The origins of Medical Physics in the USA: William Duane, Ph.D., 1913–1920
Edward W. Webster

Citation: Medical Physics 20, 1607 (1993); doi: 10.1118/1.597159
View online: http://dx.doi.org/10.1118/1.597159
View Table of Contents: http://scitation.aip.org/content/aapm/journal/medphys/20/6?ver=pdfcov
Published by the American Association of Physicists in Medicine

Articles you may be interested in
A professional doctoral degree that does not require dissertation research is an appropriate alternative to a Ph.D. as preparation for a career in medical physics
Med. Phys. 35, 2201 (2008); 10.1118/1.2901091

Baccalaureate Origins of PhD's in Physics
Phys. Today 21, 23 (1968); 10.1063/1.3034737

NAS Data Give Baccalaureate Origins of PhD's in Physics
Phys. Today 20, 53 (1967); 10.1063/1.3034433

Baccalaureate Origins of Ph.D. Physicists
Am. J. Phys. 27, 647 (1959); 10.1119/1.1934949

American Physics PhD's
Phys. Today 6, 21 (1953); 10.1063/1.3061112
The origins of Medical Physics in the USA: William Duane, Ph.D., 1913–1920
Edward W. Webster
(Received 22 July 1993; accepted for publication 23 August 1993)

A historical question of significance to the professional specialty of medical physics in the United States is the circumstances of its birth. In connection with the preparation of a pamphlet intended to acquaint young physicists with the nature and development of medical physics, the early history of the Huntington Memorial Hospital in Boston has been examined. Considerable light is shed on the ideas and practical development of radiotherapy and its physical background in the early reports of this Hospital. The first report of William Duane, Ph.D., Research Fellow in Physics and Assistant Professor of Physics at Harvard, for the year 1913–1914, is particularly revealing and should be of interest to all physicists concerned with the interface of physics with medicine. His report is reprinted below in full exactly as published as a notable document in the history of medical physics in the USA.

First, however, a description of the milieu, personal and scientific, in which Dr. Duane entered into his work on the physical aspects of radiotherapy, is appropriate. The following information is extracted from the first annual report of the Collis P. Huntington Memorial Hospital, for the year ending June 30, 1913. The report of J. Collins Warren, M.D., Chairman of the Harvard Cancer Commission and Professor of Surgery states: "The Cancer Commission of Harvard University was established in 1901 by the President and Fellows of Harvard College. In 1911 it was felt by the Commission that an opportunity to study cancer in the human being by the use of systematic laboratory methods, such as are used in the study of animal tumors, was essential to the further progress of the cancer problem. ... Through the generous gift of Mrs. Collis P. Huntington, an amount sufficient to build the Hospital was secured." The Hospital was built adjacent to Harvard Medical School and opened in March 1912. (It was subsequently closed in 1941 and its activities transferred to the Massachusetts General Hospital.) Room in the basement was provided for radium and x-ray apparatus. "During the past year an additional sum of money was contributed for the purpose of establishing a radium clinic. Reports from other institutions with regard to the efficacy of radioactive treatment of cancer have been extremely inconclusive, but it was believed that the resources of the Cancer Commission were particularly suited to the accurate scientific study of radioactive treatment for cancer patients..." "With the funds secured a certain amount of radium had been purchased and William Duane, Ph.D., formerly Professor of Physics in the University of Colorado, and later Research Fellow in the Curie Laboratory in Paris (1903–04, 1907–13), was appointed a Research Fellow of the Commission, and began work on the preparation of radium and its products for therapeutic use." "Dr. Duane has devised certain special methods for preparation of radium salts and their products for application to cancer cases. These methods involve the employment of radium emanation, and of deposited activity, and of concentrated solutions of these radioactive substances. It is the purpose of the Commission to investigate the clinical and biological effects of these products in the Huntington Hospital on cancer patients." Dr. Warren continues: "It is extremely probable that the development of the science of physics in connection with cancer research and other medical sciences (bio-physics, as this branch of science is called) will assume a place of great importance in the next few years, and this Commission is extremely fortunate in having secured already the services of Dr. William Duane as physicist." The chairman then makes a plea for donations totalling $50,000 for a laboratory building near the hospital to improve the accommodation of the scientific laboratories for physics, chemistry, and pathology. (This building containing space for radium and x-ray therapy and a biophysics laboratory was subsequently built and opened in 1922.)

REPORT OF THE BIO-PHYSICAL LABORATORY TO THE DIRECTOR OF THE CANCER COMMISSION OF HARVARD UNIVERSITY (1913–1914)

Dear Sir: It would seem that the most successful methods of treating malignant disease employ physical rather than chemical principles. Surgery itself is a removal of the diseased tissues by mechanical (i.e., physical) means. Next in importance to surgery the use of rays from radio-active substances may be mentioned. These have a somewhat limited sphere of applicability, but nevertheless satisfactory results have been obtained during the last decade, especially abroad, in the treatment of a large number of superficial cases. X-rays in certain instances produce very similar effects. Ultra-violet light has also been employed.

The Cancer Commission has founded its laboratory of bio-physics primarily for the purpose of studying the application of various forms of radiant energy to malignant tumors, bringing to bear the more advanced principles and more recent discoveries of physical science.

The first problem undertaken by the laboratory was the perfecting of methods of treating tumors by means of the radio-active substances. These methods were suggested several years ago, and described by the writer in some detail at a meeting of the American Association for Cancer Research in April 1914.

In order to make clear the principles underlying the methods it will not be out of place to state a few of the well-known facts and laws concerning radium.

Radium is a chemical element belonging to the group of metals; but, unlike most other elements, it transforms itself at a measurable rate into another substance, called radium...
emanation. The rate of transformation, however, is so slow that about 1700 years would be required for half a given quantity of radium to disappear.

The emanation is a chemically inert gas, and it, too, transforms itself into a third substance called radium A. But this is not the end. Radium A transforms itself into radium B, and radium B into radium C, etc., the last of the line known to exist being radium F, also called polonium. None of these substances except the emanation are gases, and they deposit themselves on anything and everything that comes in contact with the emanation, including the walls of the vessel containing it. For this reason radium A, B, C, etc., frequently are grouped together under one name and called collectively the "deposited activity." All of these substances transform themselves much more rapidly than their parent, radium, does. Half a given quantity of emanation disappears in 3.85 days; of radium A, in 3 minutes; of radium B, in 26.8 minutes; of radium C, in 19.5 minutes, etc. Thus the emanation lasts longer than the deposited activity; the former's life being measured in days, the latter's in hours.

These substances differ from each other very much in their physical and chemical properties, but they all have one characteristic in common; they are radio-active. By the term radio-active we mean that the substance emits a peculiar type of radiation that is quite different from ordinary heat and light radiation. The radio-active radiation, if sufficiently intense, destroys tissues, especially certain kinds of tumor tissues, and this fact forms the basis of the therapeutic application of the radio-active substances.

Among the above mentioned substances radium C produces by far the most powerful and most penetrating rays. Radium B also emits some penetrating rays. Neither radium itself nor the emanation produce rays that are capable of passing through the walls of the glass tubes in which they are usually kept. Why, then, it may be asked, are tubes containing radium used for therapeutic purposes? The answer is that they are not so used until the radium has been in them long enough for the radium B and C to accumulate. When this has occurred, the only function fulfilled by the radium is to supply radium B and C as fast as they destroy themselves, the latter being the real source of the penetrating radiation.

It follows, therefore, that if by suitable means we deposit radium B C on an applicator or in a tube we can use this applicator or tube to irradiate tissues, just as if it contained radium itself; and this is the fundamental principle of the methods about to be described.

The deposit of radium B C can be obtained in a variety of ways, among which the following may be mentioned:

(1) The emanation may be extracted from the radium and compressed into a glass or metal container of any desired shape and size, for instance into a tiny capillary tube only a few millimeters long, and the radium A B C allowed to accumulate in it. The container is then ready for use either with or without the emanation, according to the length of time required for the treatment. The emanation, if left in the container, simply prolongs the time during which the activity lasts, by keeping a supply of radium B C. The emanation itself does not add to the penetrating radiation.

(2) Radium A B C may be deposited on sheets of metal or other substances by leaving them for several hours in contact with the emanation contained in a suitable vessel. The sheets are then attached, by adhesive plaster or otherwise, to the tissues to be irradiated.

(3) Radium A B C may be dissolved in water or other liquids either by dissolving the purified emanation and allowing it to transform itself into radium A B C, or by depositing the radium A B C on grains of salt and then dissolving the salt in the liquid. In this way a large amount of activity can be put into a few drops of liquid. The liquid is then injected into the tissues or blood stream.

All of these methods have been used in the laboratories and hospital of the Cancer Commission. The first applications were made by the writer in collaboration with Dr. Robert C. Greenough, in August 1913, and subsequently in collaboration with Dr. E. E. Tyzzer, Dr. Thomas Ordway, and others. (Some early experiments by Balthazard, Bouchard, and Curie in 1904 showed that the emanation separated from radium could produce physiological changes. The Radium Institute of London, however, seems to have been the first to use, systematically, large quantities of emanation in containers for therapeutic purposes. See its reports for 1913 and 1914.)

In order that the methods should be of practical value it is necessary to have an efficient machine for collecting and purifying the emanation. Such a machine was designed several years ago by the writer. It is a modification of the apparatus previously employed by Ramsay and Soddy, Rutherford, and Dubierne. Plate 1 represents the arrangement of the glass tubes and reservoirs. The bulb A contains the radium salt dissolved in water. Radium in solution continually decomposes the water into hydrogen and oxygen gases, at the same time setting free the emanation. This mixture of hydrogen, oxygen, and emanation collects in the tube B, and passes over into the reservoir C, on lowering the mercury from C into D. When it is desired to draw off the emanation the mercury is pushed up into C, forcing the mixture of gases through the mercury trap E into the tubes F. These tubes contain a copper wire slightly oxidized, phosphoroxide and potassium hydroxide. The copper wire, when heated by an electric current, combines the hydrogen and oxygen, and the phosphoroxide absorbs the water vapor produced. The potassium hydroxide is for the purpose of absorbing any carbon dioxide gas that may be present. After the purification of the emanation, the mercury in the reservoir G is allowed to flow into H and the emanation passes into G. It is then pushed up by the mercury through the stop-cock I and into the desired tube or container, which is sealed on at N. The system of tubes and bulbs K L M is for the purpose of removing the air from the other tubes and reservoirs, etc., by means of a pump attached to M. This must be done at the beginning, and after that no air enters the reservoirs except occasionally when it becomes necessary to renew the purifying chemicals. This apparatus has been in practically continuous daily use for over a year. The bulb A contains over two
hundred milligrams of radium (element), and the quantities of emanation extracted and purified during that time, if they were all added together, would be more active than twelve grams of radium. The process of extraction does not require much time. Frequently fifty or sixty millicuries of emanation have been purified and compressed into a small glass tube having a volume less than one cubic millimeter in fifteen or twenty minutes. It will be noticed that no liquid air is required for the purification and also that the process can be repeated as often as desired without renewing parts of the machine. The importance of these points is evident if frequent supplies of emanation are required.

Plate 2 represents a few of the tubes and applicators used in treating cases. These are applied to tumor tissue according to the well-known methods of using applicators containing radium salts, that are described in the literature and textbooks on the subject. The tiny glass tubes A contain radium emanation. They fit into the steel tubes just below them, which are provided with eyes and points, as shown. These tubes while strong are used singly, either with or without the silver jackets represented at B. The silver jackets act as filters, cutting off the easily absorbed rays. As the emanation dies away and the tubes become weaker they are placed on flat applicators, as at C. D is a glass tube containing a thin sheet of metal. It illustrates the method of making deposited activity applicators, two of which are represented at E. The glass bulbs F have been used to make highly radioactive salt solutions.

The advantages of the methods outlined above appear to be (a) that the danger of losing the radium itself is reduced to a minimum, (b) that great flexibility is attained, and (c) that a large quantity of a radioactive material of long life, like radium, cannot possibly get lodged in the patient's system by accident.

Powerful applicators have been made containing fifty or sixty millicuries per square centimeter of surface, and in other cases the active substances have been spread over large areas. It is possible, also, to obtain a volume distribution of the active substances instead of a surface distribution.

A second problem undertaken by the laboratory has been the development of a method of accurately estimating the intensity and quality of X-radiation. In physical science the principle employed in measuring the intensity of X-rays has been almost without exception the fact that the rays make a gas through which they pass, a conductor of electricity. This phenomenon is called the ionization of the gas. A simple apparatus for measuring this acquired conductivity, or ionization, has been designed.

One of the most remarkable discoveries that has been made recently in this field is that X-rays and also gamma rays from radio-active substances are waves similar to light waves, and have certain definite wavelengths and frequencies. It seems, therefore, advisable to take the wavelength (or frequency, it does not matter which) of an X-ray as the measure of its quality. The above-mentioned apparatus for measuring the intensity of the X-rays is designed to estimate their wave-lengths also. The wave-lengths are determined by measuring the absorption of the X-rays as they pass through aluminum. From a careful survey of the ex-
perimental data it appears that the absorption is proportional to the cube of the wave-length.

Dr. W. T. Bovie has been working in the laboratory on photo-chemical phenomena, and has greatly increased the efficiency of his new mercury-vapor lamp, and provided means for controlling the intensity of the ultra-violet light produced. He has also completed other pieces of apparatus, which will be used in studying the chemical and physiological action of ultra-violet light and other radiations.

It may also be noted that the workshop of the Harvard Medical School has been placed under the charge of this laboratory, and we now have some excellent machines for making apparatus, and three first-class mechanicians, who have found so much to do that they frequently work overtime and into the evening.

William Duane, Ph.D.
Research Fellow in Physics

This unique first report is notable for (1) its highly readable summary of the properties of the radium daughter products, (2) the concept of secular equilibrium, (3) the description of an early apparatus for purifying radon gas and preparing sources, (4) early radon applicators, (5) mention of an early free air ionization chamber, (6) use of absorption curves in aluminum as a measure of x-ray quality, and (7) observation that absorption of (low energy) x rays is proportional to the cube of the wavelength.

Duane's subsequent reports illustrate the evolution of medical physics under his guidance and a summary of highlights for the years 1915–1920 follows.

In his report for the year 1915–1916 Duane enunciated the “Duane–Hunt” Law which states that the maximum frequency $f$ in an x-ray beam is given by $h.f = E$ where $h$ is Planck's constant and $E$ is the maximum electron energy in the x-ray tube.$^1$ In 1915 Duane supervised the construction of a duplicate of the radon apparatus for installation in the Radium Department at Memorial Hospital in New York.$^*$

For the year 1916–1917 Duane reported as follows: “A part of the writer’s time has been taken up with the actual radium treatments. On the average about 48 patients per week have been seen. Most of the tumors treated belong to the superficial types of skin cancer, in which radium produces the greatest benefit. The treatment of these cases requires a considerable knowledge of the science of radioactivity, especially of the quantitative laws used in estimating dosage, filtration, etc.”$^2,4$ In this year, part of Duane's time was spent in cooperation with the General Electric Company installing and improving a high frequency and high tension power plant to be used with one of the new Coolidge x-ray tubes. This work under the auspices of the Harvard Cancer Commission, was done primarily in the Jefferson Physical Laboratory at Harvard. In March 1917 it was agreed by the Commission that Duane should assume an advisory position at Memorial Hospital in New York “in order that they might have the benefit of his knowledge and advice on problems of radioactivity.” This appointment followed by two years the arrival of Gioacchino Failla at Memorial Hospital in 1915.

In 1917 the success of Duane’s work at the Huntington Hospital and at the Jefferson Laboratory led Harvard University to establish a Department of Bio-physics under Duane’s direction, the first in the country, and Duane was promoted with the new title “Professor of Bio-physics.” During that year 7 graduate students were working with Duane on various aspects of the properties of x rays and radioactivity related to medical use.

In 1919–1920 the Department of Bio-physics presented a course in Bio-physics which Duane believed to be the first of its kind offered in any institution. Twenty students enrolled. In the prophetic words of Duane: “It represents a pioneer movement.”

$^*$ Also in Report of Radium Department, p. 51, in the 31st Annual Report for the year 1915, Memorial Hospital, New York.