An introduction to Cosmic radiation:

What is radiation?

Part 2

This is the second part of our inaugural Australian Almanac *feature, introducing the concepts central to understanding the field of cosmic radiation. It is an abridged excerpt from the Summer 2009 21st* Century Science & Technology *magazine article, "Science for Legislators: Is the Fear of Radiation Constitutional?" by Laurence Hecht. Part I was in the August 4th edition of the* Australian Alert Service.

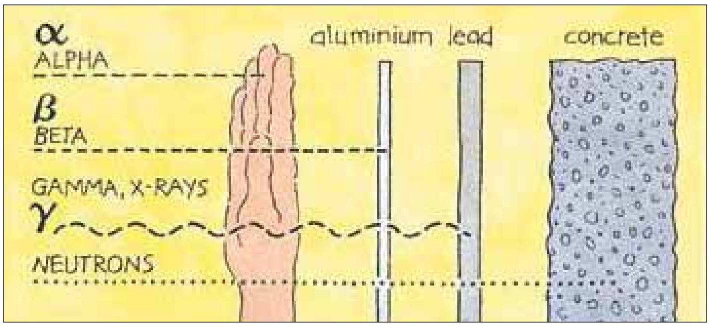
Alpha, Beta, and Gamma Rays

The Curies' work attracted worldwide attention. One of the most important lines of development led to the discovery that there was more than one type of radiation coming from the radioactive substances. Becquerel had already reported from his early experiments with uranium that he suspected this to be the case, and experiments by the Curies had also suggested it. In 1898 Ernest Rutherford, a young New Zealander working at the Cavendish Laboratory in England, used an apparatus based on the Curies' radiation detector to examine the radiation from uranium in a slightly different way. He placed powdered uranium compounds on the lower metallic plate of a Curie electrometer, and covered the powder with layers of aluminum or other metal foils.

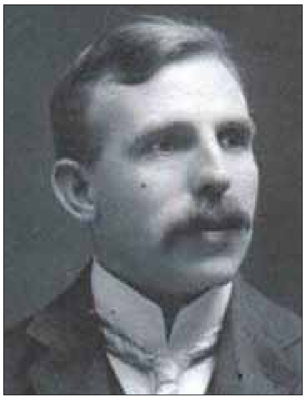
It was found that most of the radiation, as measured by the charge collected on the upper plate, was stopped by a single thin layer of foil. But some of it got through and was only stopped after a considerable number of layers had been added. The conclusion, already suggested by earlier work of Becquerel, was that there were at least two different types of radiation, to which Rutherford gave the name alpha rays for the less penetrating, and beta rays for those which were stopped only by more layers of foil.

What were these two types of rays? In 1899, Becquerel and two separate groups of experimenters in Germany, all found that the radioactive emissions from radium could be bent by a magnetic field. Although the rays are invisible, their bending could be detected in the following way: A sample of the substance was placed in a lead container with a narrow mouth, so that radiation could only escape in one direction. The container was placed between the poles of a powerful electromagnet, and by detection on a fluorescent screen, it was found that the emerging radiation was curving in the same direction as had been observed with the cathode rays mentioned above. As further experiment confirmed, the beta rays emitted by radioactive substances were found to be identical with the cathode rays produced in gas discharge tubes. Both were nothing more than beams of electrons.

More careful experiments by Pierre and Marie Curie in 1900, showed that only a part of the radiation was deflected by the magnet in these experiments. Marie Curie then showed that the undeflected part of the radiation had a lesser penetrating power. It was thus likely that this other part was the so-called alpha radiation. Under a stronger magnetic field, the alpha rays, could be deflected as well, but by a lesser angle and in the opposite direction of the beta rays, indicating that they were more massive and positively charged. It was to take a few more years before the character of the alpha rays was discovered to be identical to the nucleus of the second element in the periodic table, helium. Thus, by the first decade of the 20th Century it was understood that these newly discovered radioactive substances were regularly emitting high-speed helium nuclei (alpha particles) and electrons (beta particles).



The types of ionizing radiation differ in their ability to penetrate matter. Alpha particles lose their energy quickly and can be stopped by a sheet of paper or the first layer of skin.



Ernest Rutherford's experiments in 1898 found two types of "rays" emanating from uranium, which he named alpha and beta.

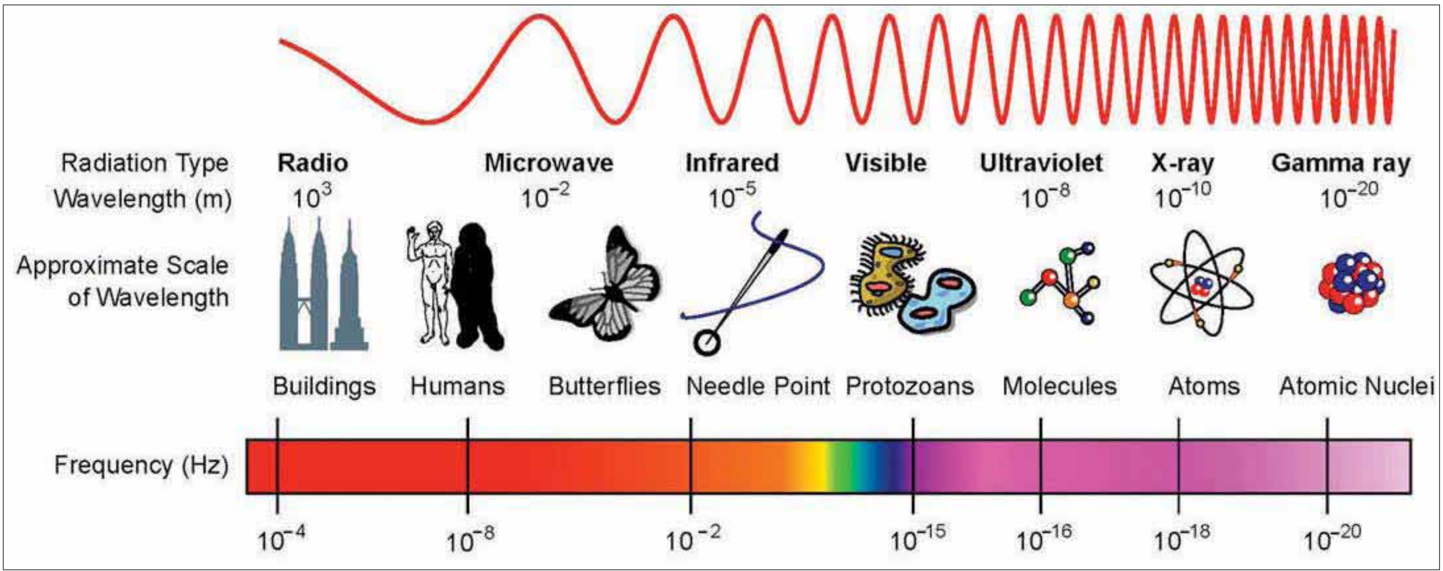
Yet a third type of radioactive emission was discovered in 1900 by the French physicist Paul Ulrich Villard. These had the power to penetrate through all the layers of aluminum foil that Rutherford had used to distinguish the alpha from the beta rays. They could only be stopped by a relatively thick piece of lead. They were not bent by the strongest magnetic or electric fields. This third type of radiation became known as gamma rays. Though some suspected that they too would correspond to some particle, it turned out that they more closely resembled light in having no detectable mass.[6]

They could be identified and measured by their wavelength, however, which was discovered in 1914 to be thousands of times shorter than visible light. A shorter wavelength means a higher frequency, and consequently higher energy for the radiation.[7]

We see thus that all the principal forms of radiation which emanate from radioactive substances were known by the year 1900. By 1914, their essential physical properties were known as well. These were the alpha ray or alpha particle (helium nucleus); the beta ray or beta particle (electron); and the gamma ray (a form of electromagnetic radiation, like light).

In 1900, Paul Villard discovered gamma rays, which were able to penetrate to a greater depth than alpha or beta rays.

As we have seen, another kind of radiation, the X-ray, was also known, and had been found to be a form of electromagnetic radiation as well. The X-rays known at that time were of a lower frequency and thus less energetic than the gamma rays emitted from radioactive substances. Thus for a long time, Xrays were defined as any radiation having a frequency of from about 10^{16} to 10^{19} cycles per second, and gamma rays any frequency above that.[8] Now however, more pow-



The various types of electromagnetic radiation are measured by their wavelength and frequency. As the graphic shows, the higher the frequency, the shorter the wavelength.

erful X-rays can be produced, and less powerful gamma rays have been found. Gamma rays and X-rays are thus distinguished today by their origin. The gamma ray is thought to originate in the atomic nucleus, while the X-ray seems to arise from the outer parts of the atom.

Transmutation of Elements

The separation of the radioactive elements, polonium and radium, by Marie and Pierre Curie soon led to the remarkable discovery that one element could be transformed into another. In 1898, Marie Curie and Gerhard Schmidt had independently discovered that a third heavy element, thorium, close to uranium in the periodic table, produced radioactive emissions.

Chemist Frederick Soddy, who worked with Rutherford, determined that radioactive thorium decayed into radium, a process he named transmutation. He and others later mapped out the types of spontaneous transmutation that occurred in the periodic table.

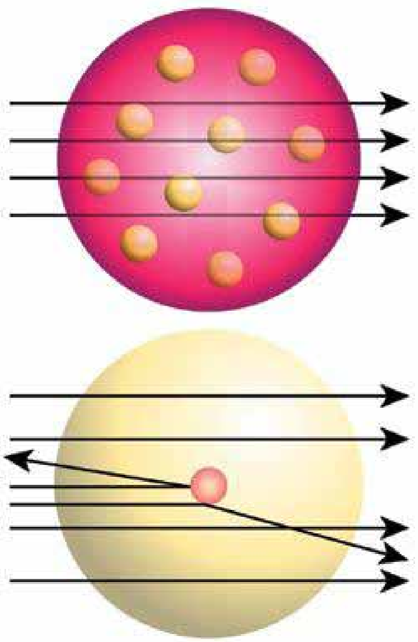
Working at McGill University in Canada, the young chemists Ernest Rutherford and Frederick Soddy first recognized in 1901 that radioactive thorium was transforming itself into radium. Soddy called it transmutation, a term previously applied to the alchemists' hope of transmuting base metals into gold. Over the course of the next decade, it was discovered that all of the elements higher than lead (atomic number 82) in the periodic table were undergoing continuous transmutation.

The Nucleus and Radiations

Gradually, a theory emerged to explain the emission of radiation and transformation of the elements. Early experiments with the canal rays had suggested to Philipp Lenard in Germany that most of the space within a substance is empty (or at least transparent to rays), and the mass is concentrated in only a very small portion of the space. He called these concentrations of mass dynamids.

In 1909, Hans Geiger and Ernest Marsden, working in Rutherford's Manchester University laboratory, carried out experiments in which they aimed alpha particles from a radioactive substance at an extremely thin layer of gold foil. Most of the positively charged alpha particles passed right through the gold foil, supporting the notion that the space between the atoms of the seemingly solid substance was devoid of matter. About 1 in 8,000 alpha particles was deflected backwards, at angles greater than 90 degrees. This suggested that tiny concentrations of positive charge were spread throughout the substance of the gold foil. Rutherford called these concentrations of charge, the nucleus of the atom.[9] By analyzing how the positively charged real alpha particles were deflected, it was possible to show that the nuclear charge was concentrated in a volume of less than one trillionth of a centimeter in radius, and occupied less than one three-thousandth of the total volume of each atom.

Over the course of subsequent decades, it was discovered that the nucleus could be viewed as a concentration of particle/ waves, known as protons, and neutral particle/waves known as neutrons. The alpha, beta, and gamma rays were recognized as originating from this nucleus. The emission of each one of these particle/waves could be correlated to a change in the character of the nucleus, a transmutation of the element. So, for example, the emission of an alpha particle (a helium nucleus consisting of 2 protons and 2 neutrons) reduces the atomic mass of the substance by 4 units and the charge (atomic



In Rutherford's experiments, alpha particles from a radioactive substance were aimed at a very thin layer of gold foil. Most of the positively charged particles passed through the foil (top), but about 1 in 8,000 particles was deflected backward at an angle greater than 90 degrees (bottom). This indicated that there were tiny concentrations of positive charge in the gold foil. Rutherford called these concentrations the nucleus of the atom, and deduced from the experimental data a relative measurement of the nucleus.

number) by 2 units.

Alpha emission is typical of the heavier elements. Another common form of radiation, the beta decay, can occur anywhere on the periodic table. The emission of a beta particle (electron), being only about 1/2,000 of the mass of a proton, scarcely changes the atomic mass of the substance. However, it causes an increase in the charge, or atomic number, of the element. Beta decay may occur from radioactive isotopes anywhere in the periodic table.

Natural Sources of Radiation

There are many other natural sources of radiation which reach us all the time. Some of the principal ones are shown in the accompanying table. These naturally occurring radioactive isotopes enter our bodies either through our food and water, or from the atmosphere. A certain amount of body radiation is also produced by collision of cosmic rays directly with our bodies, by the natural background radiation coming from radioactive elements in the Earth, and by the radiation from space such as from gamma ray bursts.

Cosmic rays and their byproducts collide with us, all the time. In an experimental device known as the cloud chamber, the evidence for the existence of the cosmic rays can be demonstrated at any location on Earth. The first cloud chamber was perfected by C.T.R. Wilson in 1911.

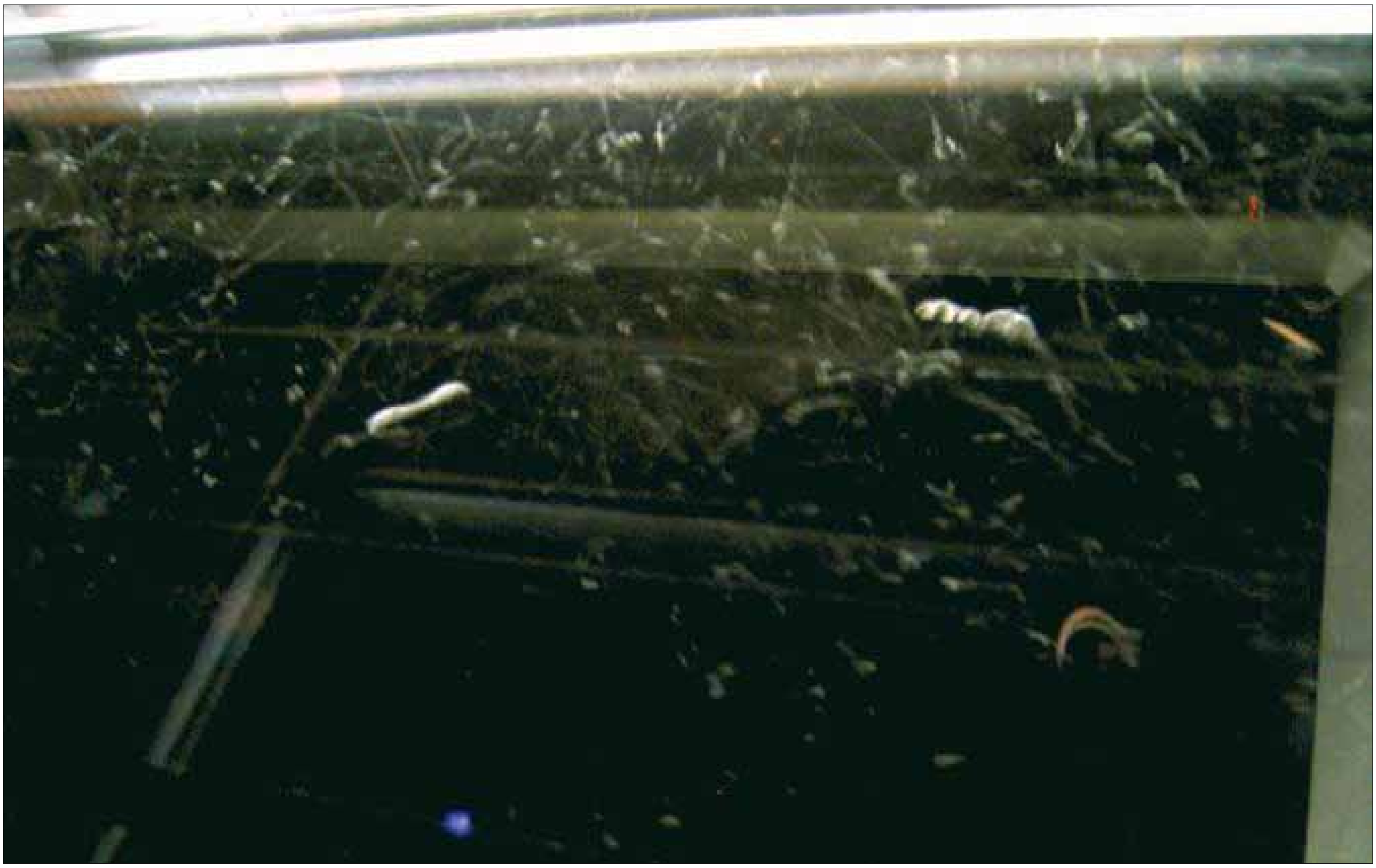
A simplified cloud chamber is easy to build, often forming the subject of a high school science project. A closed container, like a small aquarium tank, and some dry ice are the principal materials required. When the proper conditions are created inside the tank, the collision of these high-speed protons from outer space with molecules of the air in the container, trigger condensation of the water vapor in the contained air. The vapor trails provide visual evidence that the cosmic rays have passed through. These cosmic rays also pass through our bodies, and are continuously producing radioactive by-products.

Another major source of radiation is the Earth itself. Most of this radiation comes from the natural decay of uranium or thorium, which is contained in varying amounts in every portion of earth or rock. The average soil contains from 1 to 3 micrograms of uranium, rocks contain from 0.5 to 4 micrograms, and beach sand contains about 3 micrograms.

Some locations on Earth are much more radioactive than others. In some parts of the United States it is possible to obtain aeroradioactivity maps, showing the natural background radiation levels from the Earth. These maps are derived from surveys conducted during the time of atmospheric nuclear testing to try to determine base levels of radiation. But elevation can have an even greater effect on background radiation level than soil and subsoil content. People living at high elevations and airline pilots receive a considerably higher exposure than average.

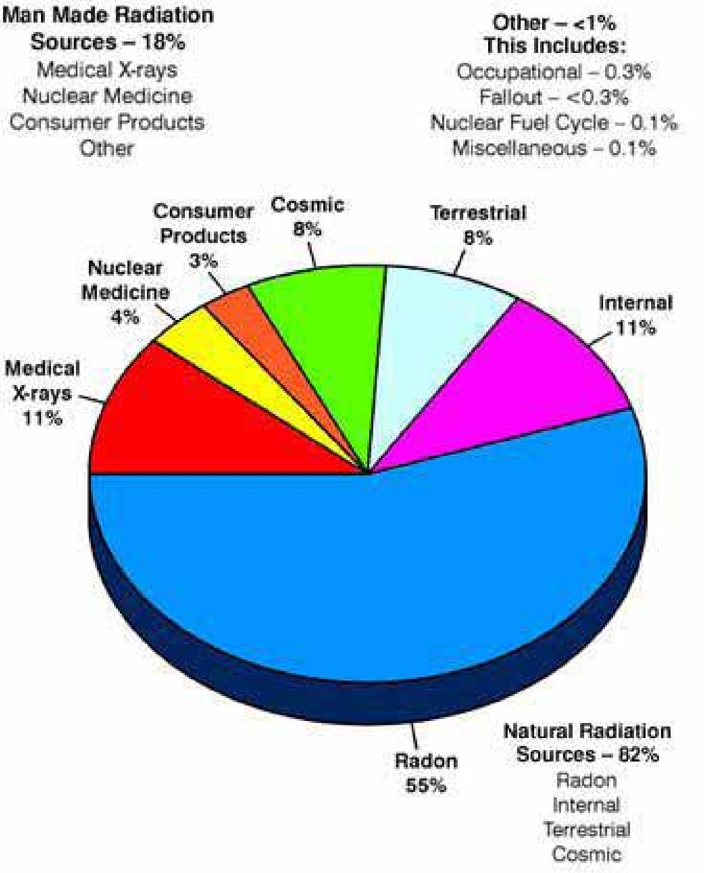
But, before you decide to abandon your home in Denver or Albuquerque, or never fly again, consider that there is no evidence whatsoever that higher background levels of radiation have a negative effect on health or longevity. In fact, there is a substantial body of scientific evidence that people exposed to low-level background radiation live longer. The experimentally proven positive effect of low-dose radiation is known as hormesis.

Low-dose radiation has been shown to enhance biological responses for immune systems, enzymatic repair, physiological functions, and the removal of cellular damage, including prevention and removal of cancers and other diseases. In Japan, advanced medical research showed that preliminary treatment with low-dose, full-body radiation could drastically reduce the dose level required for patients undergoing high-level radiation



Tracks of ionizing radiation from cosmic rays, in a cloud chamber. The thick, short tracks are alpha particles; the long, thin ones are beta particles. C.T.R. Wilson perfected the first cloud chamber in 1911.

What is radiation?



Source: National Council on Radiation Protection and Measurements (NCRP) Report No. 93, "Ionizing Radiation Exposure of the Population of the United States," 1987.

Where your radiation comes from: Natural sources account for about 82 percent of the average radiation dose to individuals. The remaining 18 percent comes from man-made sources, mostly from medical procedures. Radiation from nuclear plants is less than one-tenth of a percent.

therapy for various cancer treatments and increase the longevity of the patient.

Many healing springs and baths derive their benefits from low-dose radiation in the water, usually in the form of absorbed radon gas. In Germany, a nation which suffered an anti-radiation hysteria in the 1980s, causing the shutdown of numerous nuclear construction projects, people still flock to the traditional radioactive healing spas to bathe in radon-containing waters. In the Soviet Union, treatment with controlled doses of artificially produced radon was a standard and highly successful therapy for tuberculosis and other lung conditions.

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6. Whether a photon of light possesses mass or not remains a matter of controversy. By equating the expressions for energy of Max Planck ($E = h\nu$) and Albert Einstein ($E = mc2$), a value for the mass of a photon of any given frequency can be obtained.

7. We understand the properties of light by recourse to an analogy to waves in water, first proposed by Leonardo da Vinci. We measure light by the distance from crest to crest of each successive wave, a distance known as the *wavelength.* As we imagine the waves all to travel at a constant speed, if we were to count the number of wave crests passing a particular point in a second, we would find that light of shorter wavelength would squeeze in more crests in the course of a second than that of longer wavelength.

The number of wave crests passing a particular point in a second is known as the *frequency,* and thus is inversely proportional to the wavelength. It also turns out that at this higher frequency, or shorter wavelength, light does more work in the course of a second than that of lower frequency, and thus is described as more energetic.

Not only light, but heat, radio waves, and high-energy radiation, such as Xrays and gamma rays, can all be described by this wave analogy. The waves have both electrical and magnetic properties. Although a magnetic or electric field will not change their direction as it does that of electrons and protons, it will cause an internal change known as rotation of the plane of polarization. All these types of radiation are known generally as *electromagnetic waves,* and their vast range of frequencies is known as the electromagnetic spectrum.

8. The notation 10^{16} means 1 followed by 16 zeroes, and thus is equal to 10,000,000,000,000,000 (10 quadrillion) cycles per second. The standard unit for the *cycles per second* of frequency is now known as the *hertz* (abbreviated *Hz*).

The first measurement of the wavelength of light was made in 1801 by Thomas Young, an English opponent of the Newtonian theory of optics. Young passed a ray of light through two slits, thus causing the two separated beams to interfere with each other, producing alternating bands of darkness and light. The interpretation, later elaborated in detail by Augustin Fresnel, was that, like waves in water, the crests of the two separated beams reinforced each other where they came together, while when a crest of one beam met the trough of the other, they cancelled each other, producing darkness.

9. Said Rutherford: "It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you. On consideration, I realized that this scattering backward must be the result of a single collision, and when I made calculations I saw that it was impossible to get anything of that order of magnitude unless you took a system in which the greater part of the mass of the atom was concentrated in a minute nucleus. It was then that I had the idea of an atom with a minute massive centre, carrying a charge." Rutherford's powers considerably deteriorated later in life. After his 1919 appointment as director of Cambridge University's Cavendish Laboratory, he increasingly adopted the role of controller of scientific discovery, rather than innovator. His relentless erroneous attacks on American physical chemist William D. Harkins, who had foreseen the neutron in 1915, among other innovations, were typical. Rutherford later became notorious for his statement that any idea of attaining power form the atomic nucleus was "moonshine." More than likely, he knew better, but made the statement in the interest of British imperial policy, not science.