherford demonstrated that thorium emitted a gaseous radio-active substance which he called "thorium emanation." This gas was found to have the power of ionizing gases and of affecting photographic plates. When separated from the thorium compounds the emanation was found to lose its radio-activity rapidly. Shortly after this Madame Curie demonstrated that all bodies placed in the immediate neighborhood of radium become temporarily radio-active. It was later discovered by Dorn (1901) that this induced activity is due to radio-active substances, deposited on the object by a gas, given off

by the radium. By analogy, this gas was called "radium emanation," since in many respects it resembles the thorium emanation, particularly in its properties of radio-activity, and in the fact that it behaves chemically as an inert, unstable gas of high molecular weight.

The phenomena of the thorium and radium emanations, and their radio-active deposits, led Rutherford and Soddy to advance their theory of the atomic disintegration of radio-active substances, which is universally accepted to-day. "Radio-activity is the direct result of a spontaneous process of atomic transformation. This process goes on at a regular rate for each radio-active substance and is accompanied by the emission of alpha, beta or gamma rays and the production of new forms of matter, these new elements also transforming until finally a stable atomic form is reached. This disintegration cannot be altered or hastened by any known chemical or physical means." In the disintegration of radium it is broken down to form radium emanation, giving off at the same time ionized helium atoms commonly known as "alpha particles." The radium emanation atoms are very unstable and decay rapidly, forming atoms of a solid body known as "Radium A," at the same time giving off alpha particles. Radium A is a very quickly changing body: at the end of three minutes its atoms are reduced to one-half of the original number, being transformed into the atoms of another body, Radium B, after the emission of alpha particles. This substance has a half value period of twenty-six minutes, emits beta and gamma rays and is transformed into Radium C. Radium C has a half value period of nineteen minutes and emits alpha, beta and gamma rays in changing to Radium D. Radium D is a comparatively inactive body having an estimated half value period of sixteen and one-half years, becoming Radium E after the emission of beta rays. Radium E has a half value period of five days and gives off beta rays, becoming Radium F, originally known as polonium. Polonium has a half decay period of 136 days, emitting alpha particles in changing to the end product of the series, Radium G, a substance chemically indistinguishable from lead, but having an atomic weight of 206 while the atomic weight of ordinary lead is 207.1. The rate of loss of radio-activity of radium is spoken of in terms of the half decay or half value period, and means the reduction of the radium atoms to one-half their former number by decay, this being accompanied, of course, by a loss of one-half of its original radio-activity. This period has been estimated as being 1,680 years, and at this rate the loss of activity in 100 years is about 3 per cent. The half value period of radium emanation is three and eighty-five hundredths days, and at the end of thirty days all but half of 1 per cent of a given quantity of radium emanation will have decayed. However, the rate of growth of radium emanation from radium is directly in proportion to the rate of decay of the emanation, so that the emanation is kept at a constant equilibrium with the radium. It should be noted that the studies of the remarkable properties of radium by Rutherford, Soddy, Becquerel, Giesel, Dorn, Madame Curie, and others have compelled the revision of previously existing ideas regarding the composition of matter, especially with regard to the relation of electricity to matter and the structure of the molecule and the atom.

The effects produced by the action of the radium rays on the skin were first recorded by Walkoff in 1900, and shortly afterward Giesel described an experiment in which, after a two-hour exposure by 0.2 gm. of a radium preparation, there was an intense reaction with pigmentation after two or three weeks, followed by vesiculation and scabbing. After healing, the hair did not grow on the rayed spot. However, radium treatment did not receive its initial impetus until after the famous "Becquerel burn" in 1901. Becquerel placed a tube of very active radium in the pocket of his waistcoat, where it remained for several hours.

Two weeks later a severe inflammation of the skin appeared which was attributed to the action of the radium. Curie then made an experiment on himself and, as a result of the discovery of the new property of radium, loaned a specimen to Danlos, of the St. Louis Hospital, Paris, for medical purposes. In the same year Danlos reported on the treatment of lupus erythematosus by the use of radium chlorid. As rapidly as the amounts of radium available permitted, experiments in its use were made by other workers in Europe and America. Probably the first American to suggest radium as a therapeutic agent was Rollins, a physicist of Boston, who had previously been much interested in the development of the X-ray. In 1900 Rollins gave Williams, also of Boston, a small metal box with an aluminum front, containing 500 mg. of a radium preparation with a strength of 1,000 (1,000 times as radio-active as uranium) for use as a therapeutic agent. Williams used this radium in the treatment of rodent ulcer and lupus, but the preparation was found to be too weak to compare favorably with the X-rays and was abandoned temporarily. In 1903 Williams went abroad, where he obtained 100 mg. of pure radium bromid and a large amount of radium of less radio-activity, and on his return founded a radium clinic at the Boston City Hospital. The same year Sowers, of New York City, received a very interesting letter from Alexander Graham Bell, inventor of the telephone, which he published in the August number of the *American Magazine*, in the hope, no doubt, that it would stimulate certain physicians to follow its suggestions. This letter seems worthy of reproduction in full:

"DEAR DR. SOWERS:

I understand from you that the roentgen rays and the rays emitted by radium have been found to have a marked curative effect on external cancers, but that the effects upon deep-seated cancers have not thus far proved satisfactory. It has occurred to me that one reason for the unsatisfactory nature of these latter experiments arises from the fact that the rays have been applied externally, thus having to pass through healthy tissues of various depths in order to reach the cancerous matter.

The Crookes tube from which the roentgen rays are emitted is, of course, too bulky to be admitted into the middle of a massive cancer, but there is no reason why a tiny fragment of radium sealed up in a fine glass tube should not be inserted into the very heart of a cancer, thus acting directly upon the diseased material. Would it not be worth while making experiments along this line?

(Signed) ALEXANDER GRAHAM BELL."

Although Rollins was no doubt the first American to suggest the use of radium as a therapeutic agent, Abbe, of New York City, was the first American physician to use it with any degree of success. His first article, "Radium and Radio-activity," was published in 1904. In his second article, "The Subtle Power of Radium," he says: "It gives me pleasure to put on record such observations as I have been able to make during fifteen months, with the best radium made by the laboratory of the Curies in Paris. I was able, by cabling a very early order, to get 15 centigrams (2.25 grains) of the strength 300,000, which was part of the larger amount used by them in their experiments for calorimetric determinations (now historic). With this and other strong specimens, including one of German manufacture, denominated a million activity, I have been able to verify most of the interesting work of the foreign observers and to add some of my own."

The pioneers in Europe were Lazarus, Mache, Szilard, Danlos, Wickham and Degrais, Bashford, Becquerel, Czerny, Freund, Bayet, Schiff and others, while in this country, besides the workers named, should be mentioned Hammer, Cleaves, King, Morton, Duane, Kunz, Robarts, Trowbridge, Metzenbaum, Pegram, Piffard, Pusey, Tracy, and Winkler.

THE FIRST TREATMENT OF DISEASES BY RADIUM

Cutaneous cancer, lupus vulgaris, lupus erythematosus, psoriasis and port wine stasis (Danlos) 1902
Leukoplakia (Rehns and Salmon) . . . 1904

Keloids (Williams, Werner and Herschell) 1904
Eczema (Lassar) 1904
Warts (Abbe and Bockoff) 1904
Pigmented nevi (Hartigan) 1904
Cancer of breast (Lassar and Abbe) . .1904
Xanthoma (Barcat and Bond) 1905
Sarcoma (Morton) 1905
Cancer of the cervix (Abbe) 1905
Fibroids (Abbe) 1905
Exophthalmic goiter (Abbe) 1905
Eczema (Blaschke) 1905
Sycosis, acne rosacea, lichen ruber (Blaschke) 1905
Angiomas (Wickham and Degrais) . .1906
Eczema (Wickham and Degrais) 1906
Epithelioma of mucous surface of lips, tongue and mouth (Abbe, Dominici) 1908
Rhynophyma (Wickham and Degrais) 1909

During the first ten years of its development, radium therapy struggled with two great difficulties. These were the small amounts of radium available for the work, and the lack of a suitably accurate method for standardizing the preparation of radium for therapeutic use. To secure greater accuracy, the Congress of Radiology and Electricity, meeting in Brussels, asked Madame Curie to prepare a standard. This consisted of 21.99 mg. of pure radium chlorid sealed in a thin glass tube. In March, 1912, this standard was accepted as the International Radium Standard and is preserved at the International Bureau of Weights and Measures at Sèvres, near Paris. Duplications of the standard have been prepared by the governments of the world, that for the United States being in the possession of the United States Bureau of Standards, at Washington, D. C. Up to this time, as has been noted, the radio-activity of radium was determined by comparison with uranium. Thus, if the preparation was said to have a "strength of 1,000," its radio-activity was 1,000 times that of uranium. There then came into general use the gamma ray method of comparing quantities of radium; this was one of the most important of the advances made towards standardization of radium therapeutics. The process is relatively simple; the alpha and beta rays are screened off and the ionizing power of the gamma rays is measured on a gold-leaf electroscope. All radium sold in this country is now compared with the radium standard in Washington, D. C., by the gamma ray method over a period of thirty days, and the amount graded accordingly.

Danlos' crude applicators were modified by later workers, some of which are in use to-day. The varnish-surface plaques were introduced by Danne, and the metal tubes filled with radium salt are generally credited to Dominici, although I believe this idea originated with Alexander Graham Bell. Later these tubes were made with sharpened points to aid in the introduction into tumors. Dominici first showed the importance of suitable filters to absorb the irritating soft alpha and beta rays when treating tumors requiring considerable radiation.

Radium emanation in tubes or applicators instead of radium itself as a source of therapeutic radiations appears to have been used first in 1912 by the London Radium Institute. It had been known for some time that the best way to obtain the emanation from radium is to dissolve the preparation in water or dilute hydrochloric acid and connect the containing vessel to an ordinary mercury displacement pump where the emanation, as it is formed, can be easily collected over mercury. A solution of a radium salt when pumped off in this manner immediately begins to produce more emanation, which collects until an equilibrium value is reached corresponding to the quantity of radium present. The amount of emanation in equilibrium with 1 gm. of radium was found to be a definite quantity, and it is now known as the *curie*, in honor of the discoverer of radium. This quantity is very large for most purposes and the terms *millicurie* and *microcurie* have come into general use for quantities of emanation corresponding to 1 mg. and 0.001 mg. of radium, respectively. When

one considers the radio-active deposits of the radium emanation, it is not surprising to find that, when the gas is separated from radium and sealed in a glass tube, in three hours' time the radiation produced by the emanation is the same as if the tube had been filled with radium itself. However, such tubes gradually diminish in intensity, the duration of the tube being about thirty days, beyond which its radio-activity is so reduced in value as to be useless for therapeutic purposes. Needless to say, the emanation plant as first used by the London Radium Institute has had many modifications and improvements, and at present more than 90 per cent of the total emanation given off the radium can be collected and utilized. Emanation, although employed by many of the larger clinics and institutions, is not in common use, since it requires not less than 0.5 gm. of radium chlorid or bromid before the emanation will be given off in sufficient quantities to be utilized economically.

In 1912 a number of institutes were carrying on radium treatments extensively, the most important in point of experience probably being the Laboratorie Biologique du Radium, in Paris, under the direction of Wickham and Degrais. Next in importance was the Hospital St. Louis, Paris, with Dominici, and there were also radium institutes at Heidelberg, Vienna and London. In 1913 the medical world was thrilled by the reports given at the Gynecologic Congress at Halle when Kroenig, Gauss, Bumm, and Döderlein reported their astonishing results obtained by the use of massive doses of gamma rays, from heavily screened mesothorium preparations, in the treatment of carcinoma of the cervix uteri. A "radium fever," as it was called, spread over Europe and the production of radium could not begin to meet the demand. While harmful at the time, this propaganda really accomplished considerable good, as it encouraged many of the better hospitals and institutions to purchase large amounts of the element, which were placed under the control of conscientious and scientific observers. In the United States, radium therapy, while it was accepted, was not established as an important branch of therapeutics until after the beginning of the Great War with its upsetting of communications with Europe. This, and the fact that the bulk of the radium was being produced in the United States, gave a great impetus to its utilization, and now more than twice the amount of radium is being used for therapeutic purposes in this country as in the rest of the world. I shall not attempt to describe in detail the points in the development of radium therapy since 1912. Suffice to say that rational, steady progress has been made, even though the results do not reach the exaggerated reports of the earlier writers.

Intelligent understanding of the limitations of radium treatment, and the co-operation of the surgeon, the roentgenologist and the radiologist, have gone far to improve results; and combined methods rather than reliance on a single means, give hope that radium treatment is now on a safe and sane foundation.

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